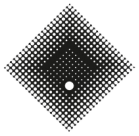
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# *Community-based research on the effectiveness of the home smoke alarm in waking up children*

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# COMMUNITY BASED RESEARCH ON THE EFFECTIVENESS OF THE HOME SMOKE ALARM IN WAKING UP CHILDREN

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This project targeted parents around Australia asking them to set off their home smoke alarm when their child was asleep and enter the results onto a special website. The main aim was to determine the likelihood of children waking up under the same alarm conditions as would apply on a typical night at home. Valid data was collected for 123 children, (60 M, 63 F, ages 5 - 15 years). Recruitment was done entirely via the media and postcards. Parents set off the smoke alarm closest to the child's bed for 30 seconds, 1-3 hours after sleep onset and 78% slept through the alarm. Younger children (5-10 years) were significantly more at risk, with 87% sleeping through, compared to 56% of 11-15 year olds. Of the 27 children who woke up, 61% knew that the sound that woke them was a smoke alarm and 47% indicated they knew they should leave the house. Our previous research suggests that some 5-10% more children may wake up if the alarm continues for three minutes. This study, consistent with previous less naturalistic studies, suggests that less than a third of children may wake up to their home smoke alarm within three minutes.

## INTRODUCTION

Smoke alarms are required in many developed countries and are believed to save lives. Although smoke alarms are felt to be especially valuable for waking sleepers, it has been reported [1] that 34% of fire fatalities during the sleeping period occurred despite a working smoke alarm. While some of these fatalities may have been a result of a person being intimate with the fire or their escape being blocked (and thus smoke alarms would have little or no value), some fatalities may have occurred because people had slept through their smoke alarm, or not been awoken by their alarm quickly enough to have sufficient time to escape. The issue of waking to smoke alarms has been the subject of a number of research studies over the last two decades (see review [2]), with several early studies considering the likelihood of children waking to a smoke alarm [3, 4, 5].

Table 1 summarises the key findings of the three studies that have tested the ability of children to wake to the high pitched smoke alarm (3000-4000 Hz). Smoke alarms are typically required to emit 85 dBA at one meter distance [6]. However, smoke alarms are often installed in hallways where, with the bedroom door open, they may be received at the pillow at a volume of 60 dBA or less [7, 8]. Under that scenario the available research suggests that very few children will wake

up.

**INSERT TABLE 1 ABOUT HERE**

Table 1. Summary of studies investigating waking to a high pitched smoke alarm in children.

Because the nature of such experimental research requires well controlled conditions, studies are very work intensive and sample sizes tend to be small. Given that the literature suggests that there is likely to be a major problem with children waking to their home smoke alarm in the event of a fire, it was decided to further explore this issue using a methodology that would

(i) provide information about what may occur in a naturalistic residential setting, and

(ii) provide a more substantial sample size.

This project targeted parents around Australia asking them to set off their home smoke alarm when their child was asleep (following detailed instructions) and then enter the results of this test onto a specially developed website.

Smoke alarm ownership and maintenance have been the main campaign message of Australian fire services in recent years. Findings from a recent Victorian study of smoke alarm ownership [9] showed that 96% reported owning a smoke alarm, although with over a third of respondents not testing their alarms, the percentage of working smoke alarms would be less. Smoke alarms have been compulsory in all homes in Victoria since 1997, but this requirement was implemented later in other states; 2006 for New South Wales and South Australia and a year later for Queensland. The Building Code of Australia requires hallway installation in the vicinity of bedrooms. Since 2004 smoke alarms sold in Australia have been required to sound in the Temporal Three (T-3) pattern [6] in which the beeps sound at half second ON-OFF intervals in groupings of three. However, alarms with both the T-3 pattern and the continuously beeping signal are currently sold in local hardware shops. It would appear from anecdotal evidence that the continuously beeping smoke alarms are much more prevalent in Australian homes than ones with the T-3 pattern.

In Australia, most primary school children receive fire safety instruction, with an emphasis on

how to escape in a home filled with smoke or what to do if clothing has been ignited. While the role of smoke alarms may be discussed it is not known whether children can identify the actual smoke alarm as indicating fire (and know how to respond) and there is, to our knowledge, no published research on this.

