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The who, what, where and why of waking to fire alarms: a review.

by

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Abstract

This review brings together several different strands of research: (i) The sleep arousal literature pertaining to auditory arousal thresholds (AAT), (ii) studies on factors affecting responsiveness to auditory signals during sleep, (iii) literature on responsiveness to smoke detector alarms during sleep and (iv) research on fire fatality statistics and victim characteristics. The review discusses the influence of age, sleep deprivation, signal frequency, background noise, hearing loss, time of night, stage of sleep, sex differences, dream incorporation, depression, signal meaningfulness, sleeping tablets, alcohol and marijuana on responsiveness during sleep. Studies using smoke alarms clearly suggest that an unimpaired sleeping adult will awaken quickly to a 55-60 dBA alarm (such as with a hallway installation), while the AAT literature suggests higher thresholds (most likely due to differences in signal frequency). However, it is argued that the level required to wake such adults under the ideal circumstances of an experimental situation should not be the minimum standard for pillow audibility. Such a level is unlikely to arouse children, those on sleep inducing medication, people with high frequency hearing loss (as may occur with age), those who are sleep deprived or those under the influence of alcohol or marijuana. The responsiveness of the unimpaired adults tested is not generalisable to the responsiveness of the people most likely to be the victims of fire occurring while they are asleep (the very young, elderly, intoxicated, or sick). The sound intensity of the alarm at the pillow should have the highest chance of arousing those most at risk of dying. It is therefore recommended that smoke detector alarms be installed in the bedrooms themselves such that the signal intensity is at the maximum level tolerable to the human ear, that is approximately 90 dBA.

Sleep as a risk factor in fire

It is well documented that although more fires are reported during the daylight hours than at night (eg 65.8% of home structure fires occurred between 8 am and 8pm[1]), those at night pose more threat to life. Statistics consistently show that about half of all residential fire deaths occur in the night hours.[1-7] Coronial reports on 114 fire fatalities[8] noted that 81% of the fatal fires were at night (8pm to 8am) and in those 86% of victims were sleeping. Moreover, in fires during the day, 31% of the victims were actually sleeping. Thus being asleep is a much stronger risk factor for dying in a fire than time of day. Three quarters of those who were asleep did not move from the room in which they were originally located, suggesting that waking either did not occur or occurred too late to allow escape.

Many countries have legislated for mandatory installation of smoke detectors in homes and in Australia the standard installation is in the hallway. Assuming they are in working order, how likely is it that a smoke detector will arouse a sleeper quickly? It would seem that the intensity of the alarm at the pillow is important in determining responsiveness, but how does the importance of this factor compare to other variables? What are the most salient risk factors that will determine whether an individual will awaken or not? If we know these risk factors how can we use this information in a practical way to reduce fire fatality risk? The following review sets out to provide answers where these may be available within the published research and seeks to clarify what information is still required.

Auditory arousal research - overview

The literature on arousal behaviour really falls into two groupings. Within the first group are the investigations by people interested in the characteristics of sleep. Indeed the first attempts to study waking thresholds were motivated by an attempt to document the varying depths of sleep across the night.[9,10] Over the last century a substantial body of literature has been published on sleep thresholds, overwhelmingly using sound stimuli. The area has been hampered by many different methodologies and environmental factors but the influence of certain key variables is clear.[11] The second group are researchers interested in human behaviour in fire and there are a small number of studies that set out to determine the likelihood of awakening to certain fire cues, notably smoke detector alarms. Salient points from both these groupings will be highlighted and compared.

