

Smoke Alarm Notification of Sleeping People Progress Report

Ian Thomas (1), Dorothy Bruck (2) and Michelle Ball (1,2)
(1) Centre for Environmental Safety and Risk Engineering
(2) School of Psychology
Victoria University, Melbourne, Australia

Introduction

This paper reports on the recent progress and gives progressive results of a series of projects designed to investigate and optimise the best means of awakening sleeping people in the event of a fire. The projects underway investigate two groups of occupants: hearing impaired adults and adults impaired by alcohol (both projects funded by the NFPA Fire Protection Research Foundation).

These projects have been informed by other projects previously completed and currently underway, in particular in relation to the types of sounds being used. The most recently completed project was a Fire Protection Research Foundation contract research project of 2005-2006 that investigated auditory arousal of sleeping older adults¹ with different alarm signals.

Previous smoke alarm studies have revealed that:

- most unimpaired adults will awaken quickly to a smoke detector signal²
- background noise, alcohol and sleep deprivation are impediments to awakening to alarm³

Results of the previous studies using young adults showed that even moderate alcohol intake had a major effect on the sound volume needed to wake up to an alarm⁴:

- when sober, 5% slept through 90 dBA
- with 0.05 BAC, 36% slept through 90 dBA
- with 0.08 BAC, 42% slept through 90 dBA

This study also showed that males were less responsive to alarms after alcohol than females with the same blood alcohol level as shown in Figure 1. The results in this figure also show that the mixed T-3 was the best of the three signals tested in that it had the least number of young adults who slept through the very loud 95 dBA signal.

It is widely known that hearing loss occurs with advancing age, particularly in the higher frequencies (more than 2000 Hz), and that this is more severe among males. It has also been found that most people with such hearing loss are unaware of the degree of loss and take no compensatory measures⁵. In this large US study of hearing impaired people it was found that⁵:

- there was a hearing loss of greater than 25 dB in 46% of 48-92 year olds
- of those with a greater than 25 dBA hearing loss only 56% awoke to 75 dBA alarm
- the most effective awakening signals were those incorporating a **lower frequency**
- of the signals tested the continuous high pitched alarm was the least effective

