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Smoke Alarm Giveaway and Installation Programs:

An Economic Evaluation

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Abstract

Background—The burden of residential fire injury and death is substantial. Targeted smoke alarm giveaway and installation programs are popular interventions used to reduce residential fire mortality and morbidity.

Purpose—To evaluate the cost effectiveness and cost benefit of implementing a giveaway or installation program in a small hypothetic community with a high risk of fire death and injury through a decision-analysis model.

Methods—Model inputs included program costs; program effectiveness (life-years and quality-adjusted life-years saved); and monetized program benefits (medical cost, productivity, property loss and quality-of-life losses averted) and were identified through structured reviews of existing literature (done in 2011) and supplemented by expert opinion. Future costs and effectiveness were discounted at a rate of 3% per year. All costs were expressed in 2011 U.S. dollars.

Results—Cost-effectiveness analysis (CEA) resulted in anaverage cost-effectiveness ratio (ACER) of $51,404 per quality-adjusted life-years (QALYs) saved and $45,630 per QALY for the giveaway and installation programs, respectively. Cost–benefit analysis (CBA) showed that both programs were associated with a positive net benefit with a benefit–cost ratio of 2.1 and 2.3, respectively. Smoke alarm functional rate, baseline prevalence of functional alarms, and baseline home fire death rate were among the most influential factors for the CEA and CBA results.

Conclusions—Both giveaway and installation programs have an average cost-effectiveness ratio similar to or lower than the median cost-effectiveness ratio reported for other interventionsto reduce fatal injuries in homes. Although more effort is required, installation programs result in lower cost per outcome achieved compared with giveaways.

Introduction

In 2009, residential fires resulted in approximately 2590 civilian deaths, 13,050 nonfatal injuries, and more than $7.8 billion in property loss.[1] Smoke alarms are one of the most effective interventions to prevent residential fire deaths.[2] Functional smoke alarms cut the risk of dying in reported home fires in half.[2] Nationwide, more than 95% of homes are estimated to have at least one smoke alarm, although about one quarter of these homes have alarms that are nonfunctional.[2]

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Despite the overall high prevalence of smoke alarms, one review of published studies of disadvantaged highrisk households found that 17 of 18 studies showed a smoke alarm prevalence below 95% and seven studies showed a prevalence below 80%.3 Because the risk of fire and related injury is also greater in such neighborhoods,4 increasing the prevalence of functional smoke alarms may substantially reduce fire-related deaths. Evaluation studies and systematic reviews have shown that programs that give away free alarms (giveaway programs) or that directly install free alarms for the residents (installation programs) were among the most effective strategies to increase the prevalence of functional smoke alarms, especially when combined with education.[5–7]

Smoke alarm programs potentially can reduce fire mortality and morbidity, but to widely implement them would have important resource implications. Resources for fire prevention have become scarce and many smoke alarm programs are being downsized. Greater pressure is being placed on smoke alarm programs to demonstrate their “bang for the buck.” Although one study showed positive net benefits associated with a giveaway program,[8] no researcher has examined the economics of installation programs in the U.S. The present study addresses this gap through decision analysis to estimate the potential health benefits of smoke alarm programs and to determine cost effectiveness and net benefits.

Methods

Smoke Alarm Programs

The study considered two types of programs: giveaway and installation. Both were assumed to have standard key features of existing smoke alarm programs.[5,9,10] Both involve program staff (e.g., firefighters) who drive into targeted communities, canvass door-to-door, assess the presence and function of smoke alarms, enroll homes without working alarms, and provide fire safety materials and education. For the giveaway program, enrolled homes are provided with free alarms or a voucher and instruction about how to install and test the alarms. For the installation program, smoke alarms are installed directly by staff at the time of the visit or scheduled and completed later.