In the sleep arousal literature the most common method to determine waking thresholds is the ascending/descending method of limits where a tone of a standard frequency is presented to a sleeping person at a certain intensity and if there is no response within a set time the intensity is increased (usually by 5 dBA) until the subject responds. The aim is to achieve both a response and a no-response to a stimulus of a particular intensity and this is then held to be as the Auditory Arousal Threshold (AAT) for the person. Another procedure, employed in the sleep literature, is the method of constant stimuli where a stimulus is presented and the number of responses recorded. This latter method is the one consistently employed in fire behaviour studies on arousal. It has been noted that within the sleep literature these two methods yield results that do not differ substantially.[11]

INSERT Table 1 here

Table 1 presents a summary of details of six studies[12-17] that have investigated waking behaviour to fire alarms. In addition, one study[18] is presented from the AAT body of research. This article was chosen as being representative of the sleep arousal literature for a number of reasons (i) it provides a detailed breakdown of AATs by age and sleep stage and individual variability (ii) the methodology and stimulus characteristics are quite standard and (iii) the results reported fall within the values reported elsewhere within this body of literature (although values do vary greatly from laboratory to laboratory).

Interpretation of Table 1 will be aided by a summary of what different smoke alarm dBAs equate to in the normal home. The unit dBA is the sound level measured in decibels which has been weighted to approximate the response of the human ear, which has varying sensitivities to different frequencies. A typical smoke detector emits a tone with a dominant frequency peak at 4,000 Hz and a second peak at 2,000 HZ , while testing of smoke alarm intensities at 10 feet showed a range from 80 to 92 dBA [19]. Field work involving eight rooms in four residential houses found that activating a smoke detector located in the hallway outside a closed bedroom door resulted in a bedside volume of 51 to 68 dBA. These values are consistent with those cited by others.[12,19-21] Interestingly, dBA reductions through doors appear to be approximately the same for all frequencies above 500 Hz.[21] Background noise levels can vary substantially from home to home and the introduction of an air conditioner into the bedroom itself can create a background level of around 50 dBA.[19]

Age and sleep deprivation

From the studies summarised in Table 1 it can be seen that most adults who participate in such studies under controlled conditions wake quickly to smoke alarms, even at 55 dBA. Consideration of the study[15] involving 16 middle-aged persons (30-59 years of age) shows that 100% woke to an alarm located in the hallway, received at 60 dBA, within 32 seconds.

The AAT study shown in Table 1[18] suggests that adults in the younger age group (18-25 years) will have higher arousal thresholds than people in the older age brackets. Yet the smoke alarm studies with the younger age groups also suggest prompt awakening by people aged 18 to late twenties. Nober and colleagues[12] found that 100% of their 18-29 year olds awoke to a 55 dBA signal within 21 seconds. Bruck and Horasan[14] report that 85% of the 60 dBA smoke alarm signals were responded to (typically within one minute) by their sleeping 18-24 year olds. Interestingly, this study was found to have a sleep deprivation confound. The 20 % of subjects who did not wake reliably to both signal presentations were noted to be sleep deprived before the experiment due to exam time pressures. Increased prior wakefulness is well documented to increase arousal thresholds,[22] and an increase in reaction time from sleep following a night restricted to four hours of sleep has been reported.[23] Some groups within the community have a high likelihood of being sleep deprived, notably adolescents[24] and shift workers and these groups may often have higher than normal arousal thresholds. Provided they are not sleep deprived it seems likely that most people over 18 will wake promptly to 55-60 dBA in 'normal' circumstances.

The two studies[15,16] involving sleeping children and smoke alarms at 60 dBA and 89 dBA clearly show that children are much less likely to be aroused than older persons. Furthermore the responsiveness of children seems to be age related with 6-10 year olds less likely to wake up than older children. These findings may relate to the age related decline in the amount of deep sleep during the night.[25]

Background noise, signal frequency and hearing loss

The level of background noise clearly influences likelihood of arousal with less responsiveness to 55 dBA alarms being reported with significant background noise of 44 dBA[13] or 53 dBA.[12] If background noise levels are an issue it has been suggested that the smoke alarm need to reach the pillow with an intensity of at least 70 dBA to facilitate arousal.[13]

AAT studies, such as by Zepelin and colleagues,[18] would suggest less responsiveness to 55 dBA than actually found in the smoke alarm studies. It is hypothesised that this difference is largely due to the characteristics of the signal used, most notably its frequency. Zepelin's 800 Hz tone is typical of the AAT studies where the tone is always less than or equal to 1,000 Hz[11] and differs from smoke alarms which peak at 4,000 Hz.

