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Findings From the National Machine Guarding Program

A Small Business Intervention: Lockout/Tagout

David L. Parker, MD, PhD, Samuel C. Yamin, MPH, Min Xi, PhD, Lisa M. Brosseau, ScD, Robert Gordon, MS, Ivan G. Most, ScD, and Rodney Stanley, BS

Objective: Failure to implement lockout/tagout (LOTO) procedures adversely affects the rate of work-related fatalities and serious traumatic injury and is one of the most frequently cited Occupational Safety and Health Administration standards. This study assesses the impact of a nationwide intervention to improve LOTO in small metal fabrication businesses. **Methods:** Insurance safety consultants conducted a standardized and validated evaluation of LOTO programs and procedures. Businesses received a baseline evaluation, two intervention visits, and a 12-month follow-up evaluation. **Results:** The intervention was completed by 160 businesses. The mean LOTO procedure score improved from 8% to 33% ($P < 0.0001$), the mean program score went from 55% to 76% ($P < 0.0001$), and the presence of lockable disconnects went from 88% to 92% ($P < 0.0001$). **Conclusions:** This nationwide intervention showed substantial improvements in LOTO. It provides a framework for assessing and improving LOTO.

In 1989, the Occupational Safety and Health Administration (OSHA) promulgated standard 1910.147 to regulate practices for the control of hazardous energy.[1] The OSHA standard covers servicing and maintaining machines and equipment in which the unexpected release of energy or inadvertent start-up could injure employees.[1] Hazard controls for these tasks are collectively known as lockout/tagout (LOTO).

Approximately 2.5 million US workers are employed in metal manufacturing.[2] The majority of these establishments have fewer than 50 employees.[2] As with many small businesses, they frequently lack occupational health and safety expertise and comprehensive safety management programs.[3–8] The large size of the workforce engaged in metal fabrication, in combination with the high rates of both injuries[9] and OSHA citations for machine guarding and LOTO,[10] highlights the importance of hazards and the potential benefits of injury prevention programs.

The OSHA standard requires a comprehensive LOTO program for all forms of energy including electrical, hydraulic, pneumatic, kinetic, potential, chemical, and thermal. There must be a clear designation of roles for employees authorized to perform LOTO as well as training to ensure that unauthorized workers do not enter danger zones. LOTO procedures must contain steps to isolate and lock out all energy sources and verify they are no longer hazardous. LOTO procedures must be audited at least annually. The standard also describes characteristics of equipment such as locks and tags to be used in LOTO.[1]

Analysis of data from the National Traumatic Occupational Fatality System for the time period 1980 to 2001 indicated that the standard had not affected the rate of work-related fatalities in manufacturing.[11,12] The failure to implement LOTO is a primary contributing cause of this problem. LOTO consistently ranks as one of the most frequently cited OSHA standards in manufacturing (NAICS 31, 32, 33).[10] In 2014, LOTO comprised 9% (2040/22,789) of Federal OSHA citations for small- and medium-sized manufacturing businesses (1 to 249 employees). Of all LOTO citations, metal manufacturing subsectors NAICS 331, 332, and 333, accounted for 7%, 26%, and 8%, respectively. The number of LOTO citations in manufacturing was only exceeded by hazard communication, which comprised 9.5% (2166).[10]

Surveillance and case study data demonstrate that a failure to follow LOTO practices is an ongoing cause of occupational fatalities and serious traumatic injuries. A narrative text analysis of 592 OSHA fatality investigation reports from 1984 to 1997 involving the control of hazardous energy showed that in only 6% of cases was lockout known to have been attempted; 5% failed because of human error and 1% was attributed to mechanical failure.[11,13] No lockout attempt was made in 59% of cases and was probably not attempted in an additional 9%. The use of LOTO was indeterminate in 26% of cases. From 2003 to 2013, 16% of non-fatal, catastrophic injuries and 9% of fatalities in manufacturing (NAICS 31, 32, 33) recorded in the OSHA Fatality and Catastrophe Investigation Summaries database were lockout-related.[14]

In 1281 fatality investigations conducted during 1982 to 1997 by the NIOSH Fatality Assessment and Control Evaluation program in 20 states,[15] 12% were related to installation, maintenance, service, or repair on or near machines. Of these, 82% of incidents involved the failure to completely de-energize, isolate, block, and/or dissipate the energy source. The failure to lockout and tagout using energy control devices and isolation points after de-energizing contributed to 11% of events. Failure to verify energy sources were de-energized before work was started contributed to 7% of incidents.[15]

