

A Randomized, Controlled Intervention of Machine Guarding and Related Safety Programs in Small Metal-Fabrication Businesses

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SYNOPSIS

Objectives. Metal fabrication employs an estimated 3.1 million workers in the United States. The absence of machine guarding and related programs such as lockout/tagout may result in serious injury or death. The purpose of this study was to improve machine-related safety in small metal-fabrication businesses.

Methods. We used a randomized trial with two groups: management only and management-employee. We evaluated businesses for the adequacy of machine guarding (machine scorecard) and related safety programs (safety audit). We provided all businesses with a report outlining deficiencies and prioritizing their remediation. In addition, the management-employee group received four one-hour interactive training sessions from a peer educator.

Results. We evaluated 40 metal-fabrication businesses at baseline and 37 (93%) one year later. Of the three nonparticipants, two had gone out of business. More than 40% of devices required for adequate guarding were missing or inadequate, and 35% of required safety programs and practices were absent at baseline. Both measures improved significantly during the course of the intervention. No significant differences in changes occurred between the two intervention groups. Machine-guarding practices and programs improved by up to 13% and safety audit scores by up to 23%. Businesses that added safety committees or those that started with the lowest baseline measures showed the greatest improvements.

Conclusions. Simple and easy-to-use assessment tools allowed businesses to significantly improve their safety practices, and safety committees facilitated this process.

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In the United States, there are approximately 6.5 million business establishments with fewer than 100 workers. These establishments employ about 97 million workers. Businesses employing 10 or fewer workers represent 16% of the total workforce, those with 50 or fewer employees account for almost 40% of workers, and 56% of the workforce is employed in establishments with 100 or fewer workers.¹⁻³ Fabricated metal product manufacturers (Standard Industrial Classification [SIC] code 34) and printers (SIC code 27) account for nearly 40% of all manufacturing firms and a similar proportion of manufacturing employees.

According to the U.S. Small Business Association, 151,000 businesses making primary metal products employed an estimated 3.1 million workers in 2004. These were included in North American Industry Classification System 331 (primary metal industries), 332 (fabricated metal products), and 333 (industrial and commercial machinery).⁴⁻⁶ More than 90% of the businesses in these industries have 100 or fewer workers.

Data from Minnesota, Michigan, and New Jersey indicate significant underreporting of amputation injuries.⁷ The true incidence of amputations is estimated at between 11.8 and 19.5 per 100,000 workers. In Minnesota, approximately 83% of these injuries occurred when body parts were caught or crushed by equipment or objects.⁸ Work-related amputations have decreased by approximately 20% since 1999 (from 11,000 amputations in 1999 to 8,600 amputations in 2001) and by approximately 40% since the early 1990s.⁹⁻¹⁴

Minnesota Sentinel Event Notification System for Occupational Risks surveillance data indicated that the rate of amputation injuries in metal fabrication was 41 per 100,000 workers. Injured workers reported that a lack of safeguards was the most common contributing factor for amputations caused by stationary machinery and hand tools. Inadvertent activation of equipment and defective tools or machines were also cited as contributing factors.¹⁵

Hasle and Limborg identified several European studies in which workers in small businesses were found to have higher injury rates and more severe injuries than those in larger establishments.¹⁶ Similar results have been shown for small businesses in the U.S. For example, the National Institute for Occupational Safety and Health found that one-third of all workplace fatalities occurred in business establishments of 20 or fewer employees, and at least one-half occurred in establishments with fewer than 100 employees.²

There is a general lack of knowledge about effective strategies to reduce hazardous exposures to workers in small business establishments.¹⁷⁻²⁰ A review of articles from different regions of the world indicates the

absence of health and safety programs for small businesses in both developed and developing nations. This includes a lack of well-evaluated and cost-effective tools to assist owners and workers in small business establishments, as well as a general lack of safety and health resources within specific places of employment.^{15,21,22}

This article presents findings from the Minnesota Machine Guarding Program. We compared the effectiveness of machine safety interventions targeted for management vs. management and employees in a randomized trial in 40 small (≤ 100 employees) metal-fabrication businesses. Outcome measures described in this article include observations of machine and business safety as determined by an impartial rater.