There has been concern expressed in the literature that older people are most likely to lose their sensitivity to higher frequencies first, proceeding in both directions from 4,000 Hz.[19] Table 2 presents an extract from normative tables[26] of threshold sound intensity levels for older persons (over 60 years) when awake. Only the 2000 Hz and 4000 Hz frequencies are shown as these relate to the smoke detector alarm signal.

Insert Table 2 here

The AATs presented by Zepelin[18] (Table 1) show that for a sleeping person aged 18-25 years the average sound level required for arousal in the lighter stages of sleep was 82 dBA at 800 Hz and for the 52-71 year olds it was 61 dBA. The paper also reports that the average hearing threshold for the stimulus when *awake* was 13 dBA for the young adults and 20 dBA for the older group. This suggests that for a young adult, the sleep-wake threshold difference, taking the lightest stages of sleep, is 69 dBA and for an older person, 41 dBA. These values pertain to a signal of 800 Hz and it is not known if the same differences can be applied to a signal of 2000 Hz to 4000 Hz. If it is assumed that this difference can be applied across the frequency range and is homogenous within the 52+ year age group, adding 41 dBA to each value in Table 2 would yield sleep arousal thresholds among the older population with hearing loss. Such calculations suggest that at least 25 % of those aged over 60 would not arouse to a hallway alarm received at 55-60 dBA at the pillow. If the alarm was received at 75 dBA at least 10 % of those aged over 70 years would not arouse. These extrapolations relate to the lightest stages of sleep, percentages would be higher in the deeper stages of sleep. However, fortunately, (in an arousal to alarms context) older persons normally have relatively small amounts of deep sleep. Given that this discussion is based on extrapolations involving assumptions, these figures should be seen as indicative of a potential problem, rather than as statistical facts. Experimental evidence on responsiveness to alarms in an elderly population with different levels of hearing loss is important.

Both the likelihood of hearing loss at smoke alarm frequencies and the fact that the elderly are the group most likely to regularly take sleeping tablets (see below) suggests it may be appropriate to explore whether older persons may be more responsive to alarm signals at other frequencies. One study[27] considered responsiveness to tones that ranged between 70 and 2000 Hz and found increased responsiveness at 120 to 250 Hz; the frequencies associated with speech. Similar results have been noted by others.[28] It could be argued that sensitivity of the sleeping human ear in terms of frequency may be bimodal, with sensitivity at the speech frequencies and the much higher "piercing" frequencies.

Time of night/stage of sleep

The sleep arousal literature has been preoccupied with the issue of whether thresholds differ significantly with the stage of sleep. This is potentially important from a fire safety point of view as stage of sleep partially relates to time of night. Most fire fatalities occur in the first half of the night's sleep (midnight to 4am[1)] while a sleeper is most likely to be in the deepest stages of sleep (stages 3 and 4) during the first third of the sleeping period. Bonnet[11] summarised 16 studies on the issue of sleep stage and thresholds and found that the likelihood of arousal decreases with the progression from stage 1 through to stage 4 and that REM sleep and stage 2 were likely to have similar thresholds. There is no clear evidence that time of night may be a factor independent of sleep stage. In other words, responsiveness during the first REM period, for example, is not different from responsiveness in the third REM period.[11] These data on sleep stage and time of night together mean that thresholds during the second and final third of the night in adults are likely to be similar. Arousal thresholds may be higher in the first part of the night because most stage 3 and 4 sleep occurs then. However, it has been noted that many of the differences between sleep stage thresholds are minor and not significant.[11] Inspection of Zepelin's values[18] in Table 1 are consistent with the idea that the variability across different stages is less important than individual differences (note the large ranges) and less important than age related changes in responsiveness. The studies on smoke alarm presentations are variable and sometimes imprecise about the time of night of presentation. Systematic manipulation of sleep stage in a smoke alarm study[14] found that while the likelihood of sleeping through the alarm was spread uniformly across stages 2, 3, 4 and REM, the latencies to arousal from stage 4 were likely to be longer and more variable.

