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RECOGNITION OF FIRE CUES DURING SLEEP

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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 that the majority of unimpaired adults will wake to minimal cues during a fire. The low level cues used were designed to mimic the early presence of fire – sounds (received at averages of 42-48 dBA), flickering light (less than 5 lux) and smoke odour (1-6 ppm). Participants were people who self-reported normal responsiveness of the senses (auditory, visual and olfactory) and normal sleeping patterns. A field experiment involving 33 subjects and 16 of their partners tested the ability to wake to two different sounds and a flickering light. A second experiment in a sleep laboratory tested the responsiveness of 17 participants to a smoke odour. There was a relatively high rate of arousal to the sound cues (91% to a crackling sound and 83% to a shuffling sound), 59% awoke to the odour and 49% responded to the flickering light. The findings indicate that most people will wake to low level auditory cues during a fire and around half will arouse to a low level flickering light or a smell. It was also found that females were more likely to arouse from sleep with an odour than males (80% versus 29%). However, no sex differences were evident for the other cues. These studies confirm fire statistics that suggest most people who are unimpaired will be aroused from sleep by low level fire cues, particularly as in a real fire situation multiple cues occur.

INTRODUCTION

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[1]. The model distinguished 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 while awake[2] and asleep[3,4,5,6,7]. 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.[8,9] (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.[10,11,12] They found that there was a low to moderate probability for recognition (see below).

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 5 a.m. to 1 a.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 1am-5am 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[13] indicates that in the four years up to and including 1995 more than 90% of homes in the US had smoke detectors. He also reports 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 indicate 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 two 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.

Findings pointing to the same conclusion come from a UK Home Office survey of people who had experienced a domestic fire[9]. 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, under which conditions, 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. In unimpaired adults the key factors[14] that influence arousal include

- stage of sleep and time of night (e.g. reduced arousal during the slow wave sleep of Stages 3 and 4 and /or early third of the night),
- condition variables (age, sleep deprivation, pharmaceutical agents),
- modality of stimulation (auditory, olfactory, tactile),
- stimulus intensity and frequency, 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 provide added motivation for cue recognition.

Most research has been done using auditory stimuli with studies showing that a normal sleeping adult will awaken quickly to a 55-60 dBA smoke alarm, while the auditory arousal literature (which uses lower frequency signals), suggests thresholds of around 82dBA (higher in deep sleep). See review by Bruck[14].

Several published studies have looked at arousal to olfactory stimuli during sleep.[11,12,10,15] One study[12] using 10 subjects with sleep disorders found 20% awoke from stage 2 to the smell of smoke (delivered via a chemical). Two studies have administered a peppermint odour and found that the percentage who awoke from stage 2 was 16.7%[15] and 26%.[10] The unpleasant odour of pyridine was found to arouse approximately 48% from stage 2.[10] Because it is impossible to know at what concentrations sleepers were experiencing the odours it is hard to make precise conclusions or comparisons (no parts per million information was provided). However, these studies all suggest that less than a half of sleepers will awaken to an odour.

One study[16] investigated the arousability of deaf and hearing people to three different types of lights, including two strobe lights. Among the hearing subjects 63.3% awoke while 89.5% of the deaf people awoke. In both groups waking latencies were mostly between 20-30 seconds. From the data presented on light intensities (bulb wattage, luminance and illuminance) it would appear 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. Given anecdotal suggestions and some experimental evidence[17] about possible gender differences in arousability, this variable was also of interest.

Experiment 1: Responsiveness to auditory and visual cues

METHOD

Participants Thirty three adult volunteers aged 25-55 years (mean age 43.2 years) who self-reported normal hearing and normal sleep patterns have been tested in their homes. There were 15 males and 18 females. The volunteers came through personal contact. No payment was involved. Sixteen of the subjects slept with their partners (6 males and 10 females) on one or more nights of the study and some data was also collected from these people. 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. The first is subsequently referred to as "crackling" and the second as "shuffling". 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 crackling sound varied at the pillow across the 42-48 dBA range with the highest sound being 58dBA at the 25^{th} second. This sound was sharper and more varied than the shuffling sound which varied from 43-45 dBA with a few higher points of 52 dBA.

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
Cues were presented in random order on three nights only. Delivering cues on three consecutive nights was avoided. 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).

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.)

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 like a signal, 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.

If the subject was sleeping with a partner, instructions were given that if the partner woke to a cue prior to the person designated as the subject, the partner was to lie still and make no attempt to awaken the subject.

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 awoken to a cue.