METHODS

We conducted the Minnesota Machine Guarding Program within the Twin Cities metropolitan area. The study and intervention design were guided by an intervention mapping model; our approach is described elsewhere.^{23,24} A community-based advisory board assisted with the development and pilot testing of interventions and outcome measures. We developed materials and programs using social cognitive theory as a framework. Our use of social cognitive theory is described elsewhere.²⁵ All data collection methods and surveys were reviewed and approved by the Park Nicollet and University of Minnesota Institutional Review Boards.

We conducted a pilot study of our intervention materials and outcome measures in four metal-fabrication businesses ranging in size from five to 120 workers.^{26,27} Pilot study results suggested that we would be able to detect a 10% change in machine scores with a power of 0.8, with 20 machines evaluated per shop per intervention group.

Sample selection and recruitment

To be eligible for participation, metal-fabrication businesses had to meet the following criteria: (1) at least five workers engaged in metal fabrication; (2) no more than 100 employees (including production workers, supervisors, and support staff); (3) only one site of a multisite company could participate; (4) at least 10 and at most 100 metal-fabrication machines from a list of 23 machine types; (5) in business for at least one year prior to recruitment; (6) located within about 50 miles of the study office; and (7) within a primary SIC code in any of 13 industries.

In 2006, approximately 237 small businesses in the Twin Cities metropolitan area met these eligibility requirements. We recruited business owners to the

study primarily through personal introduction from union leaders, insurance company employees, and other owners. We also identified businesses through telephone and trade directories as well as meetings with metal-fabrication trade groups. One investigator recruited and obtained informed consent from each business owner or a representative identified by the owner. We randomized shops at the end of the first shop evaluation into one of two intervention groups: management or management-employee.

Measuring safety levels for machines and businesses

Shop evaluation consisted of completion of machine scorecards and a safety audit at the time of enrollment and one year later. We used machine scorecards to quantify the degree and adequacy of machine guarding for 23 commonly used metal-fabrication machines. The scorecard development process is described elsewhere.²⁶

We based machine scorecards on American National Standards Institute consensus standards, which use a combination of engineering and policy criteria during the life cycle of a machine (i.e., manufacture, use, and repair).²⁸ These standards are in accordance with accepted safety practices.^{29–33} The number of scorecard items varied by the type and complexity of machine. We rated items as present and adequate, absent or inadequate, or not assessable. We assigned items that were not assessable a missing value for the purpose of data analysis. Items carried a priority score of high (six points), medium (two points), and low (one point). Each item was a dichotomous variable. We weighted and summed items for each machine to provide a normalized priority-weighted sum. Each machine could receive a maximum of 100%. We combined the machine scorecards to give a mean machine score for each business.

We randomly sampled machines based on their relative number in each of five categories. We evaluated a minimum of 10 and a maximum of 25 machines in each business. If a shop had fewer than 25 machines, then we included all qualifying machines. We selected a second random sample of machines during the follow-up evaluation.

A 25-question safety audit was used to evaluate three aspects of shop safety: general shop conditions (e.g., lighting, safety bulletin board), administrative and management policies (e.g., safety committee meeting minutes, maintenance of Occupational Safety and Health Administration [OSHA] 300 log), and employee-related work practices (e.g., use of protective eyewear, documentation of employee training).³⁴

Intervention description

Intervention elements included hazard identification and control (e.g., recommendations concerning guarding), administrative programs (e.g., lockout/tagout programs), and training (e.g., hazard recognition, lockout/tagout procedures).³⁵ A peer trainer delivered a summary report of machine and business safety evaluations to the owner or manager of businesses in both groups approximately two weeks after the first evaluation. Report delivery and discussion took approximately one hour per business.

