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VICTORIA UNIVERSITY OF TECHNOLOGY

Report on Reaction of Adults to Fire Related Cues While Sleeping

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CONTENTS

SUMMARY

Understanding of variations of human behaviour in fire is essential for predicting response to a developing fire. Victims of fire have characteristics that may predispose them to not being aroused from sleep by signals coming from the fire itself. The ability of people without these risk characteristics to wake to fire cues in time to avoid harm has received little attention and it is generally assumed that all sleeping people have a high risk of becoming a fire fatality. This project tested the hypothesis developed from fire statistics that the majority of adults, those without risk characteristics for fire fatality, will wake to minimal cues during a fire. We examined the responsiveness of sleeping adults to cues designed to mimic the presence of fire - sounds, flickering light and smoke odour. The 33 participants were people who self-reported normal responsiveness of the senses (auditory, visual and olfactory) and normal sleeping patterns. The responses of 16 partners of these participants were also recorded. A field experiment tested ability to wake to two different sounds and a flickering light. A second experiment tested the responsiveness of 17 participants to a smoke odour presented during Stage 2 sleep. It was conducted in a sleep laboratory where sleep stages and cue strength were monitored. There was a high rate of recognition of the sound cues (91% to one, 83% to the other), a 59% response to the odour and 49% recognition of the flickering light. The findings support the hypothesis that most unimpaired adults will wake to minimal cues during a fire.

BACKGROUND TO PROJECT

Accurate prediction of occupant response is required for models that are designed to assess risk to life in fires for the purpose of performance-based assessment of building safety, but quantitative data on human behaviour in fires is limited. The lack of data, and particularly of data relating to initial occupant response, is recognised worldwide.

A model of human behaviour in residential fires under development at the Centre for Environmental Safety and Risk Engineering, Victoria University, predicts the proportion of occupants in a building who will evacuate and the times that sub-groups will take to evacuate under specified fire conditions (Brennan, 2000). The model distinguishes between cue recognition and action given cue recognition and appraisal. It requires probabilities for occupant recognition of direct signs of fire, that is for awareness via the senses of smoke and flames and of noises created by the fire, as well as of second order signs such as alarms and warnings.

The recognition of alarms by people has been documented to some extent from field and experimental data for adults and/or children awake (Proulx et al, 1995) and asleep (Nober, Pierce and Well, 1983; Bruck and Horasan, 1995; Brennan 1997; Bruck, 1999; Bruck and Bliss, *in press*). Investigation of the effect of other cues has been very limited, and establishing probabilities for recognition of immediate signs of fire by occupants sleeping in or near a room of fire origin has been a particularly elusive goal.

FIRE RECOGNITION AND FIRE STATISTICS

It has been shown that the primary means of noticing the presence of a fire in domestic settings is by the sense of smell, and that flames or smoke are noticed subsequently (Wood, 1972; Bryan, 1977; MORI, 1994). (Warnings from others are also a significant cue but they assume earlier fire recognition by someone else). As most fires occur when people are awake, there is a natural bias in this finding. Recognition of odours by people asleep has been investigated as part of research into sleep (Carskadon et al, 1990). Only two studies have been located where the primary interest was in whether people would wake to something resembling the smell of smoke (Kahn, 1984; Lynch, 1998). They found that there was a low probability for recognition.

However, fire brigade statistics indicate that most people do wake to signs of fire. It is not known how many wake in sufficient time to extinguish the fire and avoid calling the fire brigade, but the fact that most occupants avoid injury and death when a reported fire occurs at night indicates the vigilance that continues during sleep.

