

Effectiveness of a Worksite Intervention to Reduce an Occupational Exposure: The Minnesota Wood Dust Study

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Exposure to wood dust has been associated with several cancers, including those of the nasal cavity, lung, and gastrointestinal tract and Hodgkin disease.^{1,2} Of these, the epidemiological evidence is strongest for cancers of the nasal cavity,^{3,4} and in 1994, the International Agency for Research on Cancer declared wood dust a known carcinogen.² Other adverse health effects of wood dust include allergic respiratory diseases, bronchitis, and dermatitis.⁵ According to the US Census Bureau, approximately 1.75 million people are employed in wood products, paper, furniture, and related product manufacturing.⁶

The state of intervention effectiveness research for occupational health and safety has been detailed in several reviews of studies conducted primarily from the 1980s through the mid-1990s.^{7–10} In general, these reviews concluded that occupational health and safety studies were more likely to focus on worker knowledge and behavior than on engineering or administrative improvements in the workplace, were usually restricted to a limited number of workers within a single worksite, were quasi-experimental or nonexperimental without a comparison group, lacked a theoretical framework, and typically based outcomes on worker self-report rather than on more objective outcomes such as a reduction in injuries or hazardous exposures. In addition, most health and safety research has targeted large industries with many employees, even though small businesses (i.e., those with fewer than 100 employees) constitute 98% of all businesses and employ approximately 57% of the US workforce.¹¹

The Minnesota Wood Dust Study was designed to address both an important health hazard—wood dust—and many of the limitations of previous research conducted in the occupational setting. To assess the effective-

Objectives. This study assessed the effectiveness of an intervention to reduce wood dust, a carcinogen, by approximately 26% in small woodworking businesses.

Methods. We randomized 48 businesses to an intervention (written recommendations, technical assistance, and worker training) or comparison (written recommendations alone) condition. Changes from baseline in dust concentration, dust control methods, and worker behavior were compared between the groups 1 year later.

Results. At follow-up, workers in intervention relative to comparison businesses reported greater awareness, increases in stage of readiness, and behavioral changes consistent with dust control. The median dust concentration change in the intervention group from baseline to follow-up was 10.4% (95% confidence interval = -28.8%, 12.7%) lower than the change in comparison businesses.

Conclusions. We attribute the smaller-than-expected reduction in wood dust to the challenge of conducting rigorous intervention effectiveness research in occupational settings. (*Am J Public Health.* 2002;92:1498–1505)

ness of an intervention aimed at reducing wood dust by approximately 26%, a reduction deemed feasible on the basis of published literature and our pilot study results,^{12,13} we randomly assigned 48 woodworking businesses, each of which employed 5 to 25 woodworkers, to intervention or comparison conditions. Drawing from the health promotion field, in which the use of interventions tailored to meet an individual's specific barriers to change has been effective in changing health-related behaviors such as smoking,¹⁴ diet,¹⁵ and breast cancer screening,^{16–19} the intervention consisted of general written recommendations, technical assistance to enhance engineering, administrative methods to control wood dust, and worker training to modify work practices associated with high dust production, based on an evaluation of the specific needs of each business. Businesses in the comparison condition received written recommendations alone. Changes from baseline to 1-year follow-up in dust concentration and worker behavior were compared between woodworking businesses assigned to the intervention and those in the comparison condition.

METHODS

Setting and Design

We conducted the Minnesota Wood Dust Study in the 7-county metropolitan region surrounding Minneapolis and St. Paul, Minn. We relied on the PRECEDE-PROCEED model of Green and Kreuter²⁰ to develop an intervention acceptable to the woodworking industry. We were guided by a planning committee of individuals in the woodworking industry, including business owners, government officials, technical-college instructors, health and safety professionals, and trade association representatives.