There are no data characterizing the extent to which manufacturing firms have implemented LOTO programs. Although case studies and incident investigations indicate that a failure to properly perform LOTO is a risk factor for serious injuries and fatalities, these data do not shed light on business-level management of the components of a LOTO program such as written policies, employee roles and training, or equipment such as the availability of locks. Nor do case studies provide a full picture of auditing, availability, and compliance of machine-specific LOTO procedures throughout a business. A more comprehensive understanding of the extent to which small industrial firms are lacking these programs and how they can improve both administrative and work practices adds practical knowledge on how to prevent traumatic injuries and fatalities.

The National Machine Guarding Program (NMGP) was a nationwide research-to-practice initiative designed using results

From the Park Nicollet Institute (Dr Parker, Mr Yamin, Dr Xi, Mr Gordon), Health Research Center, St Louis Park, MN; Division of Environmental and Occupational Health Sciences (Dr Brosseau), School of Public Health, University of Illinois at Chicago; School of Public Health (Dr Most), University of New England, Portland, ME; MEMIC (Mr Stanley), Loss Control Division, Portland, ME.

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Address correspondence to: David L. Parker, MD, PhD, Park Nicollet Institute, Health Research Center, 3800 Park Nicollet Blvd, 1-S, St Louis Park, MN 55416 (David.Parker@parknicollet.com).

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from the Minnesota Machine Guarding Study (MN-MGS). The MN-MGS was a regional study that examined the effectiveness of an intervention to improve machine guarding and related safety programs in small metal fabrication businesses. The MN-MGS demonstrated a widespread absence of adequate machine guarding as well as the importance of adding a safety committee to facilitate the remediation of hazards.[16]

Based on findings from the MN-MGS, the NMGP was designed to assist small metal fabrication businesses prevent injuries by developing safety leadership to improve machine safety including LOTO.[17,18] Insurance safety consultants were identified as partners who were capable of providing ongoing services to small businesses in widely distributed geographical areas. Insurance personnel are the most common source of safety information used by small businesses (74%), followed by state OSHA consultation (38%).[19]

This study addresses the knowledge gap in understanding LOTO work practices by describing findings from the NMGP. Findings related to machine guarding will be presented in another article. The objectives of this study are to assess whether study participants were found to (1) manage business-level LOTO administrative programs in compliance with OSHA requirements; (2) develop and maintain machine-specific LOTO procedures in accordance with regulatory standards and industry best practices; and (3) make improvements in either or both of these areas of LOTO as a result of participating in the NMGP.

METHODS

Informed Consent

Informed consent was obtained from each business owner before enrollment. The institutional review boards of the Park Nicollet Institute and the University of Illinois at Chicago approved all study methods and materials.

Study Design

The NMGP was a pre- and post-intervention trial carried out in partnership with two workers' compensation insurance companies. Research and corporate staff conducted training with all insurance safety consultants to ensure adherence to study protocols and baseline knowledge of assessment for LOTO and other machine-related hazards. After completion of training, safety consultants were responsible for business recruitment, evaluation, and intervention delivery. Participating businesses were recruited from insured businesses with metal fabrication as the primary (at least 75%) source of revenue and at least three but no more than 150 employees.

Study Software

Insurance safety consultants entered all data into software developed for the study. The software generated reports for owners, tracked intervention recommendations, and encrypted and sent data to the investigators. Software also allowed for the random selection of machines within each business.

Business Audit

Machine safety audit methods are described in detail elsewhere.[20,21] Briefly, at baseline and follow-up, all machines were enumerated and 12 machines were then randomly selected for a standardized assessment of machine safeguarding. Evaluation was performed at machine workstations using different technical checklists for each of 26 types of metal fabrication machinery.[17,20] Each machine checklist included two to seven items specific to LOTO practices (Table 1). The year a machine was manufactured was obtained whenever possible.