The main aim of this study was to determine the likelihood of children aged from 5 to 15 years waking up to their home smoke alarm set off for 30 seconds under the same sound level conditions (e.g. bedroom door open, ajar or closed) as would apply on a typical night at home. The study also explored the extent to which the children recognized the sound of their smoke alarm if it woke them during the night and whether or not they knew that they should evacuate the home on hearing the smoke alarm sound. Information about the normal location of home smoke alarms relative to the child's sleeping arrangements was also of interest.

## METHOD

### Participants

The number of children whose data was considered to be valid was 123 children, from 79 families. (Data from six other children were eliminated - see Results.) There were approximately equal numbers of males and females (60 M, 63 F) and the age range was from 5 to 15 years with the mean age being 8.82 years (SD = 2.88). The group was dichotomised into two age groups so that the younger group would be prepubescent. This is because plasma melatonin levels drop with puberty onset [10] and the melatonin hormone is known to be soporific [11]. About 70% of the participants were aged from 5 - 10 years (n = 87) and 30% from 11 - 15 years (n = 36).

Recruitment was done entirely via the media and distribution of postcards, with people being asked to log on to a specially developed website www.vu.edu.au/wakethekids linked to Victoria University. The graphic and text of the postcard are shown in Figure 1. The story was linked to the end of daylight saving time in most states of Australia, which is when people are asked to change their smoke alarm battery. The media picked up the story very well with 42 radio

interviews, 18 articles in the print media, an interview on a morning TV chat show and even a mention on a highly rated TV comedy show. In addition 40,000 postcards were distributed, mostly to 125 schools where the Principal had responded via email to either a letter or email advertising the study. Many schools also put an advertisement in their newsletter. Although the media campaign aimed to be national in scope, there was more exposure in Victoria and 52% of participants were from this state. Queensland was next with 20% of participants.

In total over 1200 people logged on to the website, however, only the parents of 129 children recorded their test results on the website.

**INSERT FIGURE 1 ABOUT HERE**

Figure 1. The front and back of the postcard used for participant recruitment

**Instructions**

Detailed instructions appeared on the website and parents were asked to print it out before the testing. The website and instructions were piloted sequentially with seven families and continuously improved based on their feedback. Note that parents were asked to keep their child 'naïve' to their participation with the aim of reducing the possible effects of priming (ie knowing they would be awoken by an alarm, which may make waking more likely [12]. The verbatim instructions that appeared on the website are reproduced below.

*BEFORE THE ALARM DRILL - during waking hours***:**

1. Try not to make your child aware that you plan to conduct an alarm drill. If they already know, or find out, the drill can still be conducted but we would like as many children as possible to be unaware of the planned drill.

2. Locate the smoke alarm closest to your child's bedroom. For multiple children - where children sleep in the *same* bedroom then test them both at the same time and clearly note which answers relate to which child on this form - perhaps also using the back. If the children sleep in *different* bedrooms you will need to do the alarm drill separately for each child and may choose to print out a set of instructions for each child. Allow sufficient time between each drill to make

sure the child to be tested is soundly asleep.

3. Press the test button on the smoke alarm to determine how you can make your smoke alarm sound continuously (or more or less continuously) for 30 seconds. A broom handle or similar may be used. Some will operate for 30 seconds with one button push, others will need repeated button presses.

4. Decide on what night you will conduct the fire drill. Two adults need to be involved. One adult needs to be a parent. (One adult will set off the alarm, the other will quietly observe the child and reassure/comfort if they wake up.). It should be a relatively normal night of sleep for your child, e.g. not excessively late and avoid medication that affects sleep if possible.

5. If it is likely that the sounding of the smoke alarm will alert your neighbours you should consider telling them of your plans.

**6.** Either *before or after* the drill we will need to know the distance between the smoke alarm and the pillow. Measure the walking distance, in a direct horizontal line, from below the smoke alarm to the middle of the child's pillow. This will be easiest if measured along the floor. *Record distance - in metres:*

7. You may wish to look at the questionnaire (preview) on the website, so you can anticipate the questions. 8. If you have any questions please email us as soon as possible (see Frequently Asked Questions on the home page).