We also conducted a pilot study¹³ in 5 woodworking businesses to guide design aspects of the study.^{21,22} Personal exposures to dust for workers in these businesses ranged from 0.3 to 36.0 mg/m³; methods to control dust were available for 53% to 72% of the daily tasks performed and were used by workers 59% to 86% of the time. Subsequent analysis (in the log scale) indicated that higher availability and use of dust control methods in these businesses could achieve a 26% relative reduction in dust concentrations

(−0.30 in the log scale) between intervention and comparison businesses. We then developed an intervention and assessed its effectiveness in reducing dust in a nested, cross-sectional, group-randomized trial design,²³ in which small businesses that manufacture wood products were the unit of randomization and different, independent samples of workers were selected to participate from each business at 2 time points.

Sample Selection, Recruitment, and Retention

We used the Minnesota Forest Products Directory (1995–1997 edition), the Minnesota Manufacturers Register (1998), the American Business Disc (1997), the Minnesota Directory of Manufacturers (1996), and Worldpages (Internet yellow pages, 1997) to assemble a sampling frame from which we randomly selected businesses for possible study participation. A business was eligible for the study if it had between 5 and 25 employees engaged in production, had been in business for at least 1 year, and was engaged in the manufacture of wood cabinets, furniture, or fixtures (Standard Industrial Classification codes 2434, 2511, 2512, 2521, 2531, and 2541). We recruited businesses sequentially over 1 year. Of the 189 businesses contacted, 122 (64.6%) were ineligible according to our criteria. A total of 48 businesses (71.6% of those eligible) agreed to participate. Master's-level industrial hygienists collected baseline data before randomization of each business to intervention or comparison condition and followed the exact procedures again in each business 1 year later. Only 1 business (assigned to the intervention) was not available at the 1-year follow-up.

Data Collection

Work practices survey. Workers and the business owner completed a self-administered questionnaire on work practices related to control of wood dust. Individuals indicated their interest in controlling wood dust, the importance they ascribed to dust control, how informed they were about dust control methods, and how confident they were in their ability to control dust. We developed a measure to stage individuals in their intentions and actions to control dust, similar to a

stages-of-change model²⁴ for behaviors such as smoking and diet. We created scales to assess workers' self-reports of perceived effectiveness of dust control (6 items) and work practices related to dust control (8 items). Workers also responded to questions about factors that encouraged or discouraged the use of dust control, such as management support (or lack thereof) or inconvenience of using dust control (e.g., ventilation), as well as the general health and safety environment in the business (e.g., presence of a health and safety officer or committee, work practice guidelines). Information about length of experience as a woodworker, number of years employed by the business, and other demographics also was collected.

Dust measurements. We randomly selected up to 5 production workers for personal sampling of inhalable dust levels on 2 days per business (10 measurements maximum per business). Personal exposures to dust were measured for each worker over the workday with inhalable samplers (IOM samplers; SKC Inc, Eighty-Four, Pa) designed by Mark and Vincent²⁵ with a gravimetric method.¹³ Inhalable sampling was selected because results could be directly compared with the proposed American Conference of Governmental Industrial Hygienists threshold limit value of 5 mg/m³ for inhalable dust.²⁶ Inhalable sampling is the most appropriate method of measuring wood dust levels because the health effects from exposure (e.g., nasal cancer, other respiratory illnesses) occur throughout the respiratory tract. Eight-hour time-weighted average concentrations of dust were calculated for each worker sampled; a dust concentration at the business level was obtained by taking the mean of the worker concentrations.

Task observation. For each worker being sampled, we simultaneously recorded (at 15-minute intervals) the specific work task performed, or tool used, and whether dust control was applicable to the task and available to the worker. If a dust control method was available, we recorded whether the worker made use of it while performing the task. For example, tasks performed with table saws create dust that can be controlled via a hood attached to a central ventilation system. If a worker was using a table saw, we checked that the tool was connected to a

ventilation duct (i.e., dust control available) and that the duct was operating while the worker used the tool (i.e., dust control used). We grouped tasks into 7 categories, based on similarities of specific tasks in function and dust production: (1) sanding with stationary tools; (2) sanding with handheld power tools; (3) sawing; (4) shaping, routing, molding, or milling; (5) cleaning in a manner that increased dust (e.g., blowing dust with compressed air); (6) cleaning in a manner that decreased dust (e.g., vacuuming); and (7) doing miscellaneous tasks that did not produce dust (e.g., reading a blueprint). For each business, we calculated the percentage of total time that workers spent in each of the 7 task groups and the percentage of total time that dust control methods were available and applied to the tasks performed.

