

# Sleeping Children and Smoke Alarms

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## ABSTRACT

A previous study found that 85% of children did not reliably awaken to a standard hallway smoke alarm received at 60 dBA. To ensure the safety of children in a fire emergency, one response may be to install smoke detectors in children's bedrooms. The aim of this study was to determine whether children will indeed awaken to a smoke alarm in their bedroom. Twenty-eight children aged 6-15 years participated and were exposed, on two different nights in their own home, to an alarm which was received at 89 dBA. Sleep/wake behaviour was determined objectively by wrist actigraphy and confirmed by self-report questionnaires, which also asked about clearheadedness and sleepiness. It was found that 50% of the children (14/28) slept through one or both of the alarm presentations. If only the 6-10 year olds are considered, 71% (10/14) did not reliably awaken. Where a child awoke, most (77%) awoke within 32 seconds of alarm activation. Subjective reports from the children suggest they did not feel very clearheaded or awake in the first three minutes after being awoken. It is recommended that all family dwellings install interconnected systems where detectors are placed in high fire risk areas and hallways and interlinked alarms are in living areas and bedrooms (especially adult bedrooms). **KEYWORDS:** sleep, smoke alarms, smoke detectors, children, arousal

## INTRODUCTION

It is anecdotally evident to most parents that children are deep sleepers. This is supported by the knowledge that the percentage of slow wave sleep (deepest sleep) is significantly higher in younger individuals [1] than adults. In a recent study [2] it was found that 85% of children aged 6-17 years slept through one or both presentations of a standard smoke alarm which was installed in the hallway outside the child's bedroom, such that the signal was received at the pillow at 60 dBA. The signal was activated between 1 and 4am on two different nights in the child's home. The signals were expected within a four night period. It was found that 11 of the 20 children (55%) slept through both presentations while six (30%) slept through one night. The results of that study have major implications for the safety of children in a nocturnal fire emergency.

While most smoke detectors sold in Australia recommend installation in every bedroom, this is not required by law. Of all the fires originating in bedrooms in Australia during 1993/4, only 1.7% had a known smoke detector present [3]. Within the intervening six years the installation of smoke detectors has increased dramatically in Australia, and is now mandatory in all homes, but the standard installation remains the hallway. The non-arousal of children by a smoke detector alarm is not a problem if the children's bedrooms are close to a bedroom where an adult will receive the alarm signal at 60 dBA or higher. Studies agree that an alarm of 55-60

dBA will reliably arouse an adult sleeper [2,4]. Adults could then arouse their children (assuming that they were not too close to the fire origin). However, if the adults close the bedroom door and reduce the dBA level below 55 dBA they may not hear a hallway smoke alarm. Moreover, if the adult and child bedrooms are at a distance, as in many newer home designs, neither the adults nor children may arouse to an alarm in the hallway near the children's bedrooms.

One response may be to promote the installation of smoke detectors in children's bedrooms. One issue with advocating this is that children are such heavy sleepers that we cannot assume that they will awaken to the 85 dBA signal they receive if the alarm was in their room. An important study of auditory arousal thresholds in prepubertal male children (both hyperkinetic and normal controls) reported a general inability to arouse to intensities of up to 123 dBA [5].

Consequently before advocating that the solution to the non-arousal of children to a hallway alarm is a bedroom alarm, further research is required. The aim of this study is to determine whether children will indeed awaken to a smoke alarm located in their bedroom, typically generating an 89 dBA signal at their pillow.

## MATERIALS AND METHODS

### Subjects

Twenty eight subjects aged between 6 and 15 participated. The age and sex distributions can be seen in Table 1. There were a total of 14 males and 14 females. Participants were recruited by word-of-mouth within the University staff and student population.

TABLE 1. Number of participants as a function of age and sex.

Age	Male	Female	Total
6	2	1	3
7	3	0	3
8	3	1	4
9	1	0	1
10	1	2	3
11	1	2	3
12	1	2	3
13	0	2	2
14	0	3	3
15	2	1	3
<b>Total</b>	<b>14</b>	<b>14</b>	<b>28</b>

Parents of all potential participants were interviewed to ensure that they considered their children to have normal hearing, normal sleeping patterns, no heavy snoring, no daytime sleepiness, no chronic illness, no ongoing medications affecting sleep/wake behaviour and were prepared to remain free of specified medications for the duration of the experiment.

Prior to participation all subjects were also required to pass a (free) hearing test (including air conduction and bone conduction) conducted by a professional audiology agency. The required thresholds values were taken from the International standard (ISO) 7029 (1984) and 90% percentile criterion was adopted for each age level.