*ALARM DRILL PROCEDURE - on the chosen night*

1. Take note of the approximate time your child went to sleep (this may be quite different to when they went to bed). *Record time.*

2. Leave their bedroom door the way it would normally be during the night while everyone in the house is asleep. *Record whether their door was open, ajar or closed.*

3. Conduct the drill at a time that is between one and three hours after you estimate that your child went to sleep.

4. One adult should quietly enter the child's bedroom. Their role is to ensure the child is not obviously awake before the alarm sounds and observe any behaviour (e.g. stirring, rolling over, waking up) once the

alarm has been activated. *Record behaviour.* If the child wakes up reassure them that there is no problem (do not say it is an alarm) ask them what woke them up (does their answer indicate they knew it was a smoke alarm?). Ask them what they would do if they heard that sound when in bed? (We want to know if they knew they should evacuate (leave) the home.) *Record answers.*

**5.** Meanwhile*:* The adult with the smoke alarm should check their watch and press the alarm button so that it sounds as continuously as possible for 30 seconds. (Wear earplugs if sensitive to the sound.) *Record time alarm was set off. Estimate how many seconds the alarm sounded.* (Ignore any short silences between ongoing beeps.)
6. Once the alarm drill is completed the child can return to sleep.

*AFTER THE ALARM DRILL*
1. If the distance between the alarm and the pillow hasn't yet been measured (step 6 above) do this before recording the results online.
2. Please record the results for each child on this website within a few days of conducting the alarm drill, and before the end of Monday 14th April 2008.
3. If your child would like a Certificate of Appreciation print this out (see homepage).
4. Ensure that the batteries in all smoke alarms in your home are replaced once a year.
5. In the morning tell your child that the alarm drill that happened the previous night was only for one night and if they hear the alarm sounding in the future they should assume there is a fire and follow the agreed evacuation procedure.

The research was approved by the Victoria University Human Research Ethics Committee.

## RESULTS

### Quality control of the data

Because the research was conducted and recorded by parents without supervision of the activation of the alarm and testing of the sleeping child the questionnaire responses were examined very carefully for ambiguities or anomalies. As a result of this process over a dozen parents were emailed and asked to clarify what had occurred. On the basis of these responses some individual results were considered invalid and six responses were deleted from the data set. One response was eliminated because the alarm was recorded as being activated for less than 25 seconds and the child did not wake up. A further three children were eliminated because the

alarm was activated for more than 60 seconds and the child did wake up (thus it was not known whether they awoke within the first 30 seconds). Two children who said they were awake when the alarm was set off were also excluded. This left a final response set relating to 123 children.

The data was then examined with respect to the estimated time between presumed sleep onset of the child and activation of the alarm. Parents had been asked to set off the alarm 1-3 hours after sleep onset. The data showed that this time frame had been complied with for 73% (n=90 out of 123) of the alarm activations – with 7% (9/123) of alarm activations reported as occurring between 30 and 59 minutes after sleep onset, and the remaining 15% (18/123) reported as occurring more than 180 minutes after sleep onset (with 5% (6/123) missing data on either activation time or estimated sleep onset time). In order to determine whether compliance to the recommended 60-180 minutes after sleep onset time frame was significantly associated with whether or not the child awoke a Chi Square test was performed and no significant difference was found ($X^2$ = .842, df = 1, p = .36, n = 117). Consequently non-compliance with the recommended awakening time frame was not used to exclude any participants.

**How many slept through?**

The results of the study indicated that 78% (96/123) of children slept through their home smoke alarm sounding for 30 seconds. Figure 2 below shows the breakdown of various responses and observations. It can be seen that most children made no visible response to the alarm sound.

**INSERT FIGURE 2 ABOUT HERE**

Figure 2: Sleeping children's responses to the alarm

There were a few parental reports of children having hearing impairments (n=2), a cold (n=4) or taking medication that may increase sleepiness (n=2). As a group these children slept through the alarm in about the same proportion as the children without these issues (75%, 6/8).

**Age differences**

Younger children (aged between 5 and 10 years) were significantly more at risk of not waking, with 87% (76/87) sleeping through the alarm, compared to 56% (20/36) of older children (aged 11 to 15 years). Analyses found that the difference between these age groups was statistically significant (Chi Square Test $\chi^2 = 15.1$, df =1, $p<.001$, n=123). A least squares regression for the proportion of children not waking by age yielded a moderate to high correlation coefficient of .66.

