Reducing Fire Deaths in Older Adults: Optimizing the Smoke Alarm Signal

Research Project

Investigation of Auditory Arousal with Different Alarm Signals in Sleeping Older Adults

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FOREWORD

Smoke alarm and signaling systems are a proven strategy for reduction of fire fatalities in the general population. However, studies have shown that the elderly do not fully benefit from conventional smoke alarm systems, particularly during the sleeping hours. In April of 2005, the Fire Protection Research Foundation was awarded a Fire Prevention and Safety Grant by the US Fire Administration for a new project to study this topic.

A portion of the study involved the conduct of human behavior studies to investigate the arousal thresholds from sleep in older adults to the current US smoke alarm and compare these thresholds to several alternative signals, and to investigate the performance abilities of older adults when awoken suddenly by an alarm. This report presents the results of this portion of the study.

The overall goal of the project is to optimize the performance requirements for alarm and signaling systems to meet the needs of an aging population. The balance of the study is presented in a companion report also published by the Foundation entitled "Reducing Fire Deaths in Older Adults: Optimizing the Fire Alarm Signal".

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The content, opinions and conclusions contained in this report are solely those of the authors.

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Investigation of auditory arousal with different alarm signals in sleeping older adults

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Report for the Fire Protection Research Foundation
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"Reducing fire deaths in older adults: optimising the smoke alarm signal."

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Executive Summary

Over the last decade research on which emergency signal will best awaken sleeping individuals has led to a recognition that more work is needed on the audibility of existing smoke alarms and the comparative waking effectiveness of alternative signals. This research focuses on these issues in a population known to have an elevated risk of dying in a fire, adults aged over 65 years. It investigates responsiveness to different signals in sleeping older adults as well as measuring performance upon awakening (sleep inertia). This comparison of arousal thresholds required a tightly controlled experimental design, with selection criteria and methodological requirements that increase the validity of such comparisons using a manageable sample size, but do not allow direct extrapolations to the field in terms of expected arousal thresholds in a real emergency or percentages of the population that may awaken to certain signals. These population and methodological factors probably result in the research to date *underestimating* the proportion of people who will not wake up to an alarm.

Aims and the relevant findings are set out below, followed by a discussion of the key conclusions and recommendations.

Responsiveness to signals:
Arousal thresholds to different sounds were determined by playing auditory signals to the participants (aged 65-85 years, n=42) when they were in deep sleep (slow wave sleep). Each signal was presented with a stepped increase in volume from 35 dBA to 95 dBA and a bedside button was pressed by the participant to indicate awakening. The same participants received all four signals over two nights.

Aim 1: To investigate the arousal thresholds from sleep in older adults (aged 65- 85 years) to the current US smoke alarm (a high frequency T-3) and compare these thresholds to several alternative signals. The three alternative signals were a mixed frequency T-3 signal, a male voice (saying Danger, Fire, Wake up) and a 500 Hz pure tone in a T-3 pattern.

The first hypothesis was that the older adult sample would have significantly higher auditory arousal thresholds to the high pitched T-3 signal than to the two signals of mixed frequency (the mixed T-3 and the male voice). This hypothesis was only partially supported, with the results showing that the volume needed to wake up to the high T-3 was significantly higher than that needed with the mixed T-3. The most important findings were that,

(a) the **older adults needed a lower volume to wake to the mixed frequency T-3 signal** (median = 45 dBA) than to the other three signals tested (male voice, 500 Hz T-3 and high T-3), and

(b) the **current high frequency T-3 needed the highest volume** (median= 65 dBA) to produce awakenings compared to the other signals.

The second hypothesis was that the older adult sample would have significantly lower arousal thresholds to all signals than a young adult sample tested under similar conditions. Mean values showed differences in the predicted direction for both the mixed and high T-3 signals but only for the mixed T-3 was the difference across age groups significant. Surprisingly, for the male voice signal the young and older adults woke to similar volumes. Individual responses from three participants of non-English speaking background (NESB) suggested that a voice alarm with English text would not be suitable for them, although the inclusion of such NESB people did not cause the overall poor performance of the voice alarm with the older adults. Overall, these results indicate that **for older adults a male voice alarm would not be a suitable alternative**.

Sleep Inertia: This study was the first to assess older adults on several cognitive and physical tasks after awakening, and compare such performance to pre–sleep (baseline) levels.

Aim 2: To investigate the performance abilities of older adults when awoken suddenly by an alarm. This sleep inertia was assessed in terms of their simple and complex cognitive functioning and physical performance (with the latter involving a psychomotor task plus getting out of bed and walking 15 metres).

The results suggest that a **decrement in physical functioning of around 10-17%** may be expected across the first five minutes after awakening. **No important effects on simple or complex cognitive functioning were evident**. There was a wide variation in performance across individuals, with perfomance under baseline conditions strongly predicting performance under sleep inertia conditions.

