Airway obstruction and hypersensitivity among young workers: 16 year follow-up of machinist and construction apprentices

Final report to WorkSafeBC

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Key findings:

We carried out a prospective study of apprentices in 4 trades (machinists, construction painters, insulators, and electricians), followed for 16 years. Each person was tested at the beginning of his or her apprenticeship, after 2 years of apprentice training, and 14 years later. The same tests were used each time (questions about lung health and several tests of lung function).

Our main findings were:

- Workers who experienced a sharp drop in lung function or who developed *new* hyper-responsive airways during the first 2 years of apprenticeship were the ones who went on to more serious respiratory health problems later.

- Among machinists who continued in their trade, chronic respiratory impairment was linked (in a ‘dose-response’ fashion) to cumulative exposure to metalworking fluid (MWF) aerosols and airway hyper-responsiveness was linked to current MWF aerosol level. The results suggest that current regulatory guidelines for exposure limits are not sufficiently protective of lung health.

- In the machine shops where we tested exposure levels, the highest exposures were found in association with grinding and with the use of computer numeric controlled (CNC) machines, even where CNC machines were fitted with enclosures. Our qualitative study of machinists revealed that this is most likely due to incomplete enclosure or insufficient aerosol extraction from the enclosed space.

Executive Summary: The UBC Lung Health Study

About the study

The UBC Lung Health Study examined a group of machinists and construction workers to learn about whether lung changes early in a person's working life, in response to irritants or allergens at work, predict the development of chronic breathing problems later on. It also looked at whether exposure to metalworking fluids in machine shops was linked to lung problems among machinists.

What we did

In 1988, we started a long-term study of apprentices in four trades in BC: machinists, who are exposed to highly irritating metalworking fluids in the air, and three other construction trades which are at lower risk for lung disease from irritants at work (painters, insulators, and electricians). We measured the function and responsiveness of their lungs three times: at the beginning of the study (1988-90), two years later (1991-1993), and then finally 16 years later (2004-2006).

Lung testing

During each phase of testing, participants performed two breathing tests:

- A simple breathing test (spirometry), which tells the researchers whether a person's air passages have become chronically damaged from exposure to irritants.
- An airway sensitivity test (methacholine challenge), which measures whether the lungs are overly responsive to short-term inhalation of irritants or allergens.

Questionnaires

By answering a questionnaire, participants also provided information about:

- their job tasks and work history, and
- their respiratory health, including whether they experienced symptoms such as cough or wheeze.

We gathered this information to see if those who experienced respiratory symptoms early in working life required treatment for lung diseases later on. We linked study participants to British Columbia's medical databases to find out whether they visited a doctor for help with asthma or another respiratory disease. This linkage was done anonymously, to protect the privacy of each participant.

What we found

Results from the first follow-up visit

When we tested the apprentices after the first two years of employment, we found that:

- 30% of all of the apprentices experienced a substantial decline in their lung function. When we tested the lung function of a group of marine workers over a similar period, only 12% of them experienced a comparable decline in lung function.

- Machinists had developed more sensitive airways and more asthma than the other apprentices, so their airways were more likely to be irritated by substances that they encountered at work.
- 14% of machinists quit their trade during the first two years of working life, compared to only 1.5% of workers in other trades.

Results from the second follow-up visit

When we tested participants again, sixteen years after beginning employment, we found that:

- Machinists were still more likely to have quit their trade than other former apprentices. However, quitting for health reasons was equally common among all trades groups.
- Workers who quit their job for health reasons (excluding injuries) were more likely to have been exposed to irritants and allergens at past workplaces, or (for former machinists) to have been exposed to higher levels of metalworking fluid contaminants than other machinists.

Effectiveness of lung testing

Our study provides information about which measurement tools are likely to be effective in predicting lung problems. We found that 2 lung function measures were effective in predicting later lung problems:

1: a very sharp decline in lung performance early in the working career (about 6% per year or more), measured by a simple breathing test; and
2: an early increase in airway sensitivity, measured by the more complicated methacholine challenge test.

Lung health symptoms and disease

When we compared what participants told us about their lung health symptoms to information about doctor visits relating to lung disease, we found that:

- Participants who had symptoms such as cough or wheeze at the beginning of their working lives were more likely to be diagnosed with asthma or other respiratory diseases.
- Participants who experienced a rapid decline in their lung function, or who developed very sensitive airways early in working life, were at increased risk of developing asthma.

