

How long do smoke alarms function? A cross-sectional follow-up survey of a smoke alarm installation programme

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Received 18 March 2013

Revised 10 June 2013

Accepted 14 June 2013

ABSTRACT

Objective To assess the functionality of lithium-powered smoke alarms that had been installed through a community-based programme called Operation Installation (OI).

Methods A random sample was chosen of homes that had received smoke alarms through OI, 2, 4, 6, 8 and 10 years previously. Sampled homes were visited, and information collected included functional status of smoke alarms. For homes in the 6-, 8- and 10-year sample, smoke alarms were removed and tested for battery and alarm function.

Results 800 homes were included in the survey results; 1884 smoke alarms had been installed through OI. The proportion of homes that had at least one functioning OI smoke alarm ranged from 91.8% for year 2 sample to 19.8% for year 10. Of the originally installed smoke alarms in year 10 sample, 45.5% had been removed and 59% (64/108) of those that were still installed were not functioning. Multivariate analysis showed that the presence of at least one working alarm in the home was associated positively with the number of smoke alarms that were originally installed and whether the original occupant was still living in the home, and negatively with the length of time since the smoke alarm was installed, and whether there was a smoker in the home. Testing of the smoke alarms revealed that most non-functioning alarms had missing or dead batteries.

Conclusions Less than a quarter of the originally installed smoke alarms were still present and functioning by year 10. These findings have important implications for smoke alarm installation programmes.

BACKGROUND

Community-based smoke alarm installation programmes have been an important part of residential fire injury prevention programmes.¹ Lithium-powered smoke alarms are advertised as functioning for 10 years. However, a study by Jackson *et al*² that evaluated an installation programme using lithium-powered smoke alarms found that only 33% of the smoke alarms were still functional after 10 years.

The Dallas Fire-Rescue Department (DFRD) and the Injury Prevention Center of Greater Dallas have partnered since 1999 to install lithium-powered ionisation-type smoke alarms in homes located in neighbourhoods with the highest fire-related injury rates in Dallas. The programme, called 'Operation Installation' (OI), was patterned after an Oklahoma City programme,³ and targeted census tracts identified as high-risk in a previous study:⁴ the main difference is that with OI, all alarms were installed.

Since 2001, we have systematically collected data for homes that received smoke alarms. To date, more than 20 000 smoke alarms have been installed in homes through OI. In 2011–2012, we surveyed a sample of those homes to determine the proportion of OI smoke alarms that were still functioning.

METHODS

From more than 8000 homes that received smoke alarms through OI between 2001 and 2010, a random sample list was created of homes that received smoke alarms 2, 4, 6, 8 and 10 years previously; for each stratum, the range included the nominal year ± 9 months. Epi Info 6.04d was used to create the random sample of homes. The random sample size was chosen to identify at least 350 homes for each study year, from which list the DFRD conducted follow-up surveys in approximately 150 homes per study year. Homes for which surveys were initially not successful were revisited twice more to attempt the survey before moving to the next home on the list.

Home survey

Between December 2011 and October 2012, home surveys were conducted by DFRD personnel using a standardised form developed for that purpose. DFRD searched the home for smoke alarms that were labelled with 'OI' or 'CDC', indicating that they were originally installed through OI; only OI alarms were recorded on the survey. Information recorded on the home survey included the number of OI smoke alarms present, whether each smoke alarm was installed correctly, whether each alarm was still functional, whether the smoke alarm had ever sounded and why it had sounded, and information about persons who lived in the home.

A total of 1533 homes were contacted by DFRD. In all, 815 (53.2%) home surveys were completed; among the 718 (46.8%) non-completed surveys, the majority were due to the home occupant not at home on three attempts (456; 63.5%), followed by the home occupant refusal to participate in the study (95; 13.2%), homes that appeared to be vacant of occupants (74; 10.3%) and other reasons (93; 13.0%).