TABLE 1. LOTO Checklist Items

Lockable disconnects score:
Is a lockable disconnect in place for each energy source?
Are disconnects in plain view?
LOTO procedures score:
Are LOTO procedures posted on or near the machine? If ''yes'', answer next four questions:
Does the LOTO procedure contain specific steps for shutting down and locking out each source of hazardous energy?
Does the LOTO procedure require that stored energy be eliminated prior to placement of lockout devices?
Does the LOTO procedure contain specific instructions for verifying the effectiveness of lockout devices and other energy control measures before maintenance is performed?
Does the LOTO procedure contain specific steps for removing LOTO devices and restoring power?
LOTO program score:
Does the shop have a written LOTO program?
Does the LOTO program designate ''authorized'' employees?
For each lock issued to an ''authorized'' employee, is there just one key that opens that lock?
Are there records verifying that all employees are trained in LOTO?
Are there records of annual audits verifying the effectiveness of written LOTO procedures for each machine?

LOTO, lockout/tagout.

A machine was considered to be properly equipped with lockable disconnects if the following criteria were observed:

- Disconnect switches or devices were in place for isolating the machine from each source of energy;
- Each disconnect was constructed such that it could be controlled either by placing a lock on it or using a lock built into the switch, in accordance with the OSHA LOTO standard.[1] A plug lockout (lockable cap enclosing the plug) was considered acceptable for ''cord and plug connected'' machines (ie, those for which all hazardous energy could be controlled by unplugging the machine and keeping the plug under control of the employee performing service or maintenance).

For each machine, safety consultants determined whether or not a LOTO procedure was required. In the case of cord and plug machines, safety consultants entered ''not applicable'' for all items on procedures, as those machines are exempt from the regulatory requirement for a written procedure.[1]

A safety management audit checklist was completed during an interview with the owner or the owner's representative. Documentation was reviewed for written programs and policies. Basic business demographic data were also collected, including the number of employees, owner's education, zip code, and years in business. The safety management audit checklist included five items pertaining to LOTO administrative programs (Table 1). For all checklist items a ''yes'' response meant that the presence of a safeguard, policy, or written document was verified by the evaluator.

Intervention Activities

Participating businesses received four visits from a safety consultant: a baseline safety audit, intervention visits at 3 and 6 months post-baseline, and a follow-up audit at 12 months. At the conclusion of the baseline evaluation, the owner and/or safety committee received a report generated by the software. Reports summarized findings related to LOTO and machine guarding as well as shop-specific recommendations for making improvements.

The safety consultant and owner subsequently used results from the summary report to develop a 1-year action plan. Owners

selected specific areas to address in conjunction with guidance from the safety consultant. If an employee-management safety committee was not present, owners were encouraged to create one as an initial step. Other recommendations included improving machine guarding, LOTO, or conducting job hazard analyses. For problems the owner decided to remediate, responsibility was assigned to one or more employees, and a target date set for completion.

At the completion of the 3- and 6-month site visits, safety consultants entered recommendations and data on progress into the software. In some instances, either the 3- or 6-month visit, but not both, was conducted via telephone. The telephone consultation consisted of a review of the business action plan as a reminder for the owner to continue to try to meet predetermined goals.

If one or more components of a complete LOTO program were absent, owners were encouraged to remediate deficiencies. Safety consultants provided and explained guidance documents and templates for a written LOTO program, supplied examples of machine-specific procedures, and worked with the safety committee to establish and/or maintain other LOTO program components such as designating authorized employees and ensuring annual employee training.

ANALYSIS

Analysis was performed using SAS (version 9.2; SAS Institute Inc, Cary, NC).[22] Cronbach α was more than 0.8 for items within each of three LOTO categories (Table 1). Three summary LOTO scores were developed as dependent variables:

- Lockable disconnects: Two questions assessed the presence of lockable disconnects on each of the 12 randomly selected machines. The business-level lockable disconnects score was computed as the total number of ''yes'' responses for these machines divided by the total of ''yes'' plus ''no'' responses. Scores were computed in the same manner for individual questions.
- LOTO procedures: Five questions assessed whether LOTO procedures were posted on or near each machine, and whether the procedures contained basic elements of compliance with the OSHA standard. Not all questions were applicable to each machine. The business-level LOTO procedures score was computed as the total number of ''yes'' responses for 12 machines divided by the combined total of ''yes'' plus ''no'' responses (maximum 60). Scores were computed in the same manner for individual questions.
- LOTO program: Five questions assessed LOTO programs and training records. The business-level LOTO program score was computed as the total number of ''yes'' responses divided by the combined total of ''yes'' plus ''no'' responses. Scores were computed in the same manner for individual questions.

Covariates included shop-level measures such as the number of employees, years in business, presence of a safety committee, and if the business received intervention services related to LOTO.

