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Detection Times to Fire-Related Stimuli By Sleeping Subjects

June 1983

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U.S. Department of Commerce
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Detection Times to Fire-Related Stimuli By Sleeping Subjects

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ABSTRACT

KAHN, MICHAEL JOEL. Detection Times to Fire-Related Stimuli by Sleeping Subjects. (Under the direction of Dr. RICHARD G. PEARSON.)

A laboratory study was conducted to determine human waking and response times to fire-related stimuli. Twenty-four college-age male subjects were tested with each subject being run for one night. Twelve subjects were exposed to smoke alarm warning signals of three intensities while a second set of twelve subjects was exposed to a smoke odor, a heat presentation, and one smoke alarm warning signal. Subjects were, without fail, awakened by alarms that reached their ears at a signal/noise ratio of 34 dB. They were considerably less effective in waking to the heat, the smoke odor, and alarm sounds that reached their ears at a signal/noise ratio of 10 dB or less. Failure to detect these latter stimuli may have resulted from a lack of familiarization with the specific fire-related cues used in this research. Had training in detection of these cues been conducted, subjects might have been more responsive. Using similar logic an argument can be made that standardization of signals used for household smoke detectors would be beneficial.

BIOGRAPHY

Michael Kahn was born in York, Pennsylvania on May 12, 1957. He was brought up in Barrington, Rhode Island where he completed his elementary and secondary education, graduating from Barrington Public High School in 1975.

The author then attended Bucknell University in Lewisburg, Pennsylvania where he majored in business management and then literature. He graduated with a B.A. in English in 1979. He spent a year as a reading skills teacher for Baldridge Reading Study Skills, Greenwich, Connecticut.

The author then moved to Raleigh, North Carolina to attend a graduate program in psychology and ergonomics at North Carolina State University. He expects to graduate from this institution with an M.S. in December, 1982.

ACKNOWLEDGMENTS

I would like to thank Dr. Richard G. Pearson for providing guidance in my selection of a topic, sharing his reference materials, and allowing me use of his laboratory facilities. More importantly, I want to thank Dr. Pearson for allowing me the opportunity to mature personally and develop skills and pride in my chosen profession.

Secondly, for his input to the methods section, results section, and writing style, I would like to thank Dr. Donald H. Mershon. These contributions enhanced the quality of this research to such a degree that they cannot be overrated. I also give special thanks to Dr. Mershon for his friendship and sensitivity to the human difficulties of a student attempting a project he is not confident he can complete.

I want to thank Dr. Michael G. Joost for his continued input toward the construction of the odor and heat apparatuses, microprocessor control system, and psychophysiological amplifier. Though I was unable to complete these final two projects, I believe what I learned under his guidance will allow me to be more successful when I undertake future engineering projects.

Gratitude is expressed to Pat Knowles for her willingness to help me by typing within time frames that were extremely inconvenient to her. Dr. Norman D. Schwalm, whose dissertation report greatly facilitated the completion of this thesis, is also acknowledged.

My thanks to fellow students who contributed their own time to help make this project work. I thank Paul Blue for his aid in the results section and Alex Little and Pat McMurtry for help with electrical and microprocessor projects. I thank all of you for your friendship.

Finally I would like to thank my parents for their love.

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INTRODUCTION

History of North Carolina State Fire Research Studies

This research is designed as a follow-up study to previous work conducted by Dr. Richard G. Pearson and Dr. Norman D. Schwalm at North Carolina State University (Pearson, 1980; Schwalm, 1979, 1980; Schwalm and Pearson, undated). The continuing rationale behind all of these studies will be briefly reviewed. The bulk of this report, however, will be to explore questions suggested by the original studies as well as questions specifically raised by Dr. Richard G. Pearson in a personal interview.

Schwalm and Pearson cite Karter (1980) who estimated that approximately 2,845,000 fires occurred in the U.S. in 1979. Associated with these fires were approximately 7,780 civilian deaths and 31,325 reported injuries.

Schwalm (1979) has stated that most fire research to date has dealt with the physical properties of fire and to a lesser degree, with simulated mass evacuation from buildings. In those studies which have dealt with human behavior (Bryan, 1975, 1976; Wood, 1972), data were gathered after the fire emergency had ended and therefore were based upon participants' subjective recollection of their actions. Schwalm argued for increased laboratory testing which will allow the experimenter to study the decision-making processes of a subject involved in a fire emergency.

In attempting to understand human decision-making, Schwalm examined several information processing models, ultimately selecting a model of human behavior in fires put forward by Canter, Breaux and Sime (1978). These authors divide human behavior in fire emergency situations into four components: 1) receiving information (the perceptual component), 2) interpreting information (the interpretation component), 3) preparing to act on the information (the decision component), and 4) acting on the information (the action component).

Schwalm applied the model of Canter et al., suggesting that a subject's attitudes and personality could affect the time that passes before the subject detects the stimuli, the time the subject expends deciding upon appropriate action, the nature of the action taken, and the time to act. Schwalm's (1979) model of human behavior in fires is shown in Figure 1. His results indicated significant effects of attitudes and personality on decision time and on action taken, while detection time results were ambiguous. (The action time component of the model is shown in broken lines as Schwalm did not actually test the relationship between attitudes and personality and action time.)

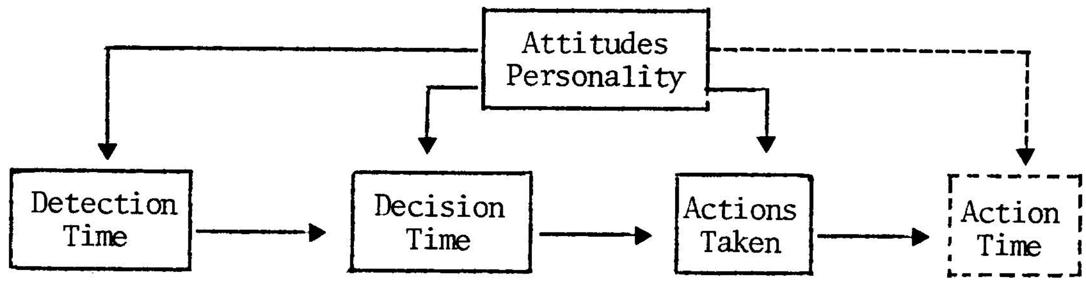

Figure 1. Schwalm's model of human behavior in fires (Schwalm, 1979).

Pearson applied further data to this model by actually determining the times required to complete actions associated with fire egress. This research utilized subjects who were blind or who were confined to wheelchairs, as well as those who were able-bodied. Subjects were warned of mock fires by an auditory alarm and then performed a number of fire egress behaviors such as calling the fire department and unlocking dead bolts. Subjects' progress was monitored and times required to perform activities derived by use of micro-switches which the subject would trip while performing the scenarios. This allowed Pearson to publish a report relating the action times required for blind, wheelchair-confined, and nonhandicapped people to perform various egress behaviors (Pearson, 1980).

In addition to providing a well-organized structure against which studies of human fire behavior can be located, the work of Pearson and Schwalm suggests that behavior is composed of steps, each of which must be performed sequentially and each of which takes a certain amount of time to complete. Successful fire behavior, either egress or fire fighting, is one in which the appropriate behavior is completed before the resident is overcome by smoke or other fire-related hazards. The more quickly this behavior is instituted and completed, the less the probability that the resident will be overcome and possibly killed. A modified version of Schwalm's model of behavior in fires can aid in determining the times necessary to complete fire-related behaviors. This model is presented in Figure 2.

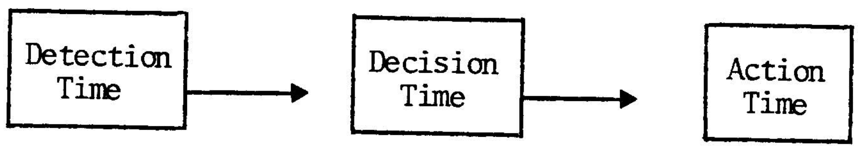

Figure 2. Time to complete human fire behaviors (after Schwalm, 1979).

As Pearson has already compiled a report relating the action times required to complete various fire behaviors and Schwalm has done the same relating decision time and action taken, a sleep study of various fire-related cues seemed a reasonable extension (Pearson, personal communication).

The Importance of Early Fire Detection

The first step to a successful escape is detecting the fire. If stimuli related to the fire are not detected, appropriate actions cannot be initiated. Several fire studies, for example, have indicated a significant time lapse between the researcher's estimate of when the fire commenced and when a person first became aware of the fire's presence (Bryan and DiNenno, 1979; Demers, 1978; Lanthrop, 1978). It can be assumed that any time lost between fire onset and fire detection may be critical, since it seems that in many actual cases by the time fire detection occurs, egress routes have been rendered impassable (Best, 1977; Demers, 1978).

This importance of early fire detection seems to have been recognized in the great number of fire detection devices being currently researched and sold. Doubtless, these devices have been instrumental in saving a great number of lives. Despite the use of mechanical detectors, however, it seems that most fires are detected as a result of other fire-related stimuli. These stimuli include odoriferous and visual components of smoke, hearing the fire-related activity of other humans such as running and/or verbal warning, and feeling heat (Bryan, 1977). Finally, even in those instances when an electromechanical smoke detector does sound an alarm, it is ultimately the human who must become aware of this stimulus. A listing of Bryan's findings as to how people become aware of fire is provided in Appendix A.

Factors Affecting Stimulus Detection by Humans

The detection threshold of a stimulus is not constant across all people and situations. In fact, to assume that because one human in one fire situation is able to detect a certain stimulus, the same or another person in a different fire situation will detect a similar stimulus might be greatly in error. It is therefore useful to isolate factors which play a role in determining thresholds to fire-related stimuli. Fortunately, cognitive psychologists have provided data on a great number of these factors.

The examination of the factors in fire emergency situations that may be most relevant to latency of human detection will be undertaken from an information processing point of view. As such, characteristics of the fire situation which the human is apt to detect will be regarded as stimuli and the human will be viewed as the perceiver and processor of these stimuli. To aid in the reader's understanding of this approach, a brief discussion of the human as an information processor will be provided. This approach will, I am sure, be familiar to those involved in psychology but may perhaps be helpful to those accustomed to working in the physical sciences.

The Human as an Information Processor

The information processing approach views the human perceptual process as being similar to a general information communications system. A general information system receives information from the outside world and encodes the information so it can be transported via a channel to a given destination. At the destination the coded message is decoded (Dember and Warm, 1979). This general communications system is shown in Figure 3.

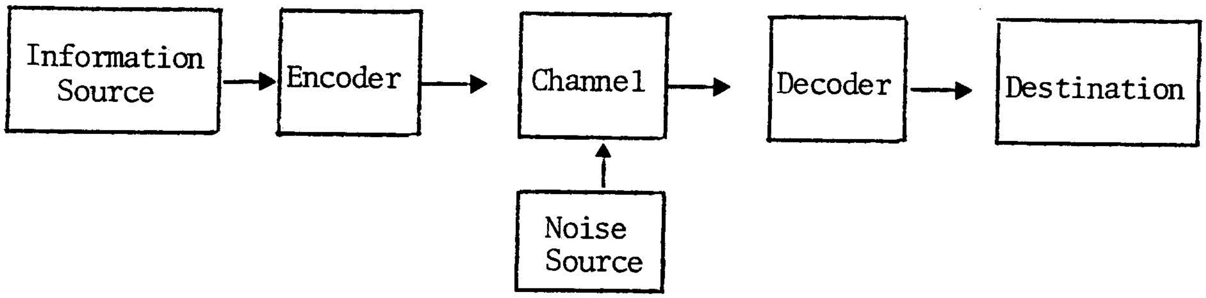

Figure 3. Schematic diagram of the flow of information through a general communications system (Dember and Warm, 1979).

Like the general communications system, the human information processing system is seen as receiving information, encoding information, sending information via a channel, and decoding at a destination. In this case, however, the incoming information is referred to as a stimulus. Stimuli are received by sensory receptors where they are encoded in the form of nerve impulses and travel via the central nervous system to the cortical brain centers. Here the nerve impulses are decoded and an appropriate response determined. A schematic diagram of the human as an information processor is shown in Figure 4.

