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An Exposure Prevention Rating Method for Intervention Needs Assessment and Effectiveness Evaluation

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This article describes a new method for (1) systematically prioritizing needs for intervention on hazardous substance exposures in manufacturing work sites, and (2) evaluating intervention effectiveness. We developed a checklist containing six unique sets of yes/no variables organized in a 2 × 3 matrix of exposure potential versus protection (two columns) at the levels of materials, processes, and human interface (three rows). The three levels correspond to a simplified hierarchy of controls. Each of the six sets of indicator variables was reduced to a high/moderate/low rating. Ratings from the matrix were then combined to generate a single overall exposure prevention rating for each area. Reflecting the hierarchy of controls, material factors were weighted highest, followed by process, and then human interface. The checklist was filled out by an industrial hygienist while conducting a walk-through inspection (N = 131 manufacturing processes/areas in 17 large work sites). One area or process per manufacturing department was assessed and rated. Based on the resulting Exposure Prevention ratings, we concluded that exposures were well controlled in the majority of areas assessed (64% with rating of 1 or 2 on a 6-point scale), that there is some room for improvement in 26 percent of areas (rating of 3 or 4), and that roughly 10 percent of the areas assessed are urgently in need of intervention (rated as 5 or 6). A second hygienist independently assessed a subset of areas to evaluate inter-rater reliability. The reliability of the overall exposure prevention ratings was excellent (weighted kappa = 0.84). The rating scheme has good discriminatory power and reliability and shows promise as a broadly applicable and inexpensive tool for intervention needs assessment and effectiveness evaluation. Validation studies are needed as a next step. This assessment method complements quantitative exposure assessment with an upstream prevention focus.

Keywords Intervention Research, Intervention Effectiveness Research, Evaluation Needs Assessment, Upstream Prevention, Hazardous Substances

NIOSH identified "intervention effectiveness research" as a National Occupational Research Agenda priority area in 1996, recognizing the need for expanded research efforts on how best to translate occupational health and safety (OHS) knowledge into exposure prevention and control in the workplace.[(1)] Yet, there remains a need for broadly applicable methods for systematically assessing intervention needs and impacts.[(2,3)] Because hazardous substance exposures contribute substantially to the burden of occupational disease,[(4)] efficient methods for rating a broad array of substances with comparable metrics would be particularly useful.

Quantitative exposure or dose assessment remains the gold standard for assessing the effectiveness of interventions on hazardous substance exposures. Several considerations, however, point to the need for complementary non-analytical methods. Quantitative exposure assessment may be appropriate where one or only a few contaminants are being addressed (e.g., in

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the recent Minnesota Wood Dust Study[5,6]), but is less feasible when the aim is to assess a variety of contaminants.

In addition, needs assessment must take prevention and control efforts into account along with exposure levels. Quantitative exposure measurements, however, do not provide information on existing control measures and do not point to upstream prevention and control alternatives. Statistical power considerations also come into play in designing intervention effectiveness evaluations. When evaluating change at the level of the work process or work site, it is often necessary to include multiple work sites in intervention and comparison groups in order to have sufficient power to detect intervention-related change. In such cases, the need for assessing intervention effectiveness across differing sets of substances by process or work site poses further feasibility and cost challenges to using quantitative exposure assessment.

We faced these challenges in evaluating the effectiveness of the Wellworks-2 intervention to reduce hazardous substance exposures. Wellworks-2 was a randomized, controlled trial examining the effectiveness of an integrated health promotion and occupational health protection intervention.[7] The central hypothesis was that blue-collar workers would be more likely to make changes in health risk factors that are primarily under their control (smoking and nutrition) if risk factors that were primarily under the company's control (occupational exposures to hazardous substances) were being addressed at the same time.

This article presents an exposure prevention (EP) rating scheme that we developed to evaluate the effectiveness of this intervention with respect to the prevention and control of hazardous substance exposures. This EP rating scheme was complemented by parallel evaluation with individual-level questionnaires and organizational-level assessment of OHS programs.[8] An earlier version of a walk-through exposure prevention assessment method, focusing solely on workplace carcinogens, was pilot tested in the Wellworks-1 trial.[9,10] This provided a starting point for the work described herein.

The EP rating scheme was designed (1) to systematically prioritize needs for intervention on hazardous substance exposures in manufacturing work sites, and (2) to evaluate intervention effectiveness. The rating scheme assesses the degree of upstream prevention efforts observable in a given process or similar exposure group. This provides a complement to—but not a replacement for—quantitative exposure assessment. Our goal was to develop a method that could be applied with modest expense by OHS researchers and other groups engaged in workplace prevention and control efforts (e.g., independent OHS professionals, company or union OHS staff). This report describes the theoretical basis, piloting and refinements, and utility for intervention needs assessment of the method. We present ratings and interrater reliability statistics for the 17 manufacturing worksites that participated in the baseline assessments of the Wellworks-2 trial and discuss our findings in relation to similar work by other investigators.