New lung health symptoms should not be ignored, as they may predict future disease.

Findings specific to machinists

We measured air concentrations of metalworking fluid aerosols on 2 occasions in many of the small machine shops in BC where machinists work. We found that the highest air concentrations were linked to grinding and to the use of computer numeric controlled (CNC) machines, especially those that are partially or ‘fully’ enclosed. We suspect this is because CNC machines, which operate at high speeds, generate very high concentrations of metalworking fluid mist which remain within the enclosure and expose the operator to a heavy burst of mist whenever the enclosure is opened.

The lung health troubles that we detected in machinists early in their working lives were still present sixteen years later, even among those who had quit the trade. We found a ‘dose-response’ relationship between low levels of lung function (using the simple breathing test) and increasing *cumulative* exposure to metalworking fluid aerosols among current machinists. We also found that machinists with *current* exposure to metalworking fluid aerosol above the 0.4 mg/m^3 range had significantly increased sensitivity of the airways.

Interestingly, we found that machinists who quit the trade early continued to have reduced lung functioning that persisted 16 years later, as well as intermediate levels of airway sensitivity.

Implications of our study

Our study is important because it tracks lung health changes over the course of 16 years, starting at the very beginning of working life. Our results will be helpful for employers and health care providers who are implementing screening programs in the workplace.

Our results will also provide incentive for machine shop operators to continue efforts to minimize exposures to metalworking fluid aerosols, especially those associated with grinding and with CNC machining.

Our results provide support for maintaining metalworking fluid levels below the current US National Institute for Occupational Safety and Health recommended limit of 0.4 mg/m^3.

For more information: If you have questions about our research study or would like to know more, please visit our website or contact us.

Study website: http://www.cher.ubc.ca/UBCLungHealthStudy/Home.htm

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Introduction and objectives

It is well established that cross-sectional studies of workers underestimate the true prevalence of airway disease (airflow obstruction and bronchial responsiveness) associated with occupational exposures.(1, 2) This underestimate, the 'healthy worker effect', is due in part to hypersensitive workers transferring out of jobs where they are exposed to irritants or sensitizers. Even prospective studies suffer from this bias if they fail to include workers from the earliest years of employment.(3, 4) Thus, in order to understand the natural history and early occupational risk factors for airflow obstruction and bronchial hyper-responsiveness, it is important to study inception cohorts, i.e. workers enrolled at entry into the workforce and followed over time.

In 1988-90 we enrolled 356 1st year apprentices in 4 trades into a prospective study of the development of bronchial hyper-responsiveness and airflow obstruction among young adult workers. Our initial goal was to examine the respiratory health consequences of early exposure to metalworking fluid aerosols among apprentices. This was motivated by previous reports suggesting a link between metalworking fluid aerosol exposure and both asthma and acute reductions in lung function among machinists.(5-10) Long-term follow-up was planned from the outset, not only to examine the chronic impact of exposure to metalworking fluid aerosols, but also to study the natural history and risk factors for the development of respiratory morbidity among industrial workers in general.

The original cohort was recruited from apprenticeship classes at the BC Institute of Technology in four trades: one ‘high risk’ industrial trade (machinists) and three ‘lower risk’ construction trades (electricians, insulators and painters). Machinists are exposed to metalworking fluid, a complex mixture of respiratory sensitizers and irritants that has been linked to acute changes in pulmonary function, increased respiratory symptoms, bronchial hyper-responsiveness and asthma. (5-13) Construction trades workers may also be exposed to irritants and sensitizers, but likely with lower intensity and frequency. (14-18) We examined the cohort at baseline and after two years. At two years, we found a significant association between machinists' exposure to metalworking fluid in the two-year interval and new bronchial hyper-responsiveness at follow-up. We also found that 29% of the cohort (all trades) had an annual decline in airflow of 100 ml or greater (compared to an "expected" annual decline of 0-30 ml), and that 22% had increased bronchial responsiveness (bronchial responsiveness). (19)

This project is the 16- year follow-up study of this inception cohort. Our aim was to investigate: 1) the relationship between these early changes and subsequent chronic airflow obstruction or bronchial hyper-responsiveness; and 2) the role of continued metalworking fluid exposure on subsequent lung health. If early changes in pulmonary function are found to be important predictors for the development of chronic lung disease, these findings could have significant implications for surveillance and prevention programs in the workplace.