Target Community

This study considered the target community to be a hypothetic community representative of U.S. communities with a population of 5000 or less. National statistics show that communities this size have the highest residential fire mortality rate.[11] Income levels and rural location make small community size a proxy for risk factors for residential fires. Many past and existing smoke alarm programs target communities of this size.[10,12–14]

Economic Evaluation Frameworks

The study applied two types of economic evaluation: cost-effectiveness analysis (CEA) and cost–benefit analysis (CBA). Both the CEA and CBA were conducted from a societal perspective. A “do nothing” scenario was used as the comparator. This is because the present policy discussion has focused on whether smoke alarms in general are a good use of societal resources, as opposed to the relative value comparison between the giveaway and installation program.

Cost-effectiveness analysis evaluates interventions' cost-effective ratio (CER). When the comparator is "do nothing," an average cost-effectiveness ratio (ACER) is calculated as the net costs of an intervention divided by the net health outcomes achieved. When multiple interventions are being compared, an incremental cost-effectiveness ratio (ICER) is also computed as the incremental cost per incremental unit of health outcome from the more effective intervention.

In the current study, health outcomes, including averted deaths and injuries, were measured by two population health indicators: (1) life-years saved and (2) quality-adjusted life-years (QALYs) saved. Net costs were computedasthose accrued when implementing a giveaway or installation program (program costs) minus averted medical costs, productivity loss, and property loss. Consistent with recommendations by the U.S. Panel on Cost-Effectiveness in Health and Medicine, productivity loss was included because they were not explicitly considered in the QALY weights used for this analysis.[15]

Cost–benefit analysis converts health outcomes into dollar equivalents and subtracts cost from monetary value of benefits to estimate the net benefit of an intervention. Two common CBA outcomes are net benefits and benefit–cost ratios (BCR). CBA considers a broad set of costs and benefits to evaluate whether a program is worth the societal opportunity costs of all the resources consumed.[16] In the current study, monetized benefits included not only tangible cost-savings (e.g., medical, productivity, and property savings) included in the CEA but also intangible cost savings (e.g., quality-of-life loss). This is consistent with several existing CBA and cost-of-illness studies of injury prevention interventions.[17–19]

Table 1 describes cost and benefit components included in the CEA and CBA, respectively. In both analyses, program costs were assumed to occur in the first year, but health and nonhealth outcomes attributable to a program were tracked for 20 years. All costs were expressed in 2011 U.S. dollars. The study discounted future health effects and costs at a rate of 3%.[15]

Decision Modeling

The study implemented both CEA and CBA with a Markov state transition model using TreeAge Pro 2009. For a given year, the model projected the number of averted fire deaths as a product of number of homes that gained functional smoke alarms, annual home fire incidence rate, mortality rate per home fire, and mortality risk reduction dueto a functional alarm. The model adjusted the number of homes with functional alarms annually by a functional rate because some installed alarms become nonfunctional because of poor maintenance and tampering. Total number of averted deaths is the summation of deaths averted during the 20-year model period. Averted nonfatal injuries and property loss were estimated in a similar manner.

The model required various inputs related to baseline community characteristics, program effectiveness, property loss, and costs of the program, home fire death, and injury. The reference-case model inputs and their plausible ranges and distributions (Table 2) were determined from structured reviews of published studies and discussed in detail in the next section. The study performed multiple one-way sensitivity analyses and probability sensitivity analyses (PSA) to assess the robustness of the results to the most-uncertain parameters.

Model Inputs

Community characteristics—According to the National Fire Protection Association (NFPA) annual fire experience surveys, the average population of communities of 5000 or less was 1836.[11] Assuming an average household size of 2.6,[20] there were approximately 706 homes in the target community. The study estimated that the annual home fire incidence rate, death rate per home fire, and injury rate per home fire for homes without functional alarms were 0.57 per 100 homes, 1.42 per 100 home fires, and 1.67 per 100 home fires, respectively (Appendix A, available online at www.ajpmonline.org).[2,11]

The plausible high and low values of these parameters were determined according to an NFPA report.[11] These rates were assumed to be constant throughout the model period based on national statistics[21] that home fire deaths have remained constant since the early 2000s. The present study assumed that a baseline of 40% (low: 20%, high: 70%) of the homes did not have functional alarms based on a systematic review[3] of published studies since 1990.