Analysis included the computation of means, standard deviations, chi-squares, and T-tests. Analysis of variance and Pearson's correlation were used to explore the relationship between each of the summary LOTO scores and shop demographics. Mean scores were calculated by machine class (eg, presses, milling/drilling/boring) and type of machine (eg, vertical mill, laser cutter, turret punch press) by aggregating all machines across all participating businesses. Multiple regression was used to determine the relationship between business size, safety committee status, and pre- and post-intervention change in LOTO scores.

RESULTS

A total of 221 businesses received a baseline evaluation (198 from insurer A and 23 from insurer B). Of these, 160 (72%) completed the entire program (146 from insurer A and 14 from insurer B). Changing insurer was the primary reason for not completing the study (61%; 37 of 61) and 15 left the study, citing a lack of time and/or interest. Nine clients from insurer A were lost to follow-up because corporate restructuring made it impossible for safety consultants to complete intervention visits on schedule. There were no significant differences between shops that did and did not complete the study with regard to mean shop size ($P = 0.32$), overall measures of machine safety ($P = 0.89$), the presence of safety management programs ($P = 0.79$), or the three LOTO scores ($P \geq 0.1$ for each measure).

At baseline, there was no significant difference between participants from insurers A and B in mean scores for overall measures of machine safety (74% vs 71%; $P = 0.26$) or the presence of safety management programs (42% vs 48%; $P = 0.22$).[17,18] Data from the two insurers were subsequently combined and final analysis was completed only on the 160 shops that completed the entire 1-year program. Table 2 shows baseline characteristics for these shops. A total of 1912 machines were evaluated at baseline and 1913 at follow-up.

Significant improvements were observed in each of the three summary LOTO measures (Table 3). At baseline, the mean business-level lockable disconnects score was 88%. This increased to 92% during the course of the intervention ($P < 0.0001$). In contrast, only 8% of shops began with procedures that were both posted and contained machine-specific steps for effective LOTO. This increased by 25% points ($P < 0.0001$). The LOTO program score increased by 21% points ($P < 0.001$). The greatest percentage increase (30% points; $P < 0.0001$) was in conducting annual audits of LOTO practices.

Table 4 shows changes in the LOTO program and procedures scores stratified by baseline performance. For the program score, shops that started with lower scores made the greatest changes. Those starting with higher scores made changes that were smaller in scope but had nearly perfect scores at follow-up. For the procedure score, 144 shops started at 24% or less of which 68 had a mean follow-up score of 61% (SD = 39%) and 13 showed a decline ($P < 0.0001$); however, neither positive nor negative changes were significant ($P > 0.2$) for the 16 shops with a baseline measure of at least 25%.

Little variation was seen between different classes of machines and the presence of lockable disconnects (Table 5); however, the presence of lockout procedures ranged from 6% for computer numeric control machines to 22% for presses. At follow-up, these values increased to 37% ($P < 0.0001$) and 46% ($P < 0.0001$), respectively. Lockable disconnects were present on 85% or more of machines in all categories.

TABLE 2. Participant Characteristics

Characteristics	Number (%)
All shops completing the intervention	160
Geographic regions	
Northeast: CT, DE, MA, ME, NH, NJ, NY, PA, VT	35
Southeast: AL, AR, FL, GA, KY, NC, SC, TN, VA	30
North central: IA, IL, IN, MI, MN, SD, WI	74
Southwest: AZ, KS, MO, NE, NM, TX	21
Number of employees	
3–10	44
11–29	65
30–49	22
50–150	29
Mean number of employees	29
Safety committee status at baseline	
Number and percent with a safety committee	55 (34%)

TABLE 3. Summary Business-Level Lockout Measures Pre- and Post-Intervention ($n = 160$)