**Alarm Location**

Figure 3 shows the breakdown of alarm locations in relation to the child's bedroom. Interestingly, across the whole sample only a few children (4) had a smoke alarm in their bedroom. Most families had their alarm situated in the area outside the child's room (87%, 105/120, 3 missing data) and, as can also be seen in Figure 3, the child's bedroom door was in most cases, where applicable, open (62%, 72/116) or ajar (23%, 27/116, 3 missing data on door status). Inspection of the results showed that the location of the alarm or the position of the door did not appear to be make much difference as to whether the child awoke or not, with 71% (51/72) sleeping through the smoke alarm when their door was fully open, compared to 78% (96/123) across the entire sample.

**INSERT FIGURE 3 ABOUT HERE**

Figure 3: Percentage of children with alarm located in different areas in relation to the child's bedroom and information about the status of the child's bedroom door during the alarm test.

Details of the distances in a straight horizontal line on the floor between each child's pillow and the alarm, as reported by the parents, are shown in Figure 4. The median horizontal distance between the location of the smoke alarm and the child's pillow was 5.6 meters (standard deviation of 8.2). As can be seen from Figure 4, most reported distances were between 2 and 6 metres.

**INSERT FIGURE 4 ABOUT HERE**

Figure 4. Percentage of children with alarms located at different reported distances between the child's pillow and the smoke alarm

**Expectancy**

Parents were asked not to tell their child if and when they would activate their smoke alarm during the sleeping period, but were told they could still participate if their child was expecting it. Figure 5 shows that parents reported that 89% (109/123) of the children were not primed in any way for the alarm being activated.

**INSERT FIGURE 5 ABOUT HERE**

Figure 5. Percentages of children with different parent-reported expectancies about being awoken by their home smoke alarm in a drill.

**Responses if awoken**

Of the 27 children who woke up, only 61% (16/27) reported that they knew the sound that woke them was a smoke alarm and almost half (47%, 13/27) indicated to their parents that they knew the alarm sound meant they should leave the house. According to the parents' report only 17% (5/27) indicated that they definitely did not know they should evacuate (with the remaining one third being unsure of what to do).

Slightly more than half (59%, 16/27) of the children who woke up were aged 11 years or over and they were more likely than the younger children to know that the sound was a smoke alarm, but the difference in percentages was minor (63% of the older children (10/16) who awoke knew it was an alarm versus 58% (6/11) of the younger ones).

## DISCUSSION

This research has tested the ability of sleeping school aged children to wake up to their home smoke alarm sounding for 30 seconds and found that the vast majority are unlikely to wake up. The results are concerning as overall only 22% awoke. Nearly nine out of ten children aged from 5 to 10 years slept through compared to the older group (11-15 years), where over half slept through.

Our previous research [13] with children has suggested that if the child is going to wake up to an alarm most will do so within the first 30 seconds. The results from that research suggest that some 5-10% more children may wake up if the alarm continued for a full three minutes. If we put that finding together with the current data we may expect that some 27% to 32% of children aged between 5 and 15 may wake up to a smoke alarm sounding in their home for *three minutes* under naturalistic conditions, between one and three hours after they have gone to sleep.

For most children in this study the smoke alarm was located in the hallway outside their bedroom and for 82% of these children their door was either fully open or ajar. Under this scenario the volume of the smoke alarm at the pillow was likely to be between about 50 and 80 dBA [8]. These features make the current result on waking effectiveness under more naturalistic conditions broadly consistent with the findings of the previous literature on this issue, as summarised in Table 1.

From the small number of children who did wake up it was disturbing to find that less than two thirds recognised the sound as a smoke alarm and only about half knew they should evacuate. A further third of the children in this sample who awoke were not sure whether or not evacuation to an alarm sounding was required.

