NOCTURNAL OLFACTORY RESPONSE TO SMOKE ODOR

EXECUTIVE DEVELOPMENT

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ABSTRACT

The Irondale Fire and Rescue Service has been teaching its constituents that they could not smell during sleep and therefore needed the protection of a smoke detector. A challenge to this idea produced the problem of not knowing whether the sense of smell will awaken a human to smoke odor stimulus. The only way to answer that challenge was to perform an inquiry (research) to affirm or deny the existence of olfactory fire protection during sleep. Through descriptive and evaluative research methods, this research project evaluated the sense of smell during sleep to learn if a sleeping adult could detect the odors of water, smoke, or citrus. These odors were first introduced to conscious subjects to screen them for olfactory response. The subjects went to sleep and a compressor pump nebulized three different odorants through an elaborate delivery system into the sleep rooms. EKG, EEG, EMG, and EOG biomeasurements were monitored for response to the stimuli. The following research questions were identified for use: (a) Can a defined group of conscious adults detect the presence of the smell of smoke odor? (b) Will the smell of smoke odor awaken a defined group of sleeping adults? and (c) Will the smells of water, smoke, or citrus odors arouse a defined group of sleeping adults? The results revealed that although a significant number of subjects responded to the stimuli, only two of the ten subjects awoke. The integration of an olfactometer into smoke detectors, the use of smell-sensitive components in building materials and household goods, a greater emphasis on smoke detector compliance, and the dissemination of the knowledge gained in this study to convince citizens to protect themselves with smoke detectors were all recommended as a result of this study.

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INTRODUCTION

Smoke detectors provide the most common and inexpensive form of early warning to the presence of night fires. Compliance issues that involve detectors continue to be a fire protection obstacle. Prior research has shown that apathy is primarily responsible for noncompliance (Management Internship Program, 1991). The only way apathy can be addressed is through a cognitive learning experience in which a value change has occurred. Because of this, it has always been the intent of the Irondale Fire and Rescue Service to effect a change in the attitude of those citizens who can be identified as being apathetic toward smoke detector compliance issues.

For more than 20 years, representatives from the Irondale Fire and Rescue Service have delivered lectures and demonstrations to various groups concerning the need for properly maintained smoke detectors. A key component of the lecture rationale was the inability of humans to smell smoke during sleep. Recently the validity of this point was called into question. A major problem developed when a review of the scientific literature failed to affirm this hypothesis as fact. No one knows if the sense of smell will awaken a human to smoke odor stimuli. Because of the importance of this issue for fire protection, a decision was made to investigate olfactory response to smoke odor during sleep. The purpose of this research is to affirm or deny the existence of olfactory fire protection during sleep. The descriptive and evaluative research methods were chosen to describe the results of this research and compare them with the findings reported in similar studies.

The following research questions will be answered in this study:

1. Can a defined group of conscious adults detect the presence of the smell of smoke odor?

2. Will the smell of smoke odor awaken a defined group of sleeping adults?

3. Will the smell of water, smoke, or citrus odors arouse a defined group of sleeping adults?

BACKGROUND AND SIGNIFICANCE

Have other fire prevention educators ever dedicated a tremendous amount of energy and expense to a noble idea and later realized that they were disseminating misleading information to the very individuals they were trying to help? The author of this report realized he was and embarked on a personal mission of validation. While the specifics of his error will be exposed later, understanding the contributing circumstances of this dilemma is important for the reader of this report. Please note that the sources for the presentation are also cited in the reference list of this paper.

The saga began some 22 years ago when a very young and inexperienced firefighter addressed a group of citizens concerned about fire prevention. Since then, more than 200 performances of the "show" have started by citing, "when fire occurs in your home, your chances for survival are two times better when smoke detectors are present than when they are not (Federal Emergency Management Agency [FEMA], 1993, p. 103)," and this is "without specifying complete coverage or operational detectors" (Cote, 1991, p. 10-21). This was repeated to target audiences ranging from the very young to the very old because young children and the elderly represent the two highest fire death risk groups (FEMA, 1990).

The firefighter's convictions were founded in the published mandates of notable reports addressing our nation's fire problem. Since their introduction in 1955 (Bukowski, 1993), residential smoke detectors were immediately embraced by public fire educators who proclaimed their promising role in cutting our national fire death rate (National Commission on Fire Prevention and Control [NCFPC], 1973). "Their economical designs and fire service support have led to their installation in the majority of American homes" (Brachtler & Brennan, 1995, p. 991). Those early prevention pioneers documented their beliefs at a number of historical gatherings. In 1966, a group of dedicated individuals met at the Wingspread Conference Center in Racine, Wisconsin, to discuss the fire problems in the U.S. Published under the building's namesake, the Wingspread I Conference Report identifies a public complacent about the rising trend of both property and life loss. Wingspread II occurred in 1976 and went on to say, "it appears that residential smoke detectors hold the most practical potential at this time for saving lives" (Rubin, 1996, p. 28). The fire service should take the leadership role in encouraging their widespread use and proper maintenance. It was reported that "public fire safety education will not achieve its potential until it is organized in a systematic manner based on human behavior" in the Wingspread III Conference of 1986 (Rubin, 1996, p.30). Just last year, Wingspread IV produced, as an ongoing issue, similar concerns about the subjects of prevention, public education, and loss of life (Rubin, 1997).

The United States government's interest in smoke detectors has been profound since the publishing of *America Burning*. The findings of this 1973 report were considered a pivotal event in the nation's fire safety evolution. Along with the recommendation of establishing a permanent Federal agency specifically concerned with fire, and a National Fire Academy, the assembled caucus of fire safety leaders advised Americans "to protect themselves and their families by installing approved early warning fire detectors and alarms in their homes" (NCFPC, 1973, p. 119). Fourteen years later, the government continued its fire protection agenda by addressing smoke detector compliance issues in the report entitled *American Burning Revisited*. It was stated in this report that "maintenance problems are eroding detector effectiveness" (FEMA, 1990, p. 57).

Enlightened by the various subject matter expert reports, the firefighter was convinced of the accuracy and validity of his lesson plan. An orientation concerning the various types of detectors and the common reasons for their failures initiated the instruction. The first reason for smoke detector failures involves the error of not using the product as it was designed. Learning that photoelectric detectors are superior at sensing large particles while the ionization type responds more quickly to fast hot fire partially addressed the "placing the detector in the wrong place" reason for failures. The second reason for nonactivation of detectors was cited as failure to maintain them by cleaning the sensing passages on a regular basis. "Of course, the biggest reason smoke detectors fail is likely due to dead or missing batteries" ("How It Works," 1993, p. 4). By examining these categories of failure, he hoped to see a changed behavior similar to one experienced in Ann Arundel County, Maryland, and Bullhead City, Arizona, that were reported by Charles A. Parks (1990) and Rick A. Southey (1995) in their *Executive Development* projects. In Parks' project, a mailer was sent out defining the need for detectors and the common maintenance problems. This increased public awareness campaign led to greater smoke detector code compliance. In Southey's project, public fire education sessions in the local elementary schools led to more than 248 household visits by fire department crews for installation of smoke detectors and the replacement of defective batteries.

Because less than two percent of households have tested their alarms using smoke, testing smoke detectors was the next topic discussed (Narriott, 1995). The test button method of evaluation does not always signify that a detector will sound in case of a fire (Cooper, 1996). The firefighter introduced an aerosol smoke detector testing product to the patrons of his show and identified a vendor for this product. A demonstration of the CRC Smoke Test® brand of smoke detector testing products was performed according to the instructions contained in the Technical Data Sheet produced by CRC (1997). It was noted that smoke detectors, like other electrical appliances, wear out and may need to be replaced at a future date (Coughlin, 1994).

Like detector failures, false smoke alarm activations were identified as problematic. The common ionization type of detector is much less expensive than the photoelectric type; however, they are prone to false alarms (Cooper, 1996). Cooking odors, steam from bathing, tobacco smoke, paint stripping, and the use of coal gas and electric bar fires were all listed as common reasons for false activation of the ionization detectors (Narriott, 1995).

The show ended with a recital of information concerning the use of smoke detectors and a question-answer opportunity. Reciting from facts provided by the National Fire Data Center, the firefighter announced that "in 1990, detectors were present in only 27 percent of the one- and two-family homes that experienced fire deaths and 43 percent of the homes that had fires" (FEMA, 1993, p. 103). By 1994, a national average of 88 percent of households reported having detectors. Unfortunately, 20 percent of all households have detectors that are nonoperational (FEMA, 1997).

To verify the accuracy of these figures, the 1996 annual report of the Phoenix (Arizona) Fire Department was obtained, and it revealed that only 3 of the 13 residents that suffered fire deaths had detectors installed in their homes. The 1996 Birmingham (Alabama) Fire and Rescue annual report was also consulted, and it listed two of the five residential fire death structures as being protected with smoke alarms. Amazingly, the firefighter discovered that 13 of the 18 deaths reported in these 2 cities occurred in structures that were not protected by smoke alarms and that figure is the exact percentage reported earlier (FEMA, 1997).