Evidence for this can be found in U.S. National Fire Incidence Reporting System (NFIRS) statistics. For example, in apartment fires in non-sprinklered buildings over a ten-year period between 1983 and 1993 there were 724 civilian fatalities from 32077 apartment building fires between 1 a.m. and 5 a.m., the peak hours for fatality rates. Most occupants in apartment buildings can be assumed to be sleeping at this time. This represents a rate of 22.6 deaths per 1000 fires during these hours, well above the overall rate of 9 deaths per 1000 fires for apartment fires or the rate of about 7 for fires from 5a.m. to 1a.m. Although the rate of fatality is almost 3 times higher during the selected 4-hour period, the figures indicate that there is a high avoidance rate by occupants who are initially asleep. Assuming that one person is present in each of the 1a.m.-5a.m. fires, over 97% of sleeping occupants (31353/32077) apparently recognise cues and respond in sufficient time to avoid becoming a fatality. If there were no one present in half of these fires, the 'avoidance' rate would be approximately 95%.

Ahrens (1998) indicates that in the four years up to and including 1995 more than 90% of homes in the US had smoke detectors. Figures 2 and 3 of the same report show that of fires attended by the fire brigade in one and two family dwellings the proportion with smoke detectors by 1995 was 51% (with about 15% rated as non-operational) and in apartments 74% (with about 20% non-operational). These figures show clearly that dwellings without detectors place many more calls to the fire brigade. While this may suggest that detectors reduce the likelihood of having a fire develop sufficiently to warrant a call to the fire brigade, it may equally suggest that fires occur with greater frequency in dwellings without detectors because there is increased hazard, whether through characteristics of the occupants or the dwelling or both.

Even in homes with smoke detectors, occupants are likely to be first alerted to a fire by means other than an alarm. The NFIRS database shows that in one and 2 family dwellings with detectors the detectors are activated in about 55% of the reported fires and in apartments with detectors the detectors are activated in about 63% of the fires. These rates refer to the operation of detectors at any stage, including after the arrival of the fire brigade, and it cannot be concluded that occupants were first alerted by an alarm even though it sounded.

DISCUSSION

The cues presented simulated sounds, smell and light changes from the early stages of a fire. The cues were presented individually, not as a composite group as might occur in a real fire incident.

The findings of this study suggest that most unimpaired people will wake to early fire cues, at least from Stage 2 sleep that predominates in the sleep cycle. There was a high rate of response to both sounds (91% and 83%), even though they are delivered at a lower strength than has been reported in the literature on arousal to a smoke detector alarm. The 59% response to the odour and 49% to the flashing light suggests that less reliance can be placed on the recognition of visual or olfactory cues. Partners who were present and asleep at the time of cue delivery showed a high rate of wakenings.

The findings suggest that individual differences are more apparent in relation to odour and light stimuli. This is in line with the few studies that are available on sensitivity to smell or light among sleeping people. The reduced responsiveness to low level light compared with the results from Nober (1990) is most likely the direct result of the use of a lower intensity of light. However, other factors may also be influencing the results:

a. The flashing light was the least controllable of all the cues and varied considerably in strength at the point of reception. It can be surmised, however, that this would be the situation in a real fire and that the position of the sleeping person *vis a vis* the light as well as the location of the fire with respect to the person would have a strong influence on effect.

b. Participants in the first experiment were mature adults with a mean age of 43 years, those in the second were considerably younger, with a mean age of 21 years. Other studies have shown that younger people are less likely to be aroused from sleep by external cues.

Caution should be used in making comparisons between the two experiments because of the difference in ages of the subject populations.
It is apparent that of the people who did wake, the majority did so fairly promptly.

The findings for recognising an odour suggest that women may be more likely to be aroused than men. Older women have higher levels of olfactory functioning than older men, but no such findings have been located reporting on younger age groups. It is possible that the gender difference in arousability to smell is a function of gender differences in sensitivity to odours in the population, but this area remains highly controversial. Other relevant factors include medication and smoking. As well, there is debate on the validity of methods for testing olfaction.