### Apparatus

The apparatus and questionnaires are similar to those used in a prior study [2]. These are described again here for completeness.

A special portable smoke detector alarm on a stand was constructed for the experiment. The alarm could be positioned at ceiling level. This was connected to a timer that could be preprogrammed for two separate activations of 3 min duration each within a five-day period.

Each subject was required to wear an actigraph (Minimitter Minilogger 2000) on each of the five nights throughout the experiment. This is a small device worn on the wrist which monitors activity and can detect the difference between sleep and wake. Each actigraph was set to collect activity data in time 'bins' of 16 s intervals, whereby it was possible to identify at what time during the night a subject awoke (within a parameter of 16 s).

Two brief questionnaires were devised for the experiment. The 'Evening Questionnaire' consisted of two questions asking for a rating of the quality of the previous night's sleep and the level of daytime sleepiness on the day just completed. Both questions required ratings compared to normal for them. The 'Upon Awakening Questionnaire' asked questions pertaining to their experience of awakening when the alarm went off and included five point ratings of how clearheaded they felt at three points of time after the alarm was activated. An adaptation of the Karolinska Sleepiness Scale [6] (5 points) was also included. A synchronised clock was placed in the living room for precise identification of how much time had elapsed at the end of completing the questionnaire.

### Procedure

All participants were fully informed as to the purpose of the experiment. The smoke alarm stand was carefully placed in the child's bedroom such that the decibel reading at the pillow was 89 dBA  $\pm$  3 dBA. The stated duration of the experiment was five nights but the alarms were always set to activate on the second and fourth nights of the study. Participants were expecting that the two alarms would go off on two of the four nights but did not know which two nights. The time of night of the alarms was 1 am and 3 am.

Prior to retiring to bed at night each subject was required to complete the Evening Questionnaire and then put on the wrist actigraph. Participants were instructed that upon hearing the alarm they were to immediately begin moving the wrist with the actigraph back and forwards (to activate the actigraph) for about 10 seconds and leave their bedroom promptly to then go to the living room and complete the Upon Awakening Questionnaire (UAQ). In all cases a parent of the child also awoke, waited quietly until the child emerged from their bedroom (if they awoke) and helped them with the questionnaire if required. The UAQ had 11 items that asked for information about their sleep/wake behaviour before/during and after the alarm was activated. Subjects were asked to rate how clearheaded

they felt at three different time points. A rating of 1 indicated 'extremely' clearheaded with 3 being 'moderately' and 5 'not at all'. The first and second ratings were retrospective evaluations, with the first being at the time the alarm was first heard and the second when the subject got out of bed (and left their room). The third was a 'right now' rating completed when they had reached the living room and commenced the UAQ. The adapted Karolinska Sleepiness Scale was also completed on a 'right now basis', and a rating between extremely sleepy (1) and extremely alert (5). Those who slept through the alarm were not required to do anything during the night.

The study was approved by the Victoria University Human Experimentation Ethics Committee.

## RESULTS

### Behavioural Response to Alarm

Of the 28 children, all were asleep at both times when the alarms were activated.

It was found that four subjects slept through both alarm presentations while 10 slept through one alarm. Thus 14 children, or 50% of the sample did not reliably awaken to the alarm located within the bedroom (89 dBA). The remaining 50% awoke on both nights (see Figure 1).

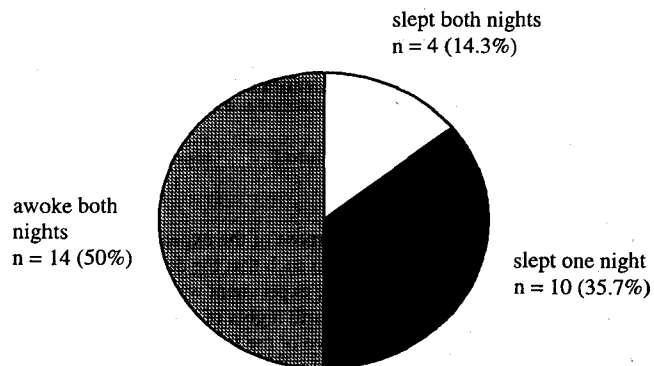


FIGURE 1. Piechart showing numbers (and percentage) of children (6 – 15 yrs) in relation to arousal to two 89 dBA smoke alarms.

Given that the sample size of this group is only 28, it is interesting to calculate the true proportion of children who may reliably awake to an 89 dBA alarm. Using a confidence interval of two standard errors (95% confidence interval), it can be estimated that the true population proportion of children who would reliably awaken is between 31.3% and 68.7%.