Of the 815 completed surveys, 15 were excluded because of our inability to verify that the smoke alarms had been installed through OI. This left 800 surveys that were included in the analysis.

To cite: McCoy MA, Roper C, Campa E, *et al*. *Inj Prev* Published Online First: [please include Day Month Year] doi:10.1136/injuryprev-2013-040824

Table 1 Smoke alarms (SA) in homes by study year stratum

Study year stratum	Number of homes	SA originally installed	SA currently installed*	Missing SA*	SA working*
Year 2	196	563	497 (88.3%)	66 (11.7%)	470 (83.5%)
Year 4	153	466	350 (75.1%)	116 (24.9%)	258 (55.4%)
Year 6	151	352	250 (71.0%)	102 (29.0%)	96 (27.3%)
Year 8	154	305	193 (63.3%)	112 (36.7%)	61 (20.0%)
Year 10	146	198	108 (54.5%)	90 (45.5%)	44 (22.2%)
Total	800	1884	1398 (74.2%)	486 (25.8%)	929 (49.3%)

*Percent of smoke alarms that had been originally installed through Operation Installation.

Smoke alarm testing

At the conclusion of the home survey, OI smoke alarms that were installed 6, 8 and 10 years ago were removed and brought to a central location for further testing. A total of 429 OI smoke alarms were removed; 1304 new smoke alarms were installed in those homes. The removed smoke alarms were examined for the presence of a battery, whether it was the original battery and whether the battery and smoke alarm were still functional.

We used two methods to test the smoke alarms. The first test used chemical smoke for the 'smoke test'. In an enclosed plastic box, the smoke alarm was sprayed with canned smoke to determine whether it emitted an alarm. The second test was the 'press test', for which the test button on the alarm was pressed to emit an alarm.

For the purpose of analysis, the functional status of the smoke alarms was based on the smoke test, which a recent study showed was the optimal test to determine smoke alarm function.⁵

Data analysis

Data forms for the home survey were entered into Epi Info 6.04d. To check for data entry accuracy, 20% of the forms were randomly selected and re-entered to determine error rates, which were <1%. The smoke alarm test data were entered into Microsoft Excel 2010.

Multivariate logistic regression analysis was conducted using Epi Info V3.5.3. The outcome variable was the presence of at least one working OI smoke alarm in the home.

RESULTS

Home surveys

Among the 800 surveyed homes that were confirmed to have had at least one smoke alarm installed through OI, there had

been 1884 smoke alarms installed (mean 2.4 per home). At the time of the survey, 1398 (74.2%) were still installed in the homes. In all, 30% of the homes had one alarm originally installed; 30% of the homes had two alarms installed; 21% had three installed; and 19% had four or more alarms installed.

Owners occupied 76.5% of the homes surveyed and 23.5% were rented. Overall, 75% of the homes had the same residents as when the alarms were originally installed and 25% had a different resident. A smoker resided in 26% of the homes, 66% of the homes had no smokers and for 8% information was unknown.

Of the smoke alarms that were still installed in the homes, 1348 (96.4%) were correctly installed and 929 (66.4%) were still working, but this varied with the time since installation. Table 1 shows the status of installed smoke alarm function by study year stratum.

Figure 1 is a graphic depiction of the percentage of the originally installed smoke alarms that were still installed by study year stratum. By year 10, only 54.5% of the smoke alarms were still present. In addition to looking at the proportion of total smoke alarms that were still working, we determined the proportion of homes that still had at least one working smoke alarm from OI. Figure 2 displays the proportion of homes that still had at least one working OI smoke alarm by study year stratum. By year 10, only approximately 20% of the homes had at least one working OI smoke alarm. From this graph, the median time that homes had at least one working OI smoke alarm appeared to be approximately 5 years.

Multivariate analysis

Multivariate logistic regression was conducted to identify factors that were associated with a home having at least one functional OI smoke alarm. Several factors were considered:

Figure 1 Percentage of currently installed smoke alarms by study year stratum.

