Human Awakening and Subsequent Identification of Fire-Related Cues

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Twenty-four college-age male subjects, employed for one night each, were evaluated on their ability to awaken and then identify fire cues. Twelve subjects were exposed to smoke alarm warning signals of three intensities, while the second twelve subjects were exposed to a smoke odor, a heat presentation, and a single smoke alarm warning signal. Subjects were, in all cases, awakened by alarms that reached their ears at signal/noise ratios of 34 dB. They were considerably less likely to be awakened by heat, the smoke odor, and alarm sounds that reached their ears at signal/noise ratios of 10 dB or less. Upon awakening, subjects repeatedly failed to correctly label radiant heat presentations and smoke alarm warnings as fire cues.

INTRODUCTION

THE FIRST STEP to a successful escape from fire is human recognition of a fire cue. Not until stimuli related to the fire are detected, will appropriate actions be initiated. Unfortunately, fire case studies have indicated a significant period of time may lapse between fire onset and residents' first awareness of the fire.[1,2,3] This time between fire onset and human detection must be viewed as a major contributor to the criticality of the fire hazard. In fact, it is not unusual for fire detection to occur only after egress routes have been rendered impassable.[2,4]

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Key Words: Fire-related cues, cue effectiveness, cue detection, response time, human awakening, human detection, alarm attenuation.

Psychological Information Processing View of Human Fire Detection

The importance of early fire detection has been recognized. However, despite the extensive use of smoke and fire detectors, post-fire surveys indicate that most fires are detected by means of other fire-related stimuli. These stimuli include human running and/or verbal warning sounds, heat cues, and the odoriferous and visual components of smoke.[5] Finally, even when an electromechanical smoke detector does sound an alarm, it is ultimately the human who must become aware of the auditory stimulus.

The ability to detect a fire cue is not constant across all people and situations. In fact, the assumption: "Because one person in one fire situation detects a certain cue, the same or another person in a different fire situation will detect a similar cue" could be greatly in error.

Research in the field of cognitive psychology has provided insight into human and environmental variables that affect the likelihood of detection of a world event. Meaningful factors include:

Cue Intensity: The louder, brighter, larger, more rapidly rising, or otherwise more potent the cue, the more likely its detection.[6,7,8]

Cue Salience: More important stimuli are more apt to be noted.[9]

Focus of Attention: A person engaged in an engrossing task is less likely to detect a cue from the environment.[10]

Asleep vs. Awake: Sleeping subjects are less apt to respond to equal stimuli than awake subjects.[11]

Drugged vs. Undrugged: Barbiturates tend to raise detection thresholds, amphetamines to lower them.[12]

A Look at Alarm Warning Signals

Five models of commercially sold smoke detector alarms were shown to generate warnings falling between 74 and 87 dBA, as measured 15 feet from the source. Each of these alarms was associated with a specific frequency pattern.[13]

Should one of these alarms be mounted downstairs in a residential home, the warning might be greatly attenuated by the time it reaches an upstairs bedroom. An 80 dBA signal, for instance, may be attenuated 40 dBA in passing through a ceiling, and a further 15 dBA passing through a closed bedroom door. The warning could then be masked by a 55 dBA air conditioner noise, finally reaching the pillow site at a signal to noise ratio of −25 dB.[14] It can be seen that, though alarm warnings are uncomfortably loud when one stands near the source, their detection is not assured when sleeping quarters are remote.

LABORATORY STUDY

Subjects: Twenty-four male undergraduate students, taken from introductory psychology classes served as subjects. Subjects had a mean age of 21.3 years. They received three hours of course credit and $5.00 for participating.

Apparatus: North Carolina State University Fire Study Laboratory: The laboratory consisted of a bedroom, a living room, a hallway, and a control room. Rooms were furnished and floors carpeted to provide a "homelike" environment (see Figure 1).