METHODS

Study Design and Population

Wellworks-2 used a randomized, controlled design with work site as the unit of randomization. After baseline data collection, study sites were randomly assigned to treatment conditions of work site health promotion only ("standard care" or control) versus work site health promotion integrated with occupational health protection ("integrated" intervention).[7]

The principal selection criteria for Wellworks-2 study sites were: (1) manufacturing industry work sites employing between 400 and 2000 workers; (2) probable use of hazardous substances; and (3) turnover rate <20 percent to avoid excessive loss to follow-up. We used Dunn's Direct Access to identify 89 manufacturing companies (defined by Standard Industrial Codes 20–39) of appropriate size that were located in eastern Massachusetts counties. All 89 companies were contacted; 41 were determined to be eligible for the study.

Seventeen sites participated in baseline assessments for the study, including three physically distinct sites from a single, large company. Table I briefly describes the participating sites by type of manufacturing and number of employees. Median establishment size was 596 employees. Employees were predominately white (81%), male (63%), middle-aged (median age category 41–50 years), hourly workers (68% hourly versus 32% salaried). Further demographic and other descriptive data on study sites and population are available elsewhere.[7]

Wellworks-2 Intervention and Evaluation Overview

A brief description of the Wellworks-2 intervention and evaluation strategy is necessary to understand the needs assessment function of the EP rating scheme. We assessed intervention outcomes and intervening variables pre- and post-intervention at three levels: (1) the physical environment (using the EP rating scheme described in this report), (2) the organization (assessment of OHS programs,[8] as well as health promotion relevant characteristics, such as smoking policies), and (3) the individual worker (through confidential employee surveys of health behaviors, work practices, perceptions of OHS conditions, and other variables).[7]

The Wellworks-2 intervention was 16 months in duration. We used baseline assessment findings to tailor intervention activities to the needs of each study site. Corresponding to our needs assessment and evaluation strategy, the interventions targeted three levels: (1) the physical work environment (through specific recommendations for changes in materials, processes, and other exposure prevention and control measures), (2) the organization (through management-level intervention on general OHS management principles), and (3) the individual worker (through worker educational activities).[7] Wellworks-2 occupational health intervention efforts focused primarily on exposures to hazardous substances, and not on other hazards. The findings of the baseline EP data were most relevant to intervention at

TABLE I
Study site descriptions and production areas assessed per site

Treatment condition	Site description	Establishment size (# of employees)	Production areas assessed (#)
(HP only)	Adhesives Mfg[A]	862	9
	Food products	516	3
	High tech mfg #1	478	8
	High tech mfg #3	1391	9
	Jewelry mfg	424	11
	Motor controls	847	5
	Paper products	468	6
	Newspaper #2	599	6
HP+ (Integrated HP/OH[A])	Abrasive products	596	7
	Automotive products	1585	14
	High tech mfg #2	442	4
	High tech mfg #4	893	3
	High tech mfg #5	399	2
	Metal fabrication #1	581	6
	Metal fabrication #2	775	16
	Metal fabrication #3	810	15
	Newspaper #1	588	7
Totals	17 sites	12,254	131

[A]Abbreviations used: Mfg = manufacturing; HP = health promotion; HP+ = health promotion integrated with occupational health protection; OH = occupational health.

the physical work environment level, which was addressed in the intervention through on-going consultations delivered by an industrial hygienist at the management or organizational level (average of 18 management OHS consultations at integrated intervention sites by staff industrial hygienists over intervention period[11]). Study staff reviewed walk-through checklist data collected at each site in detail, and presented written and oral summary reports and recommendations at the beginning of the intervention period to work site OHS staff, management, and unions (if present) in the integrated intervention.

Theoretical Basis and Checklist Content

The practice of occupational hygiene entails the anticipation, recognition, evaluation, and control of exposures to health hazards in the workplace.[12] The further "upstream" from exposure one aims in practicing occupational hygiene, the more likely one is to achieve the preferred goal of exposure prevention versus control. Hazard prevention aims to avoid the creation of hazards, whereas hazard control aims to reduce or mitigate hazards once they have been created.[13] We exposure devised our rating scheme in line with these principles.

We applied a simplified "hierarchy of controls"[14] to express a gradient of upstream (*materials* correspond with *source* of the hazard) versus midstream (*process* corresponds with *path* between source and worker) versus downstream (*human interface* corresponds with the level of the worker as the *receiver* of exposure) preventive efforts. This was combined with an examination of the balance between exposure potential and exposure protection at each of these three levels. The resulting Potential and Protection matrix, expressed as a 2×3 table, allows both a horizontal (balance of Potential and Protection at each level) and a vertical (degree to which those efforts are focused upstream) assessment of exposure prevention. Previous studies documenting upstream shifts in hazardous substance control efforts in response to toxics use reduction legislation demonstrate the feasibility and increasing receptivity of employers to this approach.[15] Valuing of an upstream focus is further reinforced by similar principles in other aspects of public health.[16]

Six sets of indicator variables (yes/no) were developed to assess exposure Potential and Protection at the Material, Process, and Human Interface levels (detailed in Table II). Three potential routes of exposure (inhalation, dermal, ingestion) and a wide range of prevention and control—or protection—methods are assessed. Material indicators include material properties, hazard monitoring, and hazard inventory-keeping. Process level indicators include specific process types, equipment, physical conditions, and engineering and other controls. Human interface indicators include work tasks, work practices, and personal protective equipment (PPE) requirements and use.

