
Smoke Alarms by Type and Battery Life in Rural Households

A Randomized Controlled Trial

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Background: Although the use of smoke alarms is widely recommended, little guidance is available on the types of alarms and batteries that function best. This study examined smoke alarm and battery function 12 months after installation in rural residential households.

Methods: An RCT, involving the installation of either a photoelectric or ionizing smoke alarm with either a lithium or carbon-zinc battery, was conducted in 643 rural Iowa households in July 2003. The functionality of each installed smoke alarm was tested 12 months later. Generalized estimating equations were used to model the effects of alarm type and battery type on alarm function and false alarms 12 months after installation.

Results: Of 643 study homes, 98.8% had at least one functioning alarm, and 81.5% had all alarms functioning 12 months after installation. No difference was observed in alarm function between photoelectric alarms and ionizing alarms 12 months after installation (OR=1.30, 95% CI=0.88, 1.92). However, photoelectric alarms had significantly lower odds of false alarms than ionizing alarms. Alarms with lithium batteries had 91% higher odds of functioning than those with carbon-zinc batteries. The main reasons for nonfunctioning included a missing battery (30.7%); a missing alarm (28%); and a disconnected battery (11.3%).

Conclusions: Although lithium batteries and photoelectric alarms are more expensive than their counterparts, the financial investment might be worthwhile in terms of overall performance. (Am J Prev Med 2008;35(1):20–24) © 2008 American Journal of Preventive Medicine

Introduction

Fires and burns are the fifth most common cause of unintentional-injury deaths in the U.S.¹ and the third leading cause of fatal home injury.² In 2005, more than 3000 Americans lost their lives in residential fires.³ Most of these fire victims died from the inhalation of smoke and toxic gases and not as a result of burns; most fire deaths occur at night while the residents are asleep.^{4,5} Smoke alarms minimize property damage, prevent injuries, and save lives by enabling residents to detect fires early and to escape safely from the building.^{6–8} Smoke alarms reduce by half the risk of dying in a fire^{7,8} and by three fourths the risk of having a reportable fire.⁷

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Smoke alarm types differ in how they detect smoke and in the power source they use to initiate an alarm. The two most commonly used smoke alarm types today are ionizing and photoelectric alarms. Ionizing alarms rely on a small energy source to create a constant electric current between two electrodes. When smoke or other particulates disrupt the current, electronic circuitry sets off the alarm. Photoelectric smoke alarms shine a small beam of light past a sensor. When particulates in the size range of smoke intervene, light is scattered into the sensor, activating the alarm. Photoelectric alarms react twice as quickly to smoldering fires, such as those caused by cigarettes igniting furniture, and are thought to reduce false alarms by being more sensitive to the chemical composition of smoke.^{7,9,10} However, photoelectric alarms cost about twice as much as ionizing alarms.¹¹

Battery-operated smoke alarms use a 9-volt battery. Most alarms include a carbon-zinc battery when purchased, and these have a short functional life compared to other battery types. Lithium batteries, in contrast, last up to ten times longer, but cost three to four times more.

No published studies as yet have examined the functionality of smoke alarm combined with battery type within rural residential households.¹²⁻¹⁶ Only two studies, one in inner-city London and one in King County, Washington, have used an RCT to examine smoke-alarm function. To date, only the London study^{12,15} has published findings; these indicated that only half of the smoke alarms installed were still working 15 months later. This leads to questions about the long-term impact of smoke alarm installation programs. The London study also found that ionizing smoke alarms with lithium batteries were the most likely to remain functioning.^{12,15} However, results from homes located in inner-city London may not generalize well to rural areas, where smoke alarm ownership is lower and fire deaths are 36% higher.¹⁷⁻¹⁹

Functioning smoke alarms may be more important in rural than urban settings because fires occur more frequently in rural homes.^{2,17,18} Rural homes are often a greater distance from neighbors as well as fire and emergency services, and occupants thus have less timely assistance in discovering a fire and escaping from the residence.^{2,17,18} Therefore, it is important to know which types of smoke alarms provide optimal outcomes in rural homes. The study's objective was to determine which smoke alarm type (photoelectric versus ionizing); battery type (lithium versus carbon-zinc); and alarm-battery combination were most likely to be functional 12 months after installation.

Methods

Study Participants

An RCT was conducted between July 2003 and June 2005 in rural Iowa homes. The study homes were recruited from 1187 households that had participated in a prospective cohort study examining multiple health outcomes. The cohort study and the characteristics of the county are described elsewhere.²⁰ As shown in Figure 1, the owners/occupants of 1005 (84.7%) of the 1187 eligible households were located.