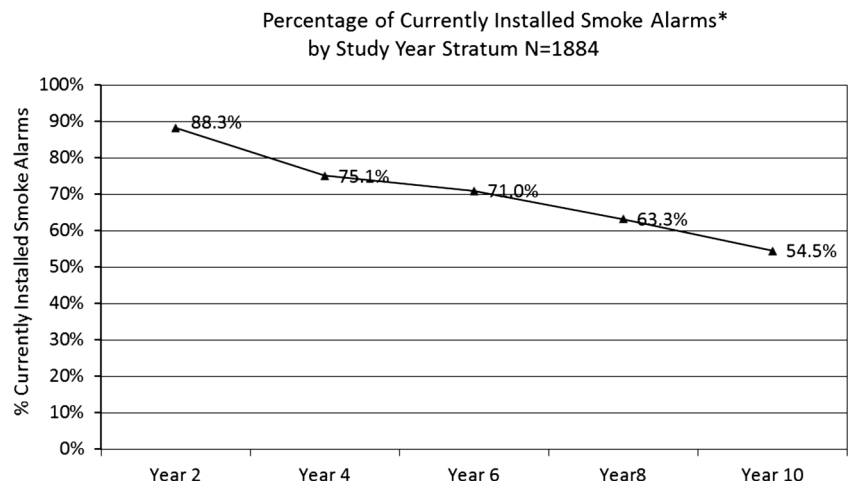
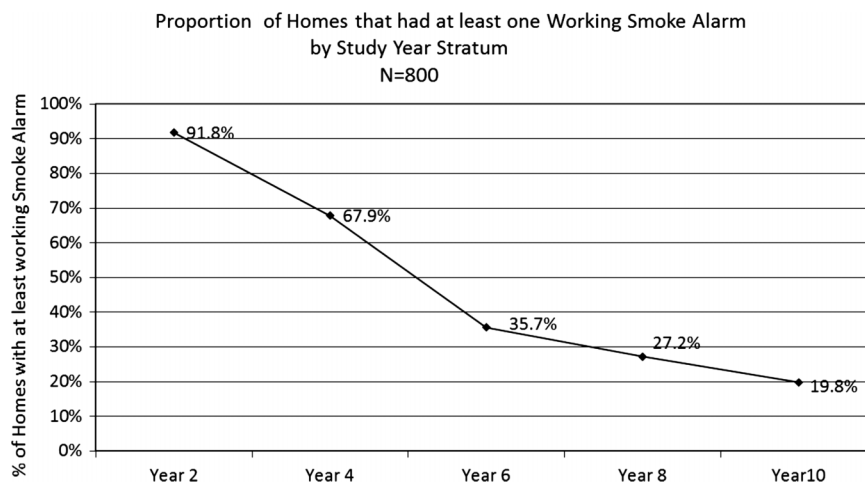


Figure 2 The proportion of homes with at least one working smoke alarm by study year stratum.



original resident present; home ownership (ie, owner-occupied vs renter-occupied); number of residents living in the home; number of residents >64 years or <5 years; presence of a disabled resident; previous false alarms; race of head of household; year the alarm was installed; number of smoke alarms originally installed in the home; and whether a smoker lived in the home. A home that had at least one working smoke alarm was the dependent (outcome) variable. Homes that had the original residents at follow-up (OR=3.46, $p<0.0001$) and homes that originally had more than one smoke alarm installed (OR=1.19, $p=0.0447$) were more likely to have a working smoke alarm. Homes with smokers (OR=0.52, $p=0.0046$) and the number of years since the smoke alarm was originally installed had lower odds of having a working smoke alarm present (see table 2). Having had a previous false alarm, a resident >64 years or <5 years, owned (vs rented), race of head of household, and number of residents or presence of disabled residents was not significantly associated with the outcome.