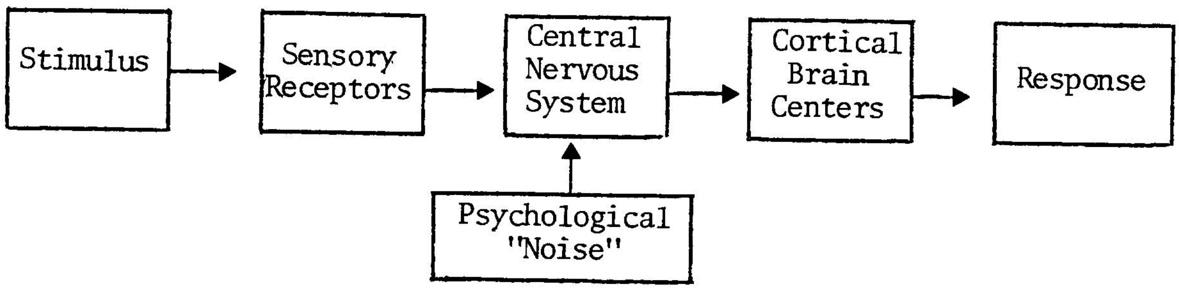

Figure 4. Schematic diagram of the human as an information processor (Dember and Warm, 1979).

A great deal of research has provided validity to the information processing models such as the one introduced by Dember and Warm. The conceptual advantage of a model such as this is that the researcher is able to picture information being transduced and passed on through the system. If for some reason a response is either not provided, or is not appropriate to the stimulus, the schematic can provide a conceptual structure for considering possible causes of the perceptual "breakdown."

Thresholds

There is often great variability in a subject's ability to detect discretely presented stimuli even though they may be of equal intensity. It is therefore necessary to establish a criterion stating the proportion of stimuli of a given intensity the subject must be able to detect before we are justified in saying, "Yes, the subject can detect a stimulus of this intensity." This criterion of successful detection has been labeled a subject's threshold.

In a general sense a threshold can be defined as the minimum strength of a stimulus required for the accomplishment of a response task. Operationally, threshold is often defined as the amount of stimulus energy needed for a response task to be accomplished with an arbitrary criterion of response. Most often this criterion is set at 50 percent. Hence, if in a number of repeated trials a subject is able to detect a sound of a certain intensity in 50 percent of the trials and unable to detect the same sound in 50 percent of the trials, that sound would be said to be at that subject's threshold. A stimulus intensity which the subject detects in greater than 50 percent of the trials is said to be above threshold, while a stimulus intensity which the subject is able to detect in less than 50 percent of the trials is said to be below threshold. Although different methods can be employed in determining an individual's threshold value, the underlying aim of the methods is to determine a stimulus intensity such that the subject is able to detect the stimulus on half the presentations and unable to detect the stimulus on the other half of the presentations.

Stimulus Intensity

As implied in the previous discussion of thresholds, a more intense stimulus is more apt to be detected by the subject. Loeb and Binford (1963), for instance, demonstrated that as auditory signal intensity increased above background noise its detection became progressively more likely.

Likewise, Loeb and Schmidt (1963) found that auditory signals presented at 60 dB were responded to more quickly than those presented at 10 dB. Employing a different stimulus modality, Barlow (1958) showed human subjects were more apt to detect a test light of greater intensity than they were one of lesser intensity.

It should be noted that the size and the duration of the stimulus presentation often interact with the stimulus intensity in determining a subject's threshold. These phenomena, referred to as spatial summation, and temporal summation respectively, operate to the effect that a subject who does not detect a certain light stimulus may do so if the target size and/or duration of presentation are increased (Barlow, 1958). Spatial and temporal summation are also relevant factors in the response to heat. Marks, Stevens and Jepper (1976) found that the threshold for detecting heat varies with the size of the area to which the heat is presented and with its duration, as well as with the intensity of the heat.

A further factor that may affect stimulus detection is the rise-time of a stimulus. LeVere, Davis, Mills, Berger and Reiter (1976) demonstrated that as rise-times of auditory stimuli decreased cortical desynchronization of sleeping subjects increased. Similarly, Kenshalo, Holmes and Wood (1968) have demonstrated that if the rate of temperature change is less than one-tenth of a degree Celsius per second

(.1^{o}C/sec.) subjects' thresholds to heat stimuli increase. Although studies of rise-time are more difficult to design for olfactory stimuli, and as far as this author knows none have been accomplished, it is reasonable to expect that rate of change will also be a salient factor in odor detection.

Stimulus intensity, target size, duration, and rise-time all have an effect on stimulus detection. It is therefore essential that an experimenter present stimuli as similar as possible to those which an actual fire would produce, if he/she wishes to generalize the results to the natural environment. It is also clear that such generalization should always be done with caution.

Salience of Stimulus

In a dichotic listening study performed by Moray (1959), subjects were told to shadow a passage presented to one ear. Moray found the subjects were apt to switch their attention and follow a message presented to the supposedly unattended ear if the message was preceded by the mention of the subject's name. The subjects, however, were not apt to follow a message presented to the "unattended" ear if this message was not preceded by their names. Explaining this, Triesman (1960) suggested that thresholds for salient stimuli are lower than those for less salient stimuli.

This lower threshold for meaningful stimuli has also been shown in sleeping subjects. Langford, Meddis and Pearson (1974) demonstrated that subjects woke more quickly to a tape recording which repeated their name than they did to the same tape played backwards. Similarly Zung and Wilson (1960) found sleeping subjects were able to discriminate and respond to signals more quickly when financially rewarded for response to these signals.

It seems reasonable to expect that, due to a fire's relative importance, a subject will maintain a lower threshold for fire-related stimuli than he/she would for innocuous stimuli. This lower threshold concept, however, is based on two suppositions: firstly, that the subject has made a mental connection between fire-related stimuli and the possibility that a fire actually exists. If a subject senses a smoke odor but does not identify the smell as fire-related, we could not expect a lower threshold. Secondly, it is necessary that the subject views fire as a meaningful event.

Subject State: High vs. Low Attention to Environment

One human-related factor that correlates with frequency of stimulus detection is the amount of attention a subject devotes to searching for the stimulus. Experiments manipulating subjects' attention have been of two sorts. Some have presented tasks to distract subjects' attention from the relevant event while others have varied the frequency of presentation of the target stimulus.

Utilizing the distraction method, Bate (1969) demonstrated that subjects engaged in tracking tasks took longer to respond to "emergency" stimuli (whether visual or auditory) as the task they were involved in became more demanding. As more of a subject's attention was devoted to the "primary" task, he/she seemed to have less attention to devote to other tasks.

A different sort of experiment, performed by Jenkins (1958), involved manipulating subjects' thresholds to stimuli by varying the frequency of stimulus presentation. Jenkins observed that, as the frequency of stimulus presentation increased, subjects were more apt to detect a given stimulus presentation.

In both the Bate study and the Jenkins study, it can be seen that as subjects' levels of attention to the environment increased, their detection rates also increased. It has been suggested (Jerison and Pickett, 1964) that such effects of attention can be attributed to changes in the frequency with which the subject "samples" the environment for a possible stimulus. Increased attention thus implies increased sampling frequency.

Subject State: Sleep vs. Awake

In an auditory response experiment, Keefe, Johnson and Hunter (1971) employed tones of 1000 Hz, presented for 5 second durations, and separated by 55 second interstimulus intervals. In this study, subjects were told to press a button when they detected the tone. Keefe et al. found that subjects' thresholds when awake, for the most part, fell between 35 dB and 40 dB. They noted, however, that when asleep, the same subjects did not awaken and respond by pressing the button until tones between 70 dB and 80 dB had been presented. In addition to noting that thresholds to auditory stimuli were higher in sleep, Keefe et al. noted a greater variance in the auditory thresholds of sleeping subjects.

This greater variance of response thresholds of sleeping subjects may be to some extent explained by evidence that suggests that the different sleep stages are associated with different detection thresholds.[1] Although Keefe et al. (1971) were unable to detect any threshold differences associated with sleep stage, Pisano, Rosadini, Rossi and Zattoni (1966), in a study utilizing electric shocks, noted that the threshold of arousal is greater in stages 2, 3, and 4 than it is in stage 1. Likewise, Rechtschaffen, Hauri and Zeitlin (1966), using 2000 Hz auditory stimuli of an unstated but constant value above ambient noise, noted their subjects demonstrated thresholds in stages 1, 2, and REM sleep which were similar but lower than waking

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[1]Rechtschaffen and Kales (1968) describe five stages of sleep as differentiated by electroencephalograms, electro-oculograms, and electromyograms (EEGs, EOGs, and EMGs, respectively). These stages have been labeled stage 1, stage 2, stage 3, stage 4, and rapid eye movement (REM).

thresholds in stages 3 and 4. Finally, Bradley and Meddis (1974), using a white noise of gradually increasing sound pressure, indicated that arousal thresholds were higher in dreaming sleep (most often associated with REM) than in other sleep stages.

It should be noted that Keefe et al., as well as Bradley and Meddis, utilized a button press as a criterion of response, while Pisano et al. made use of a verbal response, and Rechtschaffen et al., a small verbal quiz.

Keefe et al. have suggested that the difference in results across these experiments could be the result of the different arousal stimuli, different methods of stimulus presentation, and different criteria of arousal employed. Examining this point more closely, it can be seen that the concern of Keefe et al. regarding the difference in the stimuli presented and in the method of stimulus presentation is most probably based on the awareness that subtle differences in stimulus parameters may have marked effects on response thresholds (see previous section: Stimulus Intensity, Target Size, Duration, and Rise-Time).

As to how the criteria of arousal employed may bear on the measurement of sleep threshold, Keefe et al. cite the assertion by Goodenough, Lems and Shapiro (1965) that a subject may appear awake in a physiological sense, yet may not have recovered cognitive orientation and coordination. Keefe et al. therefore suggested that simple detection thresholds may be the same across different stages of sleep, but that lack of mental coordination at the moment of awakening may prevent subjects awakened from some sleep stages from making the appropriate response.

It seems that an examination of the relationship between sleep stages and effective responses to fire stimuli might produce some interesting results. Technical difficulties in determining sleep stages accurately prevent this problem from being addressed directly in the present study. The problem itself has been outlined, however, because it is important to be aware of some general points in doing any sleep research. Firstly, sleep is not a homogeneous state in which we can expect to find a constant arousal threshold. Secondly, measurements of arousal thresholds will be significantly affected by the criteria of arousal employed. Thirdly, research on sleep stages has indicated that certain parameters of the stimuli may play as great a role in detection during sleep as they do in the detection performance of waking subjects. Finally, it is clear from the complexity of sleep research that the beginning researcher should be realistic in setting research objectives and circumspect in the interpretation of sleep data.

Subject State: Drugged vs. Undrugged

Bonnet, Webb and Barnard (1979) noted drugs taken by subjects before sleeping had a marked effect on the subjects' arousal from sleep. Specifically, Bonnet et al. reported that when either flurazepam or pentobarbital was administered to subjects just before sleeping, the sound pressure (at 1000 Hz) required to wake these subjects was greater than that required to wake subjects who had been administered placebos just before sleeping. Caffeine administered before sleep, on the other hand, tended to decrease arousal thresholds.

Bonnet et al. also determined subjects' auditory thresholds immediately after the subjects had been awakened from sleep. These thresholds were consistent with values found for arousal from sleep. Flurazepam and pentobarbital were associated with higher thresholds than placebo, while caffeine was associated with lower thresholds. Thresholds determined during the waking state, however, differed in that they tended to have smaller overall means and smaller variances than those determined during sleep.

Bonnet et al. further noted that the drugs seemed to have their most profound effect early in the night, with arousal from sleep thresholds becoming more similar to those of the placebo subjects as the night continued.

Smoke Detector Alarms

Smoke detector alarms must be seen as having two functions: detecting smoke and alerting people who might be in danger. A breakdown in either function renders the alarm ineffective.

It is generally assumed that smoke detector alarms detect smoke more effectively than people. They are located at ceiling level where smoke is most dense; they function even when humans are asleep; and they are remote, thus monitoring areas where people are not present. All in all, smoke detector alarms have been considered useful devices. Schwalm states:

> There is near absolute agreement among researchers in the field of fire detection that smoke detectors comprise the single most effective early-warning system for individuals in fire situations. The fact that they 'buy' precious seconds in escape time from fires and thereby increase the probability of successful escape, is largely undisputed. (1979, p. 24)

Despite this, and rightfully so, questions concerning the alerting effectiveness of smoke detector alarms have been raised: Does the known presence of a smoke detector alarm cause people to rely on this device to such a degree that they may ignore other fire-related cues (Schwalm, 1979)? How long does it take a sleeping adult to detect and respond to a smoke alarm (Nober, Pierce, Well, Johnson and Clifton, 1980)? What are some factors that determine when and if a smoke alarm will alert a sleeping adult (Berry, 1978; Nober et al., 1980)?