Individual differences

There is clearly a large range of AATs,[18] even when age and sleep stage are taken into account. In this context it has been found[29] that there is high reliability for a person's AATs from night to night, and within a night. Furthermore those with high thresholds in one stage of sleep had high thresholds in other stages. However, there is no correlation between auditory thresholds while awake and asleep. Thus real individual differences would appear to exist. In fact (as argued above) the literature suggests that individual differences exert a stronger effect on the data than sleep stage or age. Are we able to determine the source(s) of such differences between individuals? An early study[30] reported greater responsiveness to auditory stimuli in women than men but this finding has not been replicated. A later study[18] reported a trend for older women to have higher AATs in REM sleep than men and there were some indications this may relate to increased dream incorporation in this group. Those people with higher AATs were found to be more likely to report dreams during non-REM sleep[31] (non-REM sleep is not normally associated with structured dream reports) raising the issue of possible dream incorporation. Where the possibility of dream incorporation in relation to a smoke alarm has been investigated, however, no consistent relationship was found between arousal latencies and reported dream incorporation.[14]

In one study on individual differences[32] two groups were formed based on their differential ability to fall asleep quickly in a series of day naps (sleepy versus alert). In testing on a subsequent full night of sleep it was found that in the second half of the night alert subjects were more responsive to signals than those in the sleepy group. Clinically depressed people have been found to have lower thresholds to sound with thresholds increasing as their depression improved.[33] In a study of good and poor sleepers, AATs and time to arouse were found not to differ.[34] Comparisons of AATs in normal and hyperkinetic children[35] and enuretic and non-enuretic children[36] found no differences. Clearly we are just at the beginning of trying to understand the sources of individual differences in responsiveness to sounds while asleep. It may be that such differences are genetic in origin and may be associated with a whole range of differences that are starting to be documented in sleep/wake behaviour. These include variables such as tolerance of sleep deprivation, usual sleep length, morningness-eveningness, number of spontaneous arousals during the night and sleep inertia.

Signal meaningfulness

In most of the studies in Table 1 (except the first signal presentation in Bruck and Horasan[14]) the participants were primed to expect a signal, although they sometimes did not know on which of several nights the signal would occur. Numerous studies in the sleep arousal literature have found that sleeping subjects are more likely to respond to significant or "primed" sounds than non-primed or neutral sounds. Clearly discrimination between stimuli occurs even though the brain is physiologically asleep. Perhaps the most dramatic finding was that the percentage awoken from the deepest stage of sleep reduced from 90% to 25% when subjects were not primed to respond to a certain signal.[37] An earlier study[38] found that sleeping subjects responded more often to their own name than to other names. Using a 60 dBA smoke alarm signal it was found that there was no difference in responsiveness when the signal was presented to subjects who were initially "naive" and then primed to the signal.[14] However, the authors felt that the subjects actually interpreted *both* signals as significant and verbal reports from the awoken subjects supported this interpretation. One hopes that this is also the case in real life situations involving fire alarms. It follows that it is important that the smoke alarm signal has a unique sound quality that can easily be discriminated from other electronic beeping sounds in our environment. If the sleeper is in an environment where lots of similar sounds (eg. car alarms, cooking appliances) occur during the sleeping period they may not be able to successfully discriminate a smoke alarm signal and/or may habituate to the plethora of signals.[11] In this regard it would be instructive to investigate whether environmental/cross-cultural differences exist in responsiveness to alarms within the home. Where signal discrimination is a problem the development of voice alarms may be worth pursuing- particularly as we know that the sleeping ear is particularly responsive to speech level frequencies (see above). Related to signal discrimination is the *meaning* that the signal has to the person in terms of whether they feel it is their responsibility to investigate it.[39] This is likely to be circumstance and role specific where people living in a supervised environment (eg. a nursing home) may be less motivated to arouse themselves.