Data Collection

Hazardous substance exposures were expected to be most common in production departments. Each production department at each site was briefly assessed by walk-through to identify

TABLE II
Potential/protection matrix, indicator variables, and inter-rater agreement

	Potential		Protection	
	2 Points	1 Point	2 Points	1 Point
Materials	• Materials with high vapor pressure (77)[A] • Chemical with "Skin" designation (100) • Process involves multiple sources (62) • Process involves a large surface area (62)	• Combustion products (85) • Decomposition products (100) • Drying of liquid-covered parts (73)	• Routine monitoring performed (92) • Hazard assessment performed as per PPE[B] standard (100)	• Non-routine monitoring performed (83) • MSDSs[B] present (90) • MSDSs readily available (100)
Process	• Spraying as a primary activity (100) • Generate mist or spray as a by-product (95) • Transfer of material (97) • Abrasive blasting (100) • Welding, brazing, cutting (92) • Crushing, sanding, grinding, buffing (100) • Electroplating (92) • Elevated temperatures (75)	• Open tanks or containers (100) • Mechanical mixing (92) • Molten metal (100) • Release of particulates (100) • Machining (85) • Plastic molding (100) • Semiconductor manufacturing (100) • Elevated pressure (83)	• Process is totally automated (92) • Process is totally enclosed (92) • Appropriate and adequate local exhaust ventilation (78) • Operator is totally enclosed (100)	• Process is semi-automated (69) • Process is partially enclosed (69) • Local exhaust ventilation present, but not appropriate or adequate (92) • Make-up air adequate (67) • General dilution in the area (54) • Local ventilation checked routinely (38)
Human interface	• Manual application of liquid (92) • Manual mixing or stirring of material (100) • Employees smoke at workstations (100) • Ingestion is significant route of exposure (100) • Use of compressed air for cleaning (62) • Employee health complaints from inhalation exposures (64) • Employee health complaints from dermal exposures (50) • Evidence of dermatitis or other symptoms of dermal exposures (12)	• Dipping parts into liquid (100) • Heavy workload/ increased metabolic rate (100) • Work surfaces covered with liquid (88) • Cleanup of process liquids (69) • Employees eat or drink at workstation (62) • Work practices contribute to inhalation exposure (50) • Work practices contribute to dermal exposure (12)	• Respirators required (100) • Protective clothing required (92) • Material handling automated (100) • Housekeeping better than average (77)	• Respirators used (100) • Protective clothing available and appropriate (85) • Hand cleaning facilities nearby (69) • Designated eating/ break areas (77) • Respirators readily available (36) • Respirators appropriate to task (55) • Appropriate gloves readily available (50) • Work practices contribute to protection (39)

[A]Interrater agreement (percent).
[B]Abbreviations used: PPE = Personal Protective Equipment; MSDS = Material Safety Data Sheet.

all production processes and to gain a general sense of OHS in the department (typically required 10–15 minutes). This included assessments of general air quality, housekeeping, obvious safety issues, odors, evidence of spills of potentially hazardous substances, and visible evidence of hazardous contaminants. This served to identify within each department the production area(s) or work process(es) where hazardous substance exposures were most likely, and where exposures were anticipated to be qualitatively similar (similar exposure groups). Where there was more than one process in a given department, we focused on the process of greatest concern within each department, as judged by the professional opinion of the industrial hygienist conducting the walk-through.

Criteria for choosing the process of greatest concern within a department included the use of hazardous materials with low occupational exposure limits and the amounts of such materials used, the number of workers potentially exposed, and the specifics of the process, including the manner in which contaminants were generated and the presence or absence of control measures. Plans to incorporate findings from a parallel review of each site's Material Safety Data Sheet (MSDS) files were abandoned. We judged MSDS file information not to be useful because of outdated files (e.g., materials no longer used) as well as lack of information linking hazardous substances represented in MSDS files to the areas within the work site where they might be used (data not shown).

The rationale for the "highest priority" approach was to identify systematically those exposure situations in greatest need of intervention, to distribute intervention efforts throughout the production departments of each work site, and to enable assessment at an adequate level of detail to support specific recommendations for intervention. This yielded a comprehensive and systematically prioritized assessment of hazardous substance exposures for each work site, as well as specific guidance for addressing the exposures of greatest concern.

We pilot-tested the checklist and walk-through procedures at a Boston area rope manufacturing plant that was not participating in Wellworks-2. The checklist and written procedures were then finalized before use in Wellworks-2 baseline assessments. All baseline walk-through assessments as well as pre-visit contacts, site visits, and MSDS reviews, were conducted by the same industrial hygienist. He was guided on walk-throughs by a site OHS staff person at 14 sites and by a human resources staff person at three sites. Completion of the walk-through assessment and checklist for each area typically required 20–30 minutes, with a range of 10–60 minutes per area.