Limitations of the current study arise from the fact that the parents were essentially the experimenters and thus we must rely on the validity of their observations. On the other hand, participating parents must have been quite highly motivated to absorb the detailed instructions, perform the ‘alarm drill’ and then log onto the website and complete the detailed questionnaire. It seems possible this high motivation increased the likelihood of more accurate reporting. In the

design phase of the study suggestions to include motivators, such as a lottery with prizes, were discarded as it was felt this might compromise the validity of the reporting. Parents could download a 'Certificate of Appreciation' for their child. As only 79 families were involved across the 123 children, some 44 children must have been in home test situations where more than one child was being tested. It is not known how many of these (presumably) siblings slept in their own room and were potentially also exposed to an alarm from a previous testing. It is possible that in these cases the sleep of such children was lighter than it might have been if there had been no previous alarm set off in the house. On the other hand, children typically have a strong pressure for deep sleep early in the night and are likely to re-descend into deeper sleep quite quickly [14]. After the extensive media coverage and postcard campaign the total number of responses was disappointing and reports from families who intended to participate but then didn't suggest that the two main barriers were a reluctance to wake their child and the burden of collecting and reporting the data according to the requirements. Nevertheless, this naturalistic study tested 4-5 times as many children as previous, experimental studies and we have some confidence that the results can be generalized to the community.

## IMPLICATIONS

The implications of these findings are:

1. Parents should not rely on their children waking to the smoke alarm in the event of a fire and should not assume that they will immediately evacuate if they do wake up to a fire.

2. Parents need to hear the alarm (and as loudly as possible), no matter where in the house the fire is. Given the current availability of alarm devices, the home alarm system that will achieve this is one where there are interconnected alarms. Ideally, smoke alarms should be placed in a variety of rooms around the house, including living areas and bedrooms and linked so that if smoke is detected by any alarm, all the smoke alarms in the house sound. New technology in the US has lead to bedside clock alarms that activate on detecting the T-3 signal somewhere else in the house, but of course this device assumes the notification signal is in the T-3 pattern.

3. Home safety plans should not assume children will wake up to an alarm and fire safety education should include teaching children to recognise the sound of a smoke alarm in case they do wake up. This data suggests that Australian fire safety training needs more emphasis on the need for children to evacuate the home in the event of an alarm sounding.

4. We have conducted various studies which suggest that many groups who are at risk of sleeping through the current smoke alarm (such as older adults, the hard of hearing, people who are moderately alcohol impaired and deep sleeping young adults) will wake more effectively, and at lower volumes, to a sound that is of a lower frequency and increased spectral complexity (specifically a 520 Hz square wave signal) [2, 15]. One of our studies with children suggests this sound is better for them as well – with the rate of awakening being 12 times greater with the 520 Hz square wave than the current signal [2]. Given this data, and the consistent evidence that the overwhelming majority of school aged children will not wake to the current high pitched alarm, either under naturalistic conditions or experimentally controlled conditions, it is time for an improved smoke alarm notification signal to be widely implemented. The US National Fire Protection Association 2010 Alarm Code 72 recommends that the 520 Hz square wave signal be installed in smoke alarms in all commercial bedrooms by 2014.

**ACKNOWLEDGEMENTS**

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Table 1. Summary of studies investigating waking to a high pitched smoke alarm in children.

| *Age* | *N* | *Volume at pillow* | *Duration of alarm* | *% awoke* | *Timing or sleep stage* | *Reference* |
|---|---|---|---|---|---|---|
| **6-15 years** | 20 | 60 ± 3 dBA | 3 min | 6% (reliably awoke on two nights at home) | Between 1 and 4.30 am | Bruck, 1999 [3] |
| **6-15 years** | 28 | 89 ± 3 dBA | 3 min | 50% (reliably awoke on two nights at home) | At 1 and 3 am | Bruck and Bliss, 2000 [4] |
| **6-12 years** | 24 | 100 dB | 5 min | 58% (one night in sleep lab) | Stage 4 sleep | Smith et al, 2006 [5] |

**Figure legends**

Figure 1. The front and back of the postcard used for participant recruitment

Figure 2. Sleeping children's responses to the alarm

Figure 3. Percentage of children with alarm located in different areas in relation to the child's bedroom and information about the status of the child's bedroom door during the alarm test

Figure 4. Percentage of children with alarms located at different reported distances between the child's pillow and the smoke alarm

Figure 5. Percentages of children with different parent-reported expectancies about being awoken by their home smoke alarm in a drill