


RESEARCH ARTICLE

Self-audit of lockout/tagout in manufacturing workplaces: A pilot study

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Background: Occupational health and safety (OHS) self-auditing is a common practice in industrial workplaces. However, few audit instruments have been tested for inter-rater reliability and accuracy.

Methods: A lockout/tagout (LOTO) self-audit checklist was developed for use in manufacturing enterprises. It was tested for inter-rater reliability and accuracy using responses of business self-auditors and external auditors.

Results: Inter-rater reliability at ten businesses was excellent ($\kappa = 0.84$). Business self-auditors had high (100%) accuracy in identifying elements of LOTO practice that were present as well as those that were absent (81% accuracy). Reliability and accuracy increased further when problematic checklist questions were removed from the analysis.

Conclusions: Results indicate that the LOTO self-audit checklist would be useful in manufacturing firms' efforts to assess and improve their LOTO programs. In addition, a reliable self-audit instrument removes the need for external auditors to visit worksites, thereby expanding capacity for outreach and intervention while minimizing costs.

KEYWORDS

audit, lockout/tagout, machine safety, manufacturing, occupational health, safety management

1 | INTRODUCTION

An occupational safety and health (OHS) self-audit is an assessment of workplace hazards, controls, programs, and documents performed by a business owner or employee. OHS self-auditing has been promoted as an effective means for businesses to improve, track, and maintain workplace safety and minimize hazards independent of external assistance.^{1,2} A 1999 survey of U.S. industrial and construction firms conducted by the Occupational Safety and Health Administration (OSHA) found that 85% reported performing at least an annual evaluation or audit of safety practices.¹ OSHA recommends that employers regularly conduct workplace inspections and compliance audits, and use the results to guide safety and health programs.²

Despite their widespread use in industrial firms, there is little research available on the inter-rater reliability of OHS audit tools.³⁻⁵ An audit instrument with good inter-rater reliability yields consistent results when used at the same workplace by two or more knowledgeable users. Among

comprehensive OHS management audits tested, inter-rater reliability is often low^{4,6-8} casting doubt on their usefulness.

Several self-audit tools have been developed to target specific occupational settings. These include automobile collision repair shops,⁹ residential construction sites,¹⁰ and farm tractor cabs.¹¹ These trade-specific audit tools have provided better results with regard to inter-rater reliability^{10,11} than broader audits assessing a wide range of hazards. However, problems remain with regard to accuracy,⁹ that is, workers' ability to correctly identify hazards and controls with the audit tool.

In our prior work,^{12,13} we assessed inter-rater reliability of instruments designed to allow trained research and field staff to evaluate machine safety, including compliance with OSHA standard 1910.147 for control of hazardous energy, commonly known as the lockout/tagout (LOTO) standard.¹⁴ However, employee ability to self-audit was not assessed, leaving a gap related to providing both employers and workers a tool with which to assess hazards independent of outside expertise.

LOTO is a set of practices for preventing injury through systematic control of hazardous energy during maintenance and repair of machinery. The standard is applicable whenever inadvertent startup or other energization of a machine is a risk to employees performing machine maintenance or repair. The OSHA LOTO standard¹⁴ provides employers with a framework for a LOTO management program including employee training, designation of employees authorized to perform LOTO, development and auditing of machine-specific procedures, and proper LOTO equipment.

The failure to properly perform LOTO during machine maintenance and repair is an ongoing and serious risk to workers. Nationally, LOTO ranks among the most frequently cited OSHA standards.¹⁵ In manufacturing, the failure to implement LOTO contributed to 8% of fatalities and 15% of non-fatal catastrophic injuries investigated by OSHA for the period 2005–2014.¹⁶ Analysis of OSHA incident reports on 592 fatalities involving hazardous energy between 1984 and 1997 found that LOTO was attempted in only 6% of cases.¹⁷

In the National Machine Guarding Program (NMGP), a study of machine safety in metal fabrication firms, businesses had, on average, only 55% of core elements of a LOTO program in place at baseline and complete step-by-step LOTO procedures were available at fewer than 10% of machine workstations.¹⁸ The widespread absence of LOTO programs and procedures highlighted the need for a comprehensive instrument for the assessment of LOTO. This paper describes development and testing of a LOTO self-audit instrument for manufacturing workplaces. If found sufficiently reliable, a self-audit of LOTO would allow for assessment of large numbers of businesses across wide geographic areas without the cost of sending trained evaluators to each site. This would be an important component of future outreach efforts to reduce the impact of LOTO incidents on a national scale.

2 | MATERIALS AND METHODS

The Institutional Review Board (IRB) of Park Nicollet Institute approved all materials and methods. Consent to participate was obtained from each business owner or a representative.