Measures

Figure 1 outlines the generation of measures from the walk-through checklist. For each set of checklist indicators (six cells of 2×3 matrix), a simple weighting scheme was applied wherein those factors that typically contribute more strongly to potential for or protection from exposure were assigned a value of 2 points, and those that contribute less strongly were assigned a value of 1 point (e.g., process totally enclosed = 2 points, partially enclosed = 1 point) (Table II). An ordinal score for each cell was computed by summing the points for each indicator variable observed in that cell. Ordinal scores were then categorized as representing low, moderate, or high Potential or Protection, such that each cell is weighted equally despite the varying numbers of indicators contributing to each of the six ordinal scores. The cut points for low, moderate, and high were set by the industrial hygienists as representing the qualitative assessment they would give to an area or process with the corresponding numeric score. This set of six ratings for each area provides the greatest detail for needs assessment as well as the most sensitive measures for evaluating intervention impacts.

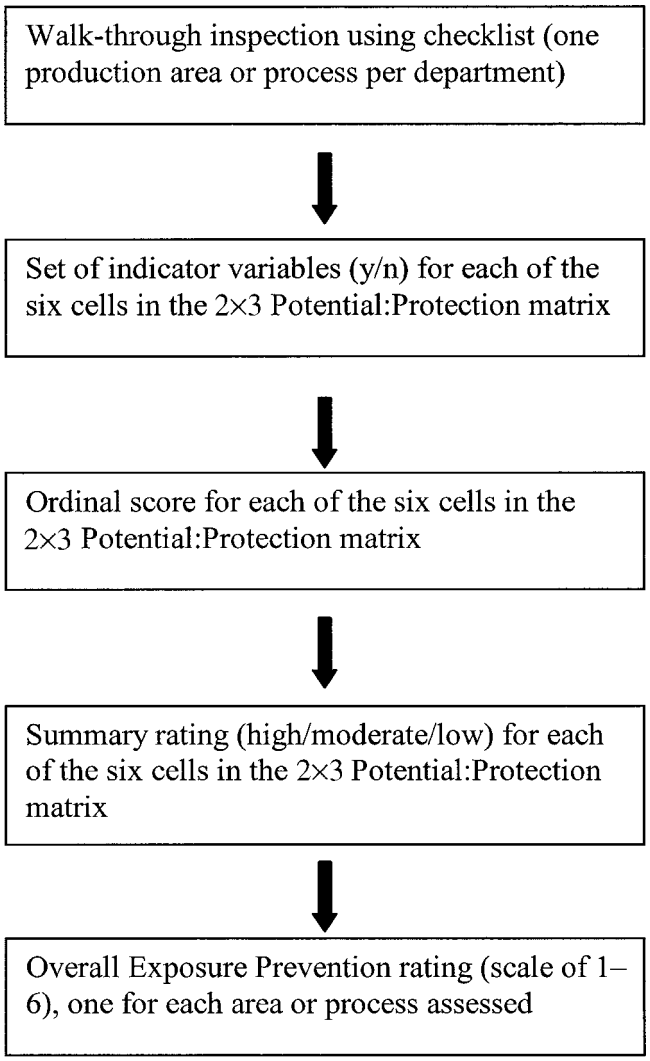

FIGURE 1
Outline of data collection and generation of exposure prevention ratings.

Next, we computed an overall rating of the degree of upstream exposure prevention effort for each area assessed (Figure 1, last step). The measure made use of 5 of the 6 cells in the

Potential/Protection matrix. The Material Protection cell was excluded for two reasons: because of poor interrater reliability, as outlined in further detail in the Results section, and because of substantial overlap with our parallel organization-level assessment of OHS programs, which is described in a separate report.[8] EP ratings ranged from 1 (best, minimal intervention, if any, needed) to 6 (worst, extensive intervention needed urgently). The best rating was defined by low potential for toxic hazards due to the use of materials with low inherent toxicity.

Where Material Potential was medium or high, but the process in which these materials were used had low Potential for emissions (low Process Potential), these areas were assigned a rating of 2. Where Material Potential was medium or high and Process Potential was medium or high, but this was offset by good engineering controls (Process Protection = high), these areas were assigned a rating of 3. Where similar conditions to a rating of 3 prevailed, but engineering controls were modest or weak (Process Protection = medium or low) and there was little potential for exposure at the Human Interface, these areas were assigned a rating of 4. Where Material Potential was medium or high, Process Potential was medium or high, engineering controls were weak or modest, but effort was made to protect workers with personal protective equipment (Human Interface Protection = high), these areas were assigned a rating of 5. Finally, if there was only a modest or weak level of personal protection under the other conditions prevailing for a rating of 5, these areas were assigned the worst rating of 6.

In short, this EP rating scheme cascades downstream in terms of proximity of preventive efforts to the source of the hazard. Accordingly, materials are considered first, followed by process, and finally by human interface. Similarly, at each level (materials, process, human interface), low potential was judged as more desirable than high protection.

Evaluation of Interrater Reliability

A second industrial hygienist also administered the walk-through checklist in 13 production areas across three study sites for the purpose of evaluating interrater reliability. The written guidelines for administration were followed by both hygienists (both were also involved in the development and the writing of the guidelines). Assessments were conducted on the same day, within a short time of each other, such that the conditions evaluated were as close to identical as possible. The two hygienists assessed each area independently and did not communicate during assessments.