Reports delineated machine-related hazards and prioritized changes that were needed for individual machines, as well as administrative problems. For example, if a machine was missing an emergency stop and a barrier guard, we made recommendations indicating these deficiencies. With regard to administrative programs, reports delineated which programs were absent (e.g., lockout and tagout). Each business also received a compact disc containing machine and business safety documents and resources, copies of machine scorecards for 23 different metal-fabrication machines, a sample written lockout/tagout program, and machine safety training materials.

If not already in existence, businesses in the management-employee intervention group were asked to identify appropriate managers and employees for a health and safety committee. Each committee participated in four one-hour educational sessions, which were offered by a peer educator (i.e., an experienced machinist trained in machine safety). We scheduled the first session within one month of the baseline evaluation, and we scheduled subsequent sessions during the next three to four months. Each session was designed to build knowledge of machine safety and provide opportunities for hands-on evaluation and decision-making. Hands-on training included the assessment of numerous machines within the business and discussions of machine-specific changes.

Data analysis

We analyzed data using SAS[®] statistical software.³⁶ Each business had two measures as defined previously: a machine score (mean of all machine scorecards) and a safety audit score. Analysis included the computation of means, standard deviations, and Chi-squares. We used linear regression to explore the relationship between machine and safety audit scores and the influence of demographic variables on each of these outcome measures.

We used linear mixed models to examine the relationship between machine scores and machine and shop characteristics. Machine score was the dependent

variable and the fixed effects included category of machine (e.g., milling/drilling/boring, cutting/shearing/sawing, presses/rolling/bending, and sanding/grinding), intervention group (0 = management only, 1 = employee/management), time of evaluation (0 = baseline, 1 = follow-up), number of employees (<25 or ≥25), safety committee (present, absent), and the interaction between intervention group and time. We chose a cut point of ≥25 employees when evaluating the effects of shop size because the Minnesota Occupational Safety and Health Administration requires safety committees in metal-fabrication businesses with ≥25 employees.

Quality control

We randomly selected 25% of business establishments for quality checks consisting of (1) proper identification and categorization of machinery, (2) adherence to the machine randomization strategy, and (3) assurance that machines were properly evaluated. We found full compliance with established study protocols for baseline and follow-up assessments.

RESULTS

Business participation

Local labor unions referred a total of 16 businesses to us; nine agreed to participate, three said no, and four were too large to be included. An insurer referred four businesses to us; of these, three agreed to participate. For the remainder, approximately 75% of shops meeting eligibility criteria agreed to participate. Of the 40 businesses, 37 participated in follow-up evaluation of

the business. Two (one in each intervention group) had gone out of business and one control declined to participate. Therefore, we had an overall follow-up participation rate of 37/38 (97%). All businesses in the management-employee intervention participated in all four training sessions.

Baseline comparisons

At baseline, minimal differences existed between shop characteristics in the two intervention groups (Table 1). There were similar numbers of shops in the two leading SIC codes 34 (fabricated metal products) and 35 (industrial and commercial machinery). Twelve out of 40 shops (30%) were unionized—six in each group. Similar numbers of shops had safety committees in each group.

Apart from language, no significant differences in demographic characteristics existed between the two intervention groups (Table 2). The percentage of workers speaking Spanish was twice as high in the management-employee group as in the management-only group. Of the employees for whom English was not their first language, 61% spoke Spanish. Almost 60% of workers in both groups had worked in metal fabrication for 10 or more years. This number was significantly higher for owners and managers.

We found no differences between the two groups for either the machine or safety audit scores (Tables 3 and 4). The baseline mean machine score was 63% in the management-employee group and 64% in the management-only group. The mean business safety audit scores were 66% and 64% for the management-employee and management-only groups, respectively.