Schwalm's argument, that fire cue detection will be inhibited by a subject's awareness of a smoke detector alarm's presence, was not supported by his data.

In a study measuring detection and response times to smoke alarms, Nober et al. (1980) tested subjects in nighttime home settings. They found mean response times of subjects, assumed to be asleep, to be 7.4 seconds at 85 dBA, 9.5 seconds at 70 dBA, and 13.6 seconds at 55 dBA. When alarms were presented against an air conditioner sound, such that mean signal/noise ratio was 21.0 dB, subjects responded in an average of 18.8 seconds. Decreasing the average signal/noise ratio to 4.2 dB resulted in a mean response time of 43.4 seconds. Response times to the 4.2 dB signal/noise ratio, however, were actually longer in that 30 percent of the Nober et al. subjects did not respond at all within a 240 second cut-off time. These subjects were excluded from the main results and analyzed separately.

The Nober et al. work makes two things apparent: 1) the detection and response to smoke alarms during sleep is not necessarily as instantaneous as our subjective experience would have us believe; 2) detection and response to a smoke alarm is contingent upon the signal/noise ratio.

Berry (1978) similarly warns that "detectors which are remote from the bedroom may not be loud enough to awaken the average person." This is due to the attenuation of the signal as it passes through space, walls, doors, and ceilings, as well as masking by sounds such as air conditioners.

The Present Study

Purpose

1) To determine response times of sleeping subjects to five specific fire-related stimuli: a smoke odor, a heat stimulus, and an auditory alarm presented at three sound pressure levels.

2) To plot a curve allowing visual comparison of response times to those treatments.

3) To compare the alerting effectiveness of an electromechanical smoke detector alarm to the alerting effectiveness of the odor stimulus itself. This evaluation will be performed with one odor and two smoke detectors.

4) To examine the effect of time elapsed since a subject has gone to bed on his response latency.

Specific Hypotheses

1) Subjects will respond more quickly to alarm sounds reaching their ears at higher intensities than they will to alarm sounds reaching their ears at lower intensities.

2) Subject response times to louder alarms will show a smaller variance than subject response times to quieter alarms.

3) Subjects will respond more quickly to the final stimulus presented during sleep than they will to earlier stimulus presentations.

4a) The mean response time of subjects to the loudest alarm employed, plus the time for the smoke detector to detect the presence of the smoke, will be smaller than the subjects' mean response time to the smoke odor.

4b) The mean response time of subjects to the least intense alarm employed, plus the time for the smoke detector to detect the presence of the smoke, will be greater than the subjects' mean response time to the smoke odor.

METHOD

Subjects

Twenty-four male students taken from introductory psychology classes were employed as subjects. Subjects received either $7.50 and two research hours toward course credit, $5.00 and three credit hours, or five credit hours. Subjects' mean age was 21.3 years, ranging from 19.1 to 24.7 years.

Subjects were those who by their own report did not use nonprescription drugs, drink to the point of intoxication, or use any type of sleep aids, more than four times per week. The screening procedure used is described in the Preliminary Interview subsection and shown in Appendix C. One subject of the twenty-nine interviewed was unusable by these specifications. It is possible a subject alternating between use of these substances could be "high" every day of the week and not separated by this procedure. Fortunately, subject responses indicate this was not the case (Appendix D).

Apparatus

Experimental Chamber

The experiment was conducted in the North Carolina State University Fire Study Laboratory which is shown in Figure 5. This laboratory consists of a bedroom chamber,

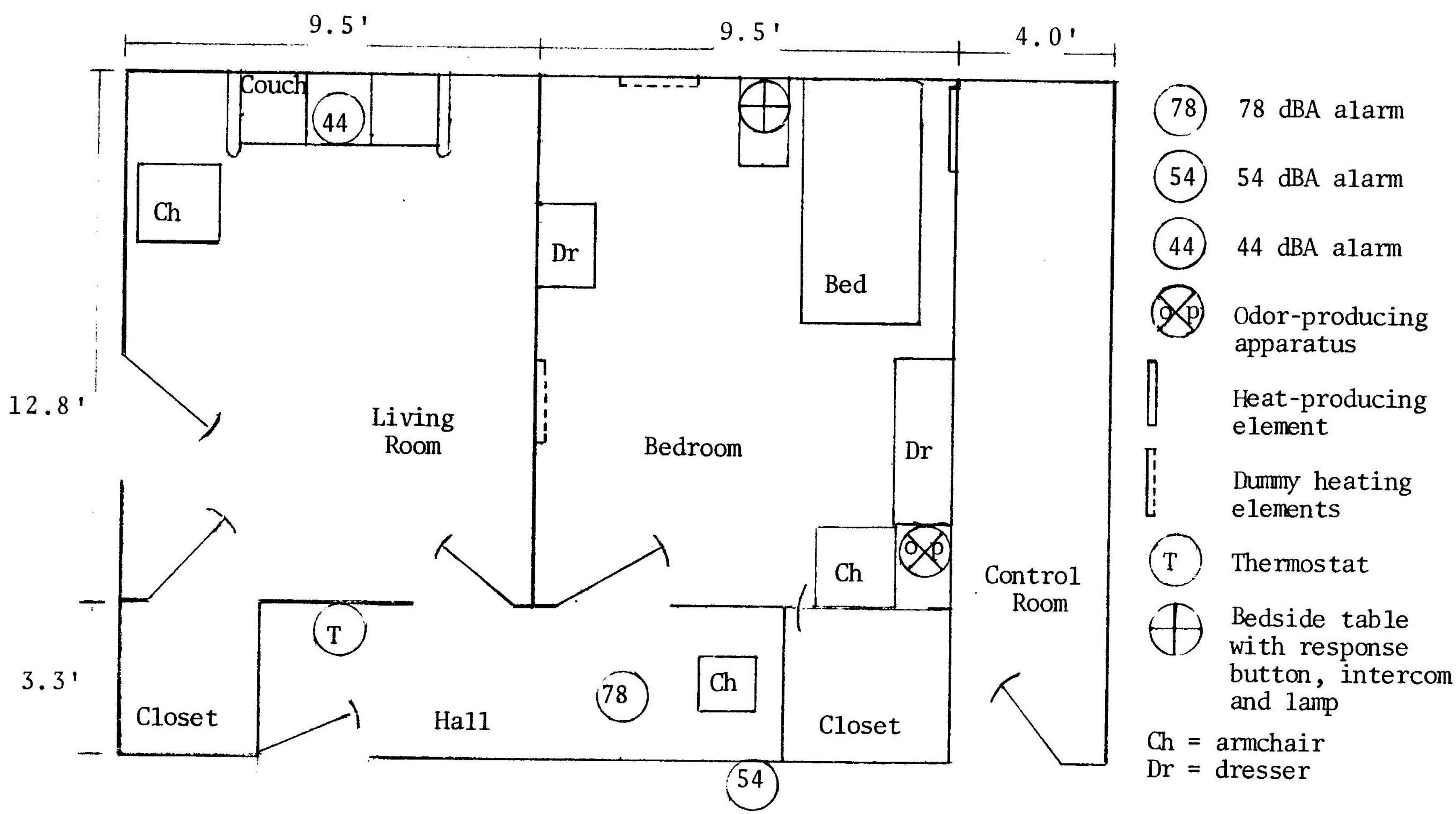

Figure 5. Layout of experimental chambers.

a living room chamber, a hallway connecting the two chambers, and a control room. Chamber floors were carpeted and ceilings covered with white stucco. Some walls were paneled while others were painted. In general the laboratory was intended to provide a soft, "homelike" environment.

Smoke Alarm

A General Electric model 8201-401 smoke alarm was employed. This alarm produces a bi-periodic signal peaking at 2000 and 4000 Hz.[2]

The smoke alarm was moved to different locations in order to create three different sound intensities as measured at the subject's head position. As was the case for every treatment in this study, the alarm could be activated remotely from the control room. All alarm presentations were made with laboratory doors closed. Attaching the alarm to the hall ceiling just outside the hall/bedroom door allowed the presentation of a 78 dBA signal. A 54 dBA signal was presented when the alarm was fastened to the outside of the outer hall wall. Finally, a 44 dBA warning could be presented by locating the alarm under a couch cushion in the living room.

All alarm treatments were presented against a 44 dBA air conditioner background. Subtracting this background

[2]When placed in the 78 dBA alarm location, and with the hall/bedroom door left open, this alarm produced an 85 dBA signal as measured at the subject's approximate head position. A frequency analysis showed 84 dBA at 2000 Hz and 70 dBA at 4000 Hz.

level from the three signal levels shows the alarm sounds provided signal/noise ratios of 34, 10, and 0 dB.

Odor-Producing Apparatus

This apparatus consisted of three 150 watt, General Electric soft-light light bulbs spray painted with flat black paint. When activated this unit produced a burning odor. A baffle constructed of two cardboard boxes was arranged around the bulbs, to contain the light which would otherwise have been visible in the dark room. The odor-producing apparatus was hidden behind a chair in the bedroom.

In order to maximize the odor produced by the unit, a fresh application of paint was made on the afternoon prior to each subject session requiring this apparatus. Three sets of bulbs were used over the twelve smoke trials to reduce any variance in odor due to accumulation of paint layers.

The experimenter's subjective evaluation of the odor is that it was blatant and had a rapid rise-time, becoming detectable at the bed within two minutes. Of the three subjects who detected the odor, two described it as "something burning," and one as, "rubber burning."

Heat-Producing Apparatus

Heat was introduced by an Aztec[3] model ATH66, 750 watt radiant heater. Visually this device resembles a 2 ft. (.6 m) by 4 ft. (1.2 m) office ceiling tile, having been designed to substitute for such tiles.

A cabinet was constructed to hold the heating apparatus such that the planar heating surface was held 2 in. (.1 m) from the wall. Positioned thus, the heating surface was 9 in. (.2 m) from the closest edge of the bed and 28 in. (.7 m) from the center of the bed (see Figure 5). The heating surface was adjacent to the bed from the head to a distance of approximately 25 in. (.6 m) down the bed. The vertical coverage of the heating surface extended from 2 in. (.1 m) above the height of the bed to 49.5 in. (1.3 m) above the height of the bed.

It was assumed that when the heater was activated the subject's closest body part would be not less than 9 in. (.3 m) and not greater than 28 in. (.7 m) from the heating surface. An equipment trial placing conventional thermometers at these two distances showed the same temperature at both locations (70°F, 22°C) upon heater activation. However, as minutes elapsed the closer thermometer recorded a more rapid heat increase showing 97°F (36°C) after 20 minutes while at the same time the further thermometer

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[3]Aztec International Ltd., 2417 Aztec Rd., N.E., Albuquerque, N.M. 87107. Actual tile measurements are 23.5 in. (.6 m) by 47.5 in. (1.2 m).

showed only 82°F (29°C). A table showing temperature increase by minute is provided in Appendix B.[4] All chamber doors were closed during heat presentations.

Two dummy heating elements were also installed in the bedroom. It was hoped these would make the presence of the working element less conspicuous. The disguise of the working heating element was considered effective in that only one subject asked the purpose of the units.

<u>Other Equipment</u>

Subject responses were made by pressing a small doorbell-type button located next to the bed. The button was dimly lit from within so as to be visible but not intrusive.

An intercom was available for communication but, except for during actual communication, was kept in an "off" mode.

Procedure

<u>Preliminary Interview</u>

Subjects who indicated a possible interest in the experiment by signing their names on a posted request were usually first contacted by telephone. During this initial

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[4]Ambient temperatures in the lab chamber varied between 64°F (18°C) and 70°F (21°C). Hence the values related earlier in this subsection and in Appendix B must be considered chiefly representative of a scenario in which the ambient laboratory temperature was 70°F (21°C). A smaller ambient temperature range would have been desirable but this was not possible as the lab chamber temperature covaried with the building temperature.

interview the subject's birthdate was determined, and drug use and sleep habits were explored. The drug use section was designed to help the experimenter identify those who used sleep aids regularly, as well as those who were regular users of alcohol and nonprescription drugs. Students who used sleep aids, alcohol to the point of intoxication, or nonprescription drugs more than four times a week were considered unusable and were not run. As previously stated, a student who alternated between use of these substances could be "high" more than four days a week and not be eliminated by this procedure (see Appendix D for subject responses to Preliminary Interview questions).