Ventilation Assessment

Almost all businesses had a central dust collection (ventilation) system, for which we computed a measure of the system's efficiency by taking the ratio of measured airflow to recommended airflow. A pitot tube and slack tube manometer were used to take measurements of the system at least 7.5 duct diameters downstream from major obstructions, bends, or disturbances, in accordance with the American Conference of Governmental Industrial Hygienists ventilation manual.²⁷ After opening all blast gates, velocity pressure was measured in the main duct, and velocity and airflow were calculated for the system. The optimum airflow was determined by adding the recommended airflows (according to the American Conference of Governmental Industrial Hygienists ventilation manual) for all the tools attached to the system. The design and condition of the system were also noted.

Randomization

For each business, we prepared a written report summarizing baseline dust concentrations, tasks and efficiency of the dust collection system, and general recommendations for reducing dust levels. We then randomly assigned the business to the intervention or comparison condition. Businesses assigned to the comparison condition received their results by mail. Businesses assigned to the inter-

vention subsequently met with an industrial hygienist to review the results and begin the intervention process.

Intervention Description

The intervention was designed to include a combination of engineering, administrative, and behavioral components, tailored to the needs of the individual business. Emphasis was placed on improving the control of dust through more efficient dust collection systems, increasing the availability of dust control methods, and changing work practices; those tasks that produced the greatest quantities of dust (e.g., sanding) were targeted.¹³

We reassessed the dust collection system to obtain additional detailed technical information. This evaluation consisted of measuring branch duct flow and velocity for each individual tool attached to the central dust collector and comparing these measurements with the tool-specific recommended values from the American Conference of Governmental Industrial Hygienists ventilation manual.²⁷ For each tool, we assessed the hood design by visually inspecting the exhaust duct location for proximity to the site of dust production, comparing contours of hood design with those recommended by the American Conference of Governmental Industrial Hygienists ventilation manual, and evaluated maintenance of the duct and hood.

A 1-hour worker training session was designed with the following goals: (1) provide information about the health effects of dust, (2) build worker confidence in controlling dust, and (3) increase interaction among workers to encourage dust control. The training session was held during working hours and was designed to be flexible, informal, and participatory. Workers were informed about dust concentrations at their worksite and the effectiveness of dust control methods and were asked to participate in a problem-solving session to find ways to reduce dust levels by means practicable for their products and environment.

The information gathered from the second dust collection system assessment and worker training was reviewed by industrial hygienists, and another set of recommendations for controlling wood dust was given to each intervention business owner. We also included fact

sheets and case studies for specific types of dust control, as needed. We then met with the owner to collaboratively set priorities and help motivate changes in the worksite. A grant (\$650) was offered toward the purchase of equipment or expertise to facilitate implementation of the recommendations.

The final intervention component was a visit to a “model” business by owners and 2 workers of their choice. This component was intended to reinforce the recommendations, build relationships between business owners, and provide an opportunity to see how other owners were effective in controlling dust. A brief education session on dust collection systems and health and safety programs was held, followed by a tour of the model business’ production activities.

Process Evaluation

We queried the owner of each intervention and comparison business about implementation of any recommendations received and calculated the proportion of total recommendations adopted. Additionally, we tracked intervention business participation in each component of the intervention and the mean number of days from baseline required to complete the activity.

Analysis

Our primary outcome was a comparison of the difference in dust concentration between baseline and follow-up for businesses assigned to the intervention compared with those assigned to the comparison condition. We also evaluated changes from baseline between intervention and comparison businesses in the percentage of time that dust control was available and used; improvement in the ventilation system; and worker knowledge, attitudes, and practices obtained from the survey. All outcome measures were aggregated across individuals within a business to provide a business-level measure of each outcome.