2.1 | LOTO self-audit checklist development

Findings from the NMGP served as the starting point for developing a LOTO self-audit checklist. Questions from the NMGP machine safety audit covering LOTO programs and procedures^{13,18,19} were modified or expanded. Items on the shop safety committee were included based on our previous findings that the presence or addition of a safety committee was an important factor in improving LOTO practices at many businesses.¹⁸ Input was collected from machine safety experts, business owners, and employees authorized to perform LOTO. Additional questions were added in order to fully assess worksite compliance with the OSHA LOTO standard.¹⁴ The final checklist allowed owners and employers to conduct a comprehensive assessment of LOTO programs, LOTO procedures, and the safety committee.

After the LOTO self-audit checklist was developed, it was assessed for content validity, that is, how completely results reflected a business's implementation of the requirements of the OSHA LOTO standard. This was a two-step process consisting of review by a machine safety engineer and pre-testing at a technical college and a business. At each test site, research staff collected feedback from shop personnel on usefulness and applicability of checklist content, question format, and clarity of language.

The final LOTO self-audit checklist consisted of four sections (supplemental file 1):

- Business demographics: Ten questions covered basic demographic data such as the role of the employee completing the LOTO self-audit checklist, total number of employees at the business, type of business and North American Industry Classification System (NAICS) code, and union status.
- LOTO programs: Eight questions covered the presence and content of written LOTO programs including employee training and designation of employees authorized to perform LOTO.
- LOTO procedures: Eighteen questions covered the availability, content, and annual re-evaluation of machine-specific LOTO procedures, as well as equipment necessary to execute LOTO procedures such as locks, tags, and lockable disconnect switches.
- Safety leadership: Six questions covered the presence, composition, and activities of a safety committee.

2.2 | Business recruitment

Businesses were recruited in partnership with a workers' compensation insurance company and contacted by either the principal investigator (DP) or an insurance representative. Participation was not restricted by business size as defined by the number of employees, or by industrial sector, as long as the establishment was a private firm with stationary machinery covered by the OSHA LOTO standard.

2.3 | LOTO audit

At each business the self-auditor (the employee who completed the LOTO self-audit checklist) was provided with brief written instructions on performing the audit. A "yes" response to a question indicated that the specified LOTO document or equipment was both present and compliant with the OSHA LOTO standard. A "no" or "unsure" response meant that the item was missing, non-compliant, out-of-date, or not verifiable. For example, one shop manager stated that employees were trained in LOTO but could not locate a training sign-in log. Two items could be marked "not applicable" as they covered specific machines or equipment configurations not present at all sites.

An external auditor who was either a machine safety expert from the research team or a safety consultant from the insurer visited each participating business. Each business was given the option of completing the LOTO self-audit checklist in advance or on the day of the site visit. Within each business, the external auditor independently completed the audit and verified the presence of written programs by having a business representative retrieve documents such as written

programs, training records, and procedures. External auditors inspected production areas to assess LOTO equipment.

2.4 | Data analysis

Demographic variables were summarized using univariate statistics. For the LOTO audit, three category scores and an overall audit score were calculated for each business, based on the responses of self-auditors and external auditors. The overall score was based on 30 to 32 items per business. Scores were calculated as follows:

2.4.1 | LOTO program score

Number of "yes" responses ÷ total number of items (eight per business) × 100.

2.4.2 | LOTO procedure score

Number of "yes" responses ÷ total number of items (16 to 18 per business) × 100.

2.4.3 | Safety leadership score

Number of "yes" responses ÷ total number of items (six per business) × 100.

2.4.4 | Overall audit score

Number of "yes" responses ÷ total number of items (30 to 32 per business) × 100.

Basic descriptive statistics were used to compare percentage scores between business self-auditors and external auditors.²⁰ The kappa statistic was used to assess inter-rater reliability and the extent of random error. Kappa values were compared to accepted benchmarks for interpreting strength of agreement; a value of 0.80-1.00 indicates excellent agreement, 0.61-0.80 substantial agreement, and 0.41-0.60 moderate agreement.²¹

Accuracy was assessed by determining the ability of the business self-auditor to correctly identify items that were present and in compliance, and, separately, those that were absent or out of compliance with regulatory requirements. External evaluators' responses were used as the standard for accuracy. For items marked "no" by the external auditor, the self-auditor's accuracy was calculated as:

$$[(\text{Number of "no" responses by self-auditor}) / (\text{number of "no" responses by external auditor})] \times 100.$$

Similarly, for items marked "yes" by the external auditor, the self-auditor's accuracy was calculated as:

$$[(\text{Number of "yes" responses by self-auditor}) / (\text{Number of "yes" responses by external auditor})] \times 100.$$

These measures were calculated for the overall audit, the three scoring categories (LOTO programs, LOTO procedures, and safety leadership), and for individual questions.