RESULTS

After each subject had completed the required days with the fire cues equipment the results file was carefully inspected to determine whether the cues had actually been delivered as planned. As some technical problems with the program arose, some subjects received fewer than three cues. Data is taken only from those nights that conformed to the planned experiment. If the subject reported that they were awake at the time when the cue was initiated and the data file showed a press of the button during the first presentation, their response was not included in the data set. However, if they pressed the button during subsequent presentations but reported that they pressed it on the *first* presentation it was assumed that they were in fact asleep and had misjudged their state. This happened on two occasions. In one case a partner was unsure as to whether they awoke to the cue or their partner's movements in pressing the button and it was conservatively assumed that their partner awoke them.

In Table 1 the number and percentages of awakenings for subjects and partners are shown separately, with a breakdown by gender. There was a high rate of awakenings to the sound cues. When considering all the people exposed to the sound cues, the vast majority (91% and 83%) awoke to the crackling and shuffling sounds, while about half (48.7%) awoke to the light. Analyses of possible gender differences for each cue were undertaken (Chi-Square) and no significant differences were found. Comparisons of the percentage of awakening among the subjects compared to the partners within each cue shows good consistency within the females, but less so for the males.

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

	Light		Crackle		Shuffle		Odour	
Males								
as a subject	4/13	(30.7)	10/12	(83.3)	8/12	(66.6)	2/7	(28.6)
as a partner	3/4	(75.0)	6/6	(100)	6/6	(100)	-	
Females								
as a subject	8/15	(53.3)	16/17	(94.0)	13/15	(86.6)	8/10	(80.0)
as a partner	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)

In most cases where subjects awoke to a sound they woke at the first presentation of a cue which lasted 30 seconds. Figure 2 shows that for the crackle sound there were 26 awakenings and of these 24 (92%) occurred during the first presentation. Similarly for the shuffling sound, 20 of the 27 awakenings (74%) occurred during the first presentation. In contrast, with the light cue, only 6 subjects of the 12 who awoke to this cue did so during the first presentation (50%).

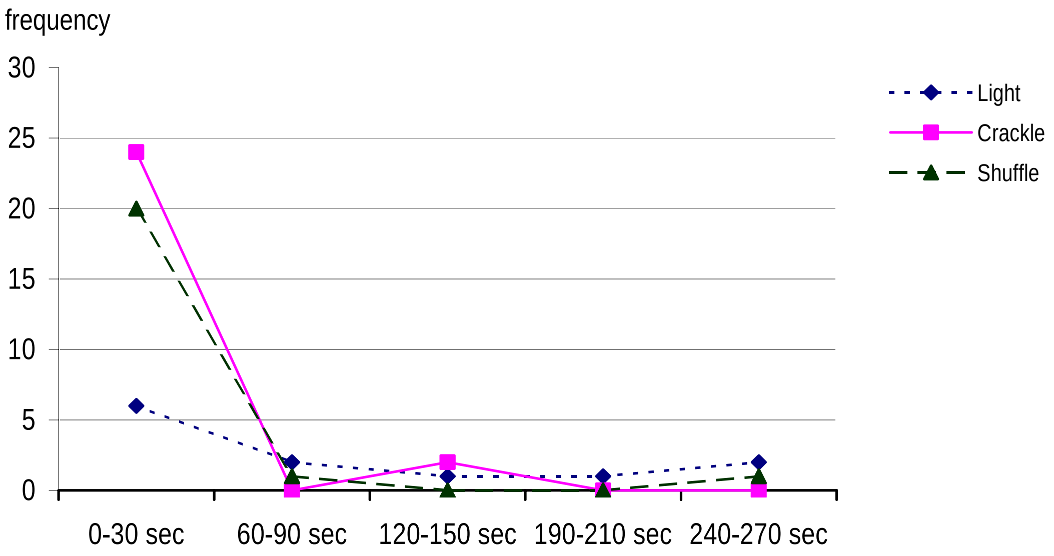

Figure 1: Frequency of awakening to different fire cues as a function of the time elapsed since the cue was initiated (Note: 30 sec. gap between each cue presentation).

Experiment 2: Responsiveness to an olfactory cue

METHOD

Participants Seventeen young adults, aged 18-26 years (mean age 21.4 years, SD= 2.57), self-reporting a normal sense of smell and the ability to sleep during the day were involved. There were ten females and seven males. The participants were students from the University and were paid $25.00 for attendance. All subjects were asked to restrict their sleep to around six hours (e.g. from 1 am to 7 am) on the previous night to enhance the likelihood of going to sleep in the afternoon. During preparation for the sleep recordings the olfactory sense of smell of all subjects was somewhat informally checked by determining whether they could smell the alcohol on a cleaning swab. One person could not (due to a cold) and she was eliminated from the study.