Analysis

The individual indicator variables and ratings were tabulated over the departments assessed, with percentages reported. Although production areas were clustered within work sites, we treated the assessment of each production area as an independent measurement for these descriptive analyses.

For assessing the interrater reliability in the 13 production areas with double assessments, we first computed the percent agreement between the two observers for each item. A priori, we set a minimum lower bound of 60 percent agreement for inclusion in computation of ratings. Secondly, percent agreement was computed for the six Potential/Protection matrix ratings (low/moderate/high), as well as for the overall upstream prevention summary ratings (6-point scale) for each area assessed. Weighted kappa statistics were then calculated for each of these seven ratings. Standard arithmetic weighting was used for the six three-point scales and the one six-point scale evaluated. The kappa statistic ranges from negative when the raters disagree more than would be expected by chance, to 0 when the amount of agreement is what would be expected by chance, and up to 1 when there is perfect agreement.

RESULTS

Production Processes Assessed

The total number of production areas assessed at each of the 17 work sites ranged from 2 to 16, with a median of 7 per site (Table I). Because one assessment was made per department, these frequencies also describe the total number of production departments at each of the 17 sites. Most commonly, there was only one process or area available for assessment in a given department ($49/131 = 37\%$), and thus no prioritization or selection among processes within these departments was required. An additional 44 departments had two ($26/131 = 20\%$) or three ($18/131 = 14\%$) processes or areas, with the remainder having more than three.

In those departments with more than one process or area, the unrated areas had minimal potential for hazardous substance exposures and were low priority for intervention relative to the rated area. Thus, the rated areas were representative of hazardous substance exposures of concern department-wide. Examples of rated (selected as highest priority by industrial hygienist) versus unrated processes within departments include: selection of assembly versus testing of electronic components; selection of degreasing versus assembly of metal parts; plating versus racking and unracking in jewelry manufacturing; cleaning versus inspection and packing at a food products plant; and printing versus cutting, hole-punching, and shrink-wrapping of paper products.

A wide variety of hazardous substances were captured in rated processes, including several carcinogens (e.g., cadmium, methylene chloride, silica, metal-working fluids), irritants (e.g., acids, nickel compounds), asthmagens (e.g., epoxies, formaldehyde), and reproductive hazards (e.g., lead, arsenic, solvents).

Needs Assessment

Findings from walk-through assessments were used to identify and prioritize intervention needs for sites randomized to the integrated intervention condition. Findings were summarized in narrative form, communicated to work sites, and used to guide intervention efforts targeting change at the levels of the physical work environment, the organization, and the worker.

While it is beyond the scope of this report to present all the details included in these reports, below we present one illustrative detailed example from an assessment of a newspaper printing operation.

Several specific recommendations for interventions at the Material, Process, and Human Interface levels were identified. These included continuing the installation of flexographic presses to eventually eliminate exposure to oil-based inks and the organic solvents required to clean such inks from the presses; investigating possible alternatives to the current petroleum-based inks, such as soy or other vegetable-based oils; installing enclosures or local exhaust ventilation for paper folders to reduce the large amount of paper dust generated during paper handling and printing; developing and implementing a comprehensive PPE training program for employees who service the presses between printing runs (including selection, maintenance, and use of PPE, as well as improved education on preferred control measures such as substitution, use reduction, and engineering controls).

Selection of Indicator Variables for Ratings

Item-by-item interrater agreement is presented in Table II. The percent agreement of most Materials indicators was good to excellent. Two items were dropped from ratings due to combined data quality concerns over fair interrater agreement and ambiguous categorization as Process versus Materials (insufficiently precise wording). These items were "process involves large surface area" and "process involves multiple sources."

Overall, Process Potential had excellent interrater agreement, with 100 percent occurring most frequently (for 8 items) and 75 percent the lowest. Process Protection was good to excellent, with half of the items at or above 92 percent agreement, and three items between 67 and 69 percent. The last two 1-point Process Protection items (Table II, lower right of Process row) were excluded from rating due to low interrater agreement (54 and 38%).

At the Human Interface level, interrater agreement varied widely, with a high of 100 percent (8 items) to a low of 12 percent (for "work practices contribute to dermal exposure" and "evidence of dermatitis or other symptoms of dermal exposure"). Sixteen items had good to excellent agreement (69% or greater). However, eleven items had fair to clearly unacceptable percent agreement (64 down to 12%). The three health complaint and symptom items had poor interrater agreement when taken as a group: "employee health complaint items from inhalation exposures" (64%), "employee health complaints from dermal exposures" (50%), and "evidence of dermatitis or other symptoms of dermal exposures" (12%). Most of these low percent agreement items were on the Potential side (7 of 11). These eleven Human Interface items were excluded from ratings.

In summary, we raised our a priori minimum of 60 percent interrater agreement to 67 percent due to the subjective judgement of reliability (the two hygienists were uncomfortable with the "multiple source" and "large surface area" questions as administered) and face validity (investigators collectively decided to delete the set of three employee symptom questions). Only those items that achieved at least 67 percent interrater agreement were retained for the next step: computation of ratings.