2.5 | Re-analysis

During the study, additional qualitative feedback on the LOTO self-audit checklist was collected in unstructured format from business self-auditors in order to identify problems with usability or content

validity. Six checklist items were identified as problematic and reviewed by the research team. Data were subsequently re-analyzed with those six items removed. Items removed prior to the re-analysis are indicated within the full 32-item checklist (supplemental file 1). Among the 26 items in the re-analysis one could be marked "not applicable."

3 | RESULTS

Ten businesses participated in the pilot study between April and September 2016. Five were enrolled in Minnesota by the research team, and five in Maine by the insurer. There were two external auditors in Minnesota and two in Maine. A range of individuals conducted the business self-audits: four were owners or senior managers, two were shop supervisors, and four were safety directors.

Six businesses specialized in metal products, two in wood products, and one each in sign and boat manufacturing. None of the businesses were unionized. Five (50%) had a safety committee that had convened at least once during the 4 months preceding the visit by the external auditor. Four participants had 3-24 employees, three had 25-99, and three had 100-250. Businesses with 25 or more employees received higher overall audit scores from the external evaluators (mean of 83% vs 26%; $P < 0.0001$).

Table 1 shows inter-rater reliability and accuracy of the LOTO self-audit. Both the self- and external auditors independently assessed 312 items in ten shops. The kappa value for the overall audit was 0.84, indicating excellent reliability. Similarly, kappa was at least 0.79 within each of the three categories: LOTO programs, LOTO procedures, and safety leadership. With regard to accuracy, self-auditors correctly identified 100% of items that were present and in compliance with the LOTO standard. Self-auditors correctly identified 81% of non-compliant items on the overall audit, and at least 75% within each category.

After omission of problematic questions, 255 paired observations were re-analyzed. The kappa value for the overall audit increased from 0.84 to 0.92 (Table 1). LOTO procedures was the area of greatest change, with the kappa value for that category increasing from 0.79 to 0.91. The proportion of missing or non-compliant items correctly identified by self-auditors increased from 81% to 90% on the overall audit and from 75% to 88% for LOTO procedures.

Table 2 shows business-level results for all participants. In general, self-auditors gave their shops higher overall scores than external auditors. Business-level kappa values for the overall audit ranged from 0.56 (moderate level of agreement) to 1.00 (perfect agreement). The proportion of non-compliant items correctly identified by self-auditors ranged from 59% to 100%.

In the re-analysis, inter-rater reliability improved in four businesses at which external auditors found at least 50% of LOTO items missing or non-compliant (Table 2). Initial business-level kappa values at those four sites were 0.56, 0.63, 0.65, and 0.71; these values improved to over 0.80 at each business. Accuracy also improved at these four sites with the self-auditors' ability to correctly identify

TABLE 1 Inter-rater reliability and accuracy of the lockout/tagout (LOTO) self-audit at ten businesses

Audit category	Analysis based on the 32-item checklist					Re-analysis using 26 items				
	Total number of applicable items ^a	Mean percentage of "yes" responses ^b by self-auditors	Mean percentage of "yes" responses by external auditors	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by all self-auditors combined	Percentage of compliant items correctly identified by self-auditors	Total number of applicable items ^c	Mean percentage of "yes" responses by self-auditors	Mean percentage of "yes" responses by external auditors	Percentage of non-compliant items correctly identified by all self-auditors combined
LOTO program	80	68	60	0.84	81	100	60	78	73	82
LOTO procedures	172	72	62	0.79	75	100	135	72	68	88
Safety leadership	60	57	55	0.97	96	100	60	57	55	96
Total audit	312	68	60	0.84	81	100	255	70	66	90

^aResponse "not applicable" was allowed for two items; therefore contribution to denominator could be 30, 31, or 32 items per business.
^bA "yes" response indicated an item was present and in compliance with regulatory requirements.
^cResponse "not applicable" was allowed for one item; therefore, contribution to denominator could be 25 or 26 items per business.

TABLE 2 Business-level results of the lockout/tagout (LOTO) self-audit

Analysis based on the 32-item checklist					Re-analysis using 26 items				
Business site	Percentage "yes" responses ^a by self-auditor	Percentage "yes" responses by external auditor	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by self-auditor	Percentage of compliant items correctly identified by self-auditor	Percentage "yes" responses by self-auditor	Percentage "yes" responses by external auditor	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by self-auditor
01	87	81	0.76	67	100	96	89	0.47	33
02	75	75	1.00	100	100	85	85	1.00	100
03	94	94	1.00	100	100	100	100	n/a ^b	100
04	84	84	1.00	100	100	81	81	1.00	100
05	90	90	1.00	100	100	92	92	1.00	100
06	13	10	0.84	96	100	12	12	1.00	100
07	84	75	0.71	63	100	89	85	0.84	75
08	39	23	0.63	79	100	36	28	0.82	89
09	68	45	0.56	59	100	64	56	0.83	82
10	42	26	0.65	78	100	40	32	0.83	88
All sites	68	60	0.84	81	100	70	66	0.92	90

^aA "yes" response indicated an item was present and in compliance with regulatory requirements.
^bSite-level kappa statistic was not applicable because both external and self-auditor responded "yes" to all items.

non-compliant items increased by 10 to 23 percentage points. For six sites with high percentage of items in compliance, inter-rater reliability and accuracy remained high except at one business.