Smoke alarm testing

Of the 429 smoke alarms recovered and brought back to a central location to be tested, 40.1% (172/429) retained their original lithium battery, 26.1% (112/429) had a non-original battery and 33.8% (145/429) had no battery. Overall, 161 (37.5%) were determined to be functional. A total of 268 (62.5%) were determined to be non-functional: 162 (37.8%) had the battery missing or disconnected, 39 (9.1%) had a dead battery and for 67 (15.6%) the alarm was not functional when tested with a new lithium battery. Overall, 75% (201/268) of the non-functioning smoke alarms worked after installing a new battery, and 25% (67/268) of the smoke alarms did not function due the alarm itself being defective. Figure 3 shows the smoke alarm testing results in a chart form.

Comparison of smoke test with press test

We used the smoke test as the gold standard to assess the functionality of the smoke alarms. When we compared the smoke test with the press test we found that the two tests agreed on 413 (96.3%) smoke alarms, and were discordant in 16 (3.7%). Among the discordant tests, three smoke alarms passed the smoke test, but failed the press test; 13 smoke alarms failed the smoke test but passed the press test.

Table 2 Association between data variables collected and homes with at least one working smoke alarm, estimated by OR from multivariate analysis

	Homes with at least one working smoke alarm	
	OR (95% CI)	p Value
Original resident at follow-up		
No*		
Yes	3.46 (2.04 to 5.87)	<0.0001
Homes with a disabled resident		
No*		
Yes	1.15 (0.72 to 1.85)	0.5357
Homes with a false alarm		
No*		
Yes	0.99 (0.64 to 1.53)	0.9943
Homes with residents >64		
No*		
Yes	1.32 (0.86 to 2.03)	0.1950
Home ownership		
Rented*		
Owned	0.88 (0.53 to 1.46)	0.6312
Home race—black		
No*		
Yes	1.41 (0.86 to 2.31)	0.1724
Homes with at least one smoker		
No*		
Yes	0.52 (0.34 to 0.82)	0.0046
Homes with residents <5 years		
No*		
Yes	1.46 (0.86 to 2.47)	0.1553
Number of residents in home	0.93 (0.83 to 1.05)	0.3037
# Of smoke alarms installed	1.19 (1.00 to 1.41)	0.0447
Years since smoke alarm installed		
Year installed 2 years ago*	1.00	
Year installed 4 years ago	0.21 (0.10 to 0.41)	<0.0001
Year installed 6 years ago	0.07 (0.03 to 0.14)	<0.0001
Year installed 8 years ago	0.04 (0.02 to 0.08)	<0.0001
Year installed 10 years ago	0.03 (0.01 to 0.07)	<0.0001

*Referent group.