This project had *two main goals:*

1) to examine whether or not early changes in bronchial responsiveness and airflow rates (in the first 2 years after enrolment in a trade) are predictive of subsequent chronic respiratory morbidity; and
2) to evaluate the impact of chronic exposure to irritants and sensitizers found in metalworking fluid aerosols on respiratory morbidity in this inception cohort.

Methodology

Cohort membership and eligibility

The original eligible study cohort (baseline, or visit 1) included all 1st year apprentices in each of 4 trades (machinists, electricians, insulators, painters) attending BCIT during a 2-year period from 1988-1990. All cohort members were eligible to be retested at the time of their 3rd year apprenticeship class (visit 2). For the current study, all cohort members tested at baseline, whether or not they are still employed in their original trade and whether or not they were included in the visit 2 testing, were eligible. All participants had provided written consent to be re-contacted at a later date which facilitated a wide variety of tracing methods and the cooperation of several organizations to assist with locating cohort members (e.g. unions; the federal National Search Unit, linkage with the BC Linked Health Data Base).

Logistics

Our original logistics plan involved testing at our clinic for the small number of cohort members living nearby; and, for those living further afield, testing at the participant's home location, using the UBC mobile pulmonary function laboratory with oversight from a physician member of the study team. This plan had to be changed considerably because the budget line item for a physician team member was not approved.[1] Our revised logistics plan required us to rely on voluntary physician oversight (from colleagues at Vancouver Hospital and from 52 generous physicians at 43 clinics and hospitals throughout BC and Alberta), to park our mobile lab outside these clinics and ask participants to travel to us, rather than us going directly to them. This change had an impact on our ability to schedule the field work efficiently and had significant consequences for subject recruitment.

Respiratory Questionnaire

The American Thoracic Society (ATS) questionnaire for epidemiologic studies (20) expanded to include validated questions about asthma symptoms from the European Community Respiratory

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[1] This lack of approval was due to the fact that WorkSafeBC was unaware that physician oversight of one of the breathing tests included in the project is mandatory, following American Thoracic Society guidelines. Despite our subsequent explanation, it was not possible for WorkSafeBC to add to the (reduced) budget already approved.

Health Survey (21) and a comprehensive personal, work, and exposure history section, and reasons for leaving each job, were administered by an interviewer (trained by the same interviewer as previously).

Pulmonary function and bronchial responsiveness testing

Measurement of air flow (FEV_1) and forced vital capacity (FVC) were carried out using a dry rolling seal spirometer (PDS Instruments Ltd), the same instrument used previously, following the ATS standard protocol. (22) Early change in lung function was assessed as: ((FEV_1, visit 2) – FEV_1, visit 1)) / (years between visit 1 and visit 2) and expressed as both ml/year and %/year. A rapid decline was defined as present if this early change was greater than 5.8%/ decline per year (this value being the lower 95% confidence limit for the whole cohort).

Non-specific bronchial responsiveness was measured using a methacholine challenge test, following a standardized tidal breathing protocol. (23, 24) The methacholine concentration associated with a 20% drop in FEV_1 (PC_{20}) was determined by linear interpolation over the full dose response curve. Bronchial responsiveness was defined as having a PC_{20} of 8 mg/ml or less.

Allergy skin testing

Allergy skin prick tests were conducted using 3 common environmental antigens and positive and negative controls. (23) A positive test is recorded if the wheal diameter is 3 mm larger than any reaction to the saline control. Atopy is defined as one or more positive skin tests.

Physician visits for asthma and bronchitis

Physician visit and hospitalization data for asthma and bronchitis in the follow-up period were obtained by linking the cohort to the BC Linked Health Database. Linkage included Medical Services Plan (physician visits), Hospital Discharge, and WCB databases to retrieve all events from the date of initial testing to the latest year available. This database is a set of administrative files with information on health care utilization, developed by the UBC Centre for Health Services and Policy Research, in cooperation with the BC Ministry of Health.

