

Smoke Alarm and Battery Function 42 Months After Installation A Randomized Trial

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Background: This randomized trial presents findings from the longest follow-up study of smoke alarm and battery function to date.

Purpose: The purpose of this study is to examine differences in long-term function of smoke alarm and battery combinations.

Methods: A total of 691 households in an ongoing cohort study were randomly allocated into smoke alarm groups of ionizing and photoelectric and battery groups of zinc and lithium. Smoke alarm function was measured in 633 (91.6%) households from January 2007 through February 2008, 42 months following original smoke alarm/battery installation. Data analyses were conducted in 2009.

Results: After 3.5 years, 81.9% of the 1898 smoke alarms were functional. Ionizing alarms with zinc batteries were the least likely to function (72.7%). In comparison, photoelectric alarms with lithium batteries were 2.9 times (95% CI=1.8, 4.5) more likely to function; ionizing alarms with lithium batteries were 2.0 times (95% CI=1.3, 3.1) more likely to function; and photoelectric alarms with zinc batteries were 1.7 times (95% CI=1.1, 2.5) more likely to function. Functionality was strongly tied to number of reports of nuisance alarms, which was higher for ionizing than photoelectric alarms.

Conclusions: Photoelectric smoke alarms and lithium batteries are the most likely to function long after smoke alarm installation, and may be worthwhile investments despite their increased cost. (Am J Prev Med 2010;39(4):368–371) © 2010 American Journal of Preventive Medicine

Introduction

Smoke alarms are among the most effective interventions to reduce residential fire deaths.^{1–6} Three RCTs^{7–9} have been conducted to identify the types of smoke alarms most likely to function up to 15 months after installation. All three studies compared the functionality of the two most common types of commercially available smoke alarms: ionization and photoelectric. Two of the studies also examined battery types and smoke alarm function. However, previous trials have not had sufficient follow-up periods to test the long-term function of battery types. This analysis follows the households from one of these randomized trials for 3.5 years (a pre-

vious analysis followed households for 1 year)—more than twice the length of previous studies⁹ to determine the alarm functionality.

Methods

Data were analyzed from an extended follow-up period for a previously published randomized trial,⁹ where details of the study methods and CONSORT diagram can be found. In summary, participants were recruited between July 2003 and June 2004 from an existing prospective cohort study.^{9,10} Both the original cohort study and the smoke alarm trial were approved by the University of Iowa IRB. Participants were randomized using a sequential random number table into one of four smoke alarm/battery combinations: ionization/zinc, ionization/lithium, photoelectric/zinc, and photoelectric/lithium. Follow-up visits 42 months following smoke alarm installation were conducted between January 2007 and February 2008. Alarm functionality was tested by a chemical smoke test. Home owners were also asked about nuisance alarms, defined as the alarm sounding without the presence of an uncontrolled fire. Analyses were conducted in 2009.

Individual alarms were examined to identify functionality by smoke alarm type, battery type, and smoke alarm/battery combinations using generalized estimating equations based on a binary outcome with an

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Table 1. Alarm function by smoke alarm and battery type, 3.5-year follow-up of 633 rural Iowa homes

Alarm and battery type	No. of alarms	No. (%) of functioning alarms	Odds (95% CI) of functioning alarm
Total	1898	1555 (81.9)	—
Smoke alarm type			
Photoelectric	978	836 (85.5)	1.59 (1.16, 2.17)
Ionization	920	719 (78.2)	ref
Battery type			
Lithium	978	846 (86.5)	1.89 (1.38, 2.60)
Carbon–zinc	920	709 (77.1)	ref
Smoke alarm and battery combination			
Photoelectric and lithium	527	468 (88.8)	2.85 (1.81, 4.48)
Photoelectric and carbon–zinc	451	368 (81.6)	1.66 (1.10, 2.49)
Ionization and lithium	451	378 (83.8)	1.99 (1.29, 3.08)
Ionization and carbon–zinc	469	341 (72.7)	ref

exchangeable correlation structure. 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.¹¹ The analyses were conducted using SAS, version 9.00.

Results

A total of 691 households were eligible for the 42-month follow-up visit. Excluded were 27 (3.9%) that could not be contacted after multiple efforts; 10 (1.4%) that were unoccupied; 6 (0.9%) whose owners no longer wished to participate; and 3 (0.4%) who had installed hard-wired alarms. Of 645 households visited, 12 (1.7%) were excluded because smoke alarm function data were not obtained or recorded. This analysis includes the remaining 633 households, which means 91.6% were involved in follow-up. Randomization led to a similar distribution of households in smoke alarm/battery categories by the number of occupants, occupant ages and genders, smokers, and age of household.

Household-Level Alarm Function

For occupants to be fully protected, all smoke alarms within a household should function. After 3.5 years, 414 (65.4%) households were fully protected (all alarms functioning); 174 (27.5%) had at least one functional and one nonfunctional alarm; and 45 (7.1%) had no functioning alarms (results not in tables). Households with ionization alarms powered with zinc batteries were the least likely to be fully protected (51.6%) and the most likely to have no functioning smoke alarms (11.6%). Households with

photoelectric alarms and lithium batteries were the most likely to be fully protected (75.9%).