Conclusions and Recommendations:

The present study, using a rigorous design and sufficient sample size of sleeping adults aged over 65 years, has found a substantial difference in the median auditory arousal threshold of 20 dBA between the current high frequency T-3 and the best performing alternative signal tested. Thus all the available data testing the waking performance of smoke alarm signals shows that a high frequency alarm signal[1] performs the *most poorly* of the alternatives tested for waking all the different population groups tested so far (i.e. children, sober and alcohol intoxicated young adults, older adults aged over 65 years). The evidence is sufficient to lead to the following recommendation:

Key Recommendation: The high frequency alarm signal currently found in smoke alarms should be replaced by an alternative signal that performs significantly better in awakening most of the adult population, once the nature of the best signal has been determined.

The findings of the current study, together with previous literature, indicate that a mixed frequency T-3 signal has *performed significantly better* than a high frequency signal in its ability to awaken sleepers in every sample group tested so far. This includes children, young adults (sober and alcohol intoxicated) and older adults. Voice signals appear to be as effective as the mixed T-3 in the children and young adult groups, but are less effective than the mixed T-3 in the older adults.

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[1] A high frequency signal is typically used in all smoke alarms, the literature reported here has variously tested both a high frequency T-3 signal or continuous pulsing high pitched beeps.

The implications of introducing a signal frequency recommendation into the standards for smoke alarm notifications are considerable, involving a retooling of the entire industry. In view of this, any signal change that is mandated must be done on the basis of rigorous evidence that the best signal has in fact been found. The research is not yet at this point. A brief outline of suggestions for future research is set out below. These may take two to three years to complete.

In the meantime there are some recommendations that can increase the chance of sleeping individuals waking to a fire.

(a) Encourage interconnected alarms. Interconnected alarms that include an alarm in each bedroom will mean that the volume at the pillow is likely to be above 85 dBA.

(b) Consider the special emergency awakening needs of "normal hearing" older adults. Given the hearing thresholds for high frequencies of older adults it is inadequate to require their current high frequency smoke alarm to be a minimum level of 75 dBA at the pillow. The current study shows that those aged over 75 were particularly poor at waking to the current high T-3 (median of 70 dBA for high T-3 compared with 40 dBA for the mixed T-3). One possibility would be to recommend that older adults should have interconnected alarms, or at the very least stand alone alarms (with the current signal) in their bedroom. An additional, more satisfactory, possibility is for smoke alarm manufacturers to market special alarms for this age group that emit a mixed T-3 signal and suggest placement, as a minimum, in the bedroom.[2]

The *future research* that should be completed prior to the mandating of a specific signal encompasses a variety of issues.

(a) Research is needed to determine the optimal pitch and pattern of an alternative signal to wake people up, using a single convenient population, such as young

[2] Such a mixed frequency alarm would also be beneficial for individuals of any age who know they have high frequency hearing loss.

adults. The option of a voice alarm should no longer be considered for adult populations. Alternative pitches and pitch patterns should be investigated within the T-3 temporal pattern, at least in the first instance.

(b) Once several signals have been shown to have the lowest auditory arousal thresholds in the one population tested, they need to be tested in other sleeping populations, especially those most at risk of dying in a fire or of sleeping through an alarm signal. The signals should also be tested for salience and/or urgency as an emergency notification signal requiring action in awake individuals.

(c) Because of the inability to generalise data from the current study to field estimates, further research is needed using large numbers of non-primed, unselected groups to yield population based estimates of waking effectiveness. It seems most likely that the research to date may be significantly *underestimating* the proportion of people who will not wake up to an alarm. This arises from a range of factors, including the important fact that almost all of the participants in the relevant empirical studies on alarms and sleep have been primed to expect that a signal will go off on one of several nights.

(d) A study characterising the spectral characteristics of the background noises in a range of "typical" bedrooms would be informative and relevant. The extent of possible masking can be determined by combining this information with the acoustical characteristics of the signal that is most likely to awaken sleepers.

1 Introduction

Around the Western world the number one priority for residential fire safety has been promotion of the installation of smoke alarms. However, when residential smoke alarms were first developed and widely distributed in the 1970s the focus was on the technology to detect heat and/or smoke and little attention was paid to the nature of the audible signal. A high frequency signal was easily generated by a small piezo device and this was included as the standard alarm signal. As noted by Berry (1978), the issue of the audibility of fire warning equipment was relegated to an Appendix of the NFPA (74-1975) and the assurances about the ability of the signal to awaken people that were provided in the Appendix were at variance with the published auditory threshold data available at the time. Fire code standards include specifications of the volume that the alarm must emit, typically as a range of volumes which are above the ambient sound pressure level (e.g. 10 dBA above ambient, and within the range of 65-105 dBA, AS1670.1-2004). Recommendations about the volume that the alarm must be received inside a bedroom were added and these are generally 75 dBA (e.g. USA, Canada and Australia) at the pillow. A caution that this level may not be adequate to awaken all sleepers is often included (e.g. AS1670.1-2004). ISO 8201 "Acoustics- Audible Emergency Signal" defined a temporal three pattern (T-3) in 1987 and this was adopted by the NFPA in July 1996 (and later by many other countries) as the required fire notification signal, including in smoke alarms. No recommendation as to a frequency level of the sound is included.