	Mean % at Baseline	Mean % at Follow-Up	Change	*P* Value
Lockable disconnects score	88	92	4	<0.0001
Is a lockable disconnect in place for each energy source?	87	92	5	0.0006
Are disconnects in plain view?	89	92	3	0.0072
LOTO procedures score	8	33	25	<0.0001
Are LOTO procedures posted on or near the machine?	9	35	26	<0.0001
If ''yes'', answer next four questions:				
Does the LOTO procedure contain specific steps for shutting down and locking out each source of hazardous energy?	9	34	25	<0.0001
Does the LOTO procedure require that stored energy be eliminated prior to placement of lockout devices?	8	33	25	<0.0001
Does the LOTO procedure contain specific instructions for verifying the effectiveness of lockout devices and other energy control measures before maintenance is performed?	7	32	25	<0.0001
Does the LOTO procedure contain specific steps for removing LOTO devices and restoring power?	8	34	26	<0.0001
LOTO program score	55	76	21	<0.0001
Does the shop have a written LOTO program?*	68	86	18	<0.0001
Does the LOTO program designate ''authorized'' employees?*	63	86	23	<0.0001
For each lock issued to an ''authorized'' employee, is there just one key that opens that lock?*	70	87	17	<0.0001
Are there records verifying that all employees are trained in LOTO?*	48	73	25	<0.0001
Are there records of annual audits verifying the effectiveness of written LOTO procedures for each machine?*	24	54	30	<0.0001

LOTO, lockout/tagout.
*Averages are based on one question per shop.

At baseline, the lockable disconnects score did not vary with business size. During the course of the intervention, significant improvements were made in all but the largest businesses (Table 6). Baseline LOTO procedures scores ranged from 4% in business with 3 to 10 employees to 15% for those with 50 to 150. Substantial and statistically significant improvements were made in all size ranges. At baseline, LOTO program scores ranged from 40% in shops with 3 to 10 employees to 66% in shops with 50 to 150 employees and significant improvements were observed in all size ranges.

Three out of 160 businesses received perfect scores for both LOTO programs and procedures. Of the remaining 157, 102 (82%) elected to remediate one or more LOTO deficiencies and subsequently received technical guidance for LOTO during at least one intervention visit. For lockable disconnects, the change between groups receiving and not receiving technical assistance was not significant ($P > 0.10$). The LOTO procedure score improved by 28% points for shops that received technical guidance on LOTO versus 5% points among those who did not ($P = 0.0001$), and LOTO program scores changed by 36 and −1% points, respectively ($P < 0.0001$).

Businesses with a safety committee had better baseline LOTO procedure and LOTO program scores when compared with those without one (Table 7). Businesses that added a safety committee during the intervention achieved a 5% point increase in the lockable disconnect score ($P = 0.007$). There was a statistically significant increase in the LOTO procedures and LOTO program scores for shops that did and did not add a safety committee; however, comparing businesses that added a safety committee during the study period with those who did not, the former showed significantly greater improvements in LOTO procedures (44% vs 14% points improvement; $P = 0.005$) and LOTO programs (33% vs 18% points; $P = 0.06$). Four shops that began the study with a safety

TABLE 4. Shops That Improved or Declined From Baseline Program and Procedure Scores

Mean Baseline Score (SD)	Number of Shops	Number With No Change	Number Improved	Mean % at Follow-Up (SD)	*P*—Within Group Change	Number Declined	Mean % at Follow-Up (SD)	P—Within Group Change
				Program score				
0%	36	13	23	81 (24)	<0.0001	0	—	—
20%	12	1	9	85 (27)	0.003	2	0 (0)	—
40	18	1	15	82 (15)	<0.0001	2	10 (14)	0.20
60%	25	6	16	96 (8)	<0.0001	3	13 (23)	0.25
80%	33	12	17	100 (0)	<0.0001	4	55 (21)	0.09
100%	36	28	0	—	—	8	73 (15)	0.007
				Procedure score				
0%	115	63	52	63 (41)	<0.0001	0	—	—
1–24%	29	0	16	63 (36)	<0.0001	13	1 (1)	0.0004
25–99%	12	0	6	82 (29)	0.057	6	37 (38)	0.07
100%	4	2	0	—	—	2	38 (54)	0.34

SD, standard deviation.

TABLE 5. Machine Class and LOTO Summary Category Scores

Machinery Class and Type	Number of Machines		LOTO Disconnects			LOTO Procedures		
	Baseline	Follow-Up	Baseline %	Follow-Up %	*P* Value	Baseline %	Follow-Up %	*P* value
Milling/drilling/boring	516	521	85	90	0.002	8	26	<0.0001
Cutting/shearing/sawing	236	258	85	93	0.003	10	26	<0.0001
Presses	76	61	94	94	0.76	22	46	0.005
Sanding/grinding	389	415	86	90	0.03	7	28	<0.0001
CNC/screw	548	522	95	98	0.008	6	37	<0.0001
Other metal-forming	147	136	91	95	0.14	17	49	<0.0001
All machines	1912	1913	89	93	<0.0001	9	33	<0.0001

CNC, computer numeric control; LOTO, lockout/tagout.

committee but finished without one were excluded from this part of the analysis.