Individual-Level Alarm Function

A total of 1898 alarms were installed in the 633 households for an average of 3 alarms per household, ranging from 1 to 5. The proportion of functional alarms was 88.8% for photoelectric alarms with lithium batteries, 83.8% for ionization alarms with lithium batteries, 81.6% for photoelectric alarms with zinc batteries, and only 72.7% for ionization alarms with zinc batteries (Table 1). Examined separately, photoelectric alarms were

significantly more likely to function than ionization alarms (OR=1.59; 95% CI=1.16, 2.17) and lithium batteries were significantly more likely to function than zinc batteries (OR=1.89; 95% CI=1.39, 2.60). The combination of a photoelectric alarm and a lithium battery was 2.85 (95% CI=1.81, 4.48) times more likely to function than an ionization alarm with a zinc battery (the referent group).

Missing and nonfunctional batteries were the main reasons that ionization alarms with zinc batteries did not work. Disconnected batteries were found in 11.5% of ionization alarms with zinc batteries but in fewer than 8% of other alarm–battery combinations. Disconnected batteries are usually an indication of nuisance alarms.

Participating households reported that 8.6% of alarms generated at least one nuisance alarm (Table 2). Ionization alarms had nearly twice the proportion of nuisance alarms than photoelectric alarms, regardless of battery type ($p<0.01$). Overall, alarms that did not generate nuisance alarms were 2.2 (95% CI=1.5, 3.1) times more likely to function than those generating nuisance alarms. The relationship between function and nuisance alarms was strongest for ionization alarms with lithium batteries, for which the OR was 4.1 (95% CI=2.0, 8.3).

Discussion

After 3.5 years, more than 90% of homes in this rural cohort had at least one functional smoke alarm, and more than 81% of alarms functioned. An earlier study⁸ found a

Table 2. Smoke alarm function by reported nuisance alarms, 3.5-year follow-up of 633 rural Iowa homes, *n* (%)

Nuisance alarm reports	Ionization		Photoelectric		Total (N=1898)
	Carbon-zinc (n=469)	Lithium (n=451)	Carbon-zinc (n=451)	Lithium (n=527)	
Nuisance alarms reported	59 (12.6) ^a	46 (10.2) ^a	28 (6.2)	30 (5.7)	163 (8.6)
Not functional	21 (35.6)	16 (34.8)	10 (35.7)	3 (10.0)	50 (30.7)
Functional	38 (64.4)	30 (65.2)	18 (64.3)	27 (90.0)	113 (69.3)
No nuisance alarms reported	410 (87.4)	405 (89.8)	423 (93.8)	497 (94.3)	1735 (91.4)
Not functional	107 (26.1)	57 (14.1)	73 (17.3)	56 (11.3)	293 (16.9)
Functional	303 (73.9)	348 (85.9)	350 (82.7)	441 (88.7)	1442 (83.1)
Odds of functionality comparing no nuisance with nuisance alarms (OR [95% CI])	1.6 (0.8, 3.0)	4.1 (2.0,8.3)	2.2 (1.0, 4.6)	n/a ^b	2.2 (1.5,3.1)

^a*p*<0.01 comparing the proportion of nuisance ionization and photoelectric alarms

^bCell size too small to calculate OR

similar proportion of functioning alarms, 84.2%, after 15 months. Another study,⁷ however, found that only 54.4% of homes had a functioning alarm, and 51.1% of study smoke alarms still functioned after 15 months. The only other study¹² to examine long-term smoke alarm function in five states found that only 33% of the study's ionization alarms with lithium batteries were functional. In contrast, 83.8% of ionization alarms with lithium batteries were functional in the present study. Based on the high percentage of nonfunctioning alarms, an earlier study⁷ suggested that smoke alarm installation programs may not be cost effective. Cost effectiveness of smoke alarm installation programs will be enhanced with a better understanding of factors that affect long-term function.

Results of previous randomized trials of smoke alarms after 15 months of follow-up were inconsistent, with one study⁸ in suburban Seattle finding photoelectric alarms and one study⁷ in low-income housing in London finding ionization alarms to be more effective. Studies with follow-up at 9 months⁸ and 12 months⁹ did not find differences in function by smoke alarm type. These inconsistent findings could be related to the different environments in which the studies were conducted, but could also be related to the influence of battery type, reported nuisance alarms, and length of follow-up (which did not extend beyond the functional life of zinc batteries).

Alarms with lithium batteries were nearly two times more likely to function than zinc batteries, a finding consistent with the two previous studies^{7,9} of battery function. In the present study, smoke alarms with zinc batteries would be functional only if the owner had changed the battery. Although 77% of alarms with zinc batteries were functional

(which indicates that the majority of owners did change the batteries), they were the least likely to function.

Reported nuisance alarms were related to function. Photoelectric smoke alarms generally respond faster to smoldering smoke, and ionization smoke alarms generally respond faster to flaming fire conditions. Ionization smoke alarms are more susceptible to nuisance alarms due to cooking.^{4,9,13} In the current study, ionization alarms had nearly twice the level of reported nuisance alarms and nearly twice the proportion of alarms with missing or disconnected batteries.

The current study had a number of important strengths. After 3.5 years, the longest follow-up period to date, more than 90% of study alarms were tested. This is the first RCT of smoke alarm function to be conducted in a rural population. The present study also had several limitations. The rural and primarily white population may not be highly generalizable to other populations. Home owners who were willing to participate in a 3.5-year follow-up period may be more safety conscious than owners not willing to participate, which may overestimate smoke alarm function (although the high response rate would make statistical influence among the nonresponders minimal). Households lost to follow-up did not differ from participating households by any measured individual or household characteristics. However, differences in the likelihood of smoke alarm function are unknown.

Conclusion

The combination of photoelectric alarms with lithium batteries was the most likely smoke alarm/battery com-

mination to function 3.5 years after installation, and the least likely combination to have nuisance alarms.

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