We used statistical techniques appropriate for group-randomized trials.²³ We ran mixed-effects multiple regression models in which group assignment (intervention vs comparison), time (baseline vs follow-up), and the interaction between group and time were treated as fixed effects. Businesses, workers

nested within businesses, and date of sampling were treated as random effects to properly account for the expected correlations for each of these components. Because the distribution of dust concentrations was skewed, we based these analyses on the natural logarithm of the dust concentrations. However, all results are reported on the original scale. The intervention effect was defined as the further reduction in median wood dust concentration in the intervention compared with the comparison condition. Use of the reported medians (on the original scale) to match the analyses (done on the logarithmic scale) requires computation of the ratio (r) of the follow-up value expressed as a fraction of the baseline value in the intervention condition relative to the comparison condition. We interpreted $100 \times (1 - r)$ as a further percentage reduction attributable to the intervention. Ninety-five-percent confidence intervals were estimated on the log scale and then transformed to 95% confidence intervals on the original scale.

The distribution of business and worker characteristics and sampling methods was similar between the intervention and the comparison businesses because of randomization (Table 1); therefore, adjustment for covariates was not needed. However, because small differences in the distribution of work tasks between intervention and comparison businesses could affect dust concentrations, we present the intervention effect on dust concentration with and without adjustment for the distribution of work tasks at baseline and follow-up.

RESULTS

The median dust concentration at baseline in the original scale was 5.87 mg/m³ among intervention businesses and 6.23 mg/m³ among comparison businesses (Table 2). One year later, the median dust concentrations were reduced to 4.71 mg/m³ (lower by 19.8% [$100 \times (5.87 - 4.71) / 5.87$]) and 5.58 mg/m³ (lower by 10.4%) from baseline in the intervention and comparison businesses, respectively. After intervention, the fractions of baseline dust concentration obtained at follow-up were therefore 0.803 and 0.896, for a ratio of 0.896 [(4.71/5.87)/

TABLE 1—Comparison of Dust Sampling Process, Work Tasks Performed, and Worker Characteristics Among Woodworking Businesses in Intervention and Comparison Conditions at Baseline and 1-Year Follow-Up

	Intervention		Comparison	
	Baseline (n = 24)	Follow-Up (n = 23)	Baseline (n = 24)	Follow-Up (n = 24)
Dust sampling process				
Mean no. of employees sampled (SD) per business	6.4 (1.7)	6.0 (1.4)	5.9 (1.0)	5.6 (1.8)
Mean no. of 8-hour dust samples per business	9.6 (0.9)	9.3 (1.2)	9.8 (1.4)	8.9 (1.5)
Mean no. of samples (SD) unusable per business	0.5 (0.8)	0.6 (1.1)	0.5 (0.8)	0.1 (0.3)
Work task distribution, % time spent				
Stationary sanding	2.5	1.6	2.6	1.6
Hand sanding	9.9	11.4	8.6	7.1
Sawing	10.9	11.2	10.9	10.1
Routing	6.1	5.5	7.7	5.2
Cleaning	2.1	1.0	1.5	0.6
Miscellaneous	68.1	69.3	68.6	75.3
Worker characteristics				
Total no. of employees completing survey	196	178	158	169
Median years (range) of experience as woodworker	9.3 (1-45)	9.0 (1-43)	7.3 (1-43)	6.5 (1-43)
Median years (range) employed at study site	2.0 (1-39)	2.0 (1-39)	2.8 (1-40)	2.0 (1-43)
Mean age (SD), y	33.8 (9.7)	35.2 (9.2)	32.5 (8.9)	32.7 (9.6)
% Male	95.9	97.2	96.2	95.3
% With some college or technical school	60.7	64.0	57.0	52.4
% Who currently smoke	33.9	37.5	39.2	38.7

(5.58/6.23)], equivalent to a further reduction of 10.4% in the intervention businesses relative to the comparison businesses. The intervention effect was somewhat stronger (14.1% relative reduction in median dust concentration) after taking task distributions at baseline and follow-up into account. However, 95% confidence limits included the null value for both the unadjusted and the adjusted estimates.