Table 1. Baseline shop characteristics of small metal-fabrication businesses in two intervention groups: management-employee and management only^a

Characteristic	Management-employee (n=20) N (percent)	Management only (n=20) N (percent)	Overall N (percent)
Safety committee (presence)	12 (60.0)	11 (55.0)	23 (57.5)
Worker union (present)	6 (30.0)	6 (30.0)	12 (30.0)
Shop size (<25 employees)	7 (35.0)	12 (60.0)	19 (47.5)
Union and safety committee (presence)	4 (20.0)	5 (25.0)	9 (22.5)
Number of years in business ^b	38 (18.0)	29.8 (19.9)	34 (19.2)
Businesses with non-English-speaking workers	12 (60.0)	11 (55.0)	23 (57.5)
Fabricated metal products (SIC 34)	13 (65.0)	11 (55.0)	24 (60.0)
Industrial machinery (SIC 35)	6 (30.0)	8 (40.0)	14 (35.0)

^aThe difference between the two intervention groups was not statistically significant.

^bFor this characteristic, the values refer to the mean and (standard deviation).

SIC = Standard Industrial Classification

Table 2. Selected worker and owner demographic characteristics of small metal-fabrication businesses at baseline for two intervention groups: management-employee and management only

	Management-employee Percent (range)	Management only Percent (range)	All shops Percent (range)
<i>Baseline worker characteristics</i>	n=374	n=476	n=850
Male	90.6 (70–100)	88.0 (73–100)	89.1 (70–100)
English as a first language	83.4 (28–100)	82.2 (56–100)	82.7 (28–100)
Spanish as a first language ^a	14.3 (0–72)	7.3 (0–42)	10.4 (0–72)
<High school	13.1 (0–43)	10.7 (0–24)	11.8 (0–43)
High school graduate	66.9 (40–89)	64.9 (33–100)	65.8 (33–100)
>High school	20.1 (0–40)	24.4 (0–67)	22.4 (0–66.7)
>10 years in trade	58.3 (0–100)	58.8 (27–95)	58.6 (0–100)
<i>Baseline management characteristics</i>	n=75	n=66	n=141
Male owner/manager	94.4 (50–100)	92.1 (33–100)	93.3 (33–100)
English as a first language	94.4 (67–100)	100.0 (100)	97.0 (67–100)
Spanish as a first language	2.8 (0–20)	0.0 (0)	1.5 (0–20)
<High school	7.9 (0–50)	1.8 (0–17)	5.1 (0–50)
High school graduate	36.5 (0–100)	55.6 (0–100)	45.3 (0–100)
>High school	55.6 (0–100)	42.6 (0–100)	49.6 (0–100)
>10 years in trade	83.8 (50–100)	76.9 (33–100)	80.6 (33–100)

^aStatistically significant at $p < 0.001$

These scores indicated that machine guarding and related safety programs were frequently missing or inadequate.

We did not see differences in the magnitude of change in either outcome measure between the two intervention groups (Tables 3 and 4). Similarities existed between the two groups when stratifying data by safety committee, union status, or number of employees. Mean machine scores significantly improved from baseline to follow-up by a similar amount (4–5 points) in each of the intervention groups ($p < 0.001$) (Table 3). Similar changes occurred in safety audit scores in both intervention groups, but were not statistically significant.

Seventeen businesses had no safety committee at the start of the study. Eight of these had added a committee by the end of the study. Businesses that added a safety

committee had greater improvements in both machine score and safety audit score when compared with other businesses (Table 5). This was statistically significant for the safety audit score but not for the machine score when using shops that started with a safety committee as the comparison group. Two businesses had disbanded the safety committee at follow-up.

Machine scores

We examined the improvements in machine scores for each group stratified on shop demographic characteristics (Table 3). When stratified on the median score, we found the largest improvements (7.5 points) in businesses in the management-employee group that started with the lowest scores, and the next largest improvements in businesses with no baseline safety committee (7.0 points). In the management-only

Table 3. Comparison of mean machine scores of small metal-fabrication businesses at baseline and follow-up stratified by business characteristics for two intervention groups: management-employee and management only^a