Exposure assessment

Exposure to sensitizers or irritants, full cohort: A questionnaire to assess details of all jobs held (including specific tasks within jobs) since last testing was administered to all cohort members. For each job, we recorded average weekly duration of work involving exposure to agents common in BC industrial workplaces linked to occupational asthma (sensitizers) and frequency of very high short term exposures to strong irritants ('gassings'). From these we calculated current exposure and duration of exposure to isocyanates (both paint and spray foam insulation) and abrasive blast cleaning (sand blasting). For electricians, we subdivided duration of work into six categories: residential construction, commercial construction, industrial construction, industrial maintenance, automotive, and electronics.

Quantitative estimates of metalworking fluid exposure, using empirical models (machinists): For all participants with a history of machining, detailed characteristics of the machining job and work site, based on an empirical model previously developed for this study were collected by questionnaire. Type of fluid and intensity of exposure to metalworking fluid aerosol were estimated for the current job and for each period during which job/work site characteristics remained stable, using information on job/site/tasks and an empirical model (see results). Cumulative exposure to metalworking fluid aerosol mass was calculated as the product of intensity and duration for each period.

Exposure monitoring sub-study

An exposure sub-study was carried out to evaluate the previously developed empirical models for metalworking fluid aerosol concentration and endotoxin. All current machinists were asked to collect a full-shift personal air sample and bulk metalworking fluid samples from all machines routinely used. Equipment, detailed instructions, and a log sheet were sent to willing volunteers, along with a letter of explanation for the employer.

Metalworking fluid aerosol concentration: The A 37 mm cassette with a PFTE filter was connected to a high-flow portable pump (calibrated before shipping and when returned to the lab) and worn for a full shift. When returned, the filter cassette was attached to a second cassette containing desiccant, stored at 4^{o}C and shipped to our lab on ice. The filters were weighed prior to and after sampling in a controlled environment room. Air concentrations of the metalworking fluid aerosol were calculated by dividing the increase in mass on the filters by the total air flow through the filters during sampling.

Bulk samples: Machinists were asked to collect bulk metalworking fluid samples from the flowing stream at the cutting points of each machine routinely used, and from the non-circulating fluid in the sump, and record machine and fluid type (and provide a material safety data sheet or "MSDS"). Samples were stored at 4^{o}C until shipped to our lab on ice. In the lab, pH and viscosity were measured. Samples were centrifuged to separate the metalworking fluid from contaminating tramp oil and tramp oil content was measured.

Endotoxin analysis of bulk and filter samples: After filters were weighed, endotoxin was extracted using a modification of ASTM Standard E-2144-01(25) and samples were stored at 4^{o}C. Endotoxin concentration in the bulk samples and filter extracts were measured using a kinetic, chromogenic *Limulus* amoebocyte lysate (LAL) assay (Kinetic-QCL, BioWhittaker, Inc.),(26, 27) using LAL from the same lot. Enhancement or inhibition of the LAL by the sample matrix was tested by spiking dilute assay samples with endotoxin and calculating recovery.

All aspects of the protocol were approved by the UBC Clinical Research Ethics Board.

Analyses were carried out using SAS-PC, starting with descriptive analyses and progressing to multivariable modeling, using standard approaches to model building guided by scientific considerations.

Results and discussion

Summary of results from visits 1 and 2

Results from visits 1 and 2 of this project (also funded by WorkSafeBC), were published in 1999 and 2004. (19, 28) Table 1 shows the demographic characteristics of the 312 eligible participants at the beginning of the overall project, indicating no important difference between machinists and the other trades at the outset, although machinists were slightly less likely to be smokers than participants from other trades. Key findings from the first follow-up (2 years after initial testing) are shown in tables 2 to 4 and figure 1. Briefly, these results indicate that machinists were more likely to quit their trade and slightly more likely to develop new asthma and bronchial responsiveness than other trades people. We also found that duration of exposure to certain types of metalworking fluids was linked to the development of new bronchial hyper-responsiveness. To our surprise, we also found that the average annual decline in lung function in this cohort, regardless of trade, was much higher than would be expected based on other studies, with 29% having annual decline in FEV_1 of 100 ml or greater (in contrast to an expected rate in the range of 0-30 ml/yr).

In an exposure evaluation study, we developed a model for determinants of exposure to metalworking fluid aerosols, using job tasks and workplace information, for use in the phase 3 follow-up. Characteristics of the model are shown in table 4.