Of these 1005 households, 691 (68.8%) agreed to participate; 100 (10.0%) were not found at home after four attempts on different days and at different times; and 214 (21.3%) declined to participate. Of the 691 who agreed to participate, 37 (5.4%) were excluded because they had electric current-operated smoke alarms. Of the remaining 654 households, eight did not respond to the follow-up survey and three did not have information on alarm function. Therefore, a total of 643 households were included in the analysis.

Randomization Procedure

A stratified random sampling was used to equally randomize the combination of alarm type (photoelectric or ionizing) and battery type (lithium or carbon-zinc) by town, farm, and rural nonfarm households. A random numbers table was used to determine the smoke alarm and battery type for each eligible household, regardless of their agreement to participate.

Study Protocol

All home visits and smoke alarm installations were conducted from July 2003 to June 2004 by one researcher, a volunteer firefighter trained in smoke alarm installation by the National Fire Protection Association (NFPA). During the visit, the researcher identified one of the homeowners or adult tenants, informed him or her of the study's objectives and procedures, and asked that person to sign an informed consent form if he or she agreed to participate in the study. In households that agreed to participate, the researcher implemented a baseline survey, examined any existing smoke alarms, and installed the free smoke alarms furnished by the study. The study's protocol and informed consent were approved by the University of Iowa IRB.

Study alarm installations. All previously installed smoke alarms, regardless of type or age, were removed. Appropriate study alarms (of a major commercial brand that met all NFPA standards) were then installed throughout the home in accordance with the NFPA smoke alarm code. All study alarms and batteries were marked

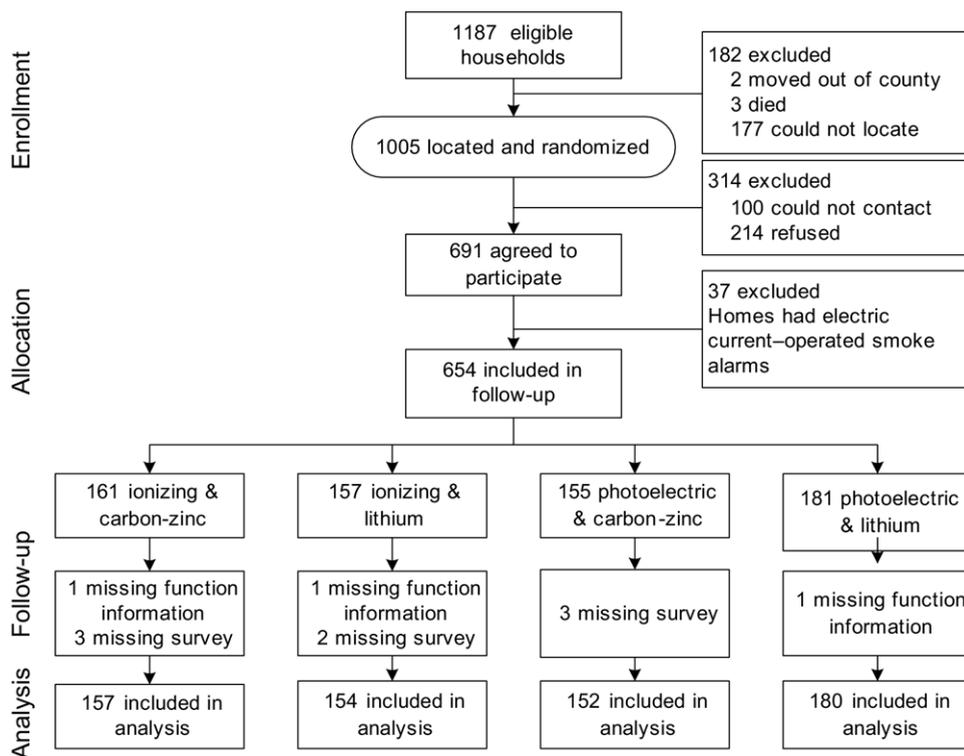


Figure 1. Flow chart of household participation in RCT of smoke-alarm functioning in a rural county.

with indelible ink to facilitate subsequent recognition. Owners/occupants were instructed orally and in writing about the number and locations of alarms installed, how to clear an alarm when activated, actions they should take if an alarm sounded, methods to test alarm function, and how to replace batteries when alarm tests indicated. Although the owners/occupants were provided with the alarm packaging and could identify the type of alarm from this material, no mention of alarm or battery type was made by the researcher.

Follow-up. The researcher revisited the home 12 months after the smoke alarm installation and collected data on the functionality of each smoke alarm, the reason for any non-functioning, and the type of alarm and battery. A brief follow-up questionnaire was administered to measure household characteristics, including the number of children and adults aged ≥ 65 living in the home, any troubles with the installed smoke alarms (e.g., false alarms), and safety measures that were taken to protect the home. The data collection was completed by June 2005.