Shop characteristic at baseline	Management-employee (n=19) Mean (SD)		Management only (n=18) Mean (SD)		Within group change	Baseline	Follow-up	Within group change	Baseline score difference between intervention groups Mean (SD)	Score change difference between intervention groups Mean (SD)
	Baseline	Follow-up	Baseline	Follow-up						
All shops	62.6 (5.4)	67.7 (3.5)	63.6 (7.1)	67.6 (5.5)	4.0 (3.0) ^c	63.6 (7.1)	67.6 (5.5)	4.0 (3.0) ^c	-1.0 (6.3)	1.2 (4.3)
Safety committee Present (n=20)	64.8 (4.2)	68.6 (2.8)	64.0 (5.3)	68.5 (3.9)	3.7 (4.1) ^d	64.0 (5.3)	68.5 (3.9)	4.5 (2.1) ^b	0.8 (4.7)	-0.8 (3.4)
Absent (n=17)	59.5 (5.4)	66.5 (4.2)	63.2 (8.9)	66.6 (6.9)	7.0 (6.2) ^d	63.2 (8.9)	66.6 (6.9)	3.4 (3.7) ^d	-3.7 (7.5)	3.6 (5.0)
Union Present (n=11)	64.8 (5.4)	69.2 (1.4)	63.1 (8.1)	67.7 (6.1)	4.4 (4.8)	63.1 (8.1)	67.7 (6.1)	4.6 (2.3) ^e	1.7 (7.0)	-0.2 (3.6)
Absent (n=26)	61.8 (5.3)	67.2 (3.9)	63.9 (7.0)	67.5 (5.5)	5.4 (5.4) ^e	63.9 (7.0)	67.5 (5.5)	3.7 (3.3) ^e	-2.1 (6.1)	1.7 (4.6)
Shop size <25 (n=17)	62.0 (6.0)	67.9 (5.1)	64.5 (7.7)	68.5 (5.3)	5.9 (6.9)	64.5 (7.7)	68.5 (5.3)	4.0 (3.3) ^e	-2.5 (7.1)	1.9 (5.1)
≥25 (n=20)	62.9 (5.2)	67.6 (2.5)	62.5 (6.8)	66.4 (6.0)	4.7 (4.1) ^e	62.5 (6.8)	66.4 (6.0)	3.9 (2.7) ^e	0.4 (5.8)	0.8 (3.6)
Baseline low/high score Low score (n=19)	58.5 (3.4)	66.0 (3.6)	58.1 (4.0)	63.2 (3.1)	7.5 (5.7) ^e	58.1 (4.0)	63.2 (3.1)	5.0 (3.2) ^e	0.3 (3.7)	2.5 (4.7)
High score (n=18)	67.1 (2.8)	69.6 (2.3)	69.1 (5.0)	72.0 (3.4)	2.5 (3.1) ^d	69.1 (5.0)	72.0 (3.4)	2.9 (2.4) ^e	-2.0 (4.1)	-0.4 (2.8)
Priority level High	67.1 (6.0)	72.8 (4.5)	67.4 (8.3)	73.0 (7.1)	5.7 (5.5) ^b	67.4 (8.3)	73.0 (7.1)	5.6 (3.7) ^c	-0.3 (7.2)	0.1 (4.7)
Medium	52.0 (8.7)	55.5 (5.4)	55.4 (8.6)	54.4 (8.1)	3.5 (8.5)	55.4 (8.6)	54.4 (8.1)	-1.0 (7.1)	-3.4 (8.7)	-1.0 (7.1)
Low	51.7 (8.9)	58.2 (5.4)	54.2 (9.5)	58.8 (9.2)	6.4 (8.6) ^e	54.2 (9.5)	58.8 (9.2)	4.5 (6.1) ^e	-2.5 (9.2)	1.9 (7.5)

^aThe maximal score for each measure was 100 (n=37 shops). Three shops were not included in the final analysis.