Other environmental changes at follow-up that were greater for intervention than for comparison businesses were the percentage of time that dust control was available; the percentage of time that dust control was used, if available; and ventilation system efficiency (Table 2). Although these changes were in a direction consistent with an intervention effect, the effect sizes were small and consistent with chance.

Workers in intervention businesses reported small declines from baseline in worker interest in dust control and perception of its importance, whereas workers in comparison businesses reported improve-

ment in these characteristics, yielding a net difference at follow-up in the direction opposite to the expected intervention effect (Table 3). Changes between baseline and follow-up in worker confidence in controlling dust, perceived effectiveness of dust control, and barriers to controlling dust were similar between both groups of businesses. However, there was substantial improvement over time, greater for workers in intervention than in comparison businesses, in the degree to which workers were informed about dust control (intervention effect=0.25; 95% CI=0.03, 0.46) and in their stage of readiness to control dust (intervention effect=0.43; 95% CI=0.08, 0.77). Workers in intervention businesses also were more likely than workers in comparison businesses to report changes in work behavior consistent with reducing dust (intervention effect=0.12; 95% CI=-0.01, 0.25).

Except for one recommendation, which was to clean and maintain the dust collection system, intervention businesses reported implementing a greater proportion of recom-

mendations than did comparison businesses (Table 4). Differences in the proportion of recommendations implemented ranged from 4.5% higher (install a dust collection system capable of exhausting dust from all stationary tools) to 32.7% higher (increase availability of dust controls for sanding tasks) among intervention businesses relative to comparison businesses.

With the exception of the tour of the model business (attended by only 50% of the businesses), intervention businesses participated fully in all activities. On average, 99 days (range=36–218 days) elapsed from baseline sampling to worker training, 136 days (range=69–238 days) to the researchers' meeting with the owner to review final dust control recommendations, 193 days (range=101–325 days) to the businesses' tour, and 292 days (range=138–644 days) before the business received a small grant.

DISCUSSION

The effectiveness of an intervention consisting of technical assistance and worker training to reduce exposure to wood dust by 26% in small woodworking businesses was not confirmed in this study. Although we observed "positive" changes in the work environment among businesses assigned to the intervention—that is, a decrease in dust concentration, an increase in the percentage of time that dust control was available and used, and an improvement in the efficiency of ventilation systems—these changes were modest. However, the intervention appeared to have some effect on workers employed by intervention businesses. At the 1-year follow-up, these workers reported that they were more informed than before about dust and dust control and indicated a greater readiness to control dust relative to workers in comparison businesses. More important, greater increases in use of dust control strategies in work practices were reported in the intervention businesses than in the comparison businesses; this result almost reached statistical significance.

Our study had many strengths. It adhered to a rigorous study design. Numerous businesses were randomly assigned to either intervention or comparison conditions. The

TABLE 2—Effect of the Intervention on Changing Dust Concentration, Availability and Use of Dust Control, and Ventilation Efficiency in Intervention and Comparison Woodworking Businesses