Results from visit 3 (this project)

Participant tracing, demographics

Our target sample size for visit 3 was 200 subjects; we surpassed this target slightly, having tested 209 subjects (59%), including 77 machinists or former machinists. Participation details by original trade are shown in Table 5. Only 68 participants (19%) were completely lost to follow-up; 12% refused to participate in the visit 3 testing for various reasons, and 7% were willing to participate but we were unable to schedule testing despite many months of effort. This was mainly due to logistics difficulties (described above). Seven men had died, including 5 painters. This is a surprisingly high mortality rate, given the young age of the cohort.

Comparison of baseline status between those tested in visit 3 and those not tested is shown in Table 6. These results indicate loss to follow-up was slightly more common among men and non-whites. The 'not tested' groups had a higher proportion of smokers (at visit 1) and slightly higher baseline lung function and increased bronchial hyper-responsiveness at visit 2 (although none of these differences were statistically significant). Overall, these comparisons suggest no serious potential for bias associated with non-participation in visit 3 testing.

Of the 209 participants tested in visit 3, 188 met the original eligibility constraints (younger than age 35 and with less than 5 years in their current trade at entry into the cohort). By the time of visit 3 testing, an average of 16 years after first testing, 58 participants had quit their original trade. Table 7 shows demographic characteristics of the eligible participants at visit 3, by current trade status. Again, those who remained in the machining and electrical trades were more likely to be non-smokers compared to the rest. Mean age at follow-up was approximately 40 years old for all groups. The average duration of follow-up between visit 1 and visit 2 was 2.0 years (range 1.0 to 3.8) and between visit 2 and visit 3, 14.0 years (range 12.1 to 16.2).

Exposure estimation and empirical model evaluation

Our exposure assessment protocol involved estimating current and cumulative exposure by applying the empirical model developed by us earlier to detailed job task and workplace characteristics for each job held by machinists. To provide support for this, we also carried out a small sub study to evaluate the characteristics of the empirical model against current conditions in the workplaces of current machinist members of the cohort.

Detailed results from the evaluation sub-study are contained in appendix 1.

In summary, both the previous 'determinants of exposure' analysis and the current air monitoring found metalworking fluid aerosol exposure increased in association with grinding and working at an enclosed or partially enclosed computer numeric controlled (CNC) machine, and lower in association with time spent vertical milling or machining aluminum (both tasks requiring lower machine speeds), and working in a shop with mechanical room ventilation and a high peaked roof. Although enclosure of CNC machinery may be seen as a control measure, enclosures are almost never complete and most machines are not equipped with mist extraction or ventilation systems, leaving the potential for high peak exposures when the enclosure doors are opened or when setting up or checking the machines. Examples of quotes from machinists regarding the strong potential for high aerosol exposures from these machines are included in Appendix 2.

Exposure estimation for machinists: Each current and former machinist was asked about 12 workroom environment characteristics and details for up to 10 tasks for each job held in the period between visit 2 and visit 3 (number of intervening jobs per machinist ranged from 1 to 6). The task details included tool type, metalworking fluid types, nature of machine ventilation, enclosure or ducting, sump size, and proportion of the shift spent at each machine. From this interview information we computed summary variables to describe each workplace and to calculate the time spent exposed to various types of machining and metalworking fluids.

The 77 machinists participating in visit 3 worked at 75 different workplaces spread throughout British Columbia and Alberta. Those currently working as machinists reported working at a total of 106 machines in the current job alone (see table 8), mainly milling machines, lathes, grinders, and drills. A majority of the milling machines were vertical mills (which tend to operate at lower speeds and do lighter work, compared to horizontal mills); about one third of machines were computer numeric controlled (CNC).

For each machine type we calculated duration of exposure to machining (from the 2^{nd} to 3^{rd} visits) as follows:

∑ over all jobs
    (∑ over all machines used
        (% of shift spent machining x % of machining time at this machine))

We had anticipated estimating duration of exposure to the different types of metalworking fluids (soluble, synthetic, and straight oils), at least for the current job, by collecting label information and material safety data sheets (MSDS) for all metalworking fluids used. However, it became apparent that most of the machine shops represented by the machinists in this project used soluble or semi-soluble metalworking fluids almost exclusively in machines with fluid sumps.