4 | DISCUSSION

To our knowledge, the current pilot study is the first to evaluate inter-rater reliability of a self-audit instrument targeted specifically to hazards and safety programs in manufacturing workplaces. Dyjack et al⁶ tested an OHS management audit described as a universal assessment instrument (UAI) using paired evaluators at four sites, three of which were manufacturing establishments. Kappa values were below 0.30 at all sites, indicating low reliability even among trained auditors from the same research team.⁶ In addition, there was not an employee self-audit component to that study.

Inter-rater reliability of the LOTO self-audit checklist compares favorably with that of OHS self-audit instruments designed for other economic sectors.^{10,11} Kaskutas et al¹⁰ developed an audit of fall prevention practices for use by workers at residential construction sites. Two evaluators simultaneously completed the audit at sixteen sites, with excellent agreement (kappa 0.93). Kelso et al¹¹ developed and evaluated a self-assessment checklist for hazards associated with tractors modified for disabled operators. Their checklist had moderate reliability (kappa 0.427) when comparing results of six evaluators to each other, and to those of an expert rater (kappa 0.555).

In testing a self-audit for safety in auto-body shops, Bejan et al⁹ found a high percentage agreement between shop owners' and outside evaluators' responses in 11 shops. However, shop owners were found deficient in identifying items that were missing or out of regulatory compliance. Owners correctly identified only 22% of non-compliant items compared with 95% of compliant items. The authors concluded that studies of self-audit reliability should include assessment of the self-auditors' accuracy in order to ensure the usefulness of the audit instrument.⁹ In the present study, self-auditors' accuracy in identifying non-compliant items was 81% on initial analysis of the 32-item checklist, and 90% on re-analysis using 26 items, indicating that the concerns with accuracy noted by Bejan et al⁹ have been addressed for the LOTO self-audit.

A reliable OHS self-audit instrument has the potential to be an important component of intervention research by eliminating the need for costly site assessment visits by external auditors. For example, in the National Machine Guarding Program (NMGP), insurance safety consultants conducted machine safety audits and entered the data into laptop computers in order to provide immediate feedback to businesses.^{13,19,22} This demonstrated the usefulness of computerized algorithms to provide business-specific recommendations for hazard remediation and safety management. The site visits, however, proved to be costly and could not be maintained beyond the intervention period,²³ a need that is bypassed with a reliable self-audit instrument.

4.1 | Limitations

The primary limitation to this pilot study was that participants were a non-random sample of businesses selected on the basis of convenience.

Therefore it is possible that high-performing shops may have been more willing to participate than poor performers. However, the sample represents both high- and low-performing businesses, as four out of ten study sites had poor audit scores (<50% of items present).

4.2 | Conclusions

Field-testing of the LOTO self-audit at ten manufacturing firms demonstrated high inter-rater reliability, indicating that it would be useful in employers' efforts to regularly assess and improve their LOTO programs. Business self-auditors attained a high level of accuracy in identifying items that were not compliant with the OSHA LOTO standard. By removing the need for costly on-site visits from external auditors, this audit instrument can help overcome barriers of geography and cost in assessing LOTO practices at large numbers of manufacturing businesses.

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AUTHORS' CONTRIBUTIONS

Mr. Yamin was responsible for overall management of the research study, data collection and analysis, and drafting the manuscript. Dr. Parker served as the principal investigator and was responsible for the design, overall integrity and accuracy of the research, and drafting the manuscript. Dr. Xi was lead statistician and data analyst, and reviewed and approved the manuscript. Mr. Stanley managed data collection at several study sites, and reviewed and approved the manuscript.

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ETHICS APPROVAL AND INFORMED CONSENT

The Institutional Review Board (IRB) of HealthPartners Institute – Park Nicollet Institute approved all materials and methods. Consent to participate was obtained from each business owner or a representative, in the form of verbal consent and a written information sheet provided to the participant. Although verbal consent was obtained, a signature was not required because the study posed no risks to individuals or businesses participating and no health data or other data on individuals were collected.

DISCLOSURE (AUTHORS)

The authors report no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven B Markowitz declares that he has no conflict of interest in the review and publication decision regarding this article.

DISCLAIMER

None.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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