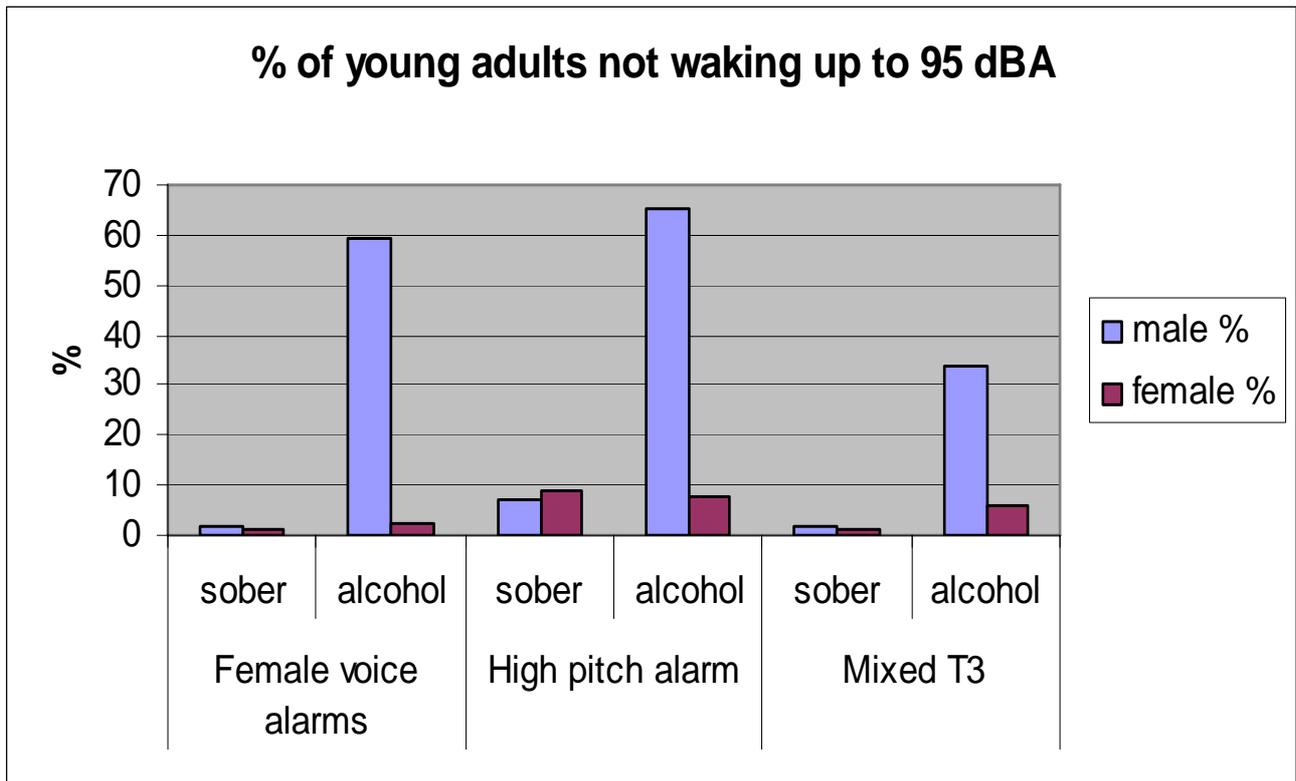


Figure 1 Effect of alcohol consumption on response to various smoke alarm signals

The current projects on mildly to moderately severely hearing impaired adults and on alcohol impaired young adults, both in residential settings, are aimed at providing data on auditory, visual and tactile signals for their ability to alert these people when asleep. More specifically, the research questions being addressed are:

- Are bed shakers (bed vibrators) and pillow shakers an effective means of waking this population from deep sleep? If so, what intensities are required for bed shakers and pillow shakers under the testing conditions of a pulsing signal in a Temporal 3 (T-3) pattern?
- What are pitch and pattern of the audible T-3 signals with the lowest auditory arousal threshold (AAT) for this population when AWAKE? When these two signals are presented to this population in deep SLEEP what is the mean and median increase in volume (over and above the audible volume when awake) for each signal that is required for effective awakening under the testing conditions?
- Do strobe lights provide a reliable means of waking up from deep sleep for the hearing impaired? Is the UL 1971 standard for the intensity of strobe lights high enough to effectively awaken this population under the testing conditions (using a T-3 pattern), or are strobes of a higher intensity required for reliable awakening?
- Does signal offset promote awakening (as well as signal onset)? If so, what are the implications of this for the temporal pattern of signal presentation?

In addition the hearing impaired study includes a preliminary investigation of what kind of provision hearing impaired individuals make in terms of products in their homes for both emergency alerting (i.e. to a fire) and for other domestic alerting needs (doorbell, telephone, etc).

Methodology

In the alcohol study six signals are being tested as shown in Table 1. Additional research questions in the alcohol impaired adults study include:

- does signal offset promote awakening? If so, what are the implications?
- are there sex differences in the AATs?

- does sleep inertia differ if awoken by an auditory or tactile signal? If so, what are the implications for emergencies?

As the *method of discrete limits* is being used in these studies EEG analyses will be required to determine any awakenings to the offset of a signal.