Smoke Alarm: A General Electric model 4201-401 household smoke alarm was employed. This alarm generates a bi-periodic signal peaking at 2,000 and 4,000 Hz. The alarm was switched between three locations in order to provide warnings of three intensities; 78, 54, and 44 dBA at the pillow site. As these alarms were presented against a 44 dBA background noise, warnings actually reached a subject's ear at signal/noise ratios of 34, 10, and 0 dB, respectively.

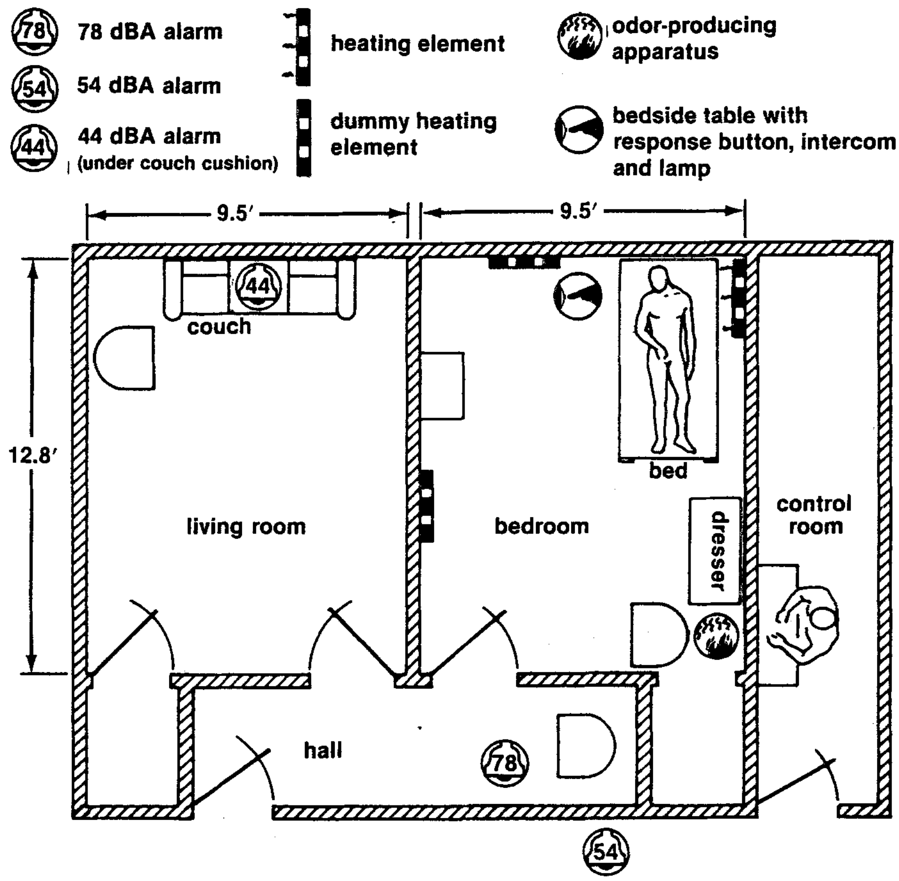

Figure 1. Layout of the fire study laboratory.

Odor Producing Apparatus: A burning odor was generated by a circuit of three, paint coated, 150-watt light bulbs. The odor was noticeable at the pillow site within 1.5 min of system activation.

Heating Unit: Heat was introduced by an Aztec model ATH66, 750-watt radiant heater.* Visually this device resembled a 2 ft (.6 m) by 4 ft (1.2 m) office ceiling tile. The unit was secured to the wall adjacent to the pillow site (see Figure 1). When the heater was activated, the temperature at the nearest edge of the bed would climb from 70° F (22° C) to 87° F (30° C) within 10 min and would reach 97° F (36° C) after 20 min. The panel and two identical dummy heaters appeared to be false windows in an otherwise windowless room.

Other Equipment: Subject responses were made by pressing a small doorbell-type button located next to the bed. The button was dimly lit from within, thus being visible but not intrusive. An intercom was installed to allow verbal communication between the experimenter and the subject.