It was felt that eliminating some subjects was the only feasible alternative, as allowing them to pursue normal high consumption patterns would introduce drug effects into the study. On the other hand, asking these individuals to refrain from their normal consumption patterns could result in subjects being tested in physiological states not usual to them.

It was then requested that subjects take no nonprescription drugs and limit their alcohol and caffeine consumption on the day preceding their scheduled session in the laboratory. If these restraints were acceptable to the subject, a time and date were set. Subjects were to arrive at the lab. between fifteen and thirty minutes before the time they normally went to sleep. (A copy of the Preliminary Interview protocol is provided in Appendix C.)

Subject Introduction

When the subject arrived at the Fire Study Laboratory, the experimenter led him to the inner chamber. Once there the experimenter entered into general conversation with the subject. This allowed the subject an opportunity to become comfortable with the experimenter and experimental setting. When the subject appeared ready to progress with the study, the experimenter read the introduction to him.

The subject introduction, which is presented in Appendix E, informed the subject that as he slept the environment in the room was apt to change. He was told that, if he noticed any changes, he should contact the experimenter by pushing the subject response button, and communicate the nature of the change verbally through the intercom.

The experimenter then left the room and went to the control room where he initiated a response button/intercom test. This procedure is shown in Appendix F. As well as minimizing the possibility of apparatus failure, this allowed the subject an opportunity to become familiar with these devices.

Presentation of Stimuli

The first stimulus of a session was presented two hours after the subject reported turning the lights out, in order to go to sleep. The second and third stimulus presentations were made after four and six hours, respectively.

Presentation of different stimuli necessitated different preparatory procedures. These included activating or deactivating the air conditioner and placing the alarm in the appropriate locations. The schedule used to guide these preparatory steps is shown in Appendix G. These preparations were usually made without any awareness on the part of the subject. At no time did any subject report hearing sounds directly related to treatment preparation.[5]

Design

Two experiments, each employing twelve subjects, were conducted concurrently. In Experiment 1 each subject received one presentation of each of the three alarm intensities. Two subjects received each of the six possible orderings of stimuli. In Experiment 2 subjects received the 54 dBA alarm, the odor stimulus, and the heat stimulus. Again, each treatment was presented once to each subject and in different orders.

A randomized block design was used, in order to reduce the possibility of introducing bias caused by any systematic change in the equipment, experimenter, or subject pool over

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[5]Early in their sessions some subjects did report hearing sounds inadvertently caused by the experimenter. These included reports of objects dropped or bumped in the control room.

time (see Appendix H). According to this design each sequential even/odd pair of ordered time slots constituted a cell. It was determined that within each cell the subject associated with one time slot would be assigned to Experiment 1 treatments and the other to Experiment 2 treatments.[6]

Secondly it was specified that each permutation of treatment order would be run before any were repeated. This divided the time slots available into an earlier and a later block with each of the twelve permutations of treatment order (six from each experiment) being run in each block.

Within these constraints assignment of experiment number and permutation to a time slot was by random number table. This final assignment is shown in Appendix H.

In all cases the dependent variable is the number of seconds which passed between the initiation of a stimulus and when the subject pushed the response button. Though it is assumed this dependent variable is a measure of the time to awake from sleep, all that can be said with certainty is that a) subjects were in bed during their normal sleep hours, and b) the experimenter observed no evidence which would indicate any subject was awake just prior to treatment presentation.

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[6]Subjects were given time slots on a first come, first serve basis. Hence it is the time slot a subject signed up for that determined in which Experiment he would take part.

RESULTS

General Perspective on Data

Experiment 1, measuring subjects' sleeping response to alarms of 78 dBA, 54 dBA, and 44 dBA, was run concurrently and according to the same format as Experiment 2. Experiment 2 measured subjects' sleeping response to the same 54 dBA alarm sound used in Experiment 1, a smoke odor, and a heat stimulus. The only difference between the two experiments was in the treatments presented.

Although inferential statistical comparisons will be confined to each experiment independently, the similarity of design and the fact that the experiments were run concurrently will make some cross-experiment analyses appropriate. One must keep in mind, however, that responses to any given stimulus are likely to be affected by the context within which it occurs; and that context did differ between Experiment 1 and Experiment 2. Nevertheless, it is interesting to note that a Mann-Whitney U Test performed on the response times to the 54 dBA signal failed to show any statistically reliable differences between the two experiments, $z = 0.27$, $p > .05$.

Descriptive Statistics

Default Values/Distribution of Data

As can be seen by consulting the summary of the data in Table 1, non-detection of stimuli was a frequent occurrence.

Table 1. Summary statistics showing response frequency and time in seconds (by treatment and hours of accumulated "sleep").*

Experiment 1

Acc. "Sleep"	78 dBA Alarm Detection			54 dBA Alarm Detection			44 dBA Alarm Detection		
	No.	Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.
2 hrs.	4	8.0	3.2	3	608.0	513.2	0	1200.0	0.0
4 hrs.	4	181.5	277.3	2	609.3	682.2	2	608.5	683.0
6 hrs.	4	59.8	103.5	2	614.3	676.4	1	901.0	598.0
Total	12	83.1	172.2	7	610.5	568.8	3	903.2	537.0

Experiment 2

Acc. "Sleep"	54 dBA Alarm Detection			Smoke Detection			Heat Detection		
	No.	Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.
2 hrs.	1	903.0	594.0	1	944.3	511.3	1	1024.3	351.5
4 hrs.	4	21.5	6.0	1	986.8	426.5	1	1117.5	165.0
6 hrs.	1	948.3	503.5	1	992.0	416.0	1	1181.3	37.5
Total	6	624.3	603.3	3	974.3	410.7	3	1107.7	214.6

*n = 4 per cell except for column totals where n = 12

In Experiment 1, 14 of the 36 (38.9%) presentations were not detected. In Experiment 2, non-detections accounted for 24 of the 36 (66.7%) observations. Default values of 1200 seconds (20 minutes) were recorded when subjects failed to detect presentations.

Looking at the raw data scores (Appendix I), it becomes apparent that, of the treatment presentations which were detected, most were detected within the first five minutes. The result is that data scores fall early or late in the treatment presentation while a relatively small percentage of the scores fall during the middle. This nearly bimodal pattern is shown in Figure 6.

Due to the extreme nature of the response time data, standard deviations tend to be high relative to the means. In Experiment 1 the standard deviation (s.d. = 565.8) actually exceeds the mean ($\bar{x}$ = 532.3), while in Experiment 2 the standard deviation (s.d. = 473.1) is greater than half of the mean ($\bar{x}$ = 902.1).

Treatment Effects

The mean treatment response latencies and associated standard deviations from both experiments can be seen in Table 1. Means and standard deviations are also presented graphically in Figure 7. Here the abscissa represents the signal/noise ratio of the alarms and the ordinate represents response time in seconds. Since the auditory alarms

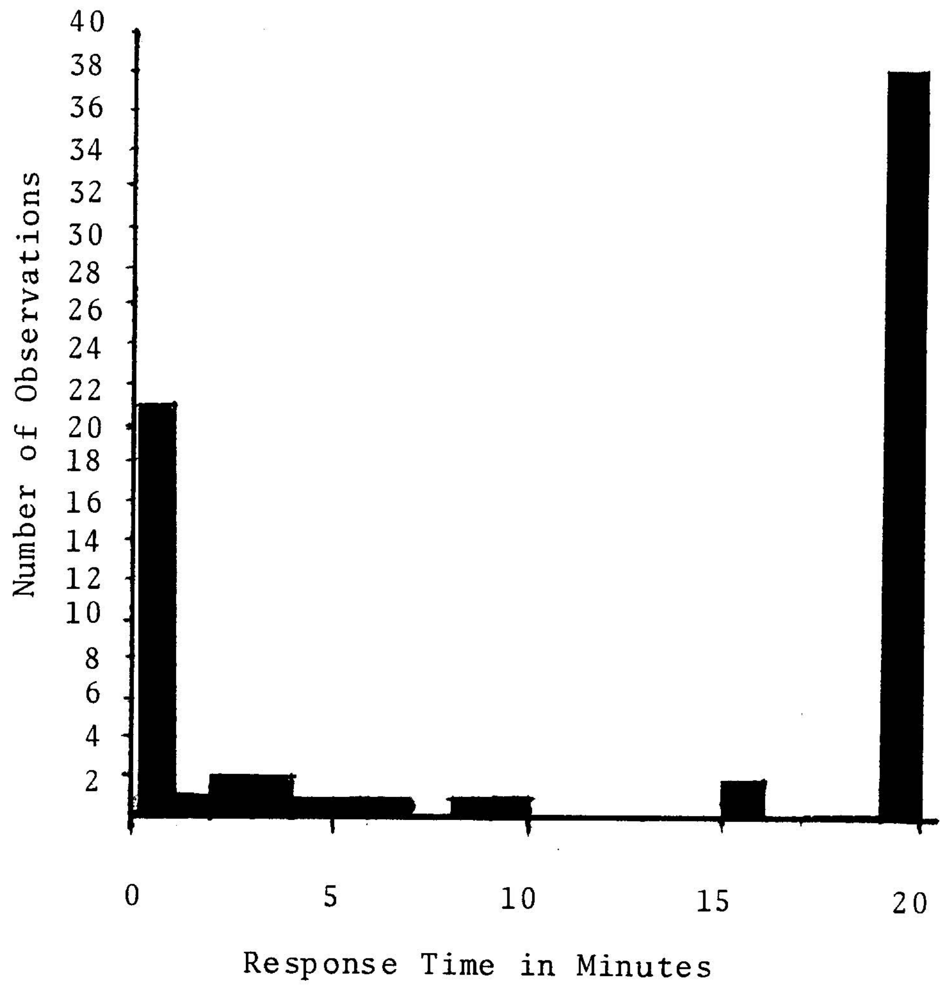

Figure 6. Distribution of response times. (Results from both experiments have been combined.)

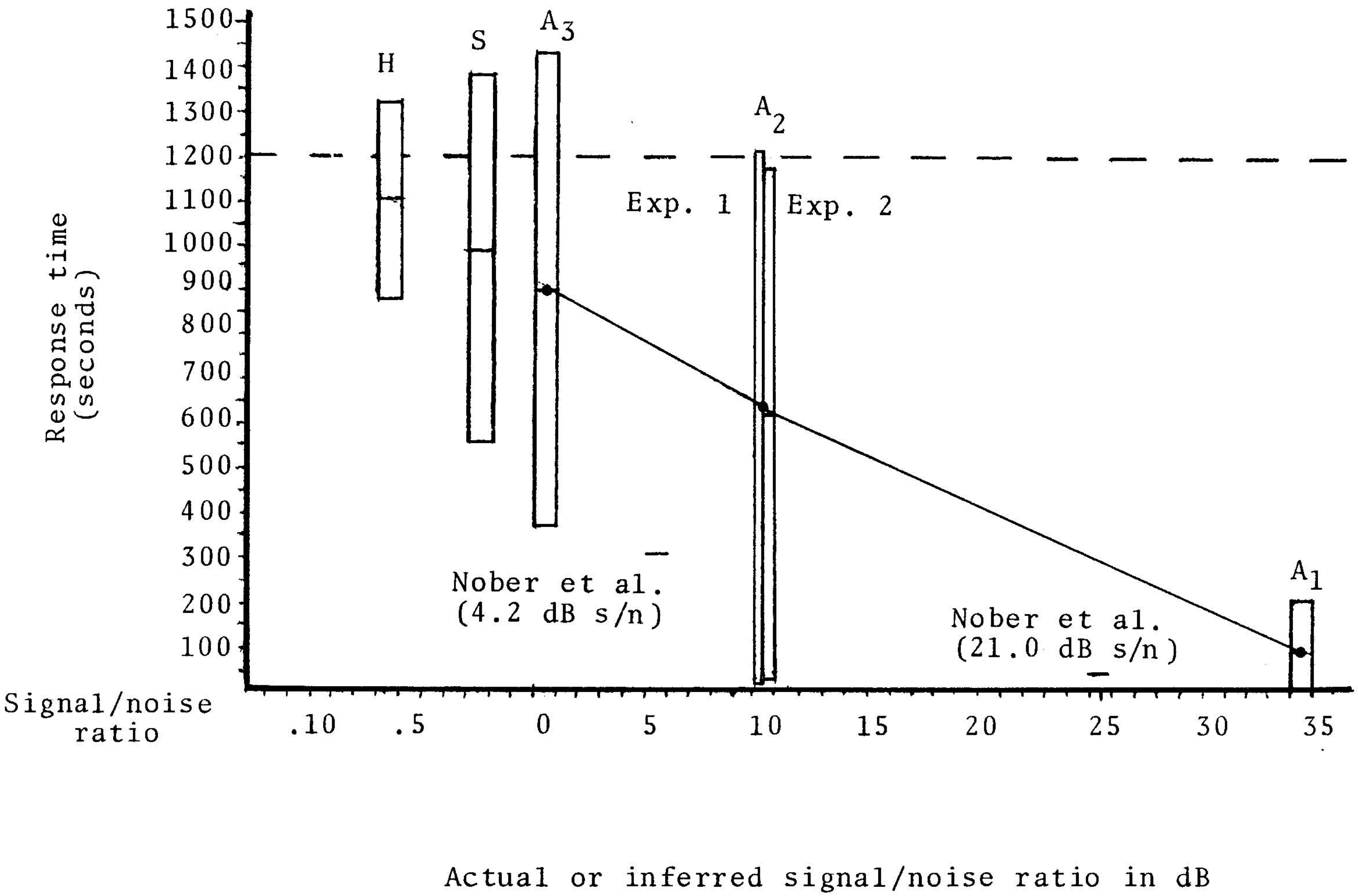

Figure 7. Means and standard deviations of treatment variables (by seconds; default value = 1200 sec.; includes means from Nober, 1980. S/n ratio for alarms was measured directly. S/n ratio for smoke and heat were inferred by projection of the regression line. A_1 = 78 dBA alarm, A_2 = 54 dBA alarm, A_3 = 44 dBA alarm, S = smoke, H = heat).