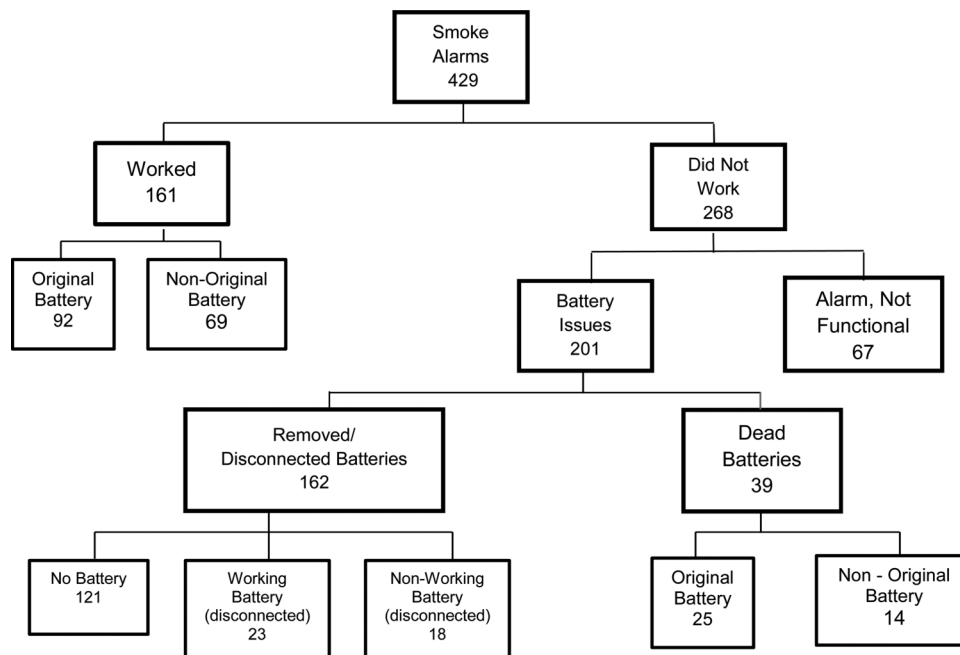


Figure 3 Results of smoke alarm testing (N=429).

DISCUSSION

The present study looked at the functionality of lithium-powered smoke alarms that had been installed 2, 4, 6, 8 and 10 years previously through a community-based installation programme. By year 10, only 54.5% of the smoke alarms were still installed, only 22.2% still functioned and just 19.9% of the households had at least one working smoke alarm. The results were similar to a CDC study that evaluated a smoke alarm installation programme after 10 years and found that only 63% of the smoke alarms were still installed and 33% of the smoke alarms were still functional after 10 years.²

Our results were only somewhat better than a study in Oklahoma City in the 1990s. That study did a 4-year follow-up of alkaline alarms that had been given to residents (not-installed) and found that 45% of the smoke alarms still functioned.³ In our study, 55.4% of the lithium-powered smoke alarms were still functioning after 4 years.

Multivariate analysis in our study identified several factors that were associated with the presence of a working smoke alarm. Original residents still living in the home were more likely to have a working smoke alarm. These occupants had received one-on-one education from fire department personnel, which may have influenced them to test and maintain the smoke alarms. If the home had a smoker present, it was less likely to have a working smoke alarm. A National Institute of Standards and Technology study found that the accumulation of cigarette smoke could trigger smoke alarms,⁶ which could have led a resident to remove or disconnect battery or remove the smoke alarms. The study by Jackson *et al* found the same associations with smokers, original residents and presence of a working smoke alarm.² In addition, we found that the number of smoke alarms originally installed was related to the presence of at least one working smoke alarm in the home, and that the length of time since installation had a negative correlation. During the early phases of OI, only one or two smoke alarms were typically installed in each home, but in more recent years, we have installed more smoke alarms per home. It is likely that the more smoke alarms installed in the home increases the probability that at least one will still be working over time.

Like other studies, we found that the majority of the smoke alarms that did not function were due to battery issues.^{2 6-8} When we tested the smoke alarms from the 6-, 8- and 10-year strata, 37.8% of the alarms had missing or disconnected batteries. Ahrens⁶ found that in three of every 5 (59%) fires in which battery-powered smoke alarms failed to sound, the batteries were missing or disconnected. It is likely that a tamper-resistant, sealed smoke alarm may prevent residents from removing batteries and thereby disabling the alarm. However, even tamper-resistant alarms may have battery failures.

We used the smoke test and the press test to assess the functionality of the smoke alarm. In all, 3% (13/429) of the smoke alarms tested failed the smoke test but passed the press test, giving a false sense of security to residents that the smoke alarm would function in a fire. Currently, the user's manuals of some manufacturers suggest the press test as the way to test the smoke alarm. However, the optimal test to determine smoke alarm function is the chemical smoke test.⁵