Straight oils were used only occasionally, for honing, or, applied by hand, for grinding. Only one machinist provided an MSDS that clearly indicated a synthetic fluid, used for a boring machine (but this was not the machine used most frequently by that machinist). This was in clear contrast to our machinist interviews at visit 2 which indicated more frequent use of synthetic fluids at that time. We are unable to determine if this is an industry trend or simply an anomaly in our data. Attempting to calculate soluble fluid exposure duration separate from semi-synthetic fluid duration was unreliable, as many machinists were unable to accurately distinguish these fluid types. Such a distinction is unlikely to be necessary, since soluble and semi-synthetic fluids are both water emusifiable oil based products, varying mainly in the percentage of oil contained therein.

Therefore, duration of exposure to metalworking fluids from the 2nd to 3rd visits was calculated in a similar fashion as for duration of machining, but we restricted the calculation to machines having a fluid sump and a fluid mist or jet applicator at the machining head. (A second 'duration of exposure to metalworking fluid' variable was also constructed which included machines at which the machinist applied the fluids by hand, but this variable was never any more informative in models, so it will not be reported here.)

Estimated metalworking fluid exposure intensity was calculated for each job by exponentiating the result of the following formula (see Appendix 1 for details):

Ln (average metalworking fluid aerosol concentration) = -**1.18**

+ **1.32** * proportion of shift grinding

- **0.34** * proportion of shift vertical milling

- **0.44** * proportion of shift machining aluminum

+ **0.6** * working at a partially enclosed, not ducted CNC machine (y/n)

+ **0.97*** presence of occasional or regular welding in the shop (y/n)

- **0.30*** presence of a mechanical ventilation system in the shop (y/n)

- **0.45*** presence of a peaked roof in the shop (y/n)

- **0.06*** shop height (m)

Cumulative metalworking fluid exposure was calculated as:

$\sum$ over all jobs (average metalworking fluid aerosol concentration x job duration in years)

Table 9 shows the results for several of the computed work history variables and for estimated average metalworking fluid aerosol concentration (in mg/m^3 for the current job) and cumulative exposure (in mg/m^3-years) for all machining jobs for all cohort members who were machinist apprentices in the initial phase of the study, by their current trade status.

As expected current machinists had somewhat longer duration of exposure to machining in general and to machining using metalworking fluids but their average cumulative exposure was no different from former machinists, suggesting that former machinists were working at jobs with estimated higher intensity exposure. In addition, many current machinists have moved into management positions where their metalworking fluid exposure is estimated to be low.

Also shown in Table 9 is the actual measured metalworking fluid (concentration, in mg/m^3) found in the evaluation sub-study.

Endotoxin was recovered from all 55 bulk 'in use' metalworking fluid samples collected by current machinists (see Appendix 1 for details). Geometric mean values were 817 EU/ml in soluble fluids and 167 EU/ml in semi-synthetic fluids. (Only 1 sample of synthetic fluid and 2 of straight oil were obtained.) These values are considerably lower (by an order of magnitude) than endotoxin levels found in bulk fluid samples in small machine shops in BC previously.(29) No endotoxin was detected by our analysis on any of the air sample filters collected. We suspect this is related to the low aerosol concentrations, the relatively low endotoxin contamination levels in the bulk fluids, and low endotoxin recovery from the filters.

Exposure to other 'asthmagens' and respiratory irritants

Table 10 shows several other work history characteristics for the full cohort, by current trade status. Work involving isocyanates was reported by both painters and insulators, but of relatively low duration (maximum duration 2281 hours, or just over 1 year). Most painters also reported exposure to abrasive blast cleaning (e.g. sand blasting or similar). About 2/3 of electricians reported work at industrial sites (maintenance or construction) where there is a risk of exposure to respiratory irritants and 'gassing' episodes. Less than 10% of all groups reported doing welding or handling disinfectants regularly as part of their current job. Some participants also reported having experienced an acute 'gassing' episode resulting in at least two lower respiratory symptoms, since they were first tested. This was most frequent among insulators.

Factors associated with job change

Almost 43% of machinists had quit the machining trade after 15 years of follow-up. This compares to 22% in the other trades. Although much of this 'drop-out' occurred after visit 2, the differential between machinists and other trades was statistically significant only for the drop-out differential between visits 1 and 2 (14% *v.* 2%, $p < 0.001$) (see table 11).