	Intervention (n = 24) Value (SE)	Comparison (n = 24) Value (SE)	Intervention Effect (95% Confidence Interval)
Dust concentration (median)			
Baseline, original scale, mg/m ³	5.87 (0.59)	6.23 (0.62)	
Follow-up, original scale, mg/m ³	4.71 (0.47)	5.58 (0.56)	
% Change ^a	-19.7 (6.4)	-10.4 (7.2)	-10.4 (-28.8, 12.7)
% Change, adjusted for task ^b			-14.1 (-33.0, 9.4)
% Time dust control available (mean)			
Baseline	48.7 (3.6)	49.9 (3.5)	
Follow-up	57.0 (3.6)	53.9 (3.6)	
Change	8.3 (3.3)	4.0 (3.3)	4.3 (-4.8, 13.4)
% Time dust control used, if available (mean)			
Baseline	94.7 (1.9)	94.4 (1.8)	
Follow-up	96.5 (1.9)	92.8 (1.9)	
Change	1.8 (2.1)	-1.6 (2.1)	3.4 (-2.6, 9.3)
Ratio of measured airflow in ventilation systems compared with recommended flow (mean)			
Baseline	62.6 (9.9)	66.9 (8.4)	
Follow-up	68.4 (9.7)	68.6 (8.6)	
Change	5.7 (13.8)	2.0 (12.0)	3.8 (-32.6, 40.2)

^aEstimated on the log scale but can be calculated from the ratio of the fractions of baseline medians achieved at follow-up for intervention vs comparison businesses, that is, ratio = 0.896 = (4.71/5.87) / (5.58/6.23); the entry is $-100 \times (1 - \text{ratio})$ with confidence intervals developed from the confidence intervals on the log scale.

^bTasks include the percentage of time spent in each of the following: (1) sanding with stationary tools; (2) sanding and cutting with handheld power tools; (3) sawing; (4) shaping, routing, molding, or milling; (5) cleaning; and (6) performing miscellaneous nondusty tasks.

tion. In addition, businesses whose levels were already below the regulatory limit but were amenable to further reduction would have been eliminated.

We randomized 48 businesses based on a 26% reduction in dust, a goal that seemed feasible from our pilot study¹³ and one that we considered a meaningful change in exposure, regardless of baseline levels in a business. Other studies had reported success in reducing inhalable dust concentrations by more than 26%, although this was achieved only at considerable effort and expense (including the installation of local exhaust systems with pull-down vacuum hoses at each sanding workstation).¹² In comparing the trial with our pilot study, we found that availability of dust control methods to businesses was comparable between studies. However, unlike the earlier pilot study, we found that workers in the trial almost always used control measures, so there was little room for improvement in that aspect. Thus, it appears that lowering dust concentrations by 26% may have been unrealistic. To detect a smaller intervention effect with confidence would have required more businesses than we had available, and at considerably higher costs.

One year may have been insufficient time to observe a change in dust concentrations in our study sample. Final recommendations to intervention businesses were provided 4 to 5 months after the baseline dust sampling was performed, and nearly a year passed before intervention businesses received their small grants. Although we attempted to motivate change in multiple ways—through technical recommendations, worker training, tours of other businesses, and incentives—these activities were each carried out only once with each intervention business during the course of the year. A more intensive intervention, provided on an ongoing basis and sensitive to the changing work environment (e.g., worker turnover), may be needed to effect greater reductions in dust levels.

All businesses received information about dust concentrations and written recommendations to improve the control of dust. This degree of intervention in comparison businesses may have compromised our ability to detect a greater change in intervention businesses, but the small changes from baseline for either

analysis was performed at the level of the business, to properly account for the similarity of workers within each business, which could otherwise inflate the standard error and overestimate confidence in our results. Our research team was interdisciplinary, representing occupational medicine, industrial hygiene, epidemiology, wood products, and biostatistics. We followed a robust model (PRECEDE-PROCEED²⁰) for intervention development and implementation to increase applicability and acceptability to the woodworking industry. Our response rate for study participation was high, and only 1 business was lost to follow-up. Our intervention targeted all levels of the hierarchy of controls—engineering, administrative, and behavioral.^{28,29} Finally, we incorporated several types of measures to assess intervention effectiveness, including worker self-report of knowledge, attitudes, and work practices; in-

dustrial hygiene observation of work practices; and environmental changes in dust concentrations.