To help target at-risk groups, the firefighter explained that there exists a direct relationship between the socioeconomic characteristics of poverty, race, age, and other factors with the risk of having a fire (Hall, 1994). Furthermore, he announced that those having fires do not usually protect themselves. With adequate numbers of detectors on each floor, 3 minutes of warning was provided 89 percent of the time in experiments; whereas the same amount of warning was provided in only 35 percent of the experiments when a single detector was placed near the bedrooms (Bukowski, 1993). At this point, he used a small interactive presentation board with moveable transparent shapes to teach where important safety devices belong in the home. The visual aid used was provided as part of the First Alert Junior Fire Inspector Program© (Timmons, 1996), and it referenced the appropriate standards that established these rules. Installation guidelines from the National Fire Protection Standard [NFPA] Number 74 (1996) and the American National Standards Institute [ANSI] Standard Number 217 (1993) were abridged for the sake of time. (The ANSI standard is also known as the United Laboratories standard.) If time permitted, he occasionally used videos to dramatize his message. For children, the he used the cartoon video *"Donald's Fire Survival Plan"* (Disney Educational Productions, 1987), which ironically starts with Uncle Donald saying, "Fire can't happen to me." For adult audiences, he used the NFPA movie entitled *"Fire Power"* (MacClary & Estus, 1986), which graphically shows the effects of fire. At this point, the show moved into its final act.

After summarizing the major points of the presentation, the firefighter gave the audience an opportunity to ask questions. If no inquiries were generated, a third person's perspective was used for addressing commonly asked questions and myths concerning home protection. Referring to product information, he explained that ionization detectors are easy to install, easy to test, and can be obtained for as little as $ 3.99 per unit (Jameson, 1994). Quoting from the NFPA Standard Number 72 (1996, p. 72-28), he advised the audience that "smoke detectors should be installed outside of each separate sleeping area in the immediate vicinity of the bedrooms and on each additional story of the family living unit, including the basements, and they should be tested in an approved manner weekly." To address any health risk concerns, he announced that the ANSI Standard No. 217 (1993) requires all ionization detectors to meet safety criteria 10-CFR 32.27 of the United States Nuclear Regulatory Commission and that the radioactive source within the detector cannot be harmful to those who handle or use the device (Bare, 1977). A brochure entitled *Smoke Detectors: Don't Stay Home Without One* was distributed for reinforcement of the concepts covered in the presentation (FEMA, 1988).

Just before the curtain fell, he took on a dangerous but commonly held myth concerning home fire protection. Unbeknownst to the firefighter, it was at this point that his credibility took a nose dive. Armed with the results of a report by the graduate students of the University of South California that stated "a popular reason for not choosing to protect one's self from fire is--I know about things like fire and I am able to handle this problem myself" (Management Internship Program, 1991, p. 1), he mounted his stump for the grand finale.

Feeling very confident and righteous, the firefighter dramatically exclaimed that because humans have no sense of smell while sleeping, our lives are in peril without the protection of a smoke detector! He had always considered this line as the "coup de grace" to any holdouts, and no challenge was ever raised to this point. Although this concept had been handed down from previous public fire education officers who had influenced him, he realized that he had never seen a reference attesting to this fact. His naiveté was destroyed in the summer of 1996 when a multiple fatality residential fire occurred in south Alabama. Local officials (frustrated with the progress of the investigation) turned their attention to a suspected smoke detection device. Since the occupants had awakened from their sleep only to perish near a window, they surmised that the detector had activated. They were also under the impression that humans could not smell during sleep. A quick literature check revealed that there were no supporting data to justify that position. It was overwhelming to consider that for over 20 years, he had based his entire life safety message on a belief that could not be substantiated. It was at this point that he decided to try to reclaim his convincing argument by researching smell during sleep. The Executive Fire Officer program of the National Fire Academy facilitated this research by exposing him to the systematic problem-solving model covered in Unit 4 (Problem-Solving) of the *Executive Development* class.

LITERATURE REVIEW

To perform a complete literature review, 25 separate libraries, medical institutions, trade organizations, governmental entities, or private companies were queried for information. Surprisingly, a very limited amount of research has been documented in this area of behavioral science. Any discussion or review of the previous related studies must begin with a short introduction about the bodily functions of sleep and smell.

Sleep

"Sleep is a normal, easily reversible, recurrent, and spontaneous state of decreased and less efficient responsiveness to external stimulations" (Goetz, 1991, p. 298). Research has shown that a number of basic states of sleep exist. These states are known as waking, REM (rapid eye movement), and NREM (nonrapid eye movement). REM sleep and NREM sleep are controlled by a separate groups of brain cells, or neurons, located in the brain stem. The brain stem is the hindmost part of the brain that regulates basic survival functions (Pollak, 1996). Specifically, the control of NREM sleep likely resides in widely ranging circuits from the area around the solitary track in the medulla, through the dorsal raphe, and in the basal forebrain area (Hauri, 1992). The responsible groups of brain cells or neurons (all located in the brain stem area) communicate with each other with chemical messengers known as serotonin and norepinephrine (Pollak, 1996).

NREM is further characterized as having four distinctive stages. Humans progress through theses stages in a predetermined order or rhythm. Stage 1 of NREM can be thought of as the boundary between wakefulness and sleep, while stage 2 is the first (lightest) bonafide level of sleep. Stages 3 and 4 represent the most remote levels of responsiveness. A person in stage 4 sleep is very hard to arouse by any outside stimuli (Coren, 1996). Specific stages of sleep have been defined through the "presence of certain electroencephalograms (EEG) patterns that occur during specific behavior sleep periods" (Hauri, 1992, p.4) (see Appendix A for typical EEG patterns). The typical sleep pattern is represented by the following model: Conscious--NREM

Stage 1, 2, 3, 4, 3, 2, REM, NREM 2, 3, 4, 3, 2, REM, etc., (Hauri, 1992). The pattern takes approximately 70 to 90 minutes to be completed and is repeated throughout the night (Goetz, 1991). Dreaming occurs in REM, and it is the easiest state of sleep from which to be aroused.

Most sleep studies are performed in stage 2 (NREM) sleep because we spend 50 percent of our time in light sleep. Stage 2 sleep is determined by a mixed voltage pattern of EEG, "Stage 2 combines spindles and K complexes with a stage 1 background" (Hauri, 1992, p. 4). Sleep spindles are naturally occurring and are the brain's electrical sleep signature. They are further defined as spindle-shaped bursts of 11.5- to 15.5-Hz waves lasting 0.5 to 1.5 seconds. K-complexes or sharp biphasic waves lasting 0.5 seconds also occur naturally or can be induced by external stimulation. Sleep is normally defined as a state in which there is a limited amount of alpha rhythm. Alpha rhythm, or conscious state, is an EEG rhythm with a frequency of 8 to 13 Hz in human adults. Although this rhythm is blocked when the eyes are open, it is very discernible when a person is conscious with their eyes closed. Alpha intrusions are considered brief superimpositions of EEG alpha activity (arousals) during a stage of sleep (Pegram, 1997). Drug abuse can cause an inordinate amount of sleep spindles or alpha intrusions during NREM sleep (Russell Laney, personal communication, May 9, 1996).

Sleep centers use polysomnography machines to monitor patients during their study. These machines typically monitor the electroencephalogram (EEG), eye movements (electrooculogram or EOG), muscle activity (electromyogram or EMG), electrocardiogram (EKG), nasal and air flow, breathing effort (measured at the chest and abdomen), and oximetry. The tracings obtained on a polysomnogram machine represent electrical activity within the cerebral cortex (EEG), voltages generated by muscle fibers (EMG), voltage shifts caused by the movements of the eyes (EOG), and voltages generated by the heart (EKG) (see Appendix B for examples of the various monitoring rhythms).

There are a number of factors that influence the quality of a person's sleep. Age tends to limit the number of hours and, consequently, the completed sleep cycles or patterns humans enjoy. The average senior adult sleeps six hours a day while an infant sleeps fourteen (Howard, 1994). Many drugs (i.e., phenobarbital, secobarbital, et al.) reduce the amount of time spent in REM sleep while other drugs (i.e., barbiturates, amphetamines, and narcotics) have been shown to produce withdrawal symptoms characterized by high percentages of REM sleep (Goetz, 1991). Periods of alpha intrusions are commonly observed in NREM sleep of drug abusers (Russell Laney, personal communication, May 9, 1996). The data clearly supports the position that drugs can have a dramatic effect on sleep

Sleep apnea, night terrors, narcolepsy, hypersomnia, somniloquy (sleep talking), somnambulism (sleepwalking), enuresis (bed wetting), bruxism (tooth grinding), and snoring are all disorders that affect the quality and patterns of sleep. Considerable attention is given to these sleep barriers in current physical as well as mental therapy plans (Goetz, 1991).

The last sleep factor to address in this study is the circadian rhythm or "body's clock" mechanism. Current research suggests that our bodies are regulated by an internal rhythm that ebbs and flows on a regular schedule. Charles Czeisler of Harvard University and the Center for Circadian and Sleep Disorders at Brigham and Women's Hospital in Boston states that "triggered by a daily pattern of sunrise and sunset, the clock can be reset by bright lights" (Howard, 1999, p. 94). If the body's clock gets thrown out of kilter by disease, aging, travel, or some other factor, our sleep patterns will be affected.

Smell

Smelling, the most primitive sense, is the other bodily function under consideration in this project. Smelling (also known as olfaction) is performed by odoriferous molecules attaching to receptor sites located in the nasal cavity. Via a chemical interaction within the receptor sites, a transfer of odor data is accomplished through olfactory dendrites, specialized nerves, and the hypothalamus region of the brain. This is a direct-link, instinctual response system that animals depend on for survival (Piotrowski, 1996). Smelling, like sleep, is controlled in the stem or base area of the brain (Pollak, 1996). This area is described as a continuation of the spinal cord into the brain, and the lowest division of the encephalon. The medulla is truly the connection between the brain and the body (Pick & Howden, 1977).