Caution is needed in generalising from these findings because of:

a. the small numbers involved. An increase in the number of subjects in the odour study is particularly desirable.

b. the motivation of participants to wake. This is an unavoidable aspect of the experiment in this experiment. It was originally planned to leave the equipment with a participant for two weeks to reduce the impact of an 'anticipation effect', whereby participants might sleep more lightly and be ready to respond. A number of participants mentioned this anticipation and that its effect was most evident on the first night (when cue presentation was avoided).

c. the stage of sleep under consideration. The attempt to deliver cues during Stage 2 and REM sleep means that the likelihood of response is increased compared to delivery in the deeper stages of sleep (Stages 3 and 4). In Experiment 2, the sleep stage was known but in Experiment 1 it can only be hypothesised that the majority of subjects were in a lighter stage of sleep because of the time of cue delivery (four hours after retiring).

The variability of noise and light effects in the immediate environment of dwellings is an uncontrolled factor that may contribute to the results. This too is a factor that might affect recognition of cues from a real fire.

The recognition of cues in this series of experiments is based on independent cues. In a fire situation, however, for people who are near the fire, it can be surmised that more than one of these cues would be present at any one time, particularly as the fire grows. Moreover, as the fire grows the strength of the cue would increase, an area not explored in this experiment. Thus we can surmise that the effects would be cumulative and awakenings among unimpaired people would be even more likely.

CONCLUSION

Results reflect statistics that suggest that most people have a high avoidance rate even when fires occur while they are asleep and intimate that many of those who are killed in fires have characteristics that predispose them to not waking. Thus it is not so much being asleep as being asleep and having other risk characteristics. Research into human behaviour in fires shows that these include age, intoxication and mobility. Most adults have the capability of waking to cues in time to avoid fatal consequences, at least during the lighter stages of sleep.

Results from this research are expected to contribute to reducing the consequences of fires by understanding how sleeping occupants, with and without risk characteristics associated with fatalities, recognise the presence of fire in the absence of alarms and warnings from others. They also will be relevant to simulation and risk computer models of fires in residential buildings by increasing the accuracy of predictions of arousal of sleeping people by cues produced directly by fires.

It would be valuable to test the recognition of cues by people who are affected by alcohol and by older people in particular, as these are two high-risk groups for fire fatalities, and to look at response during Stage 4 sleep. Further investigation of gender differences in arousal to odour is also warranted, along with consideration of the effect of smoking on sensitivity to odours.

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Findings pointing to the same conclusion come from a UK Home Office survey of people who had experienced a domestic fire (MORI, 1994). It found that smoke detectors were present in 54% of the 449 fires but only 8% of respondents reported being first alerted to the fire by the smoke alarm. Unfortunately, the study did not seek information on whether occupants were asleep when the fire occurred.

Clearly, despite the absence of alarms, occupants become aware of the presence of fire and take effective action even when the fire occurs at night. However, information on what wakes people in the absence of alarms in fires is not readily obtainable.

Present understanding of arousal capabilities in a fire is dominated by research identifying characteristics associated with fatalities and by anecdotal accounts of particular incidents. Evidence from coronial investigations of fatal fires shows that particular demographic and behavioural factors feature strongly among victims of fire (e.g. being very young and known to play with matches, being frail and elderly, being intoxicated and smoking, having low incomes). Being asleep is seen to increase risk but the degree to which it is a contributing factor independent of the presence of other fire risk characteristics is in question.

AROUSAL AND SLEEP

It is recognised that information processing continues during sleep even though it is a state of reduced awareness, and that arousal thresholds vary considerably. Elevated arousal thresholds increase the danger from fire for people who are sleeping. For fire response modelling, we need to determine not only whether people will wake to different cues but which people will wake reliably and which will not.

Studies of the effects of external stimuli on sleeping people have usually been undertaken in the course of identifying characteristics of sleep stages and sleep disorders. Bonnet (1982) and Busby, Mercier and Pivik (1994) cite research indicating that key factors that influence arousal include

- state of sleep (e.g. elevated arousal levels with the slow wave sleep of Stages 3 and 4),
- duration of sleep (a negative correlation between accumulated sleep and arousal levels),
- condition variables (age, sleep deprivation, pharmaceutical agents),
- modality of stimulation (auditory, olfactory, tactile),
- stimulus intensity, and
- stimulus significance.