Effectiveness of programs—Through a structured literature search (conducted in 2011; Appendix B, available online at www.ajpmonline.org), eight controlled trial studies[10,14,22–27] were identified made up of evaluations of four giveaway and six installation programs since 1998. Five studies[10,14,23–25] showed short-term (6–15 months) effectiveness. Two studies[22,26] showed mediumterm (3–4 years) effectiveness. One study[27] showed long-term (10 years) effectiveness. Based on results from these studies, it was assumed that the giveaway and installation programs would each reduce the percentage of homes without functional alarms by 30% and 80%, respectively, in the first year. The study assumed an annual nonfunctional rate of 15% (low: 5%, high: 25%) for installed alarms according to evidence that their functional rate was about 93% at 6 months, 84% at 15 months, and 33% at 10 years.[10,24,27]

Risk reductions—The NFPA estimates that a functional alarm is associated with a 48% reduction in home fire mortality.[2] Studies of smoke alarms' effectiveness against nonfatal injuries were generally constrained by under-reporting and have generated mixed results. A negative reduction (increase) in fire injury prevalence is possible if the early detection of a home fire causes the residents to fight the fire rather than to evacuate immediately (M Ahrens, NFPA, personal communication, Oct 10, 2010; J Hall, NFPA, personal communication, Mar 25, 2011).[2,28] The current study assumed that a functional alarm reduces the nonfatal injury rate by 0% to obtain a conservative result in the reference-case analysis. This assumption was varied to −30% and 30% in the sensitivity analysis. It is also assumed that a functional smoke alarm would reduce fire-related property loss by 10% (low: 5%, high: 15%).[2]

Life-years and quality-adjusted life-years saved—The present study estimated life-years saved per prevented death to be 32.6 by comparing the average age at which a home fire death would have occurred (in the absence of any program) and the average life expectancy for that age.[29] The study adjusted the number of life-years saved by health-related quality-of-life (HRQoL) weights for the U.S. adult population to estimate the number of QALYs saved per prevented death (29.6 QALYs).[30] The number of QALYs saved per prevented nonfatal injury was estimated to be 0.07 by multiplying the duration and HRQoL weights associated with fire-related injury derived from the Impairment and Disability Fraction Index (IDFI).[29,31]

Cost estimates—The unit cost (adjusted for inflation) per home fire death and injury of medical care, property loss, productivity loss, and quality-of-life loss were obtained from a recent study by Lawrence and colleagues (unpublished findings, U.S. Consumer Product Safety Commission, 2011). In the current study, estimates of medical costs (Table 2) came from national health surveys and insurance claims databases. Productivity loss was updated from prior estimates by Grosse and colleagues.[32] Quality-of-life loss per death was set to be the value of a statistical life ($5 million adopted by the Consumer Productivity Safety Commission) net of the value of productivity loss. Quality-of-life loss for nonfatal injury was estimated using jury verdicts or settlements for burn and anoxia injuries.[33]

Value of property loss per home fire was estimated at $29,081 after adjusting for inflation for homes without functional alarms.[2] Themodel exploredtheimpactofdownward adjusting the productivity loss by 15% based on statistics indicating that residents of high-risk communities earn less than the national average.[34] Additional sensitivity analysis explored the impact of lowering or increasing all unit costs by 15%.

The average economic cost per completed home visit (i.e., a visit that resulted in an alarm installation) for the installation program was estimated at $192 (low: $135, high: $242), based on previous cost studies (Appendix C, available online at www.ajpmonline.org).[10,35] Direct evidence for giveaway program costs was unavailable so the program was assumed to incur the same levelsof supply and transportation costs as the installation program, and 50% of its labor cost. This assumption was varied between 20% and 80% in the sensitivity analysis.