Despite these strengths, our intervention did not reduce wood dust to the levels planned. Our experience shows the enormous complexity of undertaking intervention research in the occupational setting. For example, an important requirement in designing this type of research is to specify an effect size that is likely to be meaningful for health. The Minnesota permissible exposure limit (time-weighted average) for all softwoods and hardwoods except western red cedar is 5 mg/m³ total dust,³⁰ and some may argue that a better intervention goal is to bring businesses into compliance with regulatory limits for wood dust. However, such an approach would have required determination of dust concentrations in businesses before participation to assess eligibility, an expensive proposi-

TABLE 3—Effect of the Intervention on Changing Worker Knowledge, Attitudes, and Behavior Related to Dust Control Among Employees of Intervention Relative to Comparison Woodworking Businesses

	Intervention (n = 24) Mean (SE)	Comparison (n = 24) Mean (SE)	Intervention Effect (95% Confidence Interval)
Interested in dust control ^a			
Baseline	3.41 (0.07)	3.17 (0.07)	
Follow-up	3.38 (0.07)	3.26 (0.07)	
Change	-0.03 (0.08)	0.09 (0.08)	-0.12 (-0.35, 0.11)
Importance of dust control ^a			
Baseline	3.73 (0.05)	3.54 (0.05)	
Follow-up	3.71 (0.05)	3.69 (0.05)	
Change	-0.02 (0.05)	0.15 (0.06)	-0.17 (-0.33, -0.02)
Informed about dust control ^a			
Baseline	2.81 (0.06)	2.73 (0.06)	
Follow-up	3.17 (0.06)	2.84 (0.06)	
Change	0.36 (0.07)	0.11 (0.08)	0.25 (0.03, 0.46)
Confidence in ability to control dust ^a			
Baseline	2.97 (0.07)	2.72 (0.08)	
Follow-up	3.11 (0.08)	2.86 (0.08)	
Change	0.14 (0.08)	0.14 (0.09)	<0.01 (-0.25, 0.24)
Perceived effectiveness of dust control ^a			
Baseline	3.59 (0.04)	3.54 (0.04)	
Follow-up	3.63 (0.04)	3.59 (0.04)	
Change	0.04 (0.04)	0.05 (0.05)	-0.01 (-0.14, 0.12)
Barriers to dust control ^b			
Baseline	2.95 (0.03)	2.88 (0.04)	
Follow-up	2.93 (0.04)	2.90 (0.04)	
Change	-0.02 (0.04)	0.02 (0.04)	-0.04 (-0.14, 0.06)
Stage of readiness to control dust ^c			
Baseline	2.53 (0.11)	2.38 (0.12)	
Follow-up	2.94 (0.11)	2.35 (0.11)	
Change	0.40 (0.12)	-0.02 (0.13)	0.43 (0.08, 0.77)
Self-reported dust control behavior ^d			
Baseline	2.51 (0.04)	2.43 (0.05)	
Follow-up	2.64 (0.05)	2.44 (0.05)	
Change	0.14 (0.05)	0.02 (0.05)	0.12 (-0.01, 0.25)

^aRange 1 to 4, where low score indicates not at all and high score indicates very [interested, important, informed, confident, effective].

^bRange 1 to 4, where low score indicates disagreement and high score indicates strong agreement.

^cRange 1 to 4, where low score indicates precontemplation, followed by contemplation, action, and maintenance.²⁴

^dRange 1 to 4, where low score indicates rarely or never works and high score indicates usually works in a way to control for dust.

group argue against this reasoning. Unmeasured changes in business characteristics or production aspects (e.g., new workers, change in equipment, space) after randomization could have reduced our ability to detect a stronger effect if such changes affected dust levels and were unequally distributed between intervention and comparison busi-

nesses. Finally, we were unable to assess the likelihood of contamination among comparison businesses through encounters with owners and workers from intervention businesses.