These factors are all relevant to a fire context, where added impact may also come from stimuli that deviate from normal and from the likely presence of more than one stimulus at a time. Perceived responsibility may also provide added motivation for cue recognition.

Smoke alarm studies mentioned earlier indicate that a normal sleeping adult will wake quickly to a 55-69dBA alarm. Other studies of auditory arousal use signals of lower frequency and have thresholds around 80dBA or more. Bruck, *(in press)* reviews these studies.

Studies of arousal from sleep to olfactory stimuli have less than half the subjects being aroused by an odour. The chemicals used vary and concentrations are not stated. Lynch (1998) found that 20% of subjects, all with sleep disorders, woke from Stage 2 sleep to a smell of smoke derived from barbecue flavouring. Kahn (1983) indicates that 3 of 12 subjects woke to a smell of smoke induced by paint on a light bulb. Carskadon et al (1990) found that, for subjects in Stage 2 sleep, a peppermint odour aroused 26% and an unpleasant odour of pyridine aroused 48%.

Nober, Well and Moss (1990) investigated the arousability of deaf and hearing people to three different types of light, including two strobe lights. Among the hearing subjects, 63.3% woke, while 89.5% of the people with deafness woke. The data presented on bulb wattage, luminance and illuminance suggest that the lights were quite intense.

RESEARCH QUESTION

The research question directing this project was: Are people who are asleep and who do not have characteristics associated with risk in fire likely to wake to cues that come from a fire within their dwelling?

It was hypothesised that adults with normal sleep patterns, no or low alcohol intake, and without hearing disabilities would have a high rate of responsiveness to cues presented at low strength.

Gender differences in arousability formed an additional part of the investigation.

EXPERIMENTS 1 AND 2: METHOD AND RESULTS

EXPERIMENT 1: RESPONSIVENESS TO AUDITORY AND VISUAL CUES

Participants

Thirty-three adult volunteers aged 25-55 years (mean age 43 years) who self-reported normal hearing and normal sleep patterns have been tested in their homes. There were 15 men and 18 women. Sixteen of the subjects slept with partners on one or more nights of the study and data was collected for them also. The volunteers came through personal contact. No payment was involved. All subjects agreed to limit their alcohol intake during the study.

Equipment

A laptop with a 5-day program to direct the presentation of cues and record results and electronic monitoring equipment to control the emission of cues and responses was placed outside the bedroom (to reduce interference by noise). A stand with two speakers and a light attached was placed at or near the foot of the bed. A button to be pressed by participants who woke to a cue was placed within convenient reach of the sleeping person.

A brief questionnaire was also prepared. It sought information from the participant each evening (a subjective estimate on quality of sleep on the previous night and level of sleepiness during the day, and a record of alcohol intake) and from the participant and partner, if present, each morning if they had noticed a cue (whether they were actually asleep, whether they were dreaming, what woke them and any clarifying comments).

Two auditory cues, a 'crackling' noise akin to the early stage of a timber fire and a 'shuffling' noise, and a flickering light cue were used. The sounds were chosen to represent sounds from a fire. The first sound 'Wood crackling' was from Track 81, Volume 10 of Sound Effects for Movies and Videos, Digimode, 1995. The second was 'Sail flapping in the breeze' from Track 22, Volume 23 of a BBC Sound FX CD, 1988. These contrasting sounds were selected after consideration of reports by witnesses of noises that had alerted them to a fire and of the variability in those noises. The sounds were edited to 30 seconds with the selection of sections with less variation. Intensities for presentation were decided through preliminary testing. The speakers were adjusted so that sounds were held mostly within a 42-48dBA range at the pillow. The crackling sound was sharper and more varied than the shuffling sound, although the shuffling had one momentary sound at the 25th second that reached 58dBA.