were all presented against a 44 dBA background noise, the 78 dBA alarm is plotted at 34, the 54 dBA alarm is plotted at 10, and the 44 dBA alarm is plotted at 0. The 54 dBA alarm is plotted twice, once to represent data collected in Experiment 1 and once to represent data collected in Experiment 2.

When these four alarm means are spaced on the abscissa according to signal/noise ratio, a nearly straight regression line can be drawn across them. This line has the approximate slope of -23.3 units (unit = sec./dB). Projecting this regression line at the same slope, it would cross the response time means of the odor and heat treatments at abscissa values of -3 dB and -8 dB, respectively. It is, however, probable that subject response times to alarm presentations would reach an asymptote at the default value of 1200. Thus, the "true" odor and heat response means might be equivalent to alarm response means of lower signal/noise ratios than those suggested by the straight-line extrapolation.[7]

A second trend which can be noted in Figure 7 is that, with the exception of the 78 dBA alarm, standard deviations decrease as means increase. Looking back to what has already been said of treatment non-detections, it is apparent that

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[7]Response time means from Nober et al. (1980) are also charted. These values will be addressed in the discussion section.

this decrease in the size of standard deviations is the result of the large number of missed detections and subsequent recording of default values.[8]

Accumulated "Sleep"[9]

In Experiment 1 the response time means and standard deviations (in seconds) were: after two hours accumulated "sleep," 605.3, 574.6; after four hours 466.4, 565.1; and after six hours, 525.0, 598.5. In Experiment 2 response time means and standard deviations were: after two hours, 957.2, 451.7; after four hours 708.6, 563.6; and after six hours, 1040.5, 357.6. (Specific data, showing subject responses by treatment and hours of accumulated "sleep", are provided in Table 1. Raw data scores can be seen in Appendix I.)

In both Experiments 1 and 2 the mean response time at four hours accumulated "sleep" is less than that at either two or six hours. This difference is shown graphically in Figure 8.

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[8]It is possible that in studies of this type standard deviation could prove effective in describing the asymptote of a regression line.

[9]The word "sleep" will henceforth be set off with quotation marks. This is because, as stated on page 31, all that can be said with certainty is that a fixed number of hours had passed since the subject informed the experimenter that he was turning out the lights to go to sleep. It is expected, and in many cases confirmed by intercom transmissions, that subjects were awake during a portion of this time.

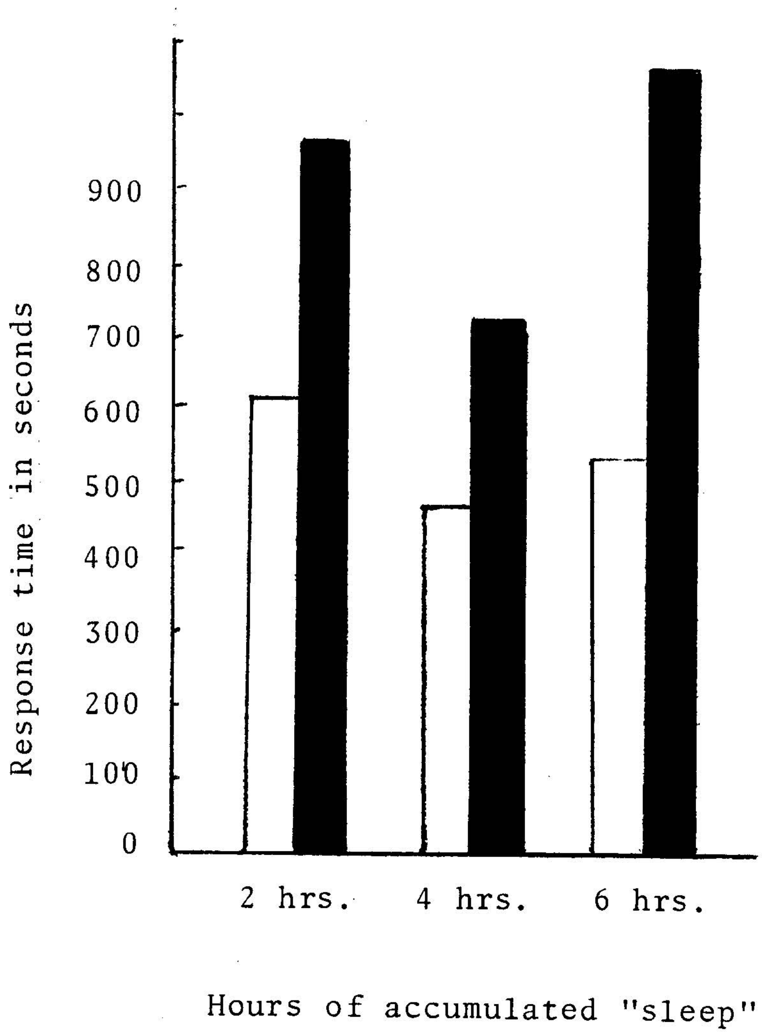

Figure 8. Mean response times for hours of accumulated "sleep." Experiment 1 ☐ and Experiment 2 ■ shown separately.

Inferential Statistics

Treatments

Analyses of variance were performed to test the effects of treatment and of accumulated "sleep" time. However, as each subject did not receive each treatment at each accumulated "sleep" hour examined (each subject received three and not nine treatment presentations), tests of interaction effects could not be performed. Two analyses were performed on the data collected from each experiment. Change-over analyses of variance (Federer, 1955) were performed because, of the parametric tests commonly used with data of this type, the change-over design is the most appropriate. However, Friedman's two-way analyses of variance (non-parametric tests) were also performed, because the clearly non-normal (actually bimodal) distribution of the data limits the validity of the parametric tests.

The change-over analysis of variance performed on data from Experiment 1 showed a significant difference, $F(2,20) = 9.44$, $p < .05$ among subject response times to alarm warnings of different levels (see Table 2). The Friedman two-way analysis of variance comparing subject response times to the three alarm treatments which was also performed provided the result, $\chi^2_r\ (2) = 12.67$. Again this was significant at $p < .05$.

Table 2. Change-over design analysis of variance for subjects, treatment, accumulated "sleep" in Experiment 1.

Source	df	SS	F
Subjects	11	2549469.0	1.06
Treatment	2	4145435.0	9.44*
Accum. Sleep	2	116733.0	.27
Error	20	4390962.0	
Total	35	11202599.0	

*significant at $p < .05$

A second change-over analysis of variance was performed on data collected in Experiment 2. Results indicate a significant difference in response times to the 54 dBA alarm, odor, and heat treatments, $F(2,20) = 4.75$, $p < .05$ (see Table 3). The Friedman analysis, however, failed to detect a significant difference among Experiment 2 treatments, $\chi_r^2\ (2) = 2.54$, $p > .05$.

Table 3. Change-over design analysis of variance for subjects, treatment, accumulated "sleep" in Experiment 2.

Source	df	SS	F
Subjects	11	2499841.6	1.44
Treatment	2	1496110.6	4.75*
Accum. Sleep	2	715627.3	2.27
Error	20	3149309.4	
Total	35	7860889.0	

*significant at $p < .05$

Results from the change-over analysis of variance and the Friedman analysis of variance were different because the former measures differences both across and within subjects while the latter sums ordinal ranks that occur within subjects. In Experiment 1 subjects consistently responded to some treatments more quickly than others and these treatments showed lower reaction time means. In Experiment 2, although some treatments showed lower overall means, a subject's response time to one treatment could not be seen as a good predictor of response time to another.

Accumulated "Sleep"

It was noted in the description of the data that there appeared to be a trend toward shorter response latencies after four hours of accumulated "sleep" than after either two or six hours. Results of change-over analyses of variance (Tables 2 and 3) show that in neither experiment is this trend significant. A Friedman two-way analysis of variance was performed on the accumulated "sleep" variable, grouped across Experiment 1 and Experiment 2.[10] This result, χ_r^2 (2) = 1.31, was also not significant.

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[10]It is felt that data from Experiment 1 and Experiment 2 can be grouped in evaluating significance of accumulated "sleep" as each treatment was presented an equal number of times at each accumulated "sleep" hour.

That the identification rate was low, however, does not seem to be the result of subjects' lack of exposure to smoke detector alarms. During a debriefing talk 14 of the 17 subjects asked reported previous exposure to smoke alarm signals, while 10 of 13 subjects asked reported that their parents owned a smoke detector alarm.[11]

Subjects' Verbal Identification of Cues

The eighteen subjects who woke and responded to an alarm treatment presentation were asked, "What do you notice?" Subjects responded they heard a noise and often identified it as being "loud" or "high pitched." When asked if they could tell the experimenter what produced the sound, only one of the eighteen labeled the sound as being an alarm signal. The following morning these subjects were questioned to see if they could identify what had caused the sound they had reported the night before. Two subjects (including the subject just mentioned) reported that the sound had been caused by a smoke detector alarm. Another reported it had been an alarm clock while a fourth subject said, "It sounded like what backs up to the trash can" (meaning the sound emitted by campus dumpster removers).

[11] All 24 subjects were not asked these questions. It was only during interviews with the earlier subjects that it became apparent to the experimenter that subjects might be acquainted with one alarm signal and fail to identify another. One such subject reported that, "We have one (smoke detector alarm) but this (treatment alarm) sounded different."

The other subjects, even with considerable prodding, were unable to label the sound they heard.[12]

Of the subjects that detected the heat stimulus, all three reported feeling heat. A fourth subject, whose results were eliminated from the data pool as he had just returned from the bathroom minutes before the heat presentation, asked that the heat be turned off until after he had gone back to sleep. Of the subjects who detected the smoke odor, two described it as "something burning" and, one as "burning rubber."

Equipment Test

Detection of Smoke Odor by Smoke Detector Alarm

Three independent equipment trials were conducted toward the purpose of comparing human smoke odor detection to alarm detection of the same smoke particles. Two of the trials employed a General Electric model 8201-401 smoke detector while the other made use of a Honeywell TC 89B detector set at its maximum sensitivity of .7 percent. In each equipment trial the smoke detector being tested was fastened vent-side down 12 in. (.3 m) from the head

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[12] The questioning revealed that one subject had detected the 44 dBA alarm yet had felt it was, "not worth reporting." That he detected the alarm is clear as he correctly identified the location of the sound source and the approximate presentation time. This highlights the lack of identifiability of the detector alarm warning. The default value recorded for this subject was not changed to a stimulus detection as response was not by the appropriate method.

of the bed and 10 in. (.3 m) above the level of the bed. The area under the alarms was left clear so that uninhibited air circulation was possible. Smoke was introduced by the painted light bulb apparatus already described. In each of the three trials the alarm failed to detect the smoke within twenty minutes.