Outcome Measures

The main outcome of interest in this study was smoke alarm function, a dichotomous variable that was based on the presence of four conditions: (1) the alarm was present; (2) the alarm's battery was present; (3) the alarm's battery was connected; and (4) the alarm successfully passed a smoke test. False alarms were a secondary outcome that was defined as a false (nuisance) alarm that occurred one or more times during the 12 months after installation and was measured by self-report.

Statistical Analysis

Statistical analyses were conducted both at the household level, which treated the entire household as a unit of analysis, and at the individual smoke alarm level, which treated each smoke alarm as a unit of analysis clustered within a household. At the household level, the study examined the number and percentages of homes with all functioning alarms and homes with at least one functioning alarm.

At the individual alarm level, the differences in functioning or false alarms by alarm type and battery type were compared using chi-square tests. Generalized estimating equations based on a binary outcome with exchangeable correlation structure were used to model the effects of smoke alarm type and battery type on smoke alarm function or false alarms 12 months after installation. Each study home was treated as a clustering variable in the analysis because smoke alarms in the same home may be affected by shared household characteristics.²¹ AORs were calculated on functioning alarms versus nonfunctioning alarms, and on false alarms versus nonfalse alarms. The analyses were conducted in SAS version 9.00.

Results

Allocation of Randomized Alarms in Study Homes

Table 1 presents the characteristics of the study homes. Overall, the four combinations of smoke alarm and battery type were well-balanced in town, farm, and rural nonfarm households ($p=0.7046$). The allocation of the four combinations was also evenly distributed across other

household characteristics (e.g., home location, marital status, household income, home ownership, presence of current smoker, presence of children aged 5 or younger, and presence of an adult aged 65 or older), with chi-square p -values ranging from 0.17 to 0.87.

Proportion of Functioning Alarms in Study Homes

The average number of installed smoke alarms was 3.08 per household. Although 635 (98.8%) households had at least one functioning alarm, in only 81.5% of study homes were all of the installed alarms functional when tested 12 months later (Table 2). There was no significant difference in the proportion of functioning alarms between homes with photoelectric alarms and homes with ionizing alarms. The proportion of functioning alarms was higher among homes with lithium batteries compared to homes with carbon-zinc batteries (Table 2).

Individual Alarm Functionality

Of 1991 study alarms installed, 1841 (92.5%) remained functional when tested 12 months later (Table 3). The main reasons for nonfunctioning included a missing battery (30.7%); a missing alarm (28%); and a disconnected battery (11.3%). Ionizing alarms constituted 70% of the alarms with a missing battery and 82% of the alarms with a disconnected battery. Of 281 (15.3%) functioning alarms that had batteries replaced, 250 (89%) originally used carbon-zinc batteries (not shown in table).

The proportion of functioning alarms was higher among those powered with lithium batteries (Table 3). In particular, lithium batteries provided a 91% increase in the odds of maintaining alarm function compared to carbon-zinc batteries (95% CI=1.30, 2.82), even after adjusting for alarm type. No significant difference in alarm function was observed between photoelectric alarms and ionizing alarms 12 months after installation (OR=1.30, 95% CI=0.88, 1.92). However, photoelectric alarms had reduced odds of 0.41 of reporting false alarms (95% CI=0.29, 0.56).

Table 1. Characteristics of study homes (N=643)

Characteristic	n (%)
Location	
Farm	217 (33.8)
Rural nonfarm	81 (12.6)
Town	344 (53.6)
Household characteristics	
Married	458 (71.2)
Household income <\$20,000	79 (12.4)
Homeowner	579 (90.1)
At least one person with high school diploma	613 (95.3)
At least one child aged ≤ 5	38 (5.9)
At least one child aged $\geq 6-17$	151 (23.5)
At least one person aged 18-64	338 (60.3)
At least one person aged ≥ 65	292 (45.4)
At least one current smoker	114 (17.8)

Table 2. Proportions of functioning alarms in study homes (N=643)

	All	Ionizing		Photoelectric	
		Carbon-zinc	Lithium	Carbon-zinc	Lithium
Number of alarms in a home, mean (range)	3.1 (1–8)	3.2 (1–8)	3.1 (1–6)	3.0 (1–5)	3.1 (1–6)
Functioning alarms ^a					
All alarms functioning in a home, <i>n</i> (%)	524 (81.5)	113 (72.0)	129 (83.8)	124 (81.6)	158 (87.8)
At least one functioning alarm in a home, <i>n</i> (%)	635 (98.8)	154 (98.1)	154 (100.0)	149 (98.0)	178 (98.9)
Proportion of functioning alarms in a home ^b , mean (range)	0.93 (0–1)	0.89 (0–1)	0.95 (0.33–1)	0.92 (0–1)	0.95 (0–1)