Smells are classified according to at least the following primary odors: camphor-like, musky, floral, ethereal, pungnant, and putrid. Woody, spicy, and burned have also been suggested as bonafide odor classifications (Piotrowski, 1996).

Due to their fragile nature, olfactory nerves regenerate in a 28-day cycle; nevertheless, about 1 percent of the sites die each year due to damage and general wear. The loss in the ability to smell (anosmia), the state of hyposmia (which is a decrease of the smell function), and dysosmia (an altered sense of smell) can all manifest themselves in numerous ways (Piotrowski, 1996). The common medical problems associated with the loss of smell are smoking habits, nasal polyps, allergic rhinitis, viral and bacterial infections, head injuries, and complications of nasal surgery and brain tumors (Larson, 1996). There is an overall weakening of our ability to smell as we get older (Petraglia, 1991). In 1957, Clalke and Dewhurts reported that 30 percent of a defined group of people over the age of 65 was unable to smell propane gas (Stevens, Cain, and Weinstein, 1987).

Historical Review of Olfactory Sleep Studies

Due to the limited amount of research in this area, the critical findings of others who have performed smoke tests on olfactory senses were somewhat hard to obtain. Early in my literature review, I talked with two medical professionals who had performed fundamental sleep research. When queried about the accumulated body of knowledge in this area, both individuals responded in a similar fashion. Dr. Pietro Badia of the Bowling Green State University Department of Physiology stated that "very few studies have been performed on olfactory response during sleep" (personal communication, May 9, 1997). Dr. Alan Hirsch of the Chicago Smell and Taste Research Foundation suggested that "much more effort needs to be committed to this type of research" (personal communication, May 9, 1997). As a barometer of the sincerity of their responses, I humbly offer their interest in the results of this research. Both individuals requested a copy of this report, and it will be forwarded to them at completion.

Related research was performed by Bryant and Woods during the 1970s. Smoke, along with other fire indicators, was introduced to the study groups to learn how people became aware of the presence of fire (DiNenno, 1988). Latane and Darley duplicated these efforts by introducing smoke into rooms that college students were using for the purpose of completing a written questionnaire (DiNenno.) In every one of these studies, the largest reported "means of awareness" category was smelt smoke.

In 1973, Kahreman concluded his report by stating that "what one perceives is largely dependent on one's needs, experience, and attitudes as well as on the physical characteristics of stimuli (Schwalm, 1991, p. 119)." He declared this after obtaining prior information on 56 subjects and then exposing them to a set of simulated fire scenarios. To obtain performance data, smoke, heat, and sound threats were presented in this experiment. The subjects were evaluated by the time they took to detect simulated fire clues, the time they took to respond to those clues, and the appropriateness of their responses (Schwalm).

Canter, Breaux, and Sime suggested that males and females might react differently when confronted with smoke or fire itself. Their research suggested conventional sex role behavior during fire scenarios and problems associated with nonresponse to stimuli due to negative conditioning. Canter, Breaux, and Sime defined conventional sex role behavior for females as passive and for males as active (Paulsen, 1984).

Murray and Campbell (1970) studied 3-day-old infants to determine their olfactory response. Though their study suggested the presence of olfactory produced response during sleep, it was completed without the benefit of polygraphic recordings and without the consideration of infantile startle response.

Odorous response during sleep was again assessed in a nonpublished proprietary study that was commissioned by a large midwestern public utility. Dr. Alan Hirsch exposed a study group to the principal odorant in natural gas to determine if it would arouse a sleeping subject. It was determined that an extraordinary concentration of the odorant (methyl mercaptan) was required to produce the desired result. In fact, Dr. Hirsch stated (personal communication, May 9, 1997) that "trigeminal or fifth cranial nerve level response was required to awake a person by the smell of methyl mercaptan." The trigeminus nerve is the great sensory nerve of the head and face and the motor nerve of the muscles of mastication (Pick & Howden, 1997). Dr. Hirsch went on to say that "this is equivalent to the odor generated by smelling sauce or a strong onion." From a fire protection point of view, the most important conclusion drawn from Dr. Hirsch's research was the finding that a response derived from a trigeminal level of methyl mercaptan also constitutes an explosive concentration of gas when mixed with an ambient atmosphere.

Intrinsically, the most valuable work in the area of olfactory responses during sleep was published by Micheal J. Kahn and Pietro Badia. In 1983, Kahn studied sleep response to the stimulus of a smoke odor, heat sensations, and auditory alarms. Twenty-four college-aged males were divided into two groups and exposed to smoke alarm sounds of different intensities. By test design, both groups were exposed to heat and smoke odor. Kahn found that sleeping subjects exposed to higher signal-to-noise ratios responded more quickly than those who were not. Kahn also attempted to address an hypothesis concerning the time required for a sleeping adult to respond to a smoke odor. Unfortunately, he reported that "comparing smoke alarm and sleeping human proficiency in detecting a smoke presentation could not be tested meaningfully" (Kahn, 1983, p. 51). He finished his presentation by calling for additional research in this area. In 1991, Pietro Badia evaluated the effects of fragrances on the quality of a person's sleep. In his discussion, he also indicated the need for additional inquiries into the perplexing topic of odor research during sleep.

In 1989, Pietro Badia, Nancy Wesenstern, William Lammers, Joel Culpepper, and John Harsh wrote a report entitled "Responsiveness to Olfactory Stimuli Present in Sleep." The results of their study showed that although the overall responsiveness to olfactory stimuli presented in sleep was low, statistically significant differences in responsiveness to odors were found for micro switch closures, EEG, EMG, and heart rate. The condition of micro switch closure involved the physical manipulation of an electrical switch attached to the patient. Ten patients were presented a peppermint and a nonfragrance air supply via a modified oxygen mask during sleep. Polysonograph machines recorded the biomeasurements listed above to assist the researchers in detecting a psychophysiological response. The patients were presented the fragrance multiple times during the night so that the related dependent variables were repeatedly assessed during the test period. The number of times a patient responded to the condition divided by the opportunities a patient had to respond resulted in a percentage of response variable. These percentages of responses were determined to be statistically significant (Sign test $=p<0.05$) for the overall group. The methodology for reporting these before and after observation was the nonparametric Sign or paired-samples t-test. All fragrance presentations occurred in stage 2 sleep. Awakenings were noted and evaluated separately to determine their rate of occurrence. Sign tests failed to reveal any significant awakening occurrences (Sign test$=p>0.05$). Although multiple trials were presented on each of the 10 patients, only 3 awakenings occurred during the study. Discovering the obvious lack of documentation in the area of olfactory sleep research challenged my natural drive for closure; however, it was the studies involving Badia that excited my aforementioned curiosity in this project and identified a methodology by which smoke odor response could be evaluated.

PROCEDURES

In order to perform a sleep study, one must be affiliated with a sleep clinic. Therefore, the first procedure was to convince one of the local bonafide sleep clinics to assist me in this endeavor. A letter of introduction was prepared and hand delivered to the offices of Dr. Vernon Pegram (800 Montclair Road, Birmingham, Alabama 35213), who is the director of the Sleep Disorder Centers of Alabama [SDCA] (see Appendix C for the letter of introduction). The

National Fire Academy's brochure explaining the Applied Research Projects was also included to validate my request (see Appendix D for the NFA brochure). Within a week of Dr. Pegram's receiving the letter, a meeting was scheduled to discuss the possibility of performing the study with the medical and business staff. Issues concerning the compatibility of this study with that of the primary study were reviewed along with the topics of feasibility and liability. Each issue was resolved and a consensus decision was made to go forward with the project. Clearly, the significance of this subject matter and the lack of recorded data available influenced the decision making process. All parties agreed that the research was needed, important, and achievable before a possible commercial application of this concept was mentioned. A leading manufacturer of smoke detectors is interested in the results of this study, and there existed a good possibility of parlaying this superficial study into a comprehensive commercially funded study. (The SDCA will explore this opportunity after this project has been completed.) A timetable for conducting the research was agreed upon and implemented. The sleep studies were completed during the month of April, 1997.

The subjects or patients in this research were 10 sleep disorder patients of the SDCA who properly responded to the olfactory screen process. This is the defined group for the purposes of this study. The number of patients to be involved in the study was predetermined to be the same number of subjects (10) used in Badia's, et al., test (1989). Dr. Vernon Pegram of the SDCA agreed that this would be an appropriate number to evaluate for similar responses. This is also the minimum population versus sample size identified in the research section of the National Fire Academy course *Executive Development*. The demographics of the group were five Caucasian females, four Caucasian males, and one African-American male. Their ages ranged from 26 to 61 years of age. The mean age for the subjects was 45.60 years of age. They were screened before participation for medication use, health concerns, allergy problems, and for responsiveness to olfactory stimuli in the waking state. The screening process was designed to identify patients with health problems that would either place the patient in jeopardy or corrupt the results of the tests. Two possible subjects were eliminated prior to the sleep portion of the study. The first subject (a Caucasian male) developed an allergic rhinitis condition immediately after the exposure to the smoke odor. This condition effectively blocked his nasal passages. This subject later admitted to being allergic to products of combustion and the event was short in duration. This reaction can be thought of as a form of validation of the authentic nature of the smoke odor selected for use in this study. The second subject (a Caucasian female) eliminated from the study failed to detect any of the odors in the screening process. This subject was referred to the medical staff for evaluation and followup. A total of 12 subjects was evaluated for participation and 2 were eliminated

All patients participating in this study were undergoing sleep studies for other reasons. They were not paid for participating in the smoke odorant research. None of the patients reported a history of smoking. All patients appeared conscious and alert prior to the sleep studies. No specialized breathing equipment such as CPAP (Continuous Positive Airway Pressure) or a nasal cannula was used in this research. Since new patients begin their sleep studies on Monday and Wednesday night, a decision was made to use these patients as the research database. The sleep studies were performed in six different sessions between the hours of midnight and 0200.