^bp<0.001

^cp<0.0001

^dp<0.05

^ep<0.01

SD = standard deviation

Table 4. Comparison of business safety audit scores for small metal-fabrication businesses at baseline and follow-up stratified by shop characteristics at baseline for two intervention groups: management-employee and management only^a

Shop characteristic at baseline	Management-employee (n=19) Mean (SD)		Management only (n=18) Mean (SD)		Baseline score difference between intervention groups Mean (SD)	Score change difference between intervention groups Mean (SD)		
	Baseline	Follow-up	Within group change					
			Baseline	Follow-up				
All shops	65.9 (14.9)	71.4 (10.8)	5.5 (11.8)	63.9 (17.6)	67.7 (14.6)	3.8 (13.6)	2.0 (16.2)	1.7 (12.7)
Safety committee ^b								
Present (n=20)	74.0 (9.9)	74.5 (9.0)	0.6 (10.7)	75.9 (14.7)	77.1 (10.3)	1.2 (16.9)	-2.0 (12.3)	-0.6 (13.8)
Absent (n=17)	55.8 (12.0)	66.4 (10.7)	10.7 (9.7) ^c	53.0 (9.2)	59.0 (10.6)	6.0 (10.2)	2.7 (10.6)	4.7 (10.0)
Union								
Present (n=11)	66.8 (14.5)	73.5 (15.5)	6.7 (8.7)	72.7 (22.3)	72.0 (8.1)	-0.7 (21.3)	-5.9 (19.2)	7.4 (16.9)
Absent (n=26)	65.6 (15.5)	70.7 (9.2)	5.1 (13.0)	59.5 (13.7)	65.6 (16.9)	6.1 (7.9) ^c	6.1 (14.7)	-1.0 (11.0)
Shop size								
<25 (n=17)	62.0 (14.7)	70.1 (11.9)	8.2 (14.0)	58.2 (13.3)	62.4 (14.9)	4.2 (5.4) ^c	3.7 (13.8)	4.0 (9.8)
≥25 (n=20)	68.3 (15.1)	72.2 (10.5)	3.9 (10.7)	71.0 (20.5)	74.4 (11.9)	3.4 (20.2)	-2.7 (17.4)	0.5 (15.1)
Baseline low/high score								
Low (n=19)	52.3 (8.6)	64.3 (8.7)	12.0 (11.6) ^c	50.2 (7.2)	59.0 (11.8)	8.7 (10.2) ^c	2.1 (7.9)	3.3 (10.9)
High (n=18)	78.2 (4.7)	77.8 (8.3)	-0.4 (8.9)	81.0 (9.0)	78.7 (9.6)	-2.3 (15.3)	-2.8 (6.9)	1.9 (12.1)

^aThe maximal score for each measure was 100 (n=37 shops). Three shops were not included in the final analysis.

^bThe safety committee item was removed from business safety score in this comparison.

^cp<0.05

SD = standard deviation

Table 5. A comparison of changes in machine and business safety audit scores for small metal-fabrication businesses based on the presence or absence of a safety committee at baseline and follow-up

Safety committee status at baseline and follow-up (n=35) ^a		Machine score Mean (SD)		Safety audit Mean (SD)		Machine score: comparison of change with businesses with safety committees at both times	Safety audit: comparison of change with businesses with safety committees at both times
		Baseline	Follow-up	Baseline	Follow-up		
Status	N						
Yes to yes	18	63.1 (4.1)	66.8 (3.6)	76.9 (10.1)	76.2 (9.5)		
No to yes	8	56.4 (5.4)	63.4 (5.1)	55.5 (14.0)	69.5 (8.4)	p=0.11	p=0.01
No to no	9	63.9 (8.7)	66.5 (7.2)	53.3 (6.3)	56.2 (9.2)	p=0.46	p=0.30

^aThree businesses disbanded and two businesses went from having to not having a safety committee.

SD = standard deviation

group, businesses with low baseline scores experienced the greatest changes (5.0 points), followed by businesses with a union (4.6 points), and those with a safety committee (4.5 points).

When stratified into businesses with <25 or ≥25 employees, machine scores improved most (4.7 points) in larger businesses in the management-employee intervention group. Smaller businesses in this intervention group also experienced higher but slightly more variable improvements (5.9 points). We did not observe these trends in the management-only intervention group.