Job change for health reasons (excluding injuries) was seen in 6.5% of machinists and 6.8% of the other trades. Results of multi-variable analyses directed at investigating potential predictors of 'health-related job change' are shown in table 12. The models tested included the full range of lung function test results at the various time points and exposure variables. The only variables significantly associated with changing jobs for health reasons were cumulative metalworking fluid exposure (odds ratio 2.0 for each exposure category) and work with exposure to any one or more of the other potential ‘asthmagens’ or irritants described on table 10 (odds ratio 5.2).

This is strong evidence that occupational exposures that have been linked to adverse respiratory health outcomes in other studies have the potential to contribute to the phenomenon of the ‘healthy worker survivor’ effect, where long term workers who continue in a job may move into lower exposure jobs and possibly have reduced respiratory morbidity compared to those who quit or change jobs earlier in their careers.(2)

OBJECTIVE 1 results:

Are early changes in lung function (between visits 1 and 2) associated with later respiratory morbidity (at visit 3)?

Table 13 shows average lung function test results (FEV_1 as % of predicted values) for each trade group, for each of the phases of this project (visits 1, 2, and 3) as well as average values for the annual decline in FEV_1 calculated for the periods visit 1 to visit 2 (2 years) and visit 1 to visit 3 (16 years). As shown, there were no differences among the trade groups. Also shown is the proportion of participants in each group whose early decline in FEV_1 (from visit 1 to visit 2) was either 100 ml/yr or more (ranging from 20 to 50% in the trade groups), or having an early annual decline greater than the 95% confidence limit (ranging from 0 to 12% in the trade groups).

Table 13 also shows the prevalence of significant bronchial hyper-responsiveness (defined as PC_{20} less than 8 mg/ml) in each of the groups at each time period. There is a trend for increasing prevalence of hyper-responsive airways over time, but no obvious trade patterns are evident in these data.

Tables 14 and 15 show results of analyses to investigate the possibility that these early changes in FEV_1 or bronchial responsiveness (in the first 2 years of the apprenticeship period, at a time when participants were in their early 20's) may predict respiratory function 16 years later. These analyses address objective 1 of this project. The dependent variables in these analyses were either FEV_1 % predicted (Table 14) or the log transformed slope of the methacholine dose-response test (Table 15) at the time of visit 3.

Potential explanatory variables considered in the models included demographic characteristics, smoking status and amount (separately for current and former smokers), change in smoking status, previous history of asthma, a measure of baseline airflow obstruction (FEV_1/FVC%) and the various measures of change in lung function or bronchial responsiveness. Due to significant co-linearity, measures of change in lung function and change in bronchial responsiveness could not be evaluated together in the same models; therefore, results from two models are shown in table 14. The results indicate that both baseline bronchial hyper-responsiveness and an *early (visit 1 to visit 2)* increase in responsiveness, *but not a later (visit 2 to visit 3)* increase in responsiveness, are associated with reduced lung function at the 16 year follow-up period. Similarly, a large annual decline in FEV_1 between visit 1 and visit 2 (more than 5.8 percentage points per year) was also significantly associated with a reduced level of FEV_1 after 16 years.

Examination of the correlations among the 3 different measures of annual decline (see Table 16) reveals that there is no significant positive correlation between the FEV_1 annual decline as measured between visits 1 and 2 and that recorded between visits 2 and 3. This suggests that early rapid decline in FEV_1 is not predictive of further (i.e. additional) rapid decline after visit 2, but rather that the decline seen in this study in the first 2 years of apprenticeship life was sustained (and not reversed) for the subsequent 14 years of follow-up. This is demonstrated more clearly in figure 2. This figure shows the average values for FEV_1 at each of the follow-up periods for three groups: 1) those whose early decline (from visit 1 to visit 2) was greater than the 95% CL; 2) those whose early decline was greater than 100 ml/yr, but not as great as group one; and 3) everyone else. It is evident that only for group 3 was early FEV_1 decline predictive of a subsequent low level of FEV_1 at visit 3. This figure reveals that the intermediate rate of early FEV_1 decline seen in group 2 was most likely the result of an anomalous (high) value at visit 1 that reverted closer to the mean in subsequent tests.

These results do suggest that a very large early change in FEV_1 in a young adult in an industrial setting (in this case, about 6 percentage points per year or more) may not be reversed over the next decade or so. The potential value of aggressive early intervention (whether treatment or exposure modification) when a large lung function drop such as this is seen, remains a subject for further research.