Immediately following two of these twenty-minute tests,the smoke alarm in question was attached to the ceiling immediately above the location of the pillow. This test, which was performed once with the General Electric and once with the Honeywell alarm, was run for five minutes. As before, alarms were not triggered by the smoke from the experimental apparatus. A subsequent test showed that both alarms were effective in detecting cigar smoke.

DISCUSSION

Hypothesis 1, which stated that subjects will respond more quickly to alarm sounds reaching their ears at higher intensities than they will alarm sounds reaching their ears at lower intensities, was fully supported. Subjects in this study were shown to react more quickly to the 78 dBA alarm than to either the 54 dBA or 44 dBA alarm. Subjects were also shown to react more quickly to the 54 dBA alarm than to the 44 dBA alarm. Finally, a nearly perfect linear relationship was shown to exist between alarm signal/noise ratio and subject response time. The exact slope of this function (23 sec./dB), however, was dependent upon (a) the default value that had been previously selected for use in cases of non-detection and (b) the high number of such default values which occurred.

To illustrate these dependencies, consider the consequences of some alternative procedures for handling non-detections: 1) If a one-hour default value had been employed, responses to the 78 dBA alarm would have been the same while means for the 54 dBA and 44 dBA alarms would have increased. In this case, since we do not know how many additional responses would have been made, it is not possible to say whether a linear relationship between alarm signal/noise ratio and subject response time would have resulted; 2) If no default limit was used, it is possible subjects would not have awakened until the next treatment presentations.

This would then modify the next presentation itself, since the continuing earlier alarm would decrease the signal/noise ratio associated with the onset of the later alarm. Some subjects might not have detected either of these two presentations and would have slept until morning. In either case, one is left with two alternatives: 1) use a default value (either explicitly set as it was in this research or implicitly set by the natural limits of sleep); 2) discard any subject not waking to all three stimuli, thereby introducing a severe sampling distortion. The adoption of an intermediate default value of 20 minutes seemed the most reasonable compromise.

Hypothesis 2, that subject response times to louder alarms will show a smaller variance than subject response times to quieter alarms, could not be tested in a meaningful way. As expected, the 78 dBA alarm showed the smallest variance. However, the response time variances for the next two alarms were inverted from the hypothesized order, with response time variance for the 54 dBA alarm being greater than that of the 44 dBA alarm.

This result is easily explained by again turning to the default effect. The 78 dBA alarm showed a small mean and variance. The 54 dBA alarm showed a larger mean and variance. The 44 dBA alarm showed the largest mean but a smaller variance than the 54 dBA alarm because so many of the data observations collected were the default value, a single value close to the mean.

Hypothesis 3, that subjects would respond more quickly to the final stimulus presented during sleep than to earlier stimulus presentations, was not supported. In fact, subjects showed a trend (non-significant) toward responding most rapidly to the second treatment presented. Hypothesis 3 had been formulated in accordance with studies that had shown significant reduction in auditory awakening thresholds as subject sleep time accumulated (Rechtschaffen et al., 1966; Watson and Rechtschaffen, 1969).

Some possible explanations which may account for this study's departure from these earlier findings will be reviewed. It is felt some of these possibilities provide valuable insight into variables associated with human detection of fire stimuli.

a) This study collected data on subjects during their first and only night in the laboratory. Most sleep studies, including that of Rechtschaffen et al. (1966), have not analyzed data collected during a subject's first laboratory night. This caution in the use of first night data is based on findings which indicate that subjects are apt to be more alert and spend less time in deeper sleep stages on their first laboratory night (Agnew, Webb and Williams, 1966). Thus when the third treatment was presented, some subjects may, in fact, have accumulated six hours of sleep while others had accumulated considerably less.

b) This study exposed each subject to only one treatment night with only three treatments being presented on that night.[13] It was felt that if "true to real life" fire detection times were to be obtained, subjects should not be allowed to become "sophisticated" in the detection of such stimuli.[14]

Despite these prescriptions, most studies of sleep arousal have collected data over a number of non-consecutive nights, presenting at least five alerting treatments during each night. Rechtschaffen et al. ran subjects seven non-consecutive nights, presenting an average of 7.6 treatments per night, while Watson and Rechtschaffen ran subjects between nine and eleven non-consecutive nights, presenting an average of at least six treatments per night. Furthermore, in the just-mentioned studies, it was not possible for subjects to sleep through any treatments as the experimenter woke the subject by other means if he did not respond to the treatment.

Regarding their findings of significant decrease in subjects' awakening thresholds across laboratory nights, Watson and Rechtschaffen state:

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[13] Results showed that only two subjects responded to all three treatments.

[14] Unfortunately, a truly independent group design with sufficient subjects and a preparatory night of laboratory sleep would have been horrendously expensive.

> The monotonic decline in AAT [auditory awakening threshold] across successive nights suggests a learning phenomenon. Since discriminations between external stimuli can be made during sleep (e.g., Beh & Barratt, 1965; Oswald, Taylor & Triesman, 1960), a progressive decline in AAT could have developed with repeated associations of the specific experimental tones with subsequent awakenings. (As noted earlier, the number of 'spontaneous' awakenings did not increase on successive nights ...). (1969, p. 642)

Oswald et al. and Beh and Barratt (cited above) have suggested that subjects can discriminate sounds in sleep and that this ability is enhanced by practice. Taking this one step further, the present author suggests that so-called accumulated sleep effects could consist largely of practice effects. These are similar to the practice effects Watson and Rechtschaffen have suggested may be the cause of variations across nights. In this regard it seems possible that, as the night continues, a subject receives more opportunities to practice, improving his ability to detect treatments toward morning.

Finally this across-night practice effect and within-night practice effect could work together further enhancing the within-night practice effect. This is because subjects who have, in most studies, been run on non-consecutive nights might on any treatment night rapidly relearn learned but not recently practiced discrimination skills.

c) Most awakening experiments, including Rechtschaffen et al. and Watson and Rechtschaffen, used pure tones of

1000 Hz while the NCSU study presented a higher pitched, multi-frequency sound. Response patterns to these two stimuli may not be constant.

Whether this study's failure to detect an accumulated sleep effect was in fact the result of any of the three possible causes discussed cannot be determined based on the data collected. To this experimenter, the second possibility, that less treatments were presented to subjects thus reducing practice effects, seems the most likely.

Hypotheses 4a and 4b, which compare smoke alarm and sleeping human proficiency in detecting a smoke presentation, could not be tested meaningfully. This is because the test alarms were not triggered by the smoke in any of the equipment trials conducted. Hence, whether smoke alarm detection of an odor plus human detection of the alarm sound was greater than or less than human detection of the smoke odor would, in this case, be dependent on the default value selected for the equipment trial.

This test, though not providing the expected results, suggests that humans, even when asleep, may be able to detect certain low particulate smoke types more effectively than smoke detector alarms.

Discussion of Detection Times

It has been noted that the results of a number of the statistical analyses performed were greatly influenced by the large number of default values recorded. This is unfortunate in a statistical sense in that we saw an artificial reduction in many response time means and standard deviations. More important than this statistical concern, however, is the suggestion that sleeping individuals may be very poor in responding to fire-related cues.

This finding at first appears to contradict the Nober et al. conclusion that:

> College-aged subjects can be awakened and alerted by smoke detector alarm levels as low as 55 dBA even with extraneous background noise when sufficiently sensitized to the signal and motivated to respond accordingly. (1980, p. ii)

Yet while cataloging different results (see Smoke Alarm section and Figure 7), Nober et al. have also provided insight into some possible causes of this difference:

1) Subjects in the Nober et al. study may have been more highly motivated to detect treatments than were subjects in the NCSU study. This would have resulted in superior awakening/response performance (Zung and Wilson, 1961). Nober et al. acquired subjects through newspaper ads and by word-of-mouth; hence, it seems likely their subjects were members of the community interested in human detection of smoke alarms. These subjects were given $25.00 and a complimentary smoke alarm for their participation. The subjects in the NCSU study were students participating for research credit and either $5.00 or $7.50.

Subject motivation to detect the stimuli may also have been greater in the Nober et al. study, as from the subjects' perspective that study would have appeared to be a project of larger scale. In the Nober et al. project an experimenter went into subjects' homes, took sound measurements, informed the subject of a procedure including participation of the city fire department, and left expensive equipment on location for over a month.

2) Subjects in the Nober et al. experiment expected an alarm presentation whereas those in the NCSU experiment did not. The Nober et al. subjects were told they were taking part in a study testing human detection of smoke alarms, that an alarm signal would be presented, and that they should turn off the alarm and call the city fire department when this occurred. Equipment, including a smoke alarm, was then left in the house. In the NCSU study, subjects had only a vague idea that some fire-related changes in the environment would occur. They did not know the specific form or even the modality in which presentations would be made (see Appendix E).

3) Subjects participating in the Nober et al. research underwent an alarm conditioning procedure during which they were allowed to hear the test alarm nine times. It is probable that the Nober et al. conditioning trials aided subjects in developing detection and discrimination skills, thus reducing response times (Beh and Barratt, 1965;

Oswald et al., 1960; Watson and Rechtschaffen, 1969). Subjects participating in the NCSU study did not hear the alarm until the actual presentation.

Discussion of Subjects' Failure to Correctly Identify Smoke Alarm Warnings

It has been related that subjects participating in the NCSU study had neither the advantage of knowing that an alarm presentation would be made nor of pre-trial training sessions. Despite this, the author had expected that smoke detector alarm signals were similar and were widely known to such an extent that a person who had heard one alarm model would instantly recognize any smoke alarm warning as being just that.

Results in this study indicate that a subject who is acquainted with the warning produced by one model of smoke detector alarm will, if awakened from sleep by another model, most likely not identify the sound he hears as being produced by a smoke detector alarm. This failure in identification could conceivably greatly increase decision times as a just wakened person attempts to label the sound he hears. More subtly, this lack of a well-learned stimulus/label association could increase awakening time itself. This is because any lower threshold advantage gained in detecting a salient stimulus is lost if the subject does not recognize the stimulus is salient.

These findings highlight the importance of people's familiarizing themselves with the signal of the smoke alarm, monitoring their environment, as well as suggesting the standardization of smoke alarm warning signals.

RECOMMENDATIONS

Some methods by which response frequency to fire-related cues might be increased will be suggested.[15]

1) Increasing people's awareness of fire frequency and dangers would increase their expectancy that they would encounter a fire. The result would be that if these people were to sense an ambiguous stimulus they would be more apt to entertain the possibility the cue could be a smoke alarm or other fire cue. Secondly, awareness of fire frequency and dangers would increase motivation to detect fire-related cues. This education could be implemented through any number of media.

2) Training people in recognizing smoke detector alarms and other fire-related cues would aid them in pairing a perceived fire stimulus with a label. This might hasten fire cue discrimination and because the cue is salient, hasten subsequent waking.

Residents are apt to be practiced in detecting the sound of their own smoke detector alarms through conscious self-training, battery testing, or inadvertent activation. Though this training is exceedingly valuable, it could be enhanced by one family member's activating the alarm while the others sleep. Feedback on response performance given

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[15] These recommendations are based on this author's logical extensions of this and other research. They were not specifically tested during the preceding experiments.

after the trial would allow family members to refine their ability to discriminate, orient, and respond to the alarm.[16] This same feedback (knowledge of results) could also instill the person with motivation to respond more quickly.

Research to establish an optimum household training procedure could be undertaken. Fire insurance companies might encourage use of this procedure by offering "low risk rates" to those willing to use the program.

3) Standardizing the sound produced by smoke detector models would in some cases increase the ease with which people discriminate and identify smoke detector warnings. Experimental results indicate that an, "If you've heard one, you've heard them all," attitude toward smoke detector alarms is both mistaken and dangerous. Many people who are trained to identify a certain smoke detector alarm sound may not recognize a signal of a different frequency as being an alarm warning. This may be especially dangerous when a person receives an alarm he has not heard as could happen in a hotel or vacation setting. Secondly, this lack of standardization could result in a reduction in the value of years of conditioning if a person moves from a residence protected by one alarm model to a second residence protected by a second alarm model.

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[16]For those who missed the alarm presentation, daytime conditioning trials and telling the trainee when the alarm would be presented may allow a first sensitizing detection.

4) Any method which would increase the detectability or identifiability of the signal produced by a smoke detector would decrease human response time. Detectability might be enhanced by linking the smoke alarms to a buzzer in the bedroom. Even a mild electrical shock alerting device, though seemingly an extreme measure, would be useful for the deaf, hard of hearing, or those known to be extremely poor at detecting other fire cue warnings.