Exposure Prevention Ratings

At the Material level, most areas were rated either low or moderate for Potential (80% combined), whereas most areas were rated high for Protection (Table III, first row). At the Process level, most areas were rated either low or moderate for Potential (82% combined), with the smallest proportion rated high (Table III, second row). Most areas were rated either high or moderate for Process Protection. In contrast to the two other levels, Human Interface Potential was usually rated low (74%), followed by moderate (21%), with very few areas rated high (5%). Human Interface Protection was almost always rated either high or moderate (91%), with few areas rated low (9%).

The definitions and frequencies of overall area EP ratings are presented in Table IV. In summary, these results suggest that there is a fairly urgent need for improvements in roughly 10 percent of the areas assessed (ratings of 5 and 6), that there is

TABLE III
Potential/protection matrix: Rating frequencies (N = 131)

	Potential			Protection		
	Rating	N	%	Rating	N	%
Materials	High: ≧ 4 points	26	19.8	High: ≧ 4 points	71	54.2
	Moderate: 2–3	54	41.2	Moderate: 2–3	44	33.6
	Low: 0–1	51	38.9	Low: 0–1	16	12.2
Process	High: ≧ 6 points	24	18.3	High: ≧ 4 points	51	38.9
	Moderate: 3–5	55	42.0	Moderate: 2–3	36	27.5
	Low: 0–2	52	39.7	Low: 0-1	44	33.6
Human interface	High: ≧ 5 points	6	4.6	High: ≧ 4 points	55	42.0
	Moderate: 3–4	28	21.4	Moderate: 2–3	64	48.8
	Low: 0–2	97	74.0	Low: 0–1	12	9.2

TABLE IV
Upstream exposure prevention rating scale: explanation and observed frequencies

Rating	Definition: Explanation	Intervention recommendations in order of preference	N	%
1	Material Potential low: Because the materials used have low inherent toxicity, Process Potential and Human Interface are of minimal concern.	• Minimal	51	38.9
2	Material Potential medium or high, but Process Potential low: Because there's limited potential for exposure from the process in question, then there's minimal potential for worker exposure at the Human Interface.	• Reduce Material Potential • Improve Engineering Controls	33	25.2
3	Material Potential medium or high, Process Potential medium or high, but Engineering Controls high: Material and Process Potential are significant or of concern, but well-addressed by permanent exposure controls.	• Reduce Material Potential • Reduce Process Potential	21	16.0
4	Material Potential medium or high, Process Potential medium or high, Engineering Controls low or medium, but Human Interface low: Material and Process Potential significant or of concern, but offset by low potential for exposure at the Human Interface.	• Reduce Material Potential • Reduce Process Potential • Improve Engineering Controls	13	9.9
5	Material Potential medium or high, Process Potential medium or high, Engineering Controls low or medium, Human Interface medium or high, but PPE high: Material and Process Potential significant, and matched with inadequate permanent exposure controls and an over-reliance on control at the worker through PPE.	• Reduce Material Potential • Reduce Process Potential • Improve Engineering Controls • Reduce Human Interface Potential • Rely less on PPE	6	4.6
6	All Potentials medium or high, and Engineering Controls and PPE low or medium: Exposure potential likely to be inadequately matched by protective measures.	• Reduce Material Potential • Reduce Process Potential • Improve Engineering Controls • Reduce Human Interface Potential • Rely on PPE only as a temporary stopgap measure	7	5.3
	Totals:		131	100

TABLE V
Exposure prevention ratings: Weighted kappa interrater reliability statistics (N = 13 areas)

Assessment level	Interrater agreement (%)	Weighted kappa	95% confidence interval
Potential/Protection matrix (high/moderate/low):			
Material Potential	85	0.80	0.58–1.00
Process Potential	77	0.70	0.43–0.96
Human Interface Potential	62	0.45	0.17–0.74
Material Protection	54	0.38	0.02–0.74
Process Protection	85	0.71	0.41–1.00
Human Interface Protection	77	0.69	0.40–0.97
Area summary score (6-point scale):			
	85	0.84	0.67–1.00

some need for improvements in another 10 percent (rating of 4), that there is still room for improvement—though not urgent—in another 16 percent (rating of 3), and that exposures were well controlled in the majority of areas assessed (64% of areas with ratings of 2 or 1). The third column in Table IV presents generic intervention recommendations in order of preference. These recommendations reflect the rationale of the rating scheme and encourage upstream over downstream intervention efforts, first emphasizing material factors, then process, with human interface intervention recommended only as a temporary stopgap measure.

Inter-Rater Reliability

The percent agreement and interrater reliability of computed ratings are presented in Table V. In the Potential/Protection matrix, Material Potential ratings (high/moderate/low) had the highest level of perfect agreement (85%), and Material Protection had the lowest (54%). Correspondingly, weighted kappa statistics ranged from a high of 0.80 (excellent) to a low of 0.38 (marginal). Landis and Koch suggest the following interpretations for kappa values: $\kappa > 0.75$, Excellent; $0.40 \leqq \kappa \leqq 0.75$, Good; $0 \leqq \kappa < 0.40$, Marginal.[17] The 95 percent confidence limits of some point estimates were wide, reflecting the small sample size (n = 13 areas), but all excluded zero (agreement equal to what would be expected by chance).