Drug intake

The sleep arousal literature also documents other sources of variability. The most important and relevant of these is responsiveness after drug intake, with sleeping tablets and alcohol being the two major drugs implicated. Studies in the US suggest that one out of every two people have taken sedatives or tranquillisers at some time and one in five uses them frequently.[40] The elderly consume disproportionately more, with aged pensioners in Australia consuming 41% of all prescribed sleeping medication (although comprising only about 10% of the population).[41] As sleeping tablets are designed to reduce the frequency of spontaneous wakings during the night they are likely to impair responsiveness to external stimuli as well as putative internal waking up stimuli. Several studies have investigated arousal after different doses of sleeping tablets. From a fire safety point of view the important findings are that a therapeutic dose of a variety of sleeping tablets (short or long acting) increase arousal threshold. Both inter-subject and intra-subject designs suggest that threshold to a pure tone can be approximately 30 dBA higher than placebo at the time when the drug is exerting its maximum effects (120-150 minutes post-ingestion). Arousal thresholds return to normal three hours after ingestion.[42] One study examined responsiveness to a smoke alarm[43] and found that 50 % of those receiving the hypnotic (triazolam) failed to respond to three 60 second 78 dBA alarms when they were presented during deep sleep about two hours after drug intake. This compared to 100% arousal from those taking the placebo.[43] The authors noted that the responsiveness of those on medication when awoken appeared to be significantly slower.

The fire fatality literature consistently notes that many fatalities are associated with alcohol intoxication. Indeed the presence of an alcohol impaired person has been reported to be the strongest independent risk factor for death in the case of a fire.[6] Unfortunately there are no published studies on how arousal thresholds may differ with alcohol ingestion. Two studies have suggested that low doses of alcohol (less than or equal to .6g/kg) lead to increased total sleep time and reduced wake activity in nocturnal sleep. Other studies have tried to document possible changes in the amount of deep sleep during the night but consistent differences are not reported, possibly because a 'whole of night' approach tends to be used. Where changes *across the night* are considered it has been shown that deep sleep is often increased in the first two hours of sleep[44] and decreased in the latter part of the night.[45] As time of day fire fatality statistics suggest that the early part of the night is associated with more fire deaths at home (with a peak from midnight to 4am[1]) this initial augmentation of deep sleep is likely to be of most significance in terms of responsiveness. In non-REM sleep (which includes deep sleep) changes in the EEG power density after alcohol ingestion have been noted. Increases at both the high frequency levels (associated with waking behaviour) and low frequency delta waves (associated with deep sleep) have been reported.[46,44] While researchers agree than alcohol does not act like a typical hypnotic, it is difficult from these architectural changes in EEG sleep to accurately predict how responsiveness to a signal across the night may be altered at different levels of intoxication and different times of the night. The reduced waking activity and initial increases in deep sleep suggest an overall reduced responsiveness, especially in the early part of the night, but actual data is required.

Given that marijuana use is prevalent in many countries, its effects on sleep are relevant. Its presence in fire victims rarely forms part of statistical fire reports but this is probably because it is (usually) an illegal substance and hence not discussed with authority figures and not routinely checked for. As with alcohol there are no published reports on how it affects responsiveness but increases in deep sleep have been noted in humans[47] and primates.[48] An increase in drowsiness when awake was noted during both the chronic use phase and the recovery phase in the latter study and may have safety implications.

Methodological issues

The literature documenting arousal to smoke alarms at varying intensities has provided valuable data from which to make inferences. While the sleep arousal literature has used many different methods of defining arousal to a stimulus (including EEG waking patterns, muscle movements and pushing a button three times) with resultant inconsistencies, the smoke alarm arousal literature has used definitions that have appropriate face validity for responding to a fire. This includes three minutes of continuous EEG wakefulness,[14] pressing a button,[12,13] getting out of bed[15,16] and evacuating.[17] However, other methodological shortcomings are evident in some cases within this literature. Kahn[13] used three awakenings within the one night and this could have lead to a cumulative deprivation effect with consequent less responsiveness later in the night. Two studies[12,17] potentially confounded the percentages awoken by allowing partners or room mates to awaken the participants in the arousal study if they awoke first. Where the number awoken by their partners is not reported[12] the true percentage of participants who awoke to the alarm cannot be accurately determined. Given that the AAT literature shows differences in responsiveness across the night and with different sleep stages (that are differentially more likely at different times) it is important to report the time of cue delivery. The extent to which participant's normal lifestyle was restricted during a study is rarely documented (eg moderating alcohol intake or regular bed times) but is potentially significant.