For statistical purposes in answering research question three, a determination was made to use three different odorants in this project. In each test, the patient was exposed to all three odorants in a predetermined order: first, a neutral odorant, then a smoke odorant, and finally, a smoke-eliminating citrus odorant. The first odorant used was a placebo of only drinking water. The second odorant administered was a product known as Charsol C-10® that is normally used as a food additive and is produced by the Red Arrow Products Co., Inc., of Manitowoc, Wisconsin. They produce the majority of smoke flavoring used in barbeque sauces in this country. Charsol C-10® smells like smoke generated by a house fire and is described in the product information as "an aqueous solution of natural smoke flavors produced by controlled pyrolysis of mixed hardwoods" (Red Arrow, 1997, p. 1). From a fire or smoke study perspective, it could be said that although there are many causes of smoke odors, the smell of burning wood is considered unmistakable. Wood smoke is the most recognizable of all the smoke odors and there is a perceived danger associated with its presence (Montagna, 1995). Charsol C-10® was chosen after consultations with the technical research staffs of the U. S. Flavors and Fragrances Company (Chicago, Illinois) and the International Flavors and Fragrances Company (Union Beach, NJ). The final odorant selected for the tests was a product known as Ultra Citrus®. It is produced by Medo Industries, Inc., of Tarrytown, New York. This product yields a strong citrus smell that effectively eliminates other odors.

These odorants were chosen for a number of reasons. By using water as a placebo, the background effects on the patient can be identified. Since water was administered in the same manner as the smoke odorant, stimuli resulting from the process of administration could be eliminated. The smoke and citrus odorants were used during the conscious test to establish the capability of the subjects to discern the smoke odor. The conscious tests were always performed prior to the sleep tests so that the subjects could associate the smoke odorant with the threat from fire. The citrus odorant was included for two reasons. Primarily, the role of the citrus product was to stimulate the sleeping subjects in a nonthreatening manner. By doing this, a smoke/citrus comparative analysis can be performed in the results of the study. The secondary reason for using the citrus odorant was to absorb the offensive and lingering smoke odor. Medo states on their product's packaging that "Ultra Citrus® chemically absorbs odors." Since this product was delivered last, the test rooms were left in a deodorized manner so that the patients could continue their primary sleep study.

Patients arrived at SDCA at 2030 hours to be prepared for the night's monitoring. The staff of the SDCA explained the research project and presented the information sheet and permission to participate form to the patients for their review and authorization (see Appendix E for a sample of the patient information sheet, and Appendix F for a sample of the permission to participate form). After the patient signed the release, a series of tests were performed to determine if the patient could discern a difference in the odorants while in a conscious state. These tests were performed to verify the patient's ability to smell the scents used during the sleep study. The conscious or olfactory sensitivity tests were performed by the staff of the SDCA and consisted of a spray discharge of 120 micro liters of the three odorants into the ambient atmosphere. These tests were performed in rooms other than the sleep rooms. After every discharge, the patients were asked to identify the smell of the odorant, and their responses were indicated on a record of observation (see Appendix G for the record of observation). All of the patients responded in a correct manner when identifying the odorants.

The patients were then given an orientation to the various monitoring leads that are customarily attached to a sleep study patient. Electrodes were secured for recording central responses known as brain waves or EEG (C3, C4, O1, O2, left and right mastoids), autonomic responses of pulse and heart rhythm (modified Lead II), eye movement or EOG (outer canthi, above and below midline), muscle movement or EMG (supra- and submental), oxygen concentration, and breathing muscle movement. The respiration belt was secured comfortably around the rib cage at or about the 4th or 5th ribs (figure H1 is a picture of a patient with the various leads attached). For approximately 30 minutes, the staff of the SDCA calibrated their monitoring devices to choreographed movements the patients were required to perform. Once the calibration ritual was complete, the patients were allowed to go to sleep. The polysomnography machine used during this study was a Nihon Kohden model 125 (figure H2 is a picture of a Nihon Kohden model 125 polysomnography machine). Observations of the patients during sleep were also of a visual nature. In addition to a regular closed circuit camera, the SDCA uses an infrared camera by which behavioral responses of the patient can be recorded in total darkness from "lights out" to "lights on."

The patients slept in electrically shielded and sound-attenuated bedrooms. The rooms that the patients sleep in contain approximately 32.5 cubic meters of ambient atmosphere (see Appendix I for a diagram of the sleep room). To isolate the patient's environment, the entrance doors of the sleep rooms were shut. The HVAC (heating, ventilation, and air conditioning) system discharge and return vents were allowed to work in their proper or designed manner to simulate normal air current patterns. None of the ionization smoke detectors activated during the sleep tests.

The patients were told that the same odors presented to them earlier in the night would be presented to them during their sleep and that they should let the observers know if they reached a state of consciousness. The tests were administered while the patients were in stage 2 sleep and this was verified by EEG.

The odorant delivery system for the sleep study was much different from that of the conscious study. The delivery system started with a W. R. Brown Company Speedy® model PC 201 AC compressor pump rated at .35 CFM at 20 P.S.I. or 9,800 milliliters per minutes (Federal Equipment Company, 1991). The compressor discharged into a 6mm (i.d.) plastic Teflon tubing that was approximately 256 centimeters long. Connected to the end of the tubing was a standard banded screw-type automotive hose clamp and the receiving end of a Hudson R.I. Neb-U-Mist® nebulizer (figure J1 is a picture of the setup). The hose clamp ensured that the nebulizer would not be blown off during the tests. The Hudson Respiratory Care, Inc., Company of Temecula, California, manufactures the Neb-U-Mist® style of nebulizer consisting of two different pieces. The first piece is called the nebulizer jar, and it usually contains the fluid or medicine to be used. This particular brand of nebulizer has the advantage of having a ribbed inlet stem that ensures a tight connection with the compressor hose. In this case, one milliliter of odorant was used in each of the three procedures. The odorant was dispensed from standard medical syringes calibrated to determine one milliliter of fluid. The second piece of the nebulizer is called the nebulizer cap, and its primary function is to catch the atomized odorant and route it into a delivery hose (figure J2 is a picture of the nebulizer). The delivery hose used in this study was a piece of 2.5-centimeter (minimum i.d.) corrugated plastic polyvinylchoride ventilator hose approximately 2.44 meters in length. This hose was routed through the ceiling membrane in the hallway, through the double firewall barrier with its insulation, and down through the ceiling membrane into the patient's room. Because the hose is flexible and semitranslucent, installation took place in such a way that the fire wall integrity was never compromised during the study (figure J3 is a picture of the hose passing through ceiling membrane). The delivery hose terminated approximately 218 centimeters away from where the nose of a prone positioned patient would be (Figure J4 is a picture of the delivery hose terminating in the sleep room). To make sure that sound would not interfere with the study, the compressor pump and the nebulizers were operated in a remote location from where the patients slept. The complete odor delivery system was tested to determine if the odor of smoke and citrus was significant enough to test olfactory senses prior to the beginning of the sleep tests. The intent of the odor delivery process was to produce a concentration of odor that is similar to that of a fire in an early stage of development. The odor generated in the sleep rooms did this and was strong enough to produce a residual odor for several hours after administration.

Usually around 0030, the SDCA technicians confirmed that the patient had reached stage 2 sleep and it was time to administer the tests. Each patient was exposed to the discharge produced from 90 seconds of pump operation in which 1 milliliter of odorant was completely nebulized. As in the previous tests, the order of delivery was predetermined and administered by the following schedule: water, smoke odorant, and citrus odorant. A minimum of two minutes of time elapsed between each of the tests conducted. Along with the visual observation of the patient, the SDCA technicians scanned the 12 electrical tracings on a polysomnogram to determine if the patient had been aroused in some way (see Appendix B for a polysomnogram tracing example). Along with any significant reactions, the beginning and ending of each of the three tests were indicated on each of the patient's hard copy monitor recording, computer file, and progress report. The computer software used for scoring (interpreting) sleep studies at the SDCA is called Sandman©, and it is produced by the Nellcor Puritan Bennett Corporation of Ottawa, Ontario. These three sources of patient data were customarily reviewed and scored by the medical staff during the following business day.

Data Analysis

The results of this study will be reported statistically from a Cochran's Q test format. The results were obtained with the assistance of a computer program known as SPSS for Windows 6.1©- PC Plus Student Ware. The program is manufactured by the Statistical Package for Social Sciences Company located in Chicago, Illinois. This methodology of reporting is a non-parametric form used to test whether several dichotomous variables have the same proportion of responses. Basically, the Cochran's Q test allows a statistical analysis of single response to conditions or tests that are of a yes-no nature. In the study performed by Pietro Badia, et al., the nonparametric Sign or paired-samples t-test was performed to evaluate the percentages of observed responses in a repeated process. Both tests evaluate similar responses as variables to the conditions of odors and nonodors presented during sleep. The difference between the tests involves the number of opportunities a subject has to respond, the breathing atmosphere the patient was exposed to, and the nature of odorants used in the tests.