^aUnit of analysis is a home^bCalculated as the number of functioning alarms in a home divided by the total number of smoke alarms within the home

Discussion

After 12 months, approximately 99% of the study homes had at least one functioning alarm, and more than 92% of the installed study alarms remained functional. However, about 18% of study homes had at least one alarm that was not functioning. A similar study^{12,15} in inner-city London found that, after 15 months, only 50% of alarms were functioning. The difference between the current study and the London study indicates that installing smoke alarms may be an effective strategy for rural households, particularly because rural homes have been less likely than urban residences to have functional alarms and are also more likely to have fires.^{17–19}

The previously published RCT of smoke alarm function in inner-city London found that ionizing alarms with lithium batteries were the most likely to remain functional over a significant period of time.^{12,15} Results from the current study regarding lithium batteries were consistent with that previous finding. However, in the current endeavor, ionizing alarms were not associated with increased alarm functionality. Photoelectric alarms, however, were associated with a lower reporting of false alarms. Although lithium batteries cost more than carbon-zinc batteries, they last much longer (up to 10 years) and do not need to be changed every 6 or 12 months. Thus, lithium batteries may be more cost effective in the long run in terms of remaining functional and consequently

reducing the seriousness of fire-related property damage as well as the risk of fire-related injuries and deaths.^{12,14,22}

The long functional life of lithium batteries, however, presents a contradiction to health-promotion messages that recommend changing smoke alarm batteries every 6 or 12 months. Such frequent battery changes would negate the beneficial effects of using lithium batteries and add extra expense. Thus, owners who regularly change their batteries may be better served by the less-expensive battery types, while owners who do not may benefit from the extra expense of lithium batteries.

Alarm removal, missing batteries, and battery detachment were the main reasons for nonfunctioning alarms. The mere installation of alarms is not sufficient to maintain adequate protection of a home.^{22,23} Proper installation is just the first step of protection from fire-related injuries and deaths. To ensure that a home is fully protected, fire safety programs must promote home-safety behaviors and make certain that household members master the knowledge and skills to properly maintain working alarms, including the regular checking and replacement of batteries. Such programs may also provide the option of installing smoke alarms that have hard-wired power sources that do not need to be replaced, or requiring new construction projects to use hard-wired smoke alarms to virtually

Table 3. ORs of functioning and false alarms (N=1991)

	Number of alarms	Functioning alarm ^a		False alarm ^a	
		Number of functioning alarms <i>n</i> (%)	Adjusted ^b OR (95% CI)	Number of false alarms <i>n</i> (%)	Adjusted ^b OR (95% CI)
Total alarms	1991	1841 (92.5)		175 (8.8)	
Smoke alarm type					
Ionizing	973	889 (91.4)	ref	120 (12.3)	ref
Photoelectric	1018	952 (93.5)	1.30 (0.88, 1.92)	55 (5.4)*	0.41 (0.29, 0.56)
Battery type					
Carbon-zinc	961	866 (90.1)	ref	84 (8.7)	ref
Lithium	1030	975 (94.7)*	1.91 (1.30, 2.82)	91 (8.8)	1.05 (0.78, 1.42)

^aUnit of analysis is an alarm (hard ware)^bAdjusted for type of smoke alarm and type of battery**p*<0.01

eliminate the major causes of nonworking smoke alarms. Owners still need to check the battery back-ups of these systems, so that the alarms can still provide a warning in case the electricity fails.

This RCT had some limitations. First, the study homes and population were rural and predominantly white. These results may not apply to either urban or other rural populations. Second, because it was not possible to recruit all eligible households, those that participated in this study might have been more concerned about home safety than those that did not participate. This could limit the generalizability of the study's results.

Conclusion

A large proportion of smoke alarms were still functioning 12 months after their installation in these rural households. Battery type, more than alarm type, was associated with the functionality of a smoke alarm with 1 year of follow-up. In particular, smoke alarms powered by the more expensive lithium batteries were more likely to be functioning than alarms powered by carbon-zinc batteries. Photoelectric alarms, however, had far fewer reports of nuisance (false) alarms. These findings suggest that homeowners may need to weigh the costs and benefits of different combinations of alarms and batteries when choosing and maintaining alarms in their homes. Physicians and health educators, who play an important role in the health and safety behaviors of their clients, can be more helpful in advocating the installation of smoke alarms in their clients' homes if they are able to answer specific questions or provide resources (e.g., fact sheets or resources for free smoke alarm installation programs) on the type and placement of alarms.

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