There were several limitations to the study. We were able to complete the home surveys for 53% of the follow-up sample; 47% of the homes could not be completed for various reasons. The inability to access many homes for the study may have led to sampling bias. The objective of the study was to determine the proportion of smoke alarms installed during OI that were still functional. The on-site testing of the smoke alarms by DFRD determined whether the smoke alarm functioned. Because DFRD did not open the alarms on-site to determine the presence of battery, additional information about reasons why the resident may have removed or disconnected batteries was not collected. We also did not collect data about why many of the original smoke alarms were no longer installed. Information about the reasons that smoke alarms were taken down or disabled may have provided information which could guide education to residents about the importance of testing and maintaining smoke alarms. Further, information about the presence and functionality of other smoke alarms in the home that were not installed by OI was not collected. Our purpose was to determine the longevity of smoke alarms that had been

What is already known on the subject

- ▶ Smoke alarms are one of the most effective ways to reduce residential fire-related injuries and deaths.
- ▶ Smoke alarm installation programmes are used by communities as part of fire injury prevention programmes.

What this study adds

- ▶ In a real-world setting, the proportion of installed and working smoke alarms was low in years 6–10 after installation, mostly because of two reasons, removal of the smoke alarm and battery issues.
- ▶ More smoke alarms installed in the home increases the probability that at least one will still be working over time.

installed through OI, and because information about non-OI smoke alarms was not collected, we probably underestimated the number of households with at least one working smoke alarm. Also, information about the room in which the smoke alarm was installed was not recorded. If the smoke alarm was installed in or near the kitchen or bathroom, residents may have experienced more false or nuisance alarms that may have occurred during cooking or showering,⁹ which could have led a resident to remove or disconnect the battery or remove the smoke alarms. However, in our multivariate analysis we did not find that a previous nuisance alarm was related to smoke alarm function.

Our results have important implications for smoke alarm installation programmes. Clearly, most smoke alarms were not functional for 10 years. The proportion of currently installed smoke alarms that were still working was substantially lower in years 6–10 compared with years 2 and 4. One of the main reasons the proportion of functional smoke alarms declined over time was due to missing smoke alarms and missing and disconnected batteries. Additional research is needed to identify reasons why residents remove or disable alarms, which may help in developing an effective intervention. The National Association of State Fire Marshals recommends the installation of smoke alarms with a silence feature, and a 10-year battery in a tamper proof, sealed unit that may prevent residents from disabling the alarm or replacing the battery.¹⁰ Additional study is needed to evaluate whether tamper-proof smoke alarms actually function longer in a real-world setting.

CONCLUSIONS

We found that in this field setting, the proportion of installed and working smoke alarms was low in years 6–10 after installation, mostly because of the removal of the smoke alarm and battery issues. The majority of non-working smoke alarms had had the batteries removed or disconnected.

These findings have important implications for smoke alarm installation programmes. Since most smoke alarms do not work for 10 years, programmes that install smoke alarms may need to be repeated in high-risk neighbourhoods before 10 years. Residents may benefit from being given more detailed instruction about maintaining and testing of smoke alarms. The use of tamper proof smoke alarms may decrease the number of smoke alarms that are disabled by residents. Regular and frequent testing of smoke alarms continues to be important, even with lithium-powered smoke alarms.⁶

Finally, the press test may overestimate by 3%–5% the proportion of smoke alarms that would function in a house fire.

Acknowledgements We are grateful to the following people: Bobby Baughn, Joy Gilmore with the City of Dallas Fire-Rescue Department and members of Inspection and Life Safety Education Division, for the coordination and collection of data; to Shane Diekman and Amy Holland with National Center for Injury Prevention and Control, Centers of Disease Control and Prevention, for their valuable guidance and review of the project.

Contributors MM, CR, SS, DC and GI contributed to the concept and design of the project. MM, CR and EC collected the data. MM and GI collaborated on the analyses, interpreting the results and writing the article. SS and DC provided administrative support for the project. MM and GI had access to all data and are responsible for the overall content. All authors reviewed and approved the final version.

Funding This work was supported by a grant from the University of Washington, subcontract title and number: Health Promotion Research Center #727922; and was also funded in part from grant 1 H28 CE000840-01, National Center for Injury Prevention and Control, Centers for Disease Control, US Department of Health and Human Services.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

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