In this project, each subject had the opportunity to respond once to each stimulus or condition. In Badia's, et al., test, each subject had a number of opportunities to respond and a percentage of responses was determined. The method of administration of odorant was through ambient air in this research and by modified oxygen masks in Badia's, et al., project. Using the ambient environment allows the simulation of a normal air current delivery of odors as opposed to the artificial environment of a mask. Using the ambient environment was also necessary due to the multiple evaluations being performed during the same sleep period (see limitations). Finally, the odorants of water, smoke, and citrus were used in this research, whereas Badia, et al., used nonscented air and peppermint. In order to make an inferential comparison between Badia's, et al., study and this one, water is considered a comparable condition to Badia's, et al., nonscented air while citrus and smoke odors are considered comparable conditions to his fragrance of peppermint. The combined variable responses of awakenings and arousals in EEG and EMG are inferentially comparable in both studies and thus form the basis for the evaluative portion of this research project.

Assumptions and Limitations

All subjects participating in this study were patients in a sleep research clinic. They were being evaluated for sleep disorders before, during, and after the various odor tests were being administered. To some degree, all of the subjects had some type of sleep disorder. However, the symptoms of the disorders were monitored and evaluated to prevent the corruption of odor research data.

Another possible limitation of this study involves the design and type of analysis performed. Each subject had one opportunity to respond to the three conditions. A better analysis might be performed in a repeated measures type of study in which each subject would have multiple opportunities to respond to various conditions, and a percentage of responses could be determined. This was not possible due to the fact that the primary reason for the sleep study was to diagnose sleep disorders.

Although the odor delivery process (identified under Procedures section) can be objectively reproduced, the condition of representing an equivalent amount of odor to that of an early stage of fire development was a subjective standard of the researcher. This assumption was made after three different staff members sampled the air in the sleep rooms to determine if the process produced a satisfactory odor. All three agreed that the concentration of the odor was significant and fairly represented the desired effect. The equipment necessary to define the concentration of ambient odors in the sleep rooms was not available to give a scientific measurement for that condition. Due to odor diffusion, that measurement would vary according to the sampling position in the room and the time a sample was taken. If complete saturation of the odorant was achieved, that concentration could be determined by dividing the capacity of the room (32.5 cubic meters) by the one milliliter of odor concentrate (see Appendix I for the various measurements of the sleep room).

Although smoke odor was assessed during this study, none of the customary fire gases were present that contribute to the problem of fire deaths. For example, an ambient exposure resulting in a 20 percent blood saturation of carbon monoxide (a common fire gas) will cause disorientation. Increase this exposure to a 40 percent saturation and unconsciousness will occur. Many of the common fire gases tend to cause loss of smell and the depression of the central nervous system. A few of the fire gases will actually cause a sleeping person to fall deeper into unconsciousness after a limited exposure (Meidl, 1970). The results of a sleep study performed in an environment of fire gases would probably be heavily influenced by this condition.

The last identified limitation involves the lack of smell deficient subjects being represented in the study. All of the subjects in this study were nonsmokers and could easily identify the odors in the screening process. There are however, a significant number of people in the general population of the United States who have a reduced olfactory ability due to smoking or medical reasons (see Smelling under Literature Review). Mr. Bill Orz of the Tobacco Institute in Washington, DC, reports that "there are between forty-two and forty-five million adult smokers in the United States alone" (personal communication, May 22, 1997). If we add the people who have medical problems, the statistics reveal that quite a few people are grouped into the category of diminished smellers. The addition of this group into our research process would probably influence the results.

RESULTS

Appendix K shows the results of the conscious fragrance screening and the proportion of responses (variables) to the three conditions of the sleep tests. Each of the 10 sleeping subjects were scored on the variables of awakenings, EEG (alpha waves or multiple K complexes), and EMG (spontaneously occurring muscle movements) arousals. If one, two, or all three of these variables occurred during a condition, the subject was scored 1 for that condition.

Answers to Research Questions

Research Question 1. The first question was whether a defined group of conscious adults could detect the presence of smoke odor. The answer is yes; all 10 subjects identified the smoke odor. They also gave appropriate responses to the conscious sensitivity tests for citrus and water odors.

Research Question 2. The second question was if the smell of smoke odor would awaken a defined group of sleeping adults. Two of the 10 subjects, or 20 percent, were actually aroused out of stage 2 sleep by the stimulus of smoke odor. This was verified by infrared camera and EEG. Remember that sustained alpha waves indicate a state of consciousness also. The answer to the second question is that smoke odor will awaken 20 percent of a defined group of adults.

Research Question 3. The third question was if the smell of water, smoke, or citrus odors aroused a defined group of sleeping adults. All 10 subjects were monitored by infrared camera, EEG, and EMG for variables or responses to the three conditions of water, smoke, and citrus. Cochran's Q test was used a nonparametric alternative to test overall differences in the proportion of responses among the three conditions. The study resulted in a Cochran's Q =9.00, p=.011. These figures indicated a significant difference among the test conditions.

Next, I followed up with two planned subanalyses performed to determine differences in the proportion of variables or responses to two of the conditions of the study. The degree of freedom rule allows only two subanalyses of the three conditions. The water-smoke and the citrus-smoke comparisons were chosen for subanalysis. Proportional results were established by reporting the number of variables occurring to each condition over the total number of subjects participating.

The water-smoke subanalysis to determine differences in the proportions of responses or variables to these two conditions resulted in a Cochran's Q = 6.00, p=.0143. The proportions (with standard deviations in parentheses) were as follows: smoke proportion = 6/10 (.51640) and water proportion = .00 (.00). These figures indicate a significant difference among the test subjects.

The citrus-smoke subanalysis to determine differences in the proportions of responses or variables to these two conditions resulted in a Cochran's Q = 3.00, p=.0833. The proportions (with standard deviations in parentheses) were as follows: citrus proportion = 3/10 (.48305) and smoke proportion = 6/10 (.51640). These figures do not indicate a significant difference among the test subjects. The third question has two answers: no, the smell of water will not awaken or arouse a defined group of sleep adults, and yes, the smell of smoke and citrus will cause arousals in the same group. These arousals occur in different proportions when responding to different conditions

DISCUSSION

The following can be said regarding olfactory sensitivity in sleep. There were significantly more EEG and EMG responses to fragrances than to nonfragrances. The present data not only indicate that sensitivity to olfactory stimuli presented in sleep can be assessed using central (EEG) and autonomic (EKG and EMG) measures, but it also yields the finding that those measures varied markedly in the various subjects.

The results of this research project can be inferentially compared with the study made by Pietro Badia, et al., discussed in the literature review. The overall results of Badia's, et al., study indicated a significant difference in the percentages of responses (variables) the subjects made to the various conditions of the study. Likewise, the overall results of this study indicate a significant difference among the subjects in their responses (variables) to similar conditions. The implications of these comparisons support a hypothesis that adults do respond to olfactory stimuli during sleep.

The subanalysis performed within the set of conditions of this study reveals some interesting data. When the condition of smoke was compared with the condition of water, the subjects responded in a significantly different proportion; however, when the condition of smoke was compared with the condition of citrus, a less than significant proportion of responses occurred. Considering this, it may be that it is just the presence of some type of fragrance versus no fragrance (i.e., water) that is important for subject response in sleep.

Unexpectedly, the data reflect that awakenings in this research occurred only to the condition of a smoke odor. Perhaps, a smoke odor is more meaningful than the citrus odor due to an association the subject(s) may have with this condition and danger.

By far, the most relevant to life safety finding derived from this research is the affirmation of Badia's, et al., observation that few people are actually awakened from a state of sleep by an odor stimulus. In this study, 2 of the 10 subjects (20 percent) awoke to the conditions of water, smoke, or citrus odors. In Badia's, et al., research, 3 of the 10 subjects (30 percent) awoke to the repeated conditions of air or peppermint odors. Statistically, these figures represent a significant difference among the test conditions. Very few of either study's sleeping subjects responded to any of the conditions mentioned by actually waking up. The implications of these findings are astonishing. The fire protection afforded by residential smoke detectors is the only prudent manner to protect oneself from the threat of fires occurring during sleep.

The results of this research project allow the Irondale Fire and Rescue Service to reclaim (with credibility) the convincing argument of smoke failing to awaken 80 percent of the participants of this study as the reason for having smoke detectors.

RECOMMENDATIONS

Recommendation 1. Fire prevention programs should incorporate the rationale that olfactory functions cannot be relied on to provide protection from fire occurring while we sleep. Manufacturers of smoke detectors, trade associations and organizations, teaching institutions, and government bodies should embrace these findings and incorporate them into print as well as audiovisual media.

Recommendation 2. Since olfactory functions cannot be relied on to provide protection during sleep, manufacturers of smoke detectors should begin a program of research and development to emulate our conscious olfactory ability. Olfactometers are currently being used for other purposes and could be incorporated into the design of smoke detectors. This would provide a reduced threshold of the detection time required to sound an alarm and therefore activate during incipient fires. The desired effect of this would be saving lives by earlier detection of fires. One of the first steps in developing an olfactometer-detector would be the integration of the carbon monoxide meter into the common smoke detector. Since most fire deaths occur as a result of carbon monoxide poisoning (DeHaan, 1991), this would be the logical place to start.