In this vein, more rapid detection and identification of hotel fire warnings might be made possible by utilizing already existing phone systems. Such a fire alert phone system would be as follows: When an alarm is triggered room telephones ring. Upon answering their phone patrons are informed (either by hotel employees or by tape recorded messages) that a fire alert is in progress. By this means patrons could also be told where the fire was and thus, which way they should proceed. It is suggested that experiments testing human reaction to a telephone alarm system be conducted before any such systems are actually installed.

Finally, other future research that has been implicated by this study includes: a) a study to determine alarm frequency (or frequencies) that provides the lowest human waking and response time; b) a study determining the value of different types and amounts of, awake and asleep, fire cue training on human waking and response to fire cues; c) a study providing a graph of human awake and asleep abilities to detect a rising non-localized presentation of heat; d) a study to determine the effect of commonly used drugs, such as valium and alcohol, on subject awakening to fire cues; 3) regarding sleep studies, a study to determine whether accumulated sleep effect is in fact cue to this or to a practice effect. Each subject could act as a control for himself, serving first in non-accumulated sleep/unpracticed and accumulated sleep/unpracticed trials, then later in non-accumulated sleep/practiced and accumulated sleep/practiced trials.

CONCLUSION

The most important finding of this research is the relative unresponsiveness of subjects to fire-related cues. In fact only two of the twenty-four subjects detected all three of the stimuli presented. (Although the faintest auditory alarm was below the level that would be achieved by a recommended placement of such a warning system, it may not present a signal unrealistic to a situation in which one alarm is mounted in order to protect an entire house.)

Low detection rates seem to be the result of subjects' unfamiliarity with the particular smoke alarm used, despite its being a common model, and a lack of expectation that a signal would be presented. In this less than optimal situation, many subjects failed to awaken to an alarm warning reaching their ears at a signal/noise ratio of 10 dB or less. Despite these factors a sufficiently loud signal (34 dB signal/noise ratio) did awaken all subjects tested. Subjects were also likely to fail to respond quickly to fire-generated gasses and heat.

Finally, should a person be awakened by a smoke detector alarm or by fire-generated heat, the data gathered in this study indicate that he may fail to properly identify the stimulus as a fire warning. The consequences of the resulting delay in making an appropriate decision are obvious.

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APPENDIX A

How People Become Aware of Fires Based on at-the-Scene Interviews by Fire Personnel

(also shows influence of distance from fire source on method of fire detection)

(Bryan, 1977)

Awareness	Feet 0-20	Percent	Feet 21-100>	Percent	Total	Percent
Smelled Smoke	94	26.3	47	25.6	141	26.0
Others Notified	66	18.4	53	28.8	119	22.0
Noise	55	15.4	41	22.3	96	17.8
Family Notified	49	13.7	22	12.0	71	13.1
Saw Smoke	38	10.6	11	6.0	49	9.0
Saw Fire	39	10.9	7	3.8	46	8.5
Explosion	5	1.4	1	0.5	6	1.1
Felt Heat	4	1.1	0	0	4	0.7
Saw/Heard Apparatus	3	0.8	1	0.5	4	0.7
Electricity Off	4	1.1	0	0	4	0.7
Pet	1	0.3	1	0.5	2	0.4
N = 11	358	100.0	184	100.0	542	100.0

APPENDIX B

Temperature Increase by Minutes from Equipment Trial of Heater Apparatus

Minutes Since Heater Activation	28" from Heater		9" from Heater	
	F°	C°	F°	C°
0	70	22	70	22
1	70	22	72	22
2	72	22	72	22
3	72	22	74	24
4	73	23	75	24
5	74	24	77	25
6	76	24	78	26
7	76	25	80	27
8	77	25	82	28
9	78	26	84	28
10	79	26	87	30
11	79	26	88	32
12	80	27	90	32
13	80	27	91	33
14	81	28	92	33
15	81	28	94	34
16	81	28	95	35
17	81	28	96	36
18	81	28	96	36
19	82	28	96	36
20	82	29	97	36

Note: (all readings are thermometer readings visually rounded to the nearest whole number.)

APPENDIX C

Preliminary Interview
(checklist format)

I. Screening section

A. Questions

1. Name?

2. Address?

3. Phone number?

4. Social security number?

5. Birthdate?
(If S is older than 24 years he will not be used in the study. This was made clear on the subject sign-up sheet.)

6. Could you tell me what time you generally go to sleep on a week night?

7. What time do you generally go to sleep on a weekend?

8. What is the earliest you go to bed on a week night?

9. What is the latest you go to bed on a week night?
(If S answers goes to sleep at a regular time and within 1 hour of that on weekend he is acceptable for weekend study providing meets other criteria. No S will be rejected on basis of time goes to sleep or irregularity unless the last stimulus would have to be presented around class times on a following week day morning. At class times ambient noise levels would be high.)

10. Do you ever take either a prescription or an over-the-counter sleep aid to help you sleep?
(If 'yes' four times a week or more must eliminate.)

11. Do you ever drink beer or smoke marijuana specifically to help you sleep?
(If 'yes' four times a week or more must eliminate.)

12. Do you drink drinks containing alcohol often?
(If drinks to point of intoxication four times a week or more must eliminate.)

13. Do you ever smoke marijuana or use any other non-prescription drugs?
    (If four or more times per week must eliminate.)

B. If S does not meet requirements he will be given two credit hours, and an explanation as to why he is not acceptable as a subject in this study.

II. Subjects who pass section one (I) will be told purpose behind drug, alcohol, caffeine limits on the day they will be run. (Evidence indicates that alcohol, caffeine or nonprescription drug use has a strong effect on sleep. As a result will ask you to limit intake of these substances in the daytime hours preceding the night you will be sleeping in the lab.)

III. Requests of Subject on day of study.

1. Do not use nonprescription drug (including marijuana) within twelve hours.

2. Do not drink more than one beer (mixed drink) within two hours of arrival or more than two beers (two mixed drinks) within four hours (one or two beers with dinner is acceptable).

3. Do not drink more than normal amounts of caffeine during course of day, especially toward the night-time hours. Caffeine is, of course, included in coffee, tea, and most soft drinks.*

IV. Wrap up

1. Set a date when S will not be under extreme academic pressure.

2. Set a time fifteen to thirty minutes before S's regular bedtime.

3. Tell S to bring pillow, pillow case and sheets.

4. Relate location of sleep lab.

5. Tell S to contact experimenter at home if any difficulties arise.

6. Make reminder call to S day before his run.

*will elaborate any points experimenter feels will be helpful

APPENDIX D

Subject Responses to Drug-Use Section of Preliminary Interview

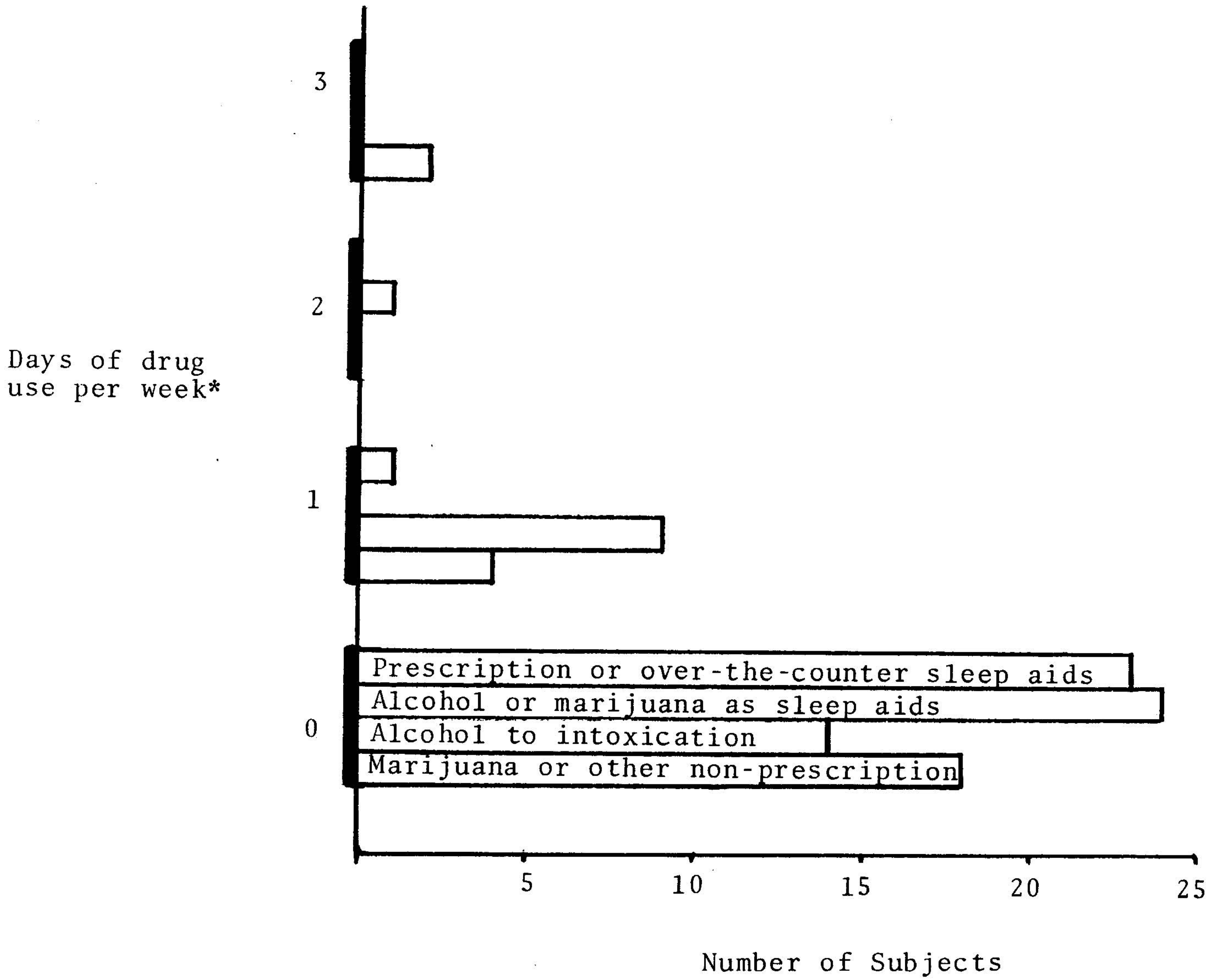

Figure A. Number of subjects using specific drug substances at certain frequencies (per week).

*Frequency values are rounded down. Marijuana use 1.5 times per week would be scored as 1.0 times.