Multiple regression was used to evaluate the 105 shops that started without a safety committee. After controlling for baseline LOTO scores and safety committee status, business size had no effect ($P > 0.10$) on pre- and post-intervention changes in LOTO scores in any of the three summary measures. Establishing a safety committee was associated with a 5% ($P = 0.12$) greater improvement in the lockable disconnect score, 39% greater improvement in LOTO procedures score ($P < 0.0001$), and a 25% greater increase in LOTO program score ($P = 0.0006$) when compared with shops that started and ended without a safety committee.

The effect of adding a safety committee was further evaluated within the context of receiving or not receiving technical services on LOTO during one or more intervention visits (Table 8). For businesses that did not receive LOTO technical services, there was no evidence of change regardless of the status of their safety committee. Analysis of this group was limited because of the small number of shops that did not receive LOTO services.

Among shops that received LOTO services, those that established a safety committee (group B) had greater increases in both LOTO procedure and program scores when compared with shops that began and ended without a safety committee. These changes were 41% versus 15% points ($P = 0.009$; not shown in table) and 49% versus 32% points ($P > 0.10$; not shown in table) respectively. For businesses with a safety committee that received LOTO services, there were significant changes in both the lockable disconnect, procedure, and program scores. In the latter group, there was no significant change in these scores if the business did not receive LOTO services.

Machine age was obtained for 44% of machines at baseline and 37% of machines at follow-up (Table 9). Machine age was stratified by year of manufacture 1989 or earlier or at least 1990, the latter being the first full year after the OSHA LOTO standard went into effect. Machines manufactured during or after 1990 were 8% more likely at baseline to have all disconnects in place than older machines ($P = 0.0003$). The proportion of machines manufactured before 1990 that were fully equipped or retrofitted with disconnects improved during the intervention period from 85% to 95% ($P = 0.001$).

DISCUSSION

The success of the NMGP in improving LOTO demonstrates the potential for insurance safety consultants to effectively work with small businesses to improve worker health and safety.

TABLE 6. Shop Size and the Presence of Lockable Disconnect, Lockout Procedures and Lockout Programs Pre- and Post-Intervention

Number of Employees	*n*		Lockable Disconnects Score As % of Total		LOTO Procedures Score As % of Total		LOTO Program Score As % of Total	
			Mean	SD	Mean	SD	Mean	SD
All shops	160	Baseline	88	18	8	22	55	37
		Follow-up	92	17	33	42	76	33
		P value	<0.0001		<0.0001		<0.0001	
3–10		Baseline	86	20	4	16	40	40
	44	Follow-up	90	21	27	42	61	42
		P value	0.0778		0.0014		0.0011	
11–29		Baseline	86	20	7	22	56	37
	65	Follow-up	93	14	40	45	80	31
		P value	0.0008		<0.0001		<0.0001	
30–49		Baseline	95	7	11	27	65	33
	22	Follow-up	99	5	31	42	90	18
		P value	0.0059		0.0137		0.0044	
50–150		Baseline	89	15	15	26	66	30
	29	Follow-up	89	19	27	36	80	24
		P value	0.9901		0.0267		0.0083	

LOTO, lockout/tagout; SD, standard deviation.

TABLE 7. Safety Committee Effect on Three Summary Lockout Scores Pre- and Post-Intervention

Pre-to-Post Intervention Safety Committee Status		Lockable Disconnects Score As Percent of Total			LOTO Procedures Score As Percent of Total			LOTO Program Score As Percent of Total		
	n	Baseline	Follow-Up	*P* Value	Baseline	Follow-Up	*P* Value	Baseline	Follow-Up	*P* Value
Group A: yes-to-yes	51	92	94	0.0478	15	38	0.0005	72	89	<0.0001
Group B: no-to-yes	42	91	96	0.0074	6	50	<0.0001	54	87	<0.0001
Group C: no-to-no	63	82	88	0.0070	4	18	0.0008	41	59	0.0006
All shops	160	88	92	<0.0001	8	33	<0.0001	55	76	<0.0001
P value for change; group B versus group C	0.95		0.0005		0.06					

LOTO, lockout/tagout.