Recommendation 3. Additional sleep studies should be performed to identify odors that are likely to arouse us from sleep. If specific odors can be identified, products that liberate that odor during fires can be incorporated into the manufacture of common building materials and home furnishings. Consequently, an incipient fire would therefore provide notice of its existence by production of chemically manipulated fire products. This concept is very similar to the industrial process of adding a chemical odorant known as methyl mercaptan to natural gas for the purpose of providing early detection.

Recommendation 4. Now that we know that our olfactory sense will not protect us from the threat of fire during sleep, we should rededicate ourselves to public fire education initiatives that address smoke detector compliance. This is not merely a fire prevention activity. In the text *Essentials of Fire Fighting*, the writer states that "while an early warning is often credited with saving the lives of the home's occupants, do not forget that the smoke detector's warning may have also protected a firefighter having to enter the structure" (Wieder, Smith, & Brackage, 1992, p. 535). Early notification of firefighters can easily translate into safer fire attack scenarios. It is usually much safer to engage in a firefighting operation in the early stages of fire development. Considered in this light, a public education campaign addressing smoke detector compliance is also addressing the firefighter's personal safety.

REFERENCE LIST

American National Standards Institute. (1993). *Standard for Safety Single and Multiple Station Smoke Detectors* (217). New York: Author.

Bachtler, J. R. & Brennan, T. F. (Eds.). (1995). *The fire chief's handbook*. (5th ed., p. 991). Saddle Brook, NJ: Fire Engineering.

Badia, P., Wesensten, N., Lammers, W., Cullpepper, J., and Harsh, J. (1989, September). *Responsiveness to olfactory stimuli presented in sleep[1]*. Bowling Green, OH: University of Bowling Green State University, Department of Psychology.

Badia, P. (1991). *Olfaction sensitivity in sleep: effects of fragrances on the quality of sleep.* Bowling Green, OH: Bowling Green State University, Department of Psychology.

Bare, W. K. (1977). *Fundamentals of fire prevention.* (pp. 14-15). Englewood Cliffs, NJ: Prentice-Hall.

Bukowski, R. W. (1993, January-February). Studies assess performance of residential detectors. *NFPA Journal,* pp. 48-54.

City of Birmingham, Alabama, Fire Department. (1997). *1996 Annual Report*. Birmingham, AL: Author.

City of Phoenix, Arizona Fire Department. (1997). *1996 annual report*. Phoenix, AZ: Author.

Cooper, L. (1996, October). Does your smoke detector really work? *Consumers' Research*, pp. 30-32.

Coren, S. (1996). *Sleep thieves: An eye-opening exploration into the science and mysteries of sleep* (pp. 23-35). New York: The Free Press.

Coughlin, P. (1994, August). Are aging smoke detectors a safety threat? *Operation Life Safety*, p. 7.

Cote, A. E. (Ed.). (1991). *Fire protection handbook*. (17th ed., chap. 10-3, p. 21). Quincy, MA: National Fire Protection Association.

CRC Industries, Inc. (1997, January). *Technical Data Sheet-Smoke Test.* Warminster, PA: Author.

DeHaan, J. D. (1991). *Kirk's fire investigation*. (3rd ed., pp. 310-314). Englewood Cliffs, NJ: Prentice-Hall.

DiNenno, P. J. (Ed.) (1988). *SFPE handbook of fire protection engineering.* (lst ed., chap. 1-16, pp. 269-285). Quincy, MA: National Fire Protection Association.

Disney Educational Productions. (1987). *Donald's Fire Survival Plan* (Rev. ed.) [video tape]. (Available from Disney Educational Productions, 105 Terry Drive, Suite 170, Newtown, PA 18940-3425).

Federal Emergency Management Agency. (1990). *America Burning Revisited* (USFA Publication No. 1990-724-156/20430, p. 57). Washington, DC: U.S. Government Printing Office.

______. (1993). *Fire in the United States 1983-1990* (USFA Publication No. FA-140, p. 103). Washington, DC: U.S. Government Printing Office.

______. (1997). Fire in the United States 1985-1994. (pp. 78-91). Unpublished raw data.

______. (1988, October). *Smoke Detectors: Don't Stay Home Without One*, (L-163) [Brochure]. Washington, DC: U. S. Government Printing Office.

Federal Equipment Company. (1991). *Equipment specifications-Speedy* [Brochure]. North Chicago, IL: Author.

Goetz, R. (Ed.). (1991). *The New Encyclopedia Britannica*. (15th ed., Vol. 27, pp. 298-308.) Chicago: Encyclopedia Britannica.

Hall, J. R. (1994, September-October). The U. S. experience with smoke detectors: Who has them? How well do they work? When don't they work? *NFPA Journal,* pp. 36-45.

Hauri, P. J. (1992). *Sleep disorders* (pp. 4-7). Kalamazoo, Michigan: The Up John Company.

How it works. (1993, Spring). *Fire Findings,* p. 4.

Howard, P. J. (1994). *The owner's manual for the brain* (pp. 92-104). Austin, TX: Leornian Press.

Jameson Home Products. (1994, August). *Owners manual* (Code One 2000 Smoke and Fire Alarm-110-284J) [Brochure]. Downers Grove, IL: Author.

Kahn, M. J. (1983, June). *Detection times to fire-related stimuli by sleeping subjects*. Raleigh: North Carolina State University, Department of Psychology.

Larson, D. E. (Ed.). (1996). *Mayo clinic family health book*. (2nd ed.). New York: Morrow.

MacClary, M. (Producer), & Estus, B. (Director). (1986). *Firepower* [videotape]. (Available from the National Fire Protection Association, Quincy, MA)

Management Internship Program. (1991, May). *Final report for the fire sprinkler advisory board of southern California*. Los Angeles: University of Southern California, Graduate School of Business Administration.

Marray, B., & Campbell, D. (1970). Difference between olfactory thresholds in two sleep states in the newborn infant. *Pyschonomic Science*, *18*, 313-314.

Meidl, J. H. (1970). *Explosive and toxic hazardous materials* (pp. 288-305). New York: Macmillian.

Montagna, F. C. (1995, March). Odor of smoke. *Fire Engineering*, pp. 69-72.

Marriott, M. D. (1995, June). Reliability and Effectiveness of Domestic Smoke Alarms. *Fire Engineers Journal*, pp. 10-13.

National Commission on Fire Prevention and Control. (1973). *America Burning* (Publication No. 1973-0-495-792). Washington, DC: U. S. Government Printing Office.

National Fire Protection Association. (1996). *National Fire Alarm Code* (NFPA 72, pp. 101-102). Quincy, MA: Author.

Parks, C. A. (1990). *Smoke Detector Compliance in Single Family Dwellings*. Executive Fire Officer Research Paper, Emmitsburg, MD: National Fire Academy.

Paulsen, R. L. (1984, May). Human behavior and fires: An introduction. *Fire technology*, pp. 15-27.

Pegram, V. (1997). *Training manual 1* (pp. 3-26). Birmingham, Alabama: Author.

Petraglia, J. S. (1991, March-April). Fire and the aging of America. *NFPA Journal*, 37-46.

Pick, H, & Howden R. (Eds.). (1977). *Gray's Anatomy* (p. 725). New York: Bounty.

Piotrowski, N. A. (Ed.). (1996). *Magill's medical guide-health and illness supplement* (Vol. 6, pp. 1603-1607). Pasadena, CA: Salem Press.

Pollak, C. (1996). Sleep [CD-ROM]. *The 1996 Grolier Multimedia Encyclopedia* (Version 8.01). Danbury, CT: Grolier Electronic Publishing.

Red Arrow Company. (1997, February). *Red Arrow Products Specifications: Charsol C-10* (Item 100110) [Brochure]. Manitowoc, WI: Author.

Rubin, D. L. (1996, November). Chief concerns--Wingspread IV. *Firehouse*, pp. 28-30.

______. (1997, March). Wingspread IV--a practical look. *Firehouse*, pp. 42-44.

Schwalm, N. D. (1981, July). The effects of attitudes and experience on human behavior in fires. *Fire Journal*, pp. 118-122.