We also examined improvements in machine scores for different priority levels (high, medium, and low) between the two groups. The largest improvement occurred in low-priority items in businesses in the management-employee intervention group (6.4 points). We found the next highest levels of improvement in the high-priority items in both intervention groups. Medium-priority items either declined (management-only group) or showed low levels of improvement (management-employee group).

Safety audit scores

Before stratification, shops in each intervention group showed significant and similar improvements in business safety from baseline to follow-up (3.8 to 5.5) (Table 4). When stratified by median baseline score (to obtain equal numbers of businesses in each group), businesses in the management-employee group that started with the lowest baseline scores had the greatest changes (12.0 points), followed by businesses without committees (10.7 points), and smaller shops (8.2 points). In the management-only group, the greatest changes were again seen in businesses that started with the lowest scores (8.7 points), followed by unionized shops (6.1 points), and those with no safety committee (6.0 points).

Multivariate model

To examine the impact of different shop-level variables, while adjusting simultaneously for other variables, we explored a multivariate model for the two primary outcome measures (Table 6). The fixed effects included the difference between baseline and follow-up machine scores or business safety audits, safety committee (present or absent), shop size (<25 or ≥25 employees), and union status (present or absent).

Because machines were of different types and located at different shops, to analyze the machine score we included the business as a random effect and machine type as a fixed effect in the model. The results corroborated our previous analyses: similar improvements in machine and business safety occurred in each group from baseline to follow-up. The presence of a safety committee had the greatest influence on improvements in machine and business safety audit scores. None of the other variables was a significant modifier of machine or business safety.

In a separate multivariate model (data not shown), we evaluated the effect of low baseline score and the addition of a safety committee. Multivariate analysis for safety committees was constrained by only having eight businesses that added safety committees and nine businesses that did not change (Table 5 [no to no = 9; no to yes = 8]). Shops that added a safety committee showed an improvement in the machine safety score ($p=0.22$) as well as the business safety audit score ($p=0.01$). We found this improvement regardless of a shop's baseline measure. However, low baseline scores also remained important.

To study the relationship between our two measures, we used the proportion of high-priority items present on the machine safety checklist as a proxy for machine safety. We used logistic regression to identify eight items in the business safety audit where the odds of a high-priority machine-guarding item being present

(e.g., barrier guard) increased with a positive response on the business safety audit ($p=0.05$). At baseline, the Pearson correlation coefficient between the proportion of high-priority items being present and the number of positive responses on the business safety audit was 0.35 ($p=0.03$). After removing two outlier shops, we found a moderate and positive relationship between the changes in both measures during the course of the intervention ($R^2=0.41$, $p=0.01$).

Process evaluation

At the end of the study, we conducted a process evaluation survey to determine how management felt about intervention programs and materials. Management completed surveys in 33 out of 37 (89%) businesses that participated in the entire program. Of these, 31 (94%) felt programs and materials helped improve their knowledge of health and safety, and 25 (76%) felt that programs improved overall safety practices. Management of businesses with safety committees at follow-up felt they had made substantial changes during the prior year ($p=0.01$). They also tended to find the overall intervention program helpful ($p=0.06$). However, we found no difference among groups or for businesses with and without safety committees with regard to feeling that study materials helped prioritize machine-guarding needs.

DISCUSSION

This study confirmed our ability to significantly decrease machine-related hazards and to improve machine-related work practices. These data also confirmed that machine-related hazards remain a serious ongoing problem in the metal-fabrication trades. One

investigator showed that the rate of injuries increased twofold when machines did not comply with accepted standards, and found a similar increase in injury risk when personal protective equipment and machine guarding were not used.³⁷

Our study had several strengths, including a high rate of business participation at baseline and follow-up. Our research team represented a wide range of participants and included the active engagement of small business owners and trade schools in intervention development. We based our machine measures on consensus standards and validated them using interrater reliability and examination of the correlation between our two primary outcome measures.

We found a substantial portion of the gains seen in this study in shops that added a safety committee and those with the lowest baseline measures. Improvements ranged from 13% (7.5/58.5 [score change/baseline score]; Table 3) for machine-guarding measures to 23% (12.0/52.3 [score change/baseline score]; Table 4) for business safety audit measures. These findings persisted with multivariate modeling.