Insurance risk consultants were able to provide simple technical guidance to businesses to help improve safety practices. Technical guidance consisted of providing businesses with sample LOTO procedures and administrative programs, both of which were frequently absent at baseline. Businesses were also provided guidance on how to establish and run a safety committee.

By the end of the study, substantial and statistically significant improvements had been made in the proportion of shops that had posted of LOTO procedures, verification of employee training, designation of one or more authorized employees, and the presence of LOTO programs, all of which are fundamental aspects of LOTO practice.[1,23] Based on state and national surveillance data,[10,13,14,24] these improvements could have a substantial effect on reducing the risk of serious work-related trauma and fatalities.

Mean business-level scores for lockable disconnects improved from 88% to 92% ($P = 0.0006$). Although smaller than increases observed for the other two summary LOTO measures, this nevertheless is of great importance because lockout cannot be properly performed in the absence of these devices.[15,23] For machines manufactured before 1990, the first full year after the OSHA LOTO standard was promulgated, the proportion of machines equipped or retrofitted with a disconnect for each energy source improved from 85% to 95%.

Apart from posting LOTO procedures at the machine workstation, all aspects of LOTO evaluation were taken from the OSHA standard; however, maintaining machine-specific LOTO procedures at each machine workstation rather than in an office or other location facilitates correct LOTO practice by ensuring immediate access to the applicable procedure when service or maintenance is performed as well as auditing at least annually.[25] Anecdotally, safety consultants performing NMGP fieldwork frequently encountered employees who were unable to locate LOTO procedures for specific machines when asked to do so during the course of the machine safety audit.

Both the MN-MGS[16] and NMGP demonstrated the importance of adding a safety committee in improving summary measures of machine safety. NMGP data demonstrate that regardless of size, LOTO practices are consistently better in shops with a safety committee when compared with those without. Businesses with a safety committee had the highest baseline and follow-up LOTO program scores. Business that added a safety committee improved both their LOTO program and procedure scores substantially more

TABLE 8. Change in LOTO Scores Stratified by Receiving Intervention Services for LOTO

Pre-to-Post Intervention Safety Committee Status	Did Not Receive LOTO Services				Received LOTO Services At Least Once				
Group A: Yes-to-Yes	*n* = 7				*n* = 29				
	Baseline %	Follow-Up %	Change %	*P* Value, Within-Group Change	Baseline %	Follow-Up %	Change %	*P* Value, Within-Group Change	*P* Value, Difference Between Groups in Change is Score
Lockable disconnects	90	96	6	0.37	90	93	3	0.03	0.42
LOTO procedures	1	15	14	0.62	13	47	34	0.0001	0.25
LOTO program	71	74	3	1	57	90	33	<0.0001	0.007
Group B: no-to-yes	*n* = 4		*n* = 27						
Lockable disconnects	89	98	9	Not shown due to small sample size	90	95	5	0.15	Not shown due to small sample size
LOTO procedures	16	17	1		5	46	41	0.0001	
LOTO program	50	70	20		35	84	49	<0.0001	
Group C: no-to-no	*n* = 11		*n* = 43						
Lockable disconnects	77	90	13	0.15	83	88	5	0.07	0.31
LOTO procedures	0	2	2	1	4	19	15	0.01	0.03
LOTO program	45	34	−11	0.31	28	60	32	<0.0001	0.001

LOTO, lockout/tagout.

TABLE 9. Presence of Lockable Disconnects for Machines Manufactured Before and After the OSHA Machine Guarding Standard Was Implemented

		Year of Manufacture		
		≥1990	≤1989	*P* Value
Is a lockable disconnect in place for each energy source?	Mean % yes at baseline	93	85	0.0003
	Number of machines at baseline	550	287	
	Mean % yes at follow-up	98	95	0.04
	Number of machines at follow-up	546	168	
	P value for change	<0.0001	0.001	

than those that started and ended without a safety committee. Nonetheless, at the final evaluation, scores in businesses that added a safety committee were not quite as high as those that started and ended with one.

Limited empirical data indicate that health and safety committees have a positive effect on workplace health and safety.[19,26–28] Cross-sectional data indicate that safety committees report resolving problems that are brought to their attention.[19] A longitudinal (1998 to 2006) study of the impact of safety committees in Pennsylvania showed contradictory results on the impact of safety committees on injury incidence; however, firms that completed training of safety committee members experienced lower injury rates than businesses that failed to do so.[29] Boden et al[30] found that safety committees had no impact on OSHA citations, whereas Akbar-Khanzadeh and Wagner[31] found that management leadership and worker participation in health and safety programs (not clearly defined as a safety committee) was correlated with fewer serious OSHA violations when compared with business that did not have such participation.