Procedure

Subjects were run one per night. Upon arrival, a subject was told that he was taking part in a fire study and that as he slept the environment in the room was apt to change. If he noticed any changes, the subject was to push the lighted response button.

The first cue of a night was presented two hours after the subject turned the light out to go to sleep. The second and third cues were introduced after four and six hours, respectively. When a subject pressed the response button, a brief interview was conducted through the intercom to determine how well he could describe the cue.

Design

Two experiments, each employing twelve subjects for one night, were conducted concurrently. In Experiment 1, each subject received one presentation of each of the three alarm intensities. In Experiment 2, subjects received the 54 dBA alarm, the odor stimulus, and the heat stimulus. A randomized block design minimized the likelihood of bias which might result from order of cue presentation within either experiment; or from changes in the equipment, experimenter, or subject pool between experiments.

The measure of cue alerting effectiveness was the time that elapsed between stimulus activation and subject pressing of the response button. If a subject did not detect a cue within 20 min, a default value of 1,200 sec was recorded. Though it is assumed subjects were asleep when cues were presented, 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 indicated any subject was awake just prior to a treatment presentation.

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* Aztec International Ltd., 2417 Aztec Road, N.W., Albuquerque, NM 87107.

RESULTS

Descriptive Statistics

Frequency of Treatment Detection: Successful cue detection accounted for 34 of the 72 presentations across the two experiments. Of the presentations that were detected, most were detected within the first 5 min. This bimodal distribution of treatment detection is shown in Figure 2. The frequency of detection by specific cue can be seen in Figure 3.

Time Until Treatment Detection: Mean response times to treatment presentations are provided in Figure 4.

*Effects of Accumulated "Sleep:"** A second area of interest was whether response latency would be influenced by hours of accumulated "sleep." Subject response time means at two, four, and six hours of "sleep" are shown in Figure 5.

Verbal Identification of Cues: Each of the 16 subjects who responded to one or more alarm presentations was asked, via intercom, to identify the sound he was hearing. Despite considerable probing, only one subject was able to identify the sound as a fire alert. The majority of the subjects could only report they were hearing a "loud" or a "high-pitched" "sound" or "noise."

A debriefing interview conducted the following morning revealed that most of the subjects had heard smoke alarm warnings at the houses of parents or friends. When told the sound he had heard was a smoke alarm, one of the subjects said, "It sounded different from my parents' alarm."

Upon awakening, none of the three subjects who responded to the heat presentation made any reference to fire. All three of the subjects responding to the odor presentation immediately identified the cue as one of "burning."

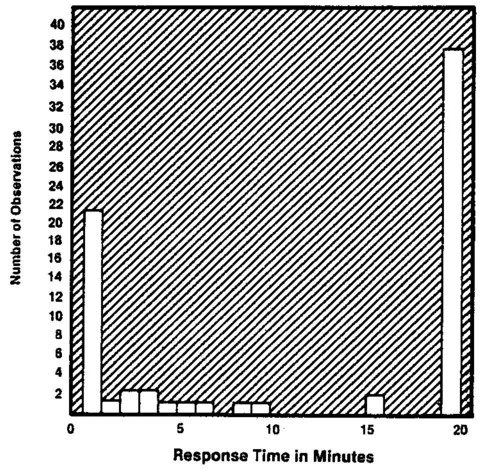

Figure 2. Distribution of response times. (Results from Experiments 1 and 2 have been combined.)

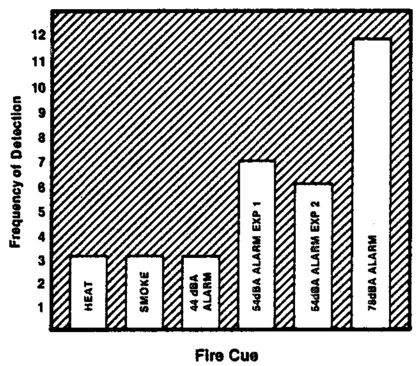

Figure 3. Frequency of detection of fire cues. (Alarm warnings presented against 44 dBA air conditioning. N = 12 per fire cue.)