Parameters for the probability sensitivity analyses—Distributions for PSA parameters were based on the recommendations from Briggs and colleagues.[36] Beta distribution was used for probability and rate parameters. Gamma distribution was adopted for cost estimates. Because the SDs of the cost estimates were not available, they were assumed to be 20% of the respective mean values.

Results

Table 3 shows the reference-case CEA results. The ACER for the giveaway program was $46,673 per life-year saved or $51,404 per QALY saved. The ACER for the installation program was $41,431 per life-year saved or $45,630 perQALY saved. Compared to the giveaway program, the installation program had an ICER of $38,285 per life-year saved or $42,165 per QALY saved.

Table 4 shows the reference-case CBA results. The giveaway program would require $41,987 to implement and result in an expected $90,815 in total monetized benefits. This corresponds to a net benefit of $48,827 or a benefit–cost ratio of 2.1. The installation program would require $105,053 to implement and would result in an expected $242,172 in total monetized benefits. This corresponds to a net benefit of $137,119 or a benefit–cost ratio of 2.3.

Appendix D (available online at www.ajpmonline.org) shows one-way sensitivity analysis results for both the CEA and CBA. Under various alternative model assumptions, the average cost per QALY saved of the giveaway program ranges from about $1000 to about $185,000; the average cost per QALY saved for the installation program ranges from about $4000 to about $119,000. The net benefit of the giveaway program ranges from a net cost of about $3000 to a net savings of about $146,000; the net benefit of the installation program ranges from a net saving of about $26,000 to about $385,000.

Other things being equal, the plausible range of values in the annual smoke alarm functional rate has the largest impact on the ACERs. Other influential parameters include the percentage of homes without functional alarms in the community, fire incidence rate, and death rate per home fire without functional alarms. In contrast, changes in plausible values of nonfatal injury–related parameters have the least impact on the CEA and CBA results. Probability sensitivity analysis results using 10,000 Monte Carlo simulations (Appendix E, available online at www.ajpmonline.org) illustrate large uncertainties associated with the ACERs for both the giveaway and installation programs. The majority of the simulation results lie below the $50,000 per QALY line for both programs.

Discussion

The present study examined the cost-effectiveness and cost-benefit of implementing either a giveaway or installation program in a hypothetic small community at high risk of residential fire death and injury. Results revealed that both giveaway ($51,404 per QALY) and installation ($45,630 per QALY) programs have an ACER between $50,000 and $100,000, which are the two most commonly used critical-value thresholds for cost effectiveness.[37] In comparison with other residential programs designed to reduce fatal injuries, results show that the giveaway ($46,673 per life-year) and installation ($41,431 per life-year) programs have ACERs moderately lower than the median ACER ($56,041 per life-year in 2011 dollars) based on 30 residential fatality-reduction interventions.[38]

The CBA result should be interpreted with caution. Despite being the preferred method for regulatory impact analysis, CBA is less commonly used in the health sector, owing to concerns about validity in assigning a monetary value to life and health-related quality of life.[37] Assigning a monetary value to quality of life lost based on jury verdicts and settlements for fire injuries in particular is controversial, although this practice has been quite common in CBA studies of injury prevention.[17–19] If quality-of-life loss is excluded from the overall benefit calculation, neither the giveaway nor the installation program would generate a positive net benefit in the reference-case analysis.

Annual nonfunctional rate of the installed alarms is one of the most influential factors for CEA and CBA results. This highlights the potential to improve both programs' economic results by increasing smoke alarm functionality after installation. Technologic improvements in smoke alarms has led some programs to adopt alarms that use tamper-proof, internal long-life lithium batteries that function for up to 10 years, which obviates the need for residents to change them and prevents removing functional batteries.