Signal/Sound	Levels	Standard
Pillow Shaker	5	Level 3
Bed Shaker	5	Level 3
S15 (400 Hz SQ)	5	Level 3 (75 dBA)
S16 (520 Hz SQ)	5	Level 3 (75 dBA)
S24 (500 Hz)	5	Level 3 (75 dBA)
Strobe	3	< Level 1

Table 1 Signals used for the alcohol impaired adults study

In this study particular care is being take to ensure that the level of intoxication is close to that required across the time needed to perform the three planned awakenings each night and to confirm this the BAC is tested before the subject initially goes to sleep and after the final awakening. The participants in this study are all young adults, 30 in number (with a minimum of 25 to complete two nights), aged 18 to 26 years, and with an approximately equal number of males and females. The rationale for using this age-group is that they are generally:

- the heaviest sleepers of all adults
- have the longest duration of deep sleep of all adults (necessary to accommodate the three planned awakenings per night)
-

The hearing of all of the participants has been screened and they all have no hearing problems in either ear.

The research questions for the hearing impaired project are:

- are bed and pillow shakers effective in waking them from deep sleep? What intensities are required?
- what two frequencies of T-3 sound have the lowest AAT when awake, what volume is required to awaken them?
- do strobe lights provide a reliable means of awakening them?
- does signal offset promote awakening (as well as signal onset)?
- what provision in their do they make for emergency and domestic alerting needs?
- does this provision depend on age, hearing level, use of hearing aids, history of hearing impairment and/or living arrangements?
- do they have different signals depending on nature of alert?
- if so, what types of signals are used?

The approach taken in this study is to test 40 adult (any age) hearing impaired participants (with a minimum of 35 to complete two nights of testing) as follows:

- using six signals during deep sleep, over two nights

- the signals presented at increasing intensities to determine the AAT when awake to
 - inform the auditory testing when asleep
 - provide a direct comparison of thresholds (wake and sleep)

It was found prior to the study that many hearing impaired people:

- use range of devices to assist in becoming aware of various occurrences or alarms
- many use a single signal with LED lights indicating signal origin (telephone, door bell, etc)

There are many definitions of degree of hearing impairment. The hearing impairment criterion used in this study was for *mild to moderately severe* hearing impairment defined by:

- loss of >25 dBA and < 71 dBA in both ears
- hearing loss based on pure-tone average of thresholds at 500, 1000, 2000 and 4000 Hz

The hearing of prospective participants was tested in their home using an audiometer with specialised headphones for use in quiet (but not specially controlled) environment.

The alarm signals used in the hearing impaired adults study are shown in Table 2.

Signal/sound	Levels	Standard
Pillow Shaker	5	Level 3
Bed Shaker	5	Level 3
S15 (400 Hz SQ)	5	Level 3 (75 dBA)
S16 (520 Hz SQ)	5	Level 3 (75 dBA)
S24 (500 Hz)	5	Level 3 (75 dBA)
S23 (High T3)	5	Level 3 (75 dBA)
Strobe	3	< Level 1

Table 2 Signals used for the hearing impaired adults study

In both studies the signal presentation method was *the method of discrete limits* with:

- each signal being presented in discrete episodes (of 30 seconds duration) during stage 4 sleep
- if the participant continues to sleep (fails to press the bedside button) this is followed by 30 seconds of silence
- if the participant still remains asleep the signal is presented again at increased intensity
- this cycle continues until the participant awakens or receives the maximum intensity of signal for 3.5 minutes

Thus all signals at each intensity level commence from a *zero* intensity but the participant may awaken during the signal on phase or during the 30 second signal pause (offset), consequently all sleep recordings have been analysed to determine the exact time of awakening time as defined by EEG, and it has been found that some do awaken during the offset.

The sounds are presented at five levels from 55dBA to 95 dBA at the pillow. The auditory signals used were those audible at the lowest volume while awake. The range of frequencies tested included those frequencies most likely to be audible by older adults with presbycusis⁶.

For the vibro-tactile signals (pillow shaker and bed shaker) the testing determines the intensity of vibration required to awaken the participant. There are no useful published standards for the intensity of these devices. It should be noted that devices defined in this project as bed shakers may be marketed for placement under mattress or pillow but pillow shakers marketed for only for placement under the pillow. These devices were presented at five levels (as for the sounds) but in this case by controlling the supply voltage.