The marginal interrater reliability of Material Protection is most likely attributable to the particular difficulty of observing this phenomenon on walk-through inspection. Assessment of activities in this category was also duplicated—and assessed in greater detail—at the organizational level in the OHS program assessment (in particular under the OHS program category of Hazard Analysis, described in a separate report[8]). Because of the poor field performance of Material Protection, its more appropriate suitability for assessment as an aspect of OHS programs, and the primacy of Material Potential over Protection, we excluded it from computation of overall area EP ratings.

The percent agreement of the overall EP ratings (6-point scale) was excellent (85%). Similarly, the weighted kappa statistic indicated excellent interrater reliability (0.84, with a lower 95% confidence limit of 0.67).

DISCUSSION

A hazardous substance EP rating method has been developed to serve the dual purposes of intervention needs assessment and effectiveness evaluation. This method complements quantitative exposure assessment with a systematic and efficient assessment of prevention and control efforts with an emphasis on upstream alternatives. It has been designed for use by practicing OHS professionals with limited budgets, and by researchers and evaluators as an intervention process and effectiveness evaluation tool.[3]

Initial field application of the EP rating method has shown it to be capable of providing common metrics across various hazardous substance exposures found in 131 work process areas at 17 large manufacturing work sites. While broad applicability and reasonable discriminatory power have been demonstrated, further development work is needed. Most importantly, this includes needs for additional indicator variables at the Materials and Human Interface levels, and validation of EP ratings against quantitative and other exposure metrics. Discussion of initial field performance and needs for further development work are discussed in turn below.

Development of Indicators and Data Collection Procedures

The initial interrater agreement screening of candidate indicator variables demonstrated that a high level of reliability can best be achieved with items that can be readily and consistently observed; thus, the Process level was clearly best, followed by Materials and Human Interface. Process level variables lent themselves best to walk-through observation in this study presumably because they tend to be permanent structural features that are observable even when a process is not running. The Material level had the lowest number of indicator variables to start with and was further reduced after dropping of two indicators

with low percent agreement. Needs for refinement of Material level indicators include developing ways to incorporate inherent toxicity, scale of use, and use of multiple hazardous substances. Insights from other investigators engaged in similar efforts are discussed below.

We observed the greatest variability in interrater agreement at the Human Interface level. This level includes certain task types and work practices, as well as PPE requirements, availability, and usage. Most of these items were difficult to observe (e.g., gloves readily available), could change momentarily (e.g., observed work practices), or would rely on questioning of the walk-through guide or workers for determination (e.g., respirators readily available, health complaints, or symptoms). By initial inclusion of health complaint and symptom questions (Human Interface level), we had hoped to integrate the results of inadequate prevention and control at all three levels (Materials, Process, and Human Interface). Without direct questioning of workers, however, these indicators are very unreliable (as well as possibly invalid) and have been dropped from consideration. However, confidential employee survey data on work-related health complaints as well as other OHS issues have also been collected and will be compared to EP ratings in a separate report.

Many of the indicators deleted might be reliably determined by additional interview of the walk-through guide, line supervisors, and workers in the area. While such interviews would surely provide a deeper and broader assessment, we anticipated that this would not be feasible in most study sites due to a combination of production pressures, the sensitivity of OHS issues in many workplaces, and other methodological issues. Methodological issues include the challenge of reliably interviewing workers in private while being guided by someone who is usually a management representative (in order to get frank responses and data of comparable quality across all areas assessed), and how to combine data in situations where different interviewees respond differently to the same or similar questions.

In summary, we believe that incorporating interviews of walk-through guide, line supervisors, and workers would overly complicate the administration of the EP rating checklist. Our strategy has been to gather data on worker perspectives (through confidential surveys at individual worker level) and OHS programs (organizational level) separately and in parallel to the EP rating assessments (physical environment level). Taken together, these three levels provide a comprehensive assessment of OHS conditions for both needs assessment and evaluation purposes.

EP Ratings

The distributions of ratings showed reasonable discriminatory power of the EP rating method, with a general pattern toward low Potential and high Protection ratings, and a distribution of overall EP ratings that was strongly skewed toward the favorable end. The frequency of favorable ratings in our sample is likely to be artificially elevated relative to the full population of manufacturing work sites due to the selection biases inherent in the study. Participating companies had to voluntarily agree to occupational health intervention together with health promotion if they were randomized to the integrated intervention group. Thus, companies that have exposure concerns or that do not place a high priority on occupational health would have been less likely to participate.

Despite the likely overestimate of favorable ratings, a gradient of intervention needs was identified in our sample. Significant fractions of the sample received the poorest ($\sim$10%) or intermediate ($\sim$26%) upstream prevention ratings. A strength of the graded upstream prevention ratings is that each rating has corresponding intervention recommendations to guide the user in shifting preventive efforts upstream to the next and subsequent ratings. In this regard, the detailed Potential/Protection matrix (set of six high/moderate/low ratings) and EP ratings perform a detailed needs assessment and prioritization function as well as providing baseline measures for effectiveness evaluation.