One evaluation of smoke alarm batteries showed that almost 80% of lithium alarms still functioned after 8 to 10 years.[27] Residents taking down smoke alarm units will continue to be a challenge for programs. Residents may disable alarms in response to nuisance alerts related to cooking or steam.[39] These inadvertent alerts can be avoided by proper alarm installation such as installing smoke alarms at least 20 feet away from the stove. Programs may address smoke alarm tampering issues by conducting in-home education that is based on behavioral theory.

Both the giveaway and installation programs could achieve better economic results by focusing on communities where the prevalence of functional alarms is lower and that of fire-related incidents is higher. Therefore, it is important to collect or examine community-specific information about fire risk factors. Communities considering adopting a smoke alarm program may want to include conditions such as the size of the fire injury prevention budget and acceptable thresholds for return on investment in their decision-making process.

Because the cost data used reflected opportunity costs of volunteer time in addition to a program's out-of-pocket costs, cost estimates should be regarded as the maximum expenditure needed for program implementation. If communities can implement a smoke alarm program with most of its activities performed by volunteers and/or by paid personnel who are not used to their full capacity, lower out-of-pocket costs may be realized and thus greater cost effectiveness and net benefits may be achieved. For example, the Meals on Wheels Association of America successfully piloted a program that combined their program and smoke alarm installation for homebound adults.[40] This approach may improve the program efficiency and thus achieve greater cost effectiveness.

The current study has several limitations. Because of lack of data, the models did not consider the differential fire incidence rates for homes with and without functional alarms, despite evidence supporting that the latter has a significantly higher incidence of fire. Many of the community baseline characteristics were based on NFPA annual fire surveys and NFIRS data. The NFPA surveys rely on self-reported fire incidence rates from local fire departments rather than observed incidence rates. Similarly, the estimation of the installation program cost was based on two studies that used data provided by the fire departments. Alternative lower and higher cost assumptions showed substantial impact on the CEA and CBA results in the sensitivity analyses. Future research should consider collecting cost data through prospective studies based on pre-specified protocols.

Conclusion

As financial resources for fire prevention have become increasingly scarce in recent years, greater pressure has been placed on smoke alarm programs to demonstrate cost effectiveness and net benefit. To the authors' knowledge, this is the first study that systematically quantifies the long-term cost effectiveness and cost–benefit of the popular giveaway and installation programs. Results show that both programs have cost-effectiveness ratios similar to or lower than other evaluated residential interventions to reduce fatal injuries.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix: Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.amepre.2012.06.021.

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Table 1

Cost components included in analysis

Cost component	Measurement	Included in CEA	Included in CBA
Program costs			
Supplies	Smoke alarms and education materials	Yes	Yes
Labor	Salary and fringe benefits for employees and the economic value of the time provided by volunteers	Yes	Yes
Transportation	Capital costs and mileage reimbursement for the use of personal and nonpersonal vehicles	Yes	Yes
Potential cost-savings			
Medical care	Emergency medical services, physician, hospital, rehabilitation, prescription drug costs, ancillary costs, long-term care, funeral/coroner expenses, and the insurance administrative costs	Yes	Yes
Property loss	Value of property damage and of property taken and not recovered	Yes	Yes
Productivity loss	Wages, fringe benefits, and value of lost household work	Yes	Yes
Quality-of-life loss	Value of the pain, suffering, and inconvenience that victims and their family experience	No	Yes

CBA, cost–benefit analysis; CEA, cost-effectiveness analysis

Table 2

Reference-case input values, plausible ranges, and distributions for sensitivity analyses