There was no difference in the number of males and females who were awoken by the alarm. For both males and females seven woke to both alarms, five slept through one alarm and two slept through both.

To determine whether variations with age existed, the group was divided into two equal groups around the median age: that is 6 – 10 year olds and 11 – 15 year olds. The frequency within each group that woke both times, slept through one alarm and slept through both alarms are shown in Figure 2. It can be seen that in the younger age group 10 out of the 14 (71%) did not reliably awake to the alarms while in the older group only four out of 14 (28.5%) did not reliably awake.

### Age Group

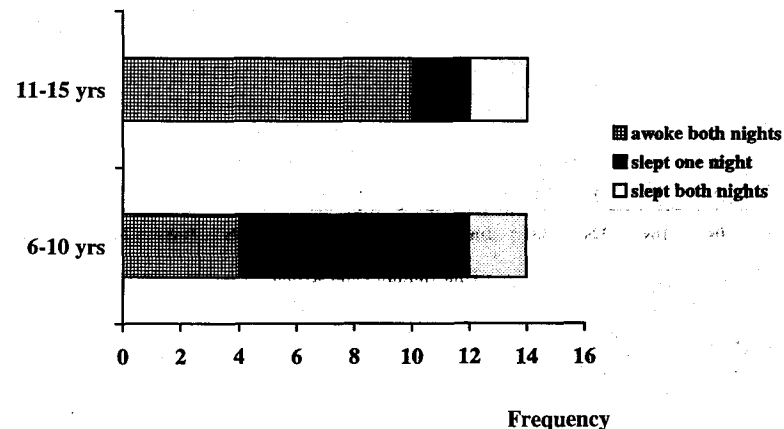


FIGURE 2. Frequency of children aged 6 – 10 years versus 11 – 15 years in relation to arousal to two 89 dBA smoke alarms across two nights.

The Evening Questionnaire was scored to identify any subjects reporting their previous night's sleep as 'a lot worse than normal' or that they were 'a lot more sleepy' during the following day. This was to identify whether participants' previous night's sleep might have affected their arousal behaviour. Of the six children (3M, 3F) who indicated severe sleep problems, or excessive sleepiness during the day, five were in the 11 to 15 year age group. Of these, four woke to both alarm presentations. While one child in the 6 - 10 year age group reported sleep 'a lot worse than normal' on Night 2 of the study (alarm presentation at 1 am), this child did not wake for the alarm presentation. The child subsequently awoke for the 3 am alarm presentation on Night 4. These results would suggest that no sequential confounding effects were evident.

### Time to arouse to the alarm

The actigraphs yielded data at 16 sec intervals and from this latencies to arouse were determined. The 56 alarm activations resulted in 35 arousals, of which approximately half

(45%) were at 1 am compared to 3 am. As can be seen in Figure 3, 77% (27/35) of all the latencies were short, taking 32 sec or less. Of the seven arousals that occurred more than 32 seconds after the alarm went off, six were at 1 am.

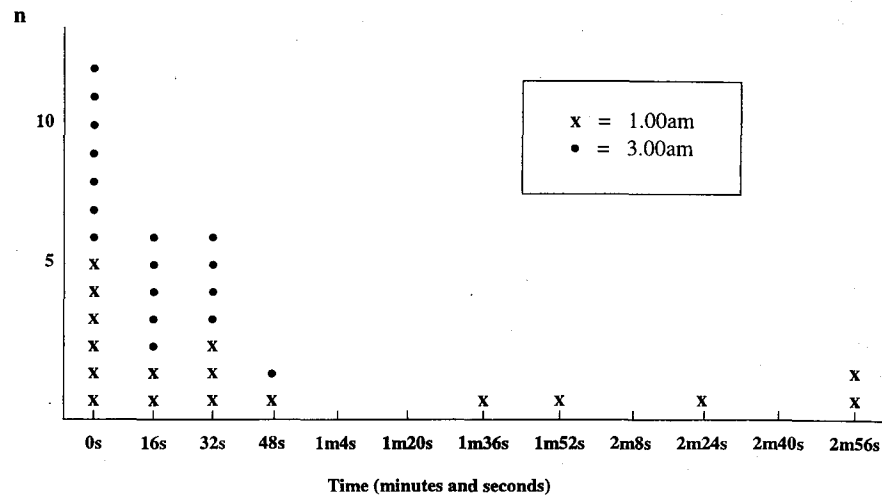


FIGURE 3. Frequency distribution of individual latencies to arouse to a 89 dBA alarm activated at 1 am or 3 am.