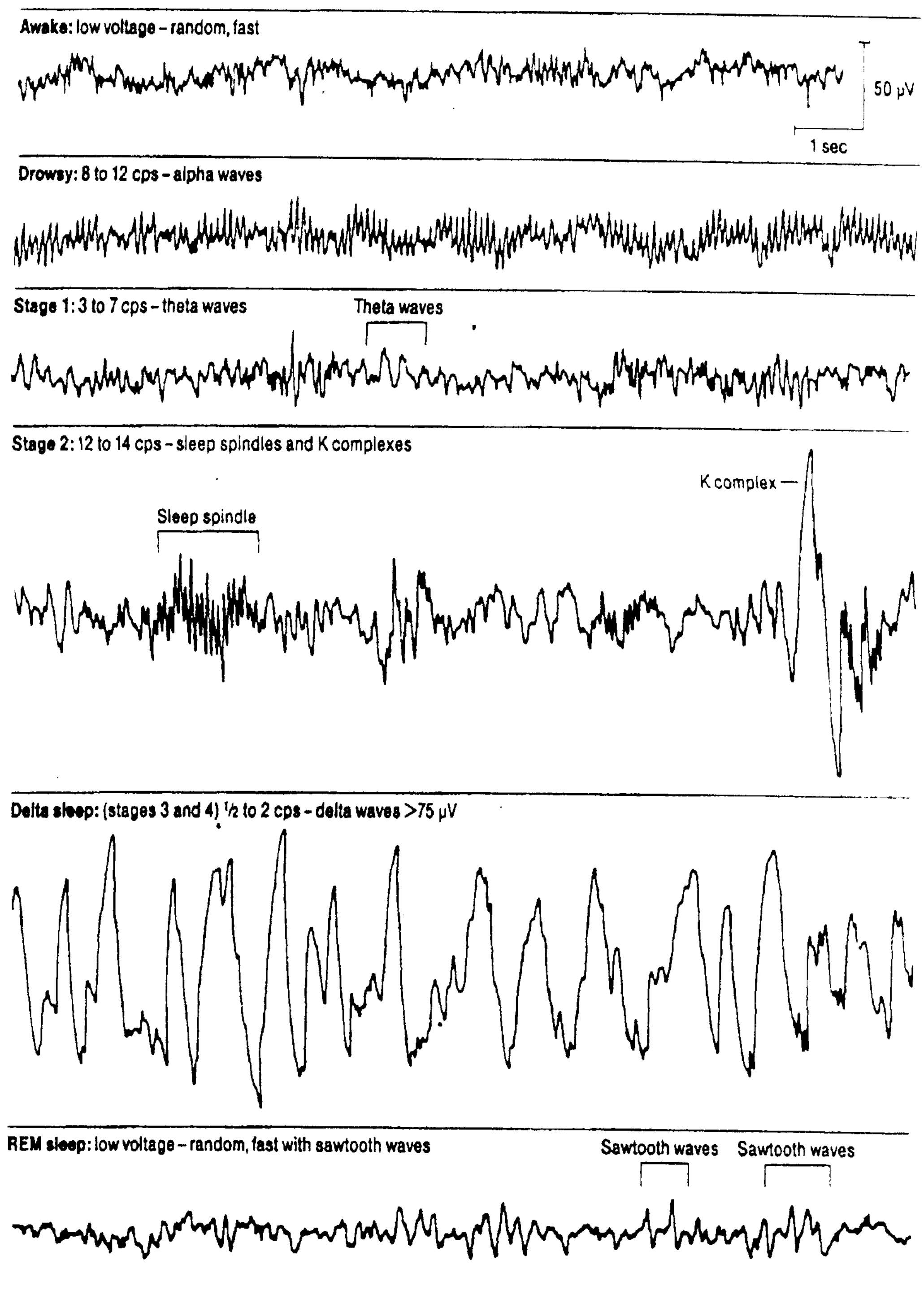
Southey, R. A. (1995). *Smoke detectors: a Bullhead City, Arizona experience*. Executive Fire Officer Research Paper, Emmitsburg, MD: National Fire Academy.

Stevens, J. C., Cain, W. S., Weinstein, D. E. (1987, August). Aging impairs the ability to detect gas odor. *Fire Technology*, *23* (3), 198-204.

Timmons, R. (Ed.). (1996, Summer). *First Alert Junior Fire Inspector Program*. (Available from BRK Brands, Inc., 3901 Liberty Street Road, Aurora, IL 60504-8122)

Wieder, M. A., Smith, C., and Brackage, C. (Eds.). (1992). *Essentials of fire fighting*. (3rd ed., p. 535). Stillwater, OK: Fire Protection Publications.

Appendix A
Typical EEG Patterns

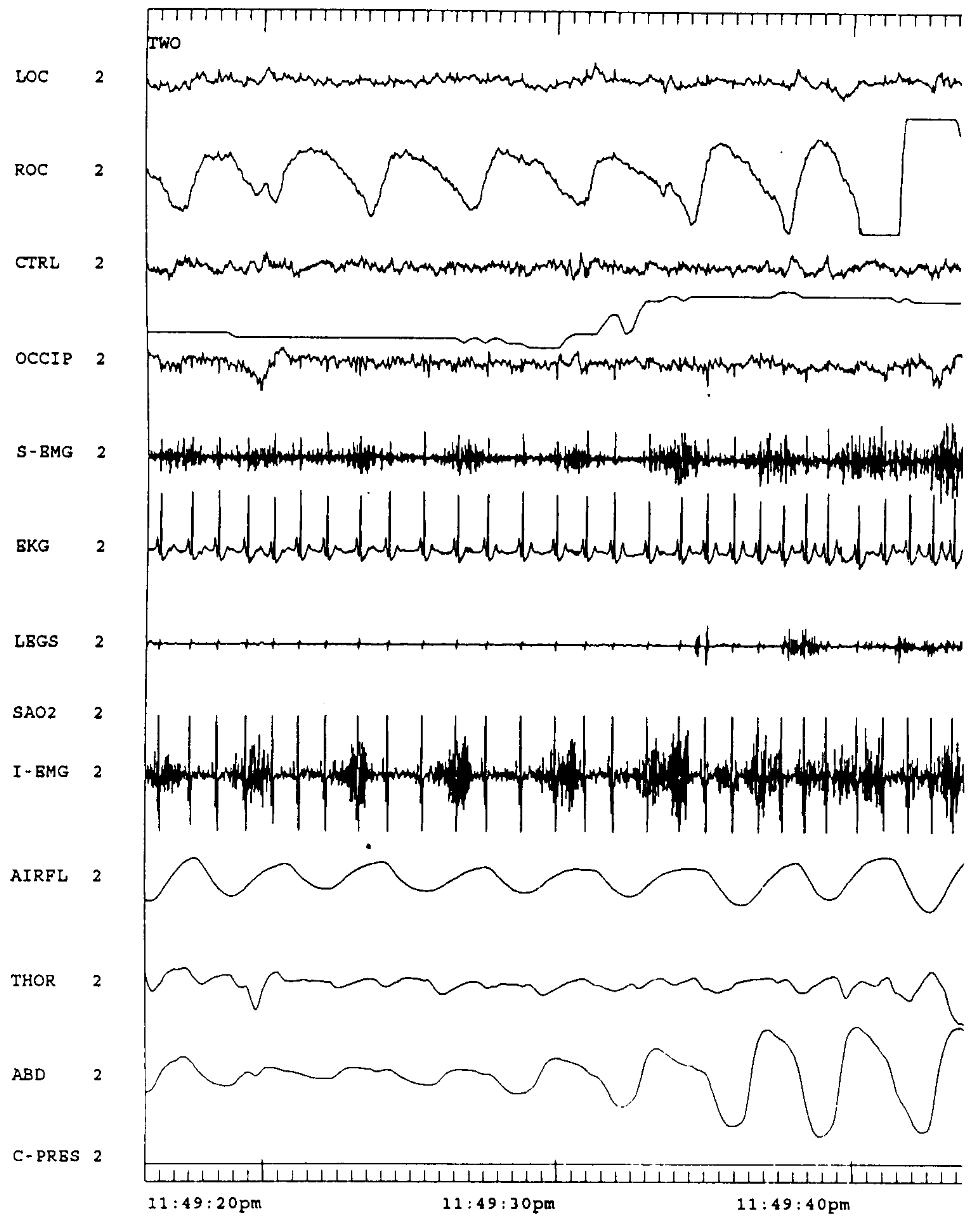

Awake: low voltage – random, fast
50 µV
1 sec
Drowsy: 8 to 12 cps – alpha waves
Stage 1: 3 to 7 cps – theta waves
Theta waves
Stage 2: 12 to 14 cps – sleep spindles and K complexes
K complex
Sleep spindle
Delta sleep: (stages 3 and 4) ½ to 2 cps – delta waves >75 µV
REM sleep: low voltage – random, fast with sawtooth waves
Sawtooth waves
Sawtooth waves

Appendix B
Various Monitoring Rythums

Appendix B
Various Monitoring Rhythms

Name :

Comments:



Appendix C
Letter of Introduction

2-26-97

Dr. Vernon Pegram
University of Alabama at Birmingham
Sleep Wake Disorder Center
1713 6th Ave. South
Birmingham, Alabama 35294-0018

Dear Dr. Pegram,

Let me start with a small introduction-My name is Joe Lynch and I need your help! Part of my responsibilities to the City of Irondale is to attend the National Fire Academy annually and to perform meaningful research associated with the various programs of the Irondale Fire Department. Smoke detector education is a fundamental element of our public education program and it is mostly driven by compliance issues. Apathy seems to be the primary cause of a noncompliance with our local smoke detector laws and ordinances. It is my belief that many of our noncompliant citizens would respond to meaningful information about the limitation of our sleep-time olfactory senses if evidence of this could be substantiated. This is the focus or reason behind my request.

I would like to determine if adult subjects can detect the odor of smoke while asleep. I propose that informed, willing, and monitored adults be subjected to a safe exposure of odorants for a brief time during sleep and after your primary studies have been completed. I would also like to have a copy of the various monitor outputs immediately before, during, and immediately after the test for the study. I am prepared to develop an information sheet to be given to the patients and a consent form for participation in the study. I will also provide a report copy back to the participants and you when my project is completed. It is my desire to perform this research on ten adults of various genders and ethnic backgrounds. I am willing to be present and administer the odorants. The method of administration would be a standard air freshener spray pump bottle delivering one (1) 120 microliter spray from a predetermined distance from the patient. The odorant will be delivered in the ambient room atmosphere. I would also like to administer the odorant tests to the subjects while they are awake to determine their ability to detect the odors. This could be performed the morning after the sleep study.

Additional information about my applied research project requirement and a copy of prior related studies is attached for your review.

Since this is part of the responsibilities associated with being the fire chief, the city's liability insurance would provide coverage for this process.

I would also like to mention that the makers of the First Alert brand of smoke detector is very interested in this project and I can see the possibility of them funding a comprehensive project in this area.