The magnitude of changes seen in the business safety audit indicated the apparent ease with which important administrative programs were remedied. For example, at baseline there was evidence of bypassing machine guarding in 19% of businesses compared with <5% at follow-up ($p>0.05$). Similarly, we found records of lockout/tagout training in 62% of businesses at baseline and 73% at follow-up ($p>0.05$). We also noted a 20% increase in the number of businesses with safety committees: from 50% to 70% ($p>0.05$).

It is unlikely that the changes seen were artifact or regression to the mean; better-performing businesses did not show a worsening of their scores at follow-up.

Table 6. Multivariate models of machine and business safety audit scores for small metal-fabrication businesses demonstrating the effect of the overall intervention and safety committee

	Machine score			Business safety audit score		
	Estimate	SE	P-value	Estimate	SE	P-value
Overall intervention (ref: baseline)	4.4	1.2	<0.001	5.2	2.5	<0.05
Baseline group difference (ref: management-only group)	0.6	1.2	NS	1.0	2.6	NS
Intervention effect (ref: management-only group)	-0.2	2.3	NS	0.1	5.1	NS
Safety committee effect (ref: absent)	2.7	1.2	<0.05	14.7	2.7	<0.0001
Shop size effect (ref: <25)	-1.1	1.2	NS	4.6	2.7	NS
Union effect (ref: absent)	1.3	1.3	NS	0.2	2.9	NS

SE = standard error

Ref. = reference group

NS = not significant

Furthermore, quality-control procedures assured adherence to study protocols throughout the study. Process evaluation data support our belief about the importance of safety committees. However, they fail to point to the most helpful parts of the intervention.

Our findings are supported by work with small enterprises in South Asia. Kogi used the active engagement of management and employees to improve the health and safety of workers within small enterprises.^{38,39} The importance of active worker engagement in health and safety in small-scale enterprises also was demonstrated in a study of nine small-scale enterprises in the Philippines, using methods defined by the International Labor Office, Work Improvement in Small Enterprises (WISE) program. Our methods are similar to those used by the WISE program.⁴⁰

Limitations

The primary limitation of this study was the lack of a truly random selection of metal-fabrication facilities. When we contacted owners who did not have knowledge of our program, they were reluctant to speak with us; thus, referral served as a major means of recruitment. Nonparticipants (those contacted who were eligible but did not participate) were similar to participating businesses with regard to SIC code, number of employees, and yearly amount of business in dollars. Owners cited lack of time or health and safety needs already being met by their workers' compensation insurer as the most common reasons for not participating.

A second limitation of this study was our inability to have a true control group. To assess a business, we believe it is our responsibility to provide information on recognized hazards to managers and employees. This information along with supporting documentation served as the management intervention. Even a minimal amount of information enabled many owners and managers to effectively modify hazards within their businesses.

Finally, we cannot definitively say that the measured changes resulted from our intervention because we found no differences between the two intervention groups. However, we believe it is likely that these changes resulted from our program for several reasons: (1) they were consistently found in some subgroups, (2) shop evaluation was carefully monitored and a 25% sample was randomly selected for quality control, and (3) machines were randomly selected to assure an unbiased estimate of our primary measure.

CONCLUSIONS

Few interventions have been conducted in business establishments with 100 or fewer employees. Reaching this large group of workers and employers remains a challenge. Interventions require the recruitment of widely dispersed establishments and the development of programs that are acceptable to an equally wide range of business owners and workers.

The absence of machine guarding and related safety programs remains a serious ongoing problem. We were able to demonstrate levels of improvement in machine and business safety as the result of interventions targeted at management that were similar to those achieved through interventions targeting management-employee health and safety committees. Process measures did not add to our ability to discern which aspects of our intervention programs were most important. However, they confirmed the importance of safety committees. We concluded that poorer performing businesses as well as those that added safety committees were the most likely to improve. It is encouraging to see changes of the magnitude found here with just modest input to employees, managers, and owners.

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