Establishment of a safety committee is the foundation of safety leadership. This entails shared responsibility between workers and management and was central to the NMGP intervention. Although there is debate on the optimal characteristics of a safety committee, shared responsibility seems central to most.[19,32] Data from the NMGP support the importance of safety committees; however, as Yassi et al[28] note, ''The literature appears to confirm that merely having a JHSC (joint health and safety committee) is not sufficient—it must be an effective committee . . ..''

In the NMGP, many shops with safety committees had substantial room for improvement in LOTO, indicating the need for other elements of safety management beyond the presence of a safety committee. NMGP participants who added or maintained a safety committee made greater improvements in audit scores if they also received technical guidance from insurance safety consultants during the intervention when compared with participants that did not receive technical assistance; however, the number of shops who did not receive LOTO services when needed was small.

The results of this study are likely to be applicable to a broad range of businesses such as plastic molding, food processing, woodworking, and other industries where large machinery is used. OSHA citations, serious traumatic injuries, and fatalities related to LOTO within these industries are common place and indicative of a widespread problem.[10,14]

LIMITATIONS

Due to the intermittent nature of machine maintenance and repair, it was not possible to conduct evaluations of shop personnel locking out machines. Instead, safety consultants assessed LOTO equipment and verified LOTO program documentation. Although the presence of safety committees was evaluated, the precise manner in which safety committees might have contributed to the success of the intervention could not be assessed. Other investigators have identified the importance of available resources, management commitment, employee engagement, the ability of safety committees to mandate changes, or the quality of educational programs as important contributors to worker safety and health.[19,33]

Tests of inter-rater reliability in the machine safety checklist audit are described elsewhere.[20] Items on lockable disconnects represented a small proportion of those data, such that it was not possible to perform a test of inter-rater reliability on those items alone. The remainder of the data collected by safety consultants was obtained from a documented review of LOTO procedures and policies, and brief interviews with business owners. It is not possible under real-world conditions for two evaluators to simultaneously make independent responses to interview question with the same interviewee.

As designed, business selection was to be completely randomized; however, this proved to be impossible for several reasons: (1) It would have placed a large burden on a few safety consultants who had large numbers of metal fabrication businesses in their jurisdiction; (2) The business model of insurer A changed shortly after business recruitment was started; and (3) recruitment became a marketing and advertising function for insurer A. It could not be determined whether participants had better safety programs in place at baseline in comparison with eligible non-participants.

This study did not have a control group. Our prior work demonstrated that even a minimal intervention had a modest impact on health and safety outcomes. [16,34] A baseline evaluation is required to have a control group; however, given the importance of LOTO and machine guarding in preventing injuries, we believe it is unethical to not provide the results of a business audit and explicit recommendations for improvement. Hence, in the presence of serious hazards, it is not possible to have a true control group. When time of enrollment was treated as a covariate, there was no difference in baseline measures between shops that were recruited during the first quarter when compared with those recruited later in the study.

Lastly, the sustainability of the intervention could not be assessed. It is important to find ways to fund long-term occupational intervention research in small-scale enterprises. There are few studies that have assessed the long-term impact of worksite safety and health intervention. The most notable exceptions are those that examined the effect of engineering controls.[35]

CONCLUSIONS

Some LOTO procedures might be complex and entail multiple steps and numerous sources of energy, including stored energy such as air pressure used to power pneumatic devices, capacitors, and compressed springs[36]; however, for most metal fabrication machines, lockout can be accomplished with a few straightforward steps. Similarly, business-level LOTO program management is largely administrative in nature, as it consists primarily of allocating personnel time for maintaining written programs and procedures, annual audits of procedures, and

conducting or arranging for employee training. Therefore, most aspects of compliant and protective LOTO programs can be achieved at relatively low expense and accomplished by insurance safety consultants.

NMGP data indicate the need for a nationwide effort to improve the management and performance of LOTO within small industrial firms. Improving LOTO could substantially reduce serious workplace trauma and work-related fatalities. This intervention provides a framework for enacting improvements in LOTO practice, having demonstrated large and statistically significant improvements in a nationwide sample.

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