Please review this package and I will contact you next week to arrange a time in which I can show you the odorants as well as the administration pump bottles.

Sincerely,

____

Joe Lynch, Fire Chief

Appendix D
NFA Brochure

Federal Emergency Management Agency
United States Fire Administration
National Fire Academy
Executive Fire Officer

Applied Research Projects

Philosophy

A significant measure of the professionalism of any occupation is the quality and quantity of the research upon which the discipline is based. The Executive Fire Officer Research project helps the National Fire Academy achieve its mission of increasing the professionalism of the fire service.

Purpose

The Applied Research Project in the Executive Fire Officer Program is designed to allow students to investigate a key issue or problem that has been identified as being important to their fire service organization. Upon completing the investigation, students will be able to reach conclusions and offer recommendations which will contribute to the improvement of their organization.

Through this process, students have an opportunity to translate what they have learned in the Executive Fire Officer courses into real-world applicants. By writing the applied research project in a professional paper format, Executive Fire Officer students are contributing to the fire service literature.

Process

Students are required to complete one applied research project for each of the four courses in the Executive Fire Officer Program. The reports are to be sent to the National Fire Academy within 6 months of completing each course. A project must be evaluated as acceptable in order for the student to continue in the Executive Fire Officer program. To be acceptable, a project must receive a grade of "C" or higher.

Product

Specific products are developed as a result of the Executive Fire Officer Applied Research Project which are beneficial to the student, local government, fire service, and the National Fire Academy. Students receive individualized evaluation to their critical thinking skills; local problems are solved; a computer data base containing the research projects is available to the Nation's fire service; and the National Fire Academy receives feedback relating to the application of the knowledge, skills, and abilities of its graduates. All of these benefits contribute to the reduction of our Nation's fire problem.

Appendix E
Patient Information Sheet

Dear Patient,

My name is Joe Lynch and I serve as Fire Chief in the City of Irondale. I am involved in an exciting research project that will hopefully prevent some of the tragic fire deaths in our community. Each and every year, a number of our neighbors experience fires during the night. Most of them are awakened by the sound of smoke detectors going off and are able to escape. Unfortunately, there are others that for some reason or another, perish in the fire. Although national statistics suggests a strong connection between having a smoke detector and being able to survive a night fire, many of our neighbors have failed to protect themselves with an inexpensive detector.

Why is smoke detector compliance a problem? It is my belief that many of our neighbors rely on their sense of smell alone to awaken them in the event of a night fire. This is why I am asking your permission and cooperation to take part in a simple procedure to determine if the smell of smoke will arouse an adult while they are sleeping. I need help to solve this simple question of great importance-***Will the smell of smoke cause an adult to wake up from sleep?***

What procedure will be used in the test? If you agree, you will be exposed to two different scents to determine if they will arouse you from sleep. This process will not interfere with your scheduled sleep study and the scents used are either actual air fresheners or their equivalent in strength. The scents do not represent a health threat to the participants of the study. The duration of the scent test will be approximately one minute and you will be constantly monitored for reaction. The scents will be lightly sprayed into the air of the room in which you are sleeping in and then allowed to dissipate. To make sure that you do not have a condition that would prevent you from detecting the scents, a base line testing process will occur either before or after your sleep test. This base line process is identical to the sleep test.

Health Risks: No health risks have been identified that are associated with these scents. The scents are natural products that smell like smoke and citrus fruit. Medical histories that would prevent you from participating in this program include asthma, pulmonary disease, heart disease, history of smoking, smelling disorders, or similar conditions that make you hypersensitive to common scents or odors.

When Will the Program Take Place? The sleep study shall take place during the months of March and April, 1997.

Release of personal information will not occur. Each patient will be classified as to gender, age, race, and known smelling disorders. Names, addresses, phone numbers and other specific patient information will not be requested or obtained for this study.

Copies of this report will be made available to the patients. A copy of my report will be presented to Dr. Pegram at the completion of the research project. Patients may obtain a copy of the report by indicating their request on the "Permission to Participate" form.

How can I help? By signing the "Permission to Participate" form you are indicating that you will participate and allow us to answer this question about the smell of smoke and sleep. The findings of this study will be the basis for the creation of a free public fire education program that I will market in the greater Birmingham area.

Appendix F
Permission to Participate Form

This form acknowledges my agreement to participate in a sleep study designed to determine if the smell of smoke will awake a sleeping adult and that I know of no health problem or sensitivity that would prevent me from participating. I understand that for purposes of describing the resulting data, my race, gender, and age will be documented and that the results of the study will be sent to me at the completion of the study utilizing the address listed at the bottom of this form.

Patient's signature:____________________ Date: ______________
Witnesses's signature:_________________

Patient Code_________

(please print)

Patient's Name: _______________________
Patient's Address: _____________________
____
____
____

Patient's Gender: Male:_______Female:_______
Patient's Age:_______

Please list any known health problems or smelling disorders: _______________________________
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Appendix G
Record of Observations

PATIENT CODE:_________

DATE OF TESTS: AWAKE:________ SLEEP:________

LOCATION OF TESTS:________________

TIME OF TESTS: AWAKE:________ SLEEP:__________

WITNESS OF TESTS:____

-OBSERVATIONS-

AWAKE

Reported Smelling Water _______

Detected Smoke Smell _______

Detected Citrus Smell _______

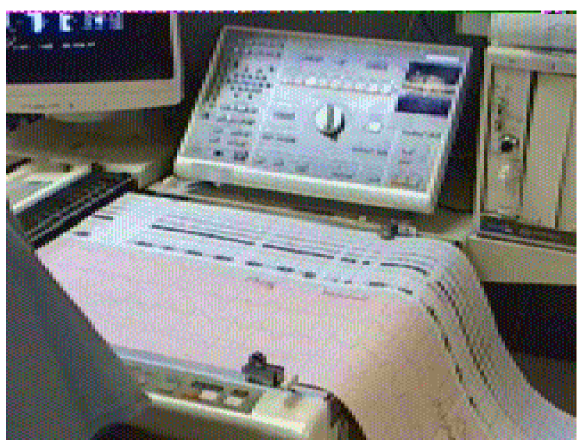
SLEEP

Water Smell Awakening _______

Smoke Smell Awakening _______

Citrus Smell Awakening _______

Appendix H
Photographs of Sleep Study



Appendix I
Diagram of Sleep Room

Appendix J
Photographs of Odor Delivery Systems

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Photographs of Odor Delivery Systems

J1 - a picture of the setup.

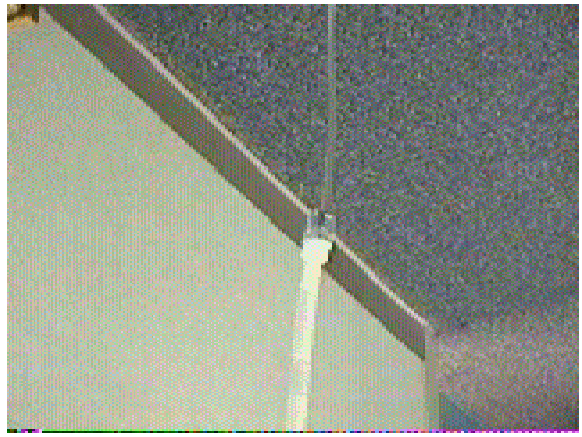

Figure J2 - a picture of the nebulizer

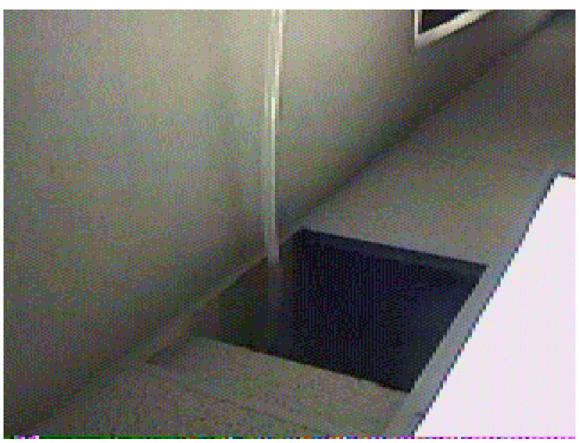

Figure J3 - a picture of the hose passing through the ceiling membrane.

Figure J4 - a picture of the delivery hose terminating in the sleep room.

Appendix K
Results of Odor Tests

Patient Code	Race	Gender	Age	Awake reactions (S) smells odor (NR) no reaction			Sleep reactions (A) Awakening (E) EEG arousal (NR) no reaction (M) EMG arousal		
				Water	Smoke	Citrus	Water	Smoke	Citrus
1	C	M	48	NR	S	S	NR	A	NR
2	C	F	41	NR	S	S	NR	E	E
3	C	F	52	NR	S	S	NR	E,M	NR
4	C	M	26	NR	S	S	NR	NR	NR
5	C	F	52	NR	S	S	NR	E,M	NR
6	C	M	40	NR	S	S	NR	NR	NR
7	AA	M	41	NR	S	S	NR	NR	NR
8	C	F	54	NR	S	S	NR	E	E
9	C	F	41	NR	S	S	NR	A	M
10	C	M	61	NR	S	S	NR	NR	NR

Note: Responses or variables were a minimum of .00 and a maximum of 1.00. N=10. Proportional results were established by reporting the number of variables occurring to each condition over the total number of subjects participating. Overall test response proportions (with standard deviations in parentheses) were Water 0 (.00), Smoke 6/10 (.51640), and Citrus 3/10 (.48305).