The U.S. Consumer Product Safety Commission initiated a project in 2003 (Lee, Midgett, & White, 2004) to review the sound effectiveness of residential smoke alarms, with a focus on children (who had been shown to not reliably awaken to a smoke alarm) and older adults (who have death rates in residential fires of more than twice the national average). Among the recommendations was the need for further research examining what deficiencies exist regarding the **audibility of current smoke alarms**. Furthermore, previous research has raised the possibility that an alarm of a **different frequency and/or different sound** may be more effective for waking sleeping individuals.

This project empirically investigates both issues with regard to sleeping individuals aged 65 to 85 years. The results may have implications for the development of a more effective alarm signal for smoke alarms. The study also examines increased cognitive confusion and performance impairment (sleep inertia) that may influence effective and timely evacuation behaviour upon awakening in an older adult population.

2 Review of Literature

2.1 Signal significance and characteristics

Contrary to popular belief the brain does not "shut down" during sleep. During sleep we continue to monitor the environment and selectively respond. Discrimination between different signals clearly occurs during sleep, showing that the arousability of an auditory signal is not simply a function of how loud it is. Because cortical analysis of the meaningfulness of a signal precedes arousal, people respond selectively to signals, depending on the level of significance to them. An early study found that sleeping participants responded more often to their own name than to other names (Oswald, Taylor & Treisman, 1960). Significance can be added to a signal by "priming" the person to respond to some signals (e.g., a doorbell), but not to others (e.g., a telephone). When participants were primed to respond to a certain signal presented during the deepest stage of sleep, awakenings increased from 25% to 90% (Wilson & Zung, 1966). Clearly, signal significance and interpretation will affect arousal likelihood and thus it is important that any emergency signal has a unique sound quality that allows it to be readily identified and easily discriminated from other electronic beeping sounds in our environment (car alarms, mobile phones, microwave ovens, etc.).

It has been found, using functional MRI technology (Portas, Krakow, Allen, Josephs, Armony & Frith, 2000), that sounds that have an emotional significance have lower arousal thresholds and an increased probability of waking up a person. The involvement of a central nervous system "pathway of learned fear" has been suggested, with a key implication being that during sleep the emotional content of a signal may be processed independently of cortical input about the meaning of the signal. Thus the use of sounds which arouse our emotions, such as a voice conveying an urgent message, may be an important consideration in emergency signals.

There is now an important body of literature about auditory alarms signals and their interpretation by individuals when awake (Edworthy, Loxley & Dennis, 1991; Edworthy and Stanton, 1995) and this has lead to design criteria suggestions to improve the effectiveness of emergency notifications in awake populations. It has been reported that signals that produce the highest ratings of perceived urgency were those with a higher frequency, a fast speed (tested across 0-500 msec), and a high level of loudness (Haas and Edworthy, 1996). The frequencies tested were across the range of fundamental frequencies from 200 Hz to 800 Hz, where each had higher component frequencies. The one that was perceived as most urgent had a fundamental frequency of 800 Hz with components of 800, 1600, 2400, 3200 and 4000 Hz .

A few studies have evaluated the alerting capabilities of alarms that are not auditory, specifically strobe lights and vibrating tactile devices located on the bed (Bowman, Jamieson & Ogilvie, 1995; Ashley, Du Bois, Klassen & Roby, 2005) especially in the context of emergency arousal for the hearing impaired. These devices are beyond the scope of the current literature review and research, which will focus exclusively on different auditory emergency devices. One reason for this selectivity is that auditory alarm devices are likely to be much lower in cost. Four types of alarm signals will be considered in this review; the high frequency beeping alarm, the Temporal 3 pattern, voice alarms and naturalistic sounds. Note that the literature evaluating their differential waking capabilities will be reviewed in Section 2.3.

A **high frequency beeping noise** is the most widely available smoke alarm signal and was most likely chosen for residential smoke alarms as high frequencies are rare in the normal environment, so they are likely to be more easily differentiated from other sounds. In addition they are subjectively piercing, not easily ignored and small battery operated devices can easily generate such sounds. Most residential smoke alarms emit beeps of a single high frequency which may be between 3000 Hz and 5000 Hz (Nober, Peirce & Well, 1981a; Ball and Bruck, 2004a; Ashley, Dubois, Klassen and Roby, 2005)