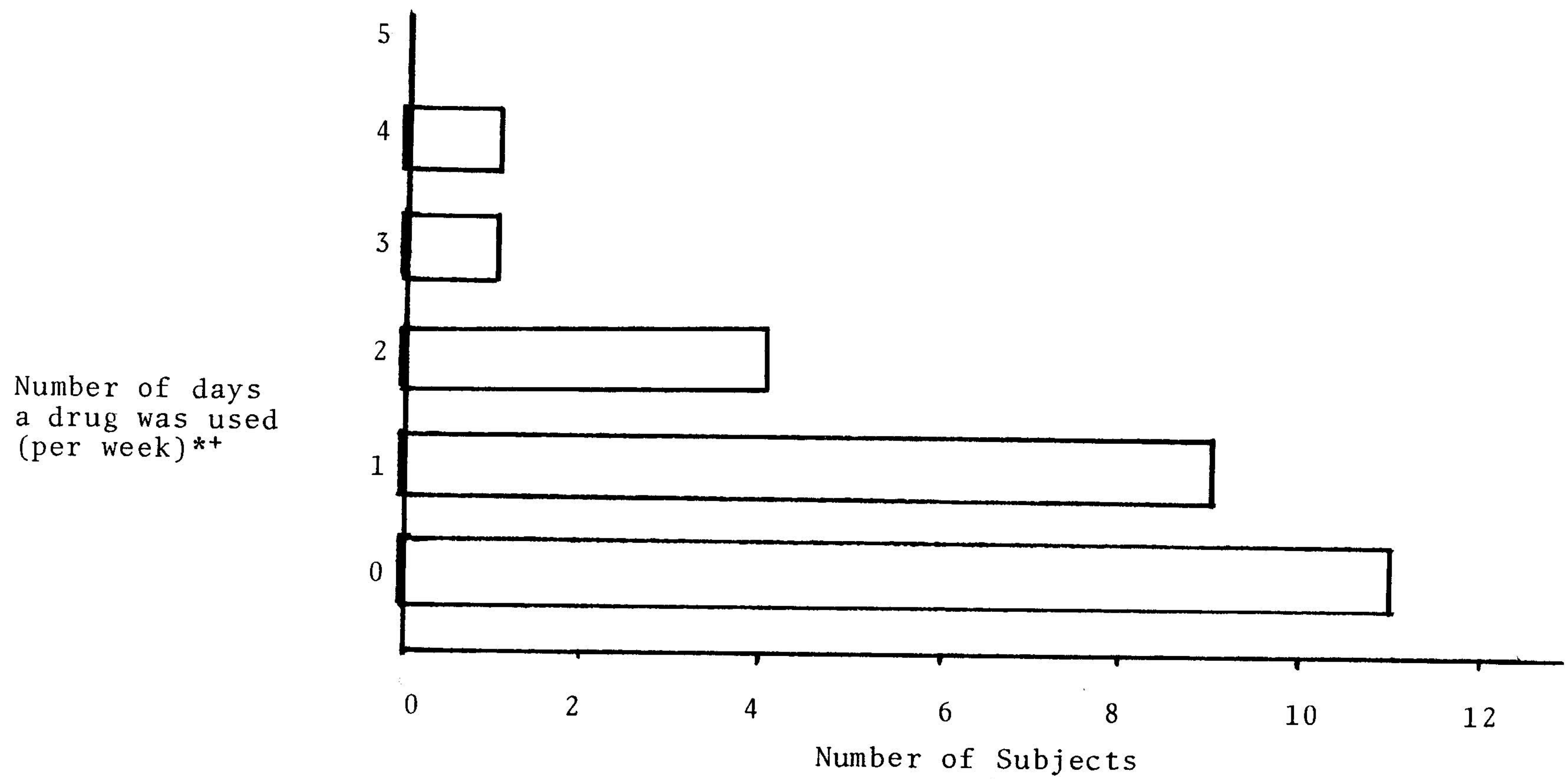

Figure B. Number of subjects by frequency of drug substance use.

*Each occasion a subject uses a drug substance counts as one day. If a subject were to become intoxicated and smoke marijuana on the same night this would be scored as two days of drug use.

+Value rounded down. Marijuana use 1.5 times per week would be scored as 1.0 times.

APPENDIX E

Subject Introduction

(Modified version of Schwalm 1979 instructions
by permission of Dr. Norman D. Schwalm)

Right here in front of you, you see a bed. I'm going to ask you to sleep here tonight so I can see if your sleep is affected by environmental conditions. I'm interested in how your sleep is, or is not, affected by certain fire-related changes in the environment.

As you sleep the situation, or environment, in this room will change. I can't be specific about these changes but I can tell you that none of them will be dangerous to you and that you may sense the changes in any sensory dimension. That is, you may feel, hear, see, or smell a change in this room while you're asleep. If you sense a change taking place please push this button (indicate subject response button). Then call me, over the intercom (indicate intercom), and report to me what change is taking place. I'll be in a room on the other side of this wall (indicate bedroom/control room wall).

To operate the intercom push the call button. You can then talk and hear through the intercom. You may be able to hear me talk through the wall but it's important for you to push the button so I can understand you more easily.

You are welcome to turn on the lamp next to the bed if you feel that would help you detect any change (subject is permitted to turn lamp on and off). After you've reported the change I will thank you and tell you, through the intercom, that you can go back to sleep.

Now, you will hear the air conditioner go on and off periodically (manipulate thermostat so air conditioner starts and stops). That isn't part of the study so if you hear the air conditioner you don't have to report that to me. You're welcome to read if that generally helps you relax before sleeping. Any questions so far?

O.K. Why don't you repeat briefly, in your own words, what you are to do from the beginning of the experiment. (Subject repeats instructions and is corrected by the experimenter if he errs or omits any essential parts of the procedure.)

Just before you turn the lights out to go to sleep I'd like you to call me on the intercom and tell me you are going to sleep. Also, call any time you want to ask a question or if you have to go to the bathroom. Will you want to go to sleep right away or do you want to stay awake for a while?

Subjects who expressed a desire to go right to sleep were told: O.K. You'll be able to go to sleep as soon as we finish an intercom test.

Subjects who expressed a desire to stay awake longer were told: O.K. We're going to do an intercom test and you can stay awake following that.

APPENDIX F

Response Button and Intercom Test and Completion of Subject Introduction

Subject's name, this is an intercom check. I want to be sure the button and intercom are working and to give you a chance to work with them. Note that when your button is down you can either send or receive. Can you hear me alright? (Engage subject in very short conversation through the intercom.)

Would you push the button you'll push if you notice anything happening? (S pushes button which extinguishes display light in control room.) Thank you. Would you push the button again to reset the little light?

Thank you.

Subjects who had expressed a desire to go right to sleep were asked: Are you going to sleep now?

All of these subjects responded affirmatively and were told: Alright, *subject's name*. Have a good sleep.

Subjects who had expressed a desire to stay awake longer were told: You can stay awake for a while if you want. Please remember to call me just before you turn out the light to go to sleep.

Upon calling to say they were going to sleep these subjects were told: Alright, *subject's name*. Thanks for telling me. Have a good sleep.

APPENDIX G

Time Record Form

Outline of Treatment Steps and

Record of Subjects' Responses

TIME RECORD

Date ______________

Subject # __________

	Stimulus Presented	Time
Check lab		
Check temp (should be 68°F)		
Spray S area w/air freshener		______
Order S area		______
Order control room		______
		______
Subject introduction		
S arrive at lab		
Read introduction to S (Appendix H)		______
Experimenter exit bedroom		______
Put up signs "EXPERIMENT IN PROGRESS"		______
S response check (Appendix I)		______
S is turning LIGHTS OUT (L.O.)		______
(time rounded to nearest 5 min.)		______
Stimulus #1		
L.O. + 45 min. Place alarm if necessary for presentation #1 (use AC to cover any noise)		______
L.O. + 1 hr. 55 min. adjust thermostat*		______
L.O. + 2 hrs. introduce stimulus #1	______	______
--Subject response onset/or		______
L.O. + 2 hrs. 20 min. terminate stimulus presentation if subject not respond)		______
Reset thermostat*		______
COMMENTS		
Stimulus #2		
L.O. + 2 hrs. 45 min. Place alarm if necessary for presentation #2 (use AC to cover any noise)		______

	Stimulus Presented	Time
L.O. + 3 hrs. 55 min. adjust thermostat*		
L.O. + 4 hrs. introduce stimulus #2		
--Subject response onset/or		
L.O. + 4 hrs. 20 min. terminate stimulus presentation (if S not respond)		
Reset thermostat*		
COMMENTS		
Stimulus #3		
L.O. + 4 hrs. 45 min. Place alarm if necessary for presentation #3 (use AC to cover any noise)		
L.O. + 5 hrs. 55 min. adjust thermostat*		
L.O. + 6 hrs. introduce stimulus #3		
--Subject response onset/or		
L.O. + 6 hrs. 20 min. terminate stimulus presentation if S not respond		
Reset thermostat*		
COMMENTS		
Subject debriefing		
Ask S questions		
Answer S's questions		
Stress S not to repeat nature of experiment		
Fill out credit sheets and pay S		
Lab clean up		
Bring in signs: "EXPERIMENT IN PROGRESS"		
Spray S area w/air freshener		
Tidy S area		
Tidy control room		
LOCK DOORS		

(L.O. = time of S's report that he is turning out lights)

*The thermostat was adjusted to guarantee that the air conditioner was activated during alarm presentations and deactivated during odor and heat presentations.

APPENDIX H

Randomized Block Design Used in Assigning Orders of Treatment Presentations to Subjects (Includes Assignments Made)

Block	Cell	Subject	Order of Presentation		
1	1	1	A_2	A_3	A_1
		2	S	H	A_2
	2	3	A_3	A_2	A_1
		4	S	A_2	H
	3	5	A_2	H	S
		6	A_3	A_1	A_2
	4	7	A_1	A_3	A_2
		8	A_2	S	H
	5	9	H	S	A_2
		10	A_1	A_2	A_3
	6	11	H	A_2	S
		12	A_2	A_1	A_3
2	7	13	A_2	S	H
		14	A_3	A_1	A_2
	8	15	A_2	A_3	A_1
		16	A_2	H	S
	9	17	A_1	A_2	A_3
		18	S	A_2	H
	10	19	A_2	A_1	A_3
		20	H	A_2	S

Block	Cell	Subject	Order of Presentation		
	11	21	A_1	A_3	A_2
		22	H	S	A_2
	12	23	S	H	A_2
		24	A_3	A_2	A_1

N = 24

A_1 = 78 dBA alarm, A_2 = 54 dBA alarm, A_3 = 44 dBA alarm,

S = Smoke, H = Heat

Cells = 12 cells so that one subject from each experiment was assigned to each cell.

Blocks = 2 blocks so there were 12 subjects in each block. Each possible order of treatment presentation appears once within each block.

APPENDIX I

Raw Data Collected in Experiments 1 and 2

EXP 1
(response time in seconds)

Subject #	Treatment			Accumulated Sleep		
	75 dBA alarm	54 dBA alarm	44 dBA alarm	2 hrs.	4 hrs.	6 hrs.
1	215	78	D	78	D	215
3	11	D	D	D	D	11
6	07	17	D	07	D	17
7*	08	40	D	D	08	40
10	11	15	04	11	15	04
12	589	D	D	D	589	D
14	05	297	D	297	05	D
15	05	857	17	857	17	05
17	10	D	D	10	D	D
19	124	D	D	D	124	D
21	04	D	17	04	17	D
24	08	22	D	D	22	08

EXP 1

	75 dBA alarm	54 dBA alarm	44 dBA alarm	2 hrs.	4 hrs.	6 hrs.
Total	997.00	7326.00	10838.00	7264.00	5597.00	6300.00
Median	9.00	857.00	1200.00	577.00	73.00	127.50
Mean	83.08	610.50	903.17	605.33	466.42	525.00
SD	172.22	568.80	537.00	574.61	565.13	598.55

EXP 2
(response time in seconds)

Subject #	Treatment: 54 dBA alarm	Treatment: smoke	Treatment: heat	Accumulated Sleep: 2 hrs.	Accumulated Sleep: 4 hrs.	Accumulated Sleep: 6 hrs.
2	D	D	870	D	870	D
4	28	177	D	177	28	D
5	D	D	D	D	D	D
8	D	D	1125	D	D	1125
9	D	D	D	D	D	D
11	14	D	497	497	14	D
13	D	D	D	D	D	D
16	12	D	D	12	D	D
18	24	D	D	D	24	D
20	20	368	D	D	20	368
22	D	347	D	D	347	D
23*	193	D	D	D	D	193

EXP 2

	54 dBA alarm	Smoke	Heat	2 hrs.	4 hrs.	6 hrs.
Total	7491.00	11692.00	13292.00	11486.00	8503.00	12486.00
Median	96.50	1200.00	1200.00	1200.00	1035.00	1200.00
Mean	624.25	974.33	1107.67	957.17	708.58	1040.50
SD	603.26	410.68	214.57	451.71	563.61	357.60

D = default value (treatment non-detection, scored as 1200 seconds)

*Data collected on the first subjects to run in the S#7 and S#23 slots were not used in the final analysis. Two substitute subjects run in addendum slots S#25 and S#26 replaced these values. S#7 was not used as an equipment failure altered his response time. S#23 was not used because he left the laboratory to use the bathroom. He returned only seven minutes before a treatment presentation. This subject clearly defied the experimental assumption that subjects would be asleep.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A laboratory study was conducted to determine human waking and response times to fire-related stimuli. Twenty-four college-age male subjects were tested with each subject being run for one night. Twelve subjects were exposed to smoke alarm warning signals of three intensities while a second set of twelve subjects was exposed to a smoke odor, a heat presentation, and one smoke alarm warning signal. Subjects were, without fail, awakened by alarms that reached their ears at a signal/noise ratio of 34 dB. They were considerably less effective in waking to the heat, the smoke odor, and alarm sounds that reached their ears at a signal/noise ratio of 10 dB or less. Failure to detect these latter stimuli may have resulted from a lack of familiarization with the specific fire-related cues used in this research. Had training in detection of these cues been conducted, subjects might have been more responsive. Using similar logic an argument can be made that standardization of signals used for household smoke detectors would be beneficial.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

auditory perception; fire alarm systems; fire detection; human behavior; human performance; odor DISCRIMINATION; residential buildings; smoke; smoke detectors

13. AVAILABILITY

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