The flickering light came from a 35mm dichroic reflector halogen lamp of 20W. It represented an approximation of the flickering light of a fire and was set up so that it reflected on to the ceiling of the room. The design (size of room, height, shape of ceiling) and surface (colour and texture) of bedrooms and the amount of light entering rooms at night from outside led to considerable variation in reflectiveness and thus in the strength of this cue. The light was directed towards the ceiling and reached the pillow at 5 lux or less. In some situations the light reading from the pillow was as low as 1 lux.

Procedure

1. Cues were presented in random order on three nights only. We avoided delivering cues on three consecutive nights. Cue delivery occurred five times over a five-minute period lasting for 30 seconds each time with 30 seconds between presentations. Each series of a cue was presented on Monday to Thursday nights, weeknights being

preferred because sleep patterns were assumed to be likely to be more regular and involve less drinking. It was planned that no cues were presented on the first night (Sunday) so that participants would have some familiarity with the equipment and perhaps be less sensitive to its presence. Participants were not told of this feature. (Two exceptions to this plan occurred, one when the program was accidentally activated early, the other when a volunteer was only available for 4 nights).

2. Participants activated the program each night by pressing a 'sleep' button on the monitor when they were preparing to go to sleep. Cue presentation began 240 minutes after this time. A four-hour time period was chosen to increase the likelihood of participants being in Stage 2 or REM sleep when the cues were delivered. These two stages have similar arousal levels. (Stage 4 sleep is more likely to occur in the first third of sleeping while Stage 2 and REM occur in the last two-thirds.)

3. Participants were told that when they were asleep a cue might be presented that they could see, hear or smell. There would be some nights without cues, though the number could not be stated. Nor could they be told when the signal might occur. If they noticed anything unusual, they were to press the button by their bed three times. This would stop the delivery and they could go back to sleep. There would be no further cues that night.

4. Participants were asked to complete the relevant sections of the questionnaire prior to going to sleep and in the morning. Partners were asked to complete the morning questionnaire if they had responded to a cue.

Results

Some participants received fewer than three cues. This may have been due to the program not running as planned, particularly in the first few runs, or to the non-activation of the program by the participant. Where runs were stopped, usually as a result of equipment failure, data are taken only from those nights that conformed to the planned experiment.

Responses are not included in the data set where subjects reported being awake at the time when the cue was presented and the data file indicated a press of the response button. However, if they pressed the button during subsequent presentations but reported that they pressed it on the first presentation, it is assumed that they were in fact asleep and had misjudged their state, and the relevant data are included. This happened on two occasions. In one other case, a partner was unsure as to whether waking was due to the cue or the participant's movements in pressing the button, so it was conservatively assumed that the participant woke them.

Results for response to the auditory and visual cues (as well as to the odour) are presented in Table 1. The number and percentages are given separately for participants and partners and for gender. There was a high rate of awakenings to the sound cues. For all exposures to the sounds more than 4/5 people woke (crackling - 91%, shuffling - 83%).

The flickering light was less effective as a cue with 12 participants waking from 28 trials, a rate of 43%. Only six woke during the first presentation.

Table 1: Numbers (percentages in brackets) of subjects and partners waking to each cue as a function of gender. (Note: Odour data relates to Experiment 2)

	Light	Crackling	Shuffling	Odour
Males				
Subjects	4/13 (30.7)	10/12 (83.3)	8/12 (66.6)	2/7 (28.6)
Partners	3/4 (75.0)	6/6 (100)	6/6 (100)	-
Females				
Subjects	8/15 (53.3)	16/17 (94.0)	13/15 (86.6)	8/10 (80.0)
Partners	5/9 (55.5)	9/10 (90.0)	7/8 (87.5)	
All participants	20/41 (48.7)	41/45 (91.1)	34/41 (83.0)	10/17 (58.8)

Times, including the 30 seconds between each presentation, for the key participants to respond are given in Table 2. Partners' times were not measured. The frequency of response and time for response varied according to the cue. In most cases where participants woke to a sound they woke to the first presentation of the cue (crackling - 92%, shuffling - 95%) and responded within the thirty seconds of cue presentation. The shuffling sound led to thequickest response overall and the light to the longest. Two or three participants report taking some time to respond after they were awake because they could not locate the button in the dark. Others report taking some seconds to determine what was happening and to remember what to do – a delay on waking termed 'sleep inertia' that has been found in other studies.