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

The cue presented was the somewhat unpleasant smell of a chemical associated with a smoke taste 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 Participants attended the sleep laboratory for an 'afternoon nap'. Sleep stages were recorded via the standard electrode montage on the scalp and face. Subjects began their nap at between 1.30 to 2.15 pm, odour presentations began 90 seconds after the person entered Stage 2 sleep and continued for a maximum of 10 minutes. Subjects 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 seventeen participants, ten (59%) woke to the odour presentation (Table 1). Of those who woke, all achieved EEG wakefulness between 45 to 205 seconds. The mean time to arouse as indicated by EEG wakefulness was 101.2 seconds (SD=56 sec). Of the 10 who awoke during the presentation of the odour, displaying EEG patterns of wakefulness, only 7 actually pressed the button. Of the remaining three, two said they thought they had not been asleep (although the EEG clearly showed continuous stage 2 sleep) and the third felt she had remained asleep, despite clear EEG wake patterns. The mean time to press the button was longer at 158.6 (SD=109.8) seconds after the first cue presentation. As the time to wake was within the first three minutes the subjects were waking to low concentrations of the odour (approximately 0.9 to 2 ppm).

Interestingly a possible gender difference was indicated by the data shown in Table 1. A Fisher Exact Test was used to determine whether the observed frequency of the males and females awakening differed from what might be expected. Even though there were only 17 subjects the gender effect was sufficient to find a significant difference at the .05 level. Males were more likely to sleep through the odour than females (29% males awoke compared to 80% females).

All subjects reported that they had restricted their night's sleep on the night prior to coming to the sleep laboratory. This varied from reports of 4.5 hours sleep to 7 hours (mean = 5.6, SD=.82). No gender differences in this amount of sleep were evident.

DISCUSSION (Experiments 1 and 2)

The findings of this study confirm that most people will wake to cues that are present at a low level, simulating early fire cues. The percentages of those who awoke depended on the sense which the cue stimulated. There was a high rate of response to both sounds (83% and 91%, based on subjects and partners), even though they were delivered at a lower intensity than has been reported in the arousal to smoke detector literature.[3,6] 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. Individual differences would seem to be more apparent in relation to the odour and light stimuli presented than the auditory stimuli. This is in line with the few studies that are available on sensitivity to smell among sleeping people[10,12,15] and the previous study using light.[16]

With the smell stimulus, the current study found higher responsiveness than previous studies. This may be due to the shorter length of time of stimuli presentation in other studies (90 sec,[12] 15 sec,[10] 3 min[15]), different intensities of odour and/or the unpleasant nature of the smell used in this study, consistent with the previous finding that unpleasant smells led to greater arousability than pleasant smells[10].

The reduced responsiveness to the low level light compared to the results of the Nober study[16] is most likely to result directly from the much lower intensity of light used in the current study. The flashing light was the least controllable of all the cues and varied considerably in strength (from 1-5 lux) 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.

Caution should be used when making comparisons between the first and second experiment because of the different ages of the two subject populations and the known influence of age on arousability.[18] Participants in the first experiment were mature adults with a mean age of 43.2 years, those in the second were considerably younger (mean of 21.4 years). It is unclear whether the longer latency to respond to the smell compared to the other stimuli is a function of the different stimuli or a function of subject differences. It is possible that the younger group took longer than the older group to acknowledge that they had recognised a cue because of an age-related difference. Most people responded to the sounds within 30 seconds, while a waking response to the odour averaged 101 seconds. The time required to respond to the light was more variable. Nevertheless, it is apparent that of the people who did wake, the majority did so fairly promptly.

The findings for recognising an odour suggest that females may be more likely to arouse than males and if this were the case it would be consistent with one study that found sleeping women to be more responsive to auditory stimuli than men.[17] However, it would be at variance with most studies on auditory arousal thresholds which suggest no gender differences.[19] It is possible that the gender difference in arousability to smell found in this study is a function of a gender difference in the detectability to smells in the population. One study notes that gender differences are sometimes reported but that there is controversy about the influence of factors such as gender, medication and smoking as well as the validity of olfactory testing.[20] Age and ethnicity have also been reported as important[21] with older women having higher levels of olfactory functioning than older men, and Africans being better at smell detection than Americans.

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 to strengthen the gender difference finding.
b. The participants were motivated to wake. This is an unavoidable aspect of the experiment. However, the fact that partners who were present and asleep at the time of cue delivery usually showed the same rate of awakening to the cues as the designated subjects (see Table 1), suggests that motivation to wake may not play an important role. Partners were specifically instructed to lie still and not disturb the bed partner and therefore they would not have been highly motivated to wake up, except perhaps because the stimulus was so novel.

c. A number of participants mentioned the existence of an “anticipation effect” and noted that this effect was most evident on the first night. For this reason the program was always set such that no signal was delivered on the first night. However, the existence of such an effect on other nights cannot be discounted and may have led to the sleep of subjects being a bit lighter or more broken than otherwise.
d. The attempt to deliver cues during Stage 2 and REM sleep means that the likelihood of a response is increased compared to delivery in the deeper stages of sleep (stages 3 and 4).[19] 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 lights out).
e. 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 even more likely in unimpaired people.