Interrater reliability of the five Potential and Protection ratings used to compute EP ratings was good to excellent, the overall EP ratings demonstrating the best reliability of all. Because the two observers were both involved in instrument and protocol development, however, this may overestimate the interrater reliability that would be observed with two completely independent reviewers working solely from the written protocol. While these results presented are favorable, further reliability studies are indicated.

Validity

The basis of the EP rating method on the hierarchy of controls supports the face validity of the measures. Furthermore, when used as pre- and post-intervention effectiveness measures as in this study, the baseline assessment of each area serves as its own reference or control, with the final evaluation metric being a measure of change. To the extent that a given area or process does not change fundamentally over the course of the intervention (e.g., gets replaced with an unrelated process or gets phased out), this strategy overcomes limitations inherent in comparing area ratings cross-sectionally.

We hypothesize that cross-sectional comparison of ratings or scores would show corresponding relative levels of hazardous substance exposures. This has not been assessed in the current study because of the developmental stage of the instrument, technical and economic feasibility issues, and concerns about decreasing participation. With respect to feasibility, numerous agents would have to be sampled many times in each area assessed, which would involve considerable expense. In addition, requests to conduct such extensive sampling in the recruitment phase would be likely to further bias the sample of participating companies toward those with relatively good exposure control programs.

One approach to validation would be to obtain summary measures from multiple quantitative exposure measurements for

each hazardous material in each area assessed. Measurements for each agent could then be transformed to a percent of a chosen set of occupational exposure limits (e.g., ACGIH, NIOSH, or OSHA). These summary percent OELs could be averaged into an overall percent OEL across the range of agents present in each given area, paired with EP ratings for each area, and analysed using standard correlational methods.

We considered requesting participating companies to share previously collected exposure data such that we could perform such a validation study. This was decided against due to the anticipated paucity of sampling data, the sensitivity of companies to sharing exposure data, and the above-described concerns about discouraging participation. The anticipated paucity of exposure monitoring data turned out to be the case: Routine monitoring was reported for only 19 of the 131 areas assessed. Importantly, this indicates that there is not enough company-collected quantitative exposure data available for validation studies. Additionally, it demonstrates a gap in workplace exposure assessment practice that might be addressed in part through the application of more economical alternative strategies such as the approach described in this report.

Applicability to Non-Manufacturing Work Contexts

With respect to the applicability of this approach to non-manufacturing work settings, we have also developed separate checklists for maintenance operations, laboratory settings, and office areas (focusing on indoor air quality). Further development of these could enable applications to non-production work areas in the manufacturing sector as well as to some non-manufacturing work settings. Similar assessment approaches to other hazardous exposures may also be feasible, such as ergonomic, safety, or other hazards. A recent report describes the development of a similar health and safety rating system for farm operations, wherein "positive aspects" are balanced against "negative aspects" for four different farm characteristics (operator attitude, operator characteristics, status of facility, and status of equipment).[18] A Site Rank Score is generated as the average ranking of the four characteristics. In this example, a very similar conceptual approach (essentially ranked protection and potential across four levels) was generated independently for a different work context. In summary, EP rating and related assessment approaches have broad applicability beyond manufacturing work settings.

Comparison to Similar Efforts by Other Investigators

In addition to the method described above for farming operations, a Web-based "COSHH Essentials" program was recently developed by the United Kingdom's Health & Safety Executive to support the implementation of the 1994 regulations on the Control of Substance Hazardous to Health (COSHH) in medium to small enterprises (www.coshh-essentials.org.uk).[19] In outline, "COSHH Essentials" combines yes/no and other questions (e.g., task duration) on an electronic form; the user enters information on the process or area level for the materials used and their inherent toxicity, various process or operational factors, and the scale of use.[19–21]

The entered information is processed by computer, the result being direction of the user to one or more of ~60 unique two-page advice sheets on appropriate control strategies.[19] This activity is generally referred to as "risk assessment" in Europe and Australia, but is roughly equivalent to what we have described in this article as intervention needs assessment. While "COSHH Essentials" provides a more sophisticated assessment of exposure potential and protection, it was not designed to serve as an intervention effectiveness evaluation measure.

Both the farm-based ranking method and the "COSHH Essentials" program were reported on after we had collected Wellworks-2 baseline data for our EP rating scheme in 1997. Working independently toward overlapping goals, the logic of the methods developed by these two independent groups and ours is strikingly similar. Differences between the methods provide opportunities for improvements in each. For example, the "COSHH Essentials" method provides insights for improving the assessment of Material Potential in our method, whereas the EP rating and farm hazard assessment methods provide insights for generating summary metrics from "COSHH Essentials."

CONCLUSIONS

The EP rating method shows great promise as a new tool for interventionists and intervention researchers alike, fulfilling needs assessment and evaluation functions that can be used singly or in combination. Most importantly, this systematic approach complements quantitative exposure assessment with its focus on assessing preventive efforts rather than the downstream phenomenon of worker exposure. The method guides and directs the user toward upstream prevention solutions to common hazardous substance exposure issues, encouraging prevention- over control-oriented occupational health practice in the workplace. The EP rating checklist and written administration guidelines are available to interested readers free of charge on request.

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