Previous research has shown that a continuous bed shaker was 92% effective in awakening hearing able adults, but was 82% effective for adults with partial hearing and 93% for deaf adults. An intermittent bed shaker was found to be 100% effective for all hearing levels. The greater effectiveness of intermittent bed shaker compared with the continuous shakes is compatible with an expectation based on cognitive psychology that habituation is more likely with an unchanging signal and therefore a higher level is required for awakening.

NFPA 72 requires strobes to

- flash at 1 to 2 Hz
- have an intensity of 177 candela (cd) or 110 cd depending on their position

However, these specified intensities do not relate directly to the received intensity *at the pillow*, which is what the sleeping person receives. In this study the intensity at the pillow has been measured.

There is little information available on the waking effectiveness of strobes. There is only one study that controlled sleep stage and intensity at pillow in which it was found that less than 30% of normal hearing female participants awoke. Another study used a 110 cd 1Hz strobe and the waking effectiveness was found to be 34-57% (~ hearing ability).

In the current study the strobe flashes in the T-3 pattern at 2 Hz. The strobes are positioned at end of bed and directed at pillow and they flash at three levels of intensity (using one, two and then three identical strobes). It has been determined that a single one of these strobes has a higher intensity than a strobe rated under NFPA 72 as 177 cd.

Apparatus and Procedure

The participants are tested in own homes using portable sleep monitoring equipment (EEG) over two non-consecutive nights, three signals each night. They are required to ensure that the previous night's sleep was normal and that they had no or minimal alcohol prior to bed. The sound delivery volume was adjusted in their bedroom to deliver the correct level at their pillow.

The sleep of the participants was monitored and after 90 seconds of stage 4 sleep the desired signal was presented starting at the lowest level and if necessary increasing as stated above until bedside button is pressed (unless the participant sleeps through this signal). After they wake to the first signal they return to sleep and the procedure is repeated for the second and then third signals. The order of signal presentation is counterbalanced to ensure there is no bias due to order of presentation.

Preliminary results on incomplete data set

It must be understood that the results below are based on an incomplete data set and thus the results may differ when the testing is complete. Table 3 presents some results for the alcohol impaired young adults and Table 4 the results for the hearing impaired adults.

Signal/Sound	% awoke at or below standard	% awoke above standard	% slept through	Standard	N
Pillow Shaker	55%	18%	27%	L3	11
Bed Shaker	62%	15%	23%	L3	13
S15 (400 Hz SQ)	100%	0%	0%	L3 (75 dBA)	11
S16 (520 Hz SQ)	100%	0%	0%	L3 (75 dBA)	11
S24 (500 Hz)	92%	0%	8%	L3 (75 dBA)	12
	% awoke Level A	% awoke Level B&C	% slept through		
Strobe	25%	58%	17%	All levels above standard	12

Table 3 Interim results for alcohol impaired adults

Sound/signal	% awoke at or below standard	% awoke above standard	% slept through	Standard	N
Pillow Shaker	82%	9%	9%	L3	11
Bed Shaker	77%	8%	15%	L3	13
S15 (400 Hz SQ)	80%	10%	10%	L3 (75 dBA)	10
S16 (520 Hz SQ)	90%	10%	0%	L3 (75 dBA)	10
S24 (500 Hz)	50%	50%	0%	L3 (75 dBA)	6
S23 (High T3)	88%	13%	0%	L3 (75 dBA)	8
Signal/Sound	% awoke at or below standard	% awoke above standard	% slept through	Standard	N
Strobe	25%	42%	33%	All levels above standard	10

Table 4 Interim results for hearing impaired adults

Discussion

A great deal of caution must be used in interpreting these incomplete results. However it can be seen that there are clear differences between the results for the various signals and it is to be expected that this will remain the case when the data collection is complete.

It is not appropriate to draw firm conclusions based on this interim data but it appears likely that the effectiveness of strobes, in particular, as warning devices for sleeping hearing impaired adults will not be high.

References

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