CONCLUSION

Results provide some support for statistics that suggest that most people who are unimpaired have a high avoidance rate even in fires occurring while they are asleep.

Results from this research are expected to contribute to an understanding of how sleeping occupants, without risk characteristics associated with fatalities, recognise the presence of fire in the absence of alarms and warnings from others. The data will also support 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. Further investigation of gender differences in arousal to odour is also warranted.

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[1] Brennan, P. (in press). Modelling cue recognition and evacuation response. *Proceedings of the 6th International Symposium on Fire Safety Science,* Poitiers, 5-9 July 1999. International Association for Fire Safety Science.

[2] Proulx, G., Laroche, C. and Latour, J.C. 1995. Audibility Problems with fire alarms in apartment buildings. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting*, 989-993.

[3] Nober, E.H., Peirce, H. and Well, A. 1981. Waking effectiveness of household and fire detection devices. *Fire Journal*, 86-91(+130).

[4] Bruck, D. and Horasan, M. 1995. Non-arousal and non-action with a smoke detector alarm in normal sleepers. *Fire Safety Journal*, 25(2), 125-140.

[5] Brennan, P. 1997. Timing human response in real fires. *Proceedings of the 5th International Symposium on Fire Safety Science.* Y. Hasemi (Ed.), International Association for Fire Safety Science, 807-818.

[6] Bruck, D. 1999. Non-awakening in children in response to a smoke detector alarm. *Fire Safety Journal*, 32, 369-376.

[7] Bruck, D. and Bliss, R.A. (in press). Sleeping children and smoke alarms. *Proceedings of the 4th Asia-Oceania Symposium on Fire Science and Technology*, Tokyo, May 2000.

[8] Bryan, J.L. 1977 . *Smoke as a determinant of human behaviour in fire situations (Project People).* Report No. NBS-GCR-77-94, Washington, DC: National Bureau of Standards.

[9] MORI. 1994. *Domestic First Aid Firefighting* Research study conducted for the Home Office, Fire Research and Development Group.

[10] Carskadon, M.A., Bigler, P.J., Carr, J., Gelin, J., Etgen, G., Davis, S.S. and Herman, K.B. 1990. Olfactory arousal thresholds during sleep. *Sleep Research*, 19, 147.

[11] Kahn, M.J. 1984. Human awakening and subsequent detection of fire-related cues. *Fire Technology*, 20(1) 20-26.

[12] Lynch, J. 1998. Nocturnal olfactory response to smoke odour. *Human Behaviour in Fire Proceedings of First International Symposium* (Ed. T.J. Shields), University of Ulster, Fire SERT Centre 231-242.

[13] Ahrens, M. 1998. Batteries not included. *NFPA Journal*, May/June, 98-109.

[14] Bruck, D. (in press). The who, what, where and why of waking to smoke alarms: a review. *Fire Safety Journal* 2001.

[15] Badia, P., Wesensten, N., Lammers, W., Hughes, R. and Boecker, M. (1989). Olfactory sensitivity in sleep. *Sleep Research*, 18, 151.

[16] Nober, E.H., Well, A.D. and Moss, S. 1990. Does light work as well as sound? Smoke Alarms for the Hearing-Impaired. *Fire Journal*, 27-30.

[17] Wilson, W.P. and Zung, W.K. 1966. Attention, discrimination and arousal during sleep. *Archives of General Psychiatry*, 15: 523-528.

[18] Busby, K.A., Mercier, L. and Pivik, R.T. 1994. Ontogenetic variations in auditory arousal threshold during sleep. *Psychophysiology,* 31, 182-188.

[19] Bonnet, M. 1982. Performance during sleep. In *Biological Rhythms, Sleep and Performance*, W.B. Webb (Ed.), John Wiley and Sons Ltd. Ch. 8, 205-237.

[20] Moberg, P.J., Agrin, R., Gur, R.E., Gur, R.C., Turetsky, B.I. and Doty, R.L Sept 1999. *Olfactory dysfunction in schizophrenia*. Neuropsychopharmacology, 21 (3).

[21] Barber, C.E. 1997. Olfactory acuity as a function of age and gender: A comparison of African and American samples. International Journal of Aging and Human Development, 44 (4) 317-334.