Of the 21 alarm activations that did not result in the correct response of shaking the wrist and leaving the bedroom, it was noted that in six cases the child did stir, registering movement on the actigraph but then went back to sleep.

#### Clearheadedness and sleepiness ratings

All children who woke up rated their clearheadedness at three points over an approximate three minute period from when they were aroused. The data from the 14 children who consistently awoke was then averaged across the two nights. The mean clearheadedness ratings are shown in Table 2 and it can be seen that the ratings did not change much over time.

TABLE 2. Mean ratings (and standard deviation) of clearheadedness at three time points (1 = extremely clearheaded and 3 = moderately clearheaded on the five point scale).

	Mean Rating	Standard Deviation
When alarm first went off	3.3	0.82
When you got out of bed	2.8	0.75
When in the living room	2.9	0.81

Comparison of the ratings at the three minute point in this study and in the previous study [2] suggest that the present sample of children were less clearheaded than the earlier group of adults and children studied. (Current study rating is 2.9 compared to 1.86 from previous sample to 16 adults and 14 children. The earlier data combined the two groups as no significant differences were found.)

In the current study, of the 14 children who rated their clearheadedness, only three noted an improvement across all three time points, while nearly half (six) reported no improvement at all.

A single sleepiness rating on a five point scale was made about three minutes after each child awoke and the resultant mean of the 14 data points was 2.2 (standard deviation = 0.54). This places the consistent wakers in the "sleepy but no difficulty staying awake" category. Two children reported themselves as "extremely sleepy - fighting sleep" (1).

#### DISCUSSION

This study clearly demonstrates that locating a smoke detector in a child's bedroom will not solve the problem of non-arousal to an alarm. Half the children will not reliably wake to an 89 dBA alarm. If we only consider the 6 - 10 year old group, 71.5% will not reliably wake to such an alarm. Given that we know that younger children have more deep sleep [1] than older children we can assume that even more children aged under 6 will sleep through an alarm.

These results are from the middle third of a child's normal sleeping period and, given what is known about sleep architecture and arousal [7], can be generalised to the final third of the night. Because the stages of sleep with the highest arousal thresholds occur differentially in the first third of the night [6] it is likely that arousals from alarms in the first 2-3 hours of sleep will be even less likely than reported in this study.

When the children did awake to the 89 dBA alarm the latencies were usually short, with 77% taking 32 seconds or less to begin shaking their wrist as instructed. If they did take longer to respond, it is most likely (6 out of 7 cases) that the alarm had sounded at 1 am rather than 3 am. This is consistent with the fact that the deeper stages of sleep are most likely to occur early in the night.

Comparisons of the subjective ratings of clearheadedness and sleepiness in this study with those of the previous study [2] provide some suggestion that children report less improvement in how clearheaded they feel during the first three minutes after awakening than adults. While research has established that this "sleep inertia" does produce significant decrements in adults on a variety of performance indices (eg. decision making [8]), comparative studies with children remain to be published. From a fire safety point of view this study suggests that children do not feel very clearheaded or awake in the first three minutes after being suddenly aroused, and therefore provides tentative evidence that their ability to make life-saving decisions may be impaired.

The previous study [2] of arousal in children to a 60 dB alarm concluded that the standard hallway installation of a smoke detector is insufficient if the parent's and children's bedrooms

are at a distance. The parents may not be able to reach the children in time if a fire moved first to the hallway near the children's bedroom before the parent's bedroom area. This installation is also insufficient if the parent's and children's bedrooms are clustered together but the parents sleep with their bedroom door closed.

## CONCLUSIONS

The current study clearly demonstrates that the solution to the problems presented above is not to install a smoke detector alarm in a child's bedroom. We cannot say with any certainty that this would awaken the child. There is also the problem that smoke alarms in a bedroom may not detect as many fires during the sleeping period as hallway detectors. The main cause of fires during the period when both children and adults are asleep is heating, electrical distribution equipment and appliances (Australia 1993/94) [9] and these are, in general, less likely to occur in a child's bedroom than in any other room of the house, where smoke may then travel to the hallway.

The best solution is for all family dwellings to install interconnected systems whereby the detector components are placed strategically in risk areas and hallways, where smoke can be expected to travel; while the alarms are placed in living/kitchen areas (for day fires) and in bedrooms (especially adult bedrooms) to arouse people during the sleeping period. With this installation adults can sleep, with their door open or closed, confident that they will be quickly aroused to a fire wherever in the house it may occur.

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