Recommendations for alarm intensity

Berry[49] considered several reports from the AAT literature and felt that 75 dBA may be enough to awaken most people. This sound intensity has been adopted as the British Standard for alarm intensity at the head of the bed.[50] The AAT literature, however, is not generalisable to waking to a smoke alarm because of the differences in signal frequency (see above) and the differences in findings between AAT study predictions and smoke alarm responsiveness support this conclusion. The current review suggests that a 55-60 dBA smoke alarm will wake most people who participate in these type of experiments and are not sleep deprived, intoxicated, drugged, or coping with high background noises. Berry[49] goes on to list a number of very pertinent variables affecting responsiveness, which in many cases anticipate subsequent investigations. These variables include the existence of large individual differences in AAT, hearing impairments, sleeping tablets and alcohol ingestion and background noise level. (From the review above being a child or teenager, sleep deprivation and possibly also ingestion of marijuana could be added.) Given the possible presence of factors such as these, Berry notes, a signal of over 100 dBA may be required.

The fact is that we really do not know what signal will awaken people under these conditions, but the level required to wake adults under ideal circumstances should *not* be the standard, nor should an arbitrary midpoint. Adults in ideal circumstances do not form the most high risk group in terms of night time fire fatalities. An examination of the breakdown of statistics of night time fire fatalities in terms of victim characteristics makes this clear.

Fire fatality statistics and victim characteristics

The NFIRS database[2] shows that, excluding buildings with sprinklers, there were 724 civilian fatalities from 32,077 apartment building fires between 1 a.m. and 5 a.m., the peak hours for fatality rates. 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. Most occupants in apartment buildings can be assumed to be sleeping at this time. Although the figures emphasise the fire risk arising from being asleep it is important to note that the percentages indicate that there is a *high avoidance rate* by occupants who are initially asleep. Assuming that one person is present in each of these fires, over 97% of sleeping occupants apparently recognise cues and respond in sufficient time to avoid becoming a fatality.

Given that so many people manage to avoid death by fires occurring when they are probably asleep it is useful to examine the characteristics of the people who do die in fires where sleep/wake status is documented. Some studies have emphasised the increased risk to the elderly and mobility impaired during the daylight hours compared to at night, [5,7] but it cannot be assumed that this population group is awake during the day. Brennan[8] reports that among those aged over 65 years there were twice as many deaths when the victim was asleep at the time of the fire compared to being awake, and, as noted earlier, 31% of victims of day fires were actually asleep. Drinking alcohol, a major fire risk factor, occurs during the day or night and the impaired victims may be either awake or asleep. Brennan notes that for the fire victims aged between 18 and 74 nearly half of her sample of 74 had alcohol readings over .05. Males in their early 20s and from 40-50 years were most at risk.

Sekizawa[5] has published a detailed breakdown of fire fatality characteristics of 3,629 victims of residential fires in Japan (1983-1987). Among the 6-64 year olds more than 65% had ingested alcohol at the time of their death by fire and, of these, 40% were asleep. Some key information about fatalities during sleep from the Sekizawa study is summarised below. [The first two percentages have been obtained from secondary analyses of the data presented the paper.[*]]

- ♦ Asleep, sober, aged 6-65 years, able bodied = 11%
- ♦ Asleep, sober but very young, elderly, bedridden, sick or disabled = 22%
- ♦ Asleep and drunk = 13.5%
- ♦ Awake (includes those with a range of risk factors) = 53.5%

This analysis demonstrates that sleeping adults in ideal circumstances (ie sober, aged 6-65 years, not bedridden, not disabled, not sick) are a relatively low risk group (11% of all fire fatalities), although they form the great majority of the population. Some of the deaths of people in this category arise from them trying to help others escape (eg dependent children)[8]. It is not known how many of those who died could have been saved if the fire had been detected earlier- either by the victims themselves or some able-bodied person in the vicinity. Furthermore, the prevalence of working smoke alarms and alternative exit routes in these fatal fire incidents is unknown.