* "Sleep" is in quotes because subject sleep was assumed rather than assured by electroencephalography (EEG).

Inferential Statistics

Treatment Effects: A Friedman two-way analysis of variance, performed on the data from Experiment 1, indicated a significant difference in subject response times to the three alarm treatments, $X_r^2(2) = 12.67, p < .05$. The same test, repeated with Experiment 2 data, failed to detect significant differences in response times between the 10 dBA alarm, the odor presentation, and the heat treatment, $X_r^2(2) = 2.54, p < .05$.

Accumulated Sleep Effects: A third Friedman two-way analysis of variance suggested there were no significant differences in response latency after two, four, and six hours of accumulated "sleep," $X_r^2(2) = 1.31, p > .05$.

DISCUSSION AND CONCLUSIONS

Response Time Latencies

The most important finding of this research is the relative unresponsiveness of subjects to four of five specific fire-related cues. Subjects repeatedly slept through alarm warnings equal in intensity to those presented in degraded, but not unusual, home settings. Subjects were similarly unsuccessful in awakening to radiant heat and smoke odor cues.

Accumulated Sleep

This research failed to find any significant correlation between hours of accumulated sleep and fire cue detection.

Failure to Identify Fire Cues

Subjects in this study were unable to identify smoke alarm sounds

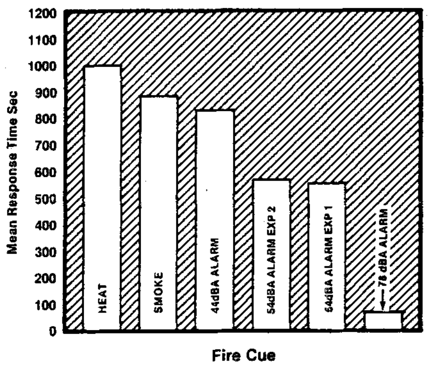

Figure 4. Mean response latencies to fire cues. (Alarm warnings presented against 44 dBA air conditioning. Cue nondetection scored as 1,200 sec default. N = 12 per fire cue).

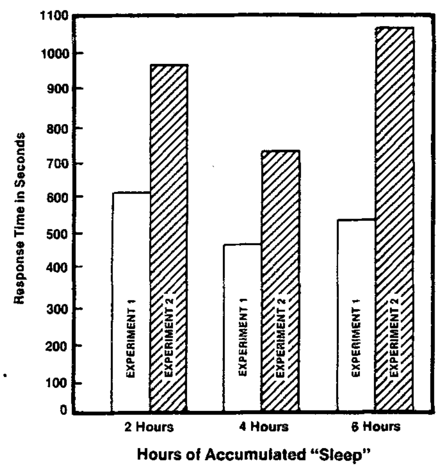

Figure 5. Mean response times at hours of accumulated sleep.

despite the fact that many had heard alarms before. It seems likely that, during battery testing, cooking, etc., subjects had inadvertently trained themselves in pairing an alarm label to an alarm sound. When awakened by a different alarm sound, the stimulus was unfamiliar, training was lost, and the subject was not able to identify the alarm as a fire warning.

RECOMMENDATIONS

It is clear that, to be considered effective, a smoke alarm warning must reach relevant pillow sites in excess of some unknown value which is greater than a 10 dB signal to noise ratio. Should future research identify this value more specifically, fire safety standards could be improved.

The triggering of a remotely located alarm will not necessarily present a cue sufficient to awaken a person. Thus, it is essential to bring more potent fire cues to the sleeping quarters. Methods of tying remote smoke detectors into alarms proximal to the bed should be sought.

The assumption: "Once you've heard one alarm, you've heard them all" may be gravely in error. If future research confirms this hypothesis, the benefits of standardizing smoke alarm warnings should be considered.

The benefits of training people in alarm stimulus/label pairing have been suggested. If further research shows training improves human awakening frequency and/or cue labeling, self-training methods should be devised.

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