No significant gender differences were found for these three cues. From Table 1 it can be seen that there was greater consistency in response among women than among men when the response of key participants is compared with partners.

The mean times to respond to the sounds were 24 and 30 seconds, to the light 90 seconds.

Table 2: ***Number of participants responding by time to respond***

Time in seconds	Light	Crackling	Shuffling
0-30 (1st cue presentation)	6	19	18
31-60		5	2
61-90(2nd presentation)	2		1
91-120			
121-150 (3rd presentation)	1	2	
151-180			
181-210 (4th presentation)	1		
211-230			
231-260 (5th presentation)	1		
265	1		
Range	3-265sec	10-138sec	9-85sec
Mean	90sec	30sec	24sec

EXPERIMENT 2: RESPONSIVENESS TO AN OLFACTORY CUE

Participants

Seventeen young adults, aged 18-26 years (mean age 21.4 years, SD 2.57), self-reporting normal sense of smell and ability to sleep during the day were involved. There were ten women and seven men. The participants were students from the University and were paid $25.00 for attendance. All participants were asked to restrict their sleep to around six hours (e.g. from 1am to 7am) on the previous night to enhance the likelihood of going to sleep in the afternoon. On arrival at the sleep laboratory all subjects were asked how many hours they had actually slept the previous night. Times varied between 4 and 7 hours and there were no clear gender differences.

During preparation for the sleep recordings an informal check was made of subjects' ability to smell by asking them whether they could smell the alcohol on a cleaning swab. One person who could not was eliminated from the study. Smoking habits were not recorded.

Equipment

Sleep monitoring equipment (electrodes) in the Victoria University Sleep Laboratory was used to detect when participants had entered Stage 2 sleep.

The cue presented was the unpleasant smell of a chemical that is a basis for the smoke taste and smell in food flavourings (Guaiacol). This was prepared in an ethanol base at a 5% concentration level in an aerosol container. A dispenser emitted puffs of the mixture at the rate of nine puffs per minute and this odour was dispersed into the bedroom via a duct and fan. Low levels were used, where the parts per million were an average of 0.9 (± 0.4) at one minute to 6.0 ppm (± 1.0) at 10 minutes at the pillow. As the human nose is very sensitive the smell was clearly evident at the pillow 20 seconds after dispensing began when the concentrations were well below 1 ppm.

Procedure

1. Participants attended the sleep laboratory for an 'afternoon nap'.

2. Sleep stages were recorded via the standard electrode montage on the scalp and face.

3. Participants began their nap between 1.30 and 2pm. Odour presentations began 90 seconds after the person entered Stage 2 sleep and continued for a maximum of 10 minutes.

4. Participants were asked to press a button three times if they became aware of the presence of a stimulus that they could see, smell or hear.

Results

Of the 17 participants, 10 woke to the odour presentation (59%) as shown in Table 1. Of those who woke, all achieved EEG wakefulness in 45 to 205 seconds. The mean time to arouse as indicated by EEG wakefulness was 101 seconds (SD 56 seconds). Only 7 of the 10 who displayed EEG patterns of wakefulness actually pressed the button to record waking. Two of the remaining three reported that they thought they had not been sleeping (though the EEG pattern showed continuous Stage 2 sleep). The third felt that she remained asleep, although the EEG wake patterns were clear.

The mean time to respond to the odour by pressing the button was 158.6 seconds (SD 109.8) after the first cue presentation. As the time to wake was within the first three minutes, participants were waking to low concentrations of the odour (approximately 0.9ppm to 2ppm).

The data in Table 1 indicate a possible gender difference in responsiveness to odour in sleep, although the numbers are small. A Fisher Exact Test indicates a significant difference at the .05 level between male and female participants, with men more likely to continue sleeping.