Implications for fire risk prevention

The findings from the literature on arousal thresholds during sleep which suggest that most adults will awaken to a smoke alarm in the hallway (60 dBA) should *not* form the basis for the minimum signal intensity criteria in residential buildings. This is because

[*] The paper reports that 46.5% (n=1687) of the victims were asleep and 33% (n=1197) were asleep and sober. Of those that were asleep and sober 40% were aged 6-64 years (n=479). 1.4% of all the fatalities were sick but not elderly (n=51) and we will assume that 50% of these may have been asleep at the time of the fire (n=25). Thus 454 victims were asleep, sober and not sick at the time of the fire. If we assume that 4% (n=47) of the 1183 victims who were bedridden or disabled were aged 6-65 years and asleep then the total number of victims who were asleep and sober, not sick, not bedridden and not disabled is 395 or

the responsiveness of the adults in these studies (tested under 'ideal circumstances') is not generalisable to the responsiveness of the people most likely to be victims of a fire occurring when they are asleep. Put simply it cannot be stated with any certainty that even a 75 dBA will arouse most of those most at risk. While there are clearly gaps in the literature on responsiveness it can be concluded from the available data that

- young children are unlikely to arouse to 75 dBA
- those who are sleep deprived will be harder to arouse
- significant background noise increases arousal thresholds
- 25% of those over 60 years may be unlikely to wake to a 55 dBA alarm and 10% of those over 70 years may sleep through 75 dBA (due to hearing loss at the higher frequencies in older persons)
- significant individual differences in arousal thresholds exist
- if the nature of the alarm signal or its perceived intensity is insufficiently unique to be a meaningful stimuli, responsiveness will be reduced
- those under the influence of sleep inducing medication are unlikely to arouse to 75 dBA (and such medication is in high use among the elderly)
- those under the influence of alcohol and marijuana are likely to be harder to arouse than the non-intoxicated due to the changes in sleep patterns increasing deep sleep

Reducing the number of fire fatalities among the high risk groups is probably best achieved with multiple strategies including social improvements and improved fire consciousness among high risk groups such as the elderly.[51] However, one of the

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11% of the total number of fatalities (n=3,629). If 11% were asleep and able bodied then the others that were asleep and sober must number 22% (as a total of 33% were asleep and sober).

strategies should be the setting of a minimum smoke alarm intensity level at the pillow in residential structures. In order to try to reduce the number of fatalities during the sleeping period smoke alarms should be installed such that they are perceived by the sleeper at the maximum level that is tolerable to the human ear, that is around 90 dBA. Installation of alarms should thus include the bedroom itself. Ideally, in order to enhance the chance of early detection of fires that begin in other rooms of the residence, the detecting devices should also be placed in other high risk areas (eg kitchen and living areas) and smoke alarms interconnected. These two measures would significantly enhance the chances of early detection of fires by a wider range of people, including those most at risk of dying by fire occurring while they sleep.

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Table 2. Hearing threshold values (dBA*) for males and females over 60 years of age, which 10%, 25% and 50% of the population would fail (based on ISO standard 7029-1984[26]).

		Males		**Females**	
	Frequency	**60-69 years**	**70+ years**	**60-69 years**	**70+ years**
50% FAIL	**2000 Hz**	12	19	11	16
	4000 Hz	23	38	11	19
25% FAIL	**2000 Hz**	21	30	18	34
	4000 Hz	37	57	21	43
10% FAIL	**2000 Hz**	29	39	25	34
	4000 Hz	50	74	31	43

* The ISO standard gives values in dBHL. These have been converted to dBA for this table and thus for the 4,000 HZ values 5 has been subtracted from dbHL values.