Our results identified barriers to success in reducing hazardous exposures in the work environment. Dust control methods were available for only about half of the tasks per-

formed by workers, and this changed very little during the course of the year. Central ventilation systems were poorly designed, with more tools attached than were allowed by manufacturer specifications for optimal functioning. Several of our recommendations encompassed major and costly structural changes to these systems or the installation of downdraft tables or sanding booths; these were least likely to be adopted by either intervention or comparison businesses. Although other recommendations appeared to be more acceptable (e.g., purchasing small vacuum systems with compatible handheld power sanders), overall compliance with recommendations among intervention businesses usually was less than 50%. Because we saw little evidence that intervention businesses were willing to implement costly improvements for dust control, and because such changes are beyond the control of workers, the lack of improvement we found in workers' confidence or in barriers to dust control appears to accurately reflect the work environment.

Although numerous group-randomized trials have been conducted at worksites to assess interventions designed to promote lifestyle or behavioral changes such as smoking cessation, weight control, or improved screening behaviors among individuals,^{31–37} little occupational health and safety research using a similar design exists to which we could compare our results. We identified only 6 reports of health protection interventions in which the unit of randomization was the group.^{38–43} Randomized groups included 120 local unions (total membership not provided),³⁸ 19 small businesses with between 10 and 100 employees,³⁹ 14 coke operating facilities with more than 400 workers,⁴⁰ 4 fire-fighting districts with 469 firefighters,⁴¹ 108 farms in 14 counties with about 2 workers per farm,⁴² and 24 manufacturing sites with 250 to 2500 workers per site.⁴³ Interventions consisted of training to increase knowledge of health hazards and change work practices and typically avoided the more difficult challenge to change the work environment that we took up. Similar to our findings, most of these studies reported interventions to be effective in increasing worker knowledge and changing some work practices. However, all relied on workers' self-reports, with only 2, in addition,

TABLE 4—Summary of Recommendations Made at Baseline and Implemented at Follow-Up Among Woodworking Businesses in Intervention and Comparison Conditions

Recommendation	No. of Businesses That Received Recommendation	Mean % of Owners Reporting Recommendation Implementation
Increase availability of dust controls for sanding tasks		
Intervention	22	72.7
Comparison	20	40.0
Increase availability of dust controls for cutting tasks		
Intervention	17	35.3
Comparison	16	18.8
Use portable vacuums to control dust from handheld tools		
Intervention	23	56.5
Comparison	21	23.8
Use downdraft tables or sanding booths to control dust from handheld tools		
Intervention	23	10.9
Comparison	21	2.4
Install a dust collection system capable of exhausting dust from all stationary tools		
Intervention	20	15.0
Comparison	19	10.5
Clean and maintain dust collection system		
Intervention	21	30.7
Comparison	22	32.6
Use a vacuum to clean shop		
Intervention	16	31.3
Comparison	13	7.7
Attach hoods to stationary tools		
Intervention	15	15.6
Comparison	NA	NA

Note. NA = not applicable.

challenges and the costs of conducting rigorous research in the occupational setting. Although we did not show a strong effect with our intervention, we believe that our experience will be illuminating for future research efforts supported by the National Institute for Occupational Safety and Health. ■

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incorporating a direct measure of workplace hazards or incidence of injuries.^{39,41}

The National Institute for Occupational Safety and Health recently presented the National Occupational Research Agenda.⁴⁴ Intervention effectiveness research was among the priorities identified through consensus building among National Institute for Occupational Safety and Health staff, researchers, stakeholders, and health professionals. The National Institute for Occupational Safety and Health described several considerations for carrying out intervention research, including the need for industry partnership and multidisciplinary approaches, an assessment of economic feasibility, taking organizational culture and worker attitudes into account,

and “integration of behavioral interventions to influence workers’ attitudes, knowledge and behavior.”⁴⁵

Our study fit well with these criteria but did not substantially reduce dust concentrations. On the basis of our unique experience with small businesses, we would emphasize that the owner’s role is critical as gatekeeper for establishing priorities and supporting health and safety efforts, that efforts should be directed toward achievable goals that are meaningful for the business as well as for health, and that interventions should concentrate on areas where changes could yield the greatest improvement in health hazards. Attending to these considerations in planning scientifically sound research increases the

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