Variable	Reference-case value	Range	Studies	Included in PSA	Distribution[a]	M (SD)
Community characteristics						
Proportion of homes without functional alarms	0.4	0.2 to 0.7	42	Yes	Beta	0.4 (0.1)
Annual home fires per 100 homes	0.57	0.31 to 0.82	2, 11	Yes	Beta	0.57 (0.057)
Deaths per home fire without functional alarms	0.0142	0.0097 to 0.0157	2, 11	Yes	Beta	0.0142 (0.00355)
Injury per home fire without functional alarms	0.0167	0.0162 to 0.0520	2, 11	No	—	—
Intervention effectiveness rate (%)						
Giveaway program[b]	30	10 to 50	9	No	Beta	0.3 (0.03)
Installation program[b]	80	60 to 100	10, 13, 14	No	Beta	0.8 (0.08)
Functional alarm against death	48	43 to 55	2	No	—	—
Functional alarm against injury	0	−30 to 30	2, 28	No	—	—
Functional alarm against property loss	10	5 to 15	2	No	—	—
Alarm annual nonfunctional rate (%)	15	5 to 25	10, 13, 27	Yes	Beta	0.15 (0.03)
Costs (in 2011 dollars)						
Cost per complete home visit	—	—	—	—	—	—
Installation program	240	±25%	10, 35	Yes	—	—
Labor cost of giveaway program as percentage of installation program (%)	50	20 to 80	Assumption	No	Beta	0.5 (0.1)
Cost per incomplete visit/cost per complete visit (%)	50	30 to 80	Assumption	No	—	—
Medical cost per fire death	21,617	±15%[c]	Unpublished[d]	Yes	Gamma	20,691 (4,138)
Medical cost per fire injury	6,317	±15%[c]	Unpublished[d]	No		
Productivity loss per fire death	944,859	±15%[c]	Unpublished[d]	Yes	Gamma	904,383 (180,877)
Productivity loss per fire injury	7,887	±15%[c]	Unpublished[d]	No	—	—
Productivity loss adjustment factor (%)[e]	15	0 to 30	Assumption	—	—	—
Quality-of-life loss per fire death	5,586,471	±15%[c]	Unpublished[d]	Yes	Gamma	5,347,156 (1,069,431)
Quality-of-life loss per fire injury	71,167	±15%[c]	Unpublished[d]	No		

Variable	Reference-case value	Range	Studies	Included in PSA	Distribution[a]	M (SD)
Property loss per home fire without functional alarms	29,081	—	2	—	Gamma	29,081 (5,816)
Average life expectancy						
Home fire death victim	32.6	—	29	No	—	—
Home fire injury victim	49.2	—	29	No	—	—
QALYs saved per fire prevented						
Home fire death	29.6	—	29, 30	No	—	—
Home fire injury	0.07	—	29, 31	No	—	—

[a] Monte Carlo distribution charts of variables used in the PSA are available on request.

[b] Percentage reduction in homes without functional alarms

[c] Varied simultaneously

[d] Unpublished findings, U.S. Consumer Product Safety Commission, 2011

[e] Adjustment for lower productivity loss among high-risk community residents PSA, probability sensitivity analysis; QALY, quality-adjusted life-year

Table 3

Reference-case cost-effectiveness results (in 2011 dollars)

Program	Net cost[a]	Effectiveness			Average cost-effectiveness ratio		Incremental cost-effectiveness ratio	
		Deaths averted	Life-years saved	QALYs saved	$/Life-year	$/QALY	$/Life-year	$/QALY
Giveaway program	23,045	0.02	0.5	0.45	46,673	51,404	ref	ref
Installation program	54,540	0.04	1.3	1.20	41,431	45,630	38,285	42,165

[a] Net costs=program costs - averted medical costs - averted productivity loss - averted property loss. QALY, quality-adjusted life-year

Table 4

Reference-case cost–benefit results (in 2011 dollars)

Program	Program Costs	Benefits					Net benefits (B–C)	B/C
		Medical	Property	Productivity	Quality of life	Total		
Giveaway program	41,987	325	6,460	12,158	71,872	90,815	48,827	2.1
Installation program	105,053	875	17,222	32,416	191,659	242,172	137,119	2.3

B, benefits; C, costs