Table 15 shows similar results when examining potential predictors of bronchial responsiveness at 16 year follow-up, in that both baseline level of bronchial responsiveness and a clinically relevant increase in bronchial responsiveness in the early follow-up period were associated with later bronchial hyper-responsiveness. These findings support the contention above that aggressive intervention in response to early career major functional changes may have benefit.

Factors associated with physician visits for respiratory disease

As part of this project we also examined physician visits for respiratory disease outcomes for all members of this cohort in the period between visit 2 and visit 3. This was carried out by a graduate student, Cheryl Peters, under the supervision of Dr. Kennedy. Results have been published (30) and will be summarized here.

Health care utilization data for the period 1991 to 2005 were obtained from the BC Linked Health database (a data resource containing dates and diagnostic codes for all physician and hospital visits in BC). During the follow-up period, cohort members visited a physician an average of six times per year, mostly for injury and musculoskeletal problems. Among cohort members, there were 762 visits coded for one of the 5 respiratory outcomes of interest. Atopic subjects, women, and painters were more likely to have visits coded as asthma; men, machinists, and current smokers were more likely to have visits coded as bronchitis.

Asthma was defined as 2 or more physician visits in a one year period with an ICD-9 code for asthma; bronchitis was defined similarly (but with 3 or more visits in a year), using 4 ICD-9 codes for bronchitis and respiratory symptoms.

Asthma incidence rates were 3.6 per 1000 per year (excluding subjects with self-reported asthma at baseline) with 16 cohort members meeting the case definition for new asthma (based on physician visits alone); bronchitis incidence rates were 5.9 per 1000 per year (with 20 cohort members meeting the case definition).

Analyses were directed at examining potential predictors of 1) visit rates over the full time period and 2) becoming an asthma or bronchitis case (based on the case definitions above).

Key results for these analyses are shown in Table 17. We found that bronchitis symptoms at the visit 1 (year one of apprenticeship) were associated with increased rates of physician visits for bronchitis outcomes in the follow-up period after visit 2 (i.e. 5-12 years later), and with the risk of becoming a 'bronchitis' case. Health care utilization for asthma (both increased rate of physician visits and meeting the case definition) was linked with evidence of hyper-reactive airways at baseline (PC20 < 8 at visit 1), with *early* new development of increased bronchial responsiveness (between visit 1 and visit 2) and with presence of asthma-like symptoms at visit 2 (but interestingly, not at visit 1 – although keeping in mind that subjects with an existing diagnosis of asthma at baseline were excluded). An early large decline in FEV_1 (more than 5 percentage points per year) was also associated with a three fold increase in the risk of asthma in the later follow-up period, although the confidence interval was wide.

In summary, subjects who had asymptomatic hyper-reactive airways (but no asthma diagnosis) at baseline, those who became hyper-reactive or who developed asthma symptoms in the first 2 years of follow-up, and those who had a very large annual decline in FEV_1 in the first 2 follow-up years, were the ones who went on to have increased physician utilization for asthma, indicating that the early development of asthma-like symptoms, significant obstruction, and hyper-responsive airways may well be reliable predictors of later frank asthma development.

Summary of results regarding objective 1

In summary, the results of the intensive follow-up involving physiologic testing at visit 3 and results based on examining administrative data for health care utilization over the follow-up period provide a consistent message. An early, dramatic decline in lung function (FEV_1 decline in the lowest 5^{th} percentile, or approximately 6% per year) and evidence of the *new* development of hyper-responsive airways within 2 years of entering the active industrial or construction work-force among a population of young apprentices were both linked with increased respiratory morbidity over the following 14 years.

Comparison of our objective 1 results to other studies

Previous longitudinal studies of working populations have shown that an excessive decline in lung function over an extended period of the working life (in the range of 60 ml/year or greater – or 1.5% per year, for a person with an FEV_1 of 4 litres) was associated with increased cardio respiratory mortality and morbidity;(31, 32) others have indicated a link between a rapid lung function decline in the first few years of employment (also in the 60-100 ml/yr range) and later airflow obstruction.(33-35) This is in contrast to our finding that only very extreme early lung function decline (greater than the cohort lower 95% confidence limit of 5.8% decline per year) was predictive of later respiratory morbidity. However, as Hnizdo pointed out recently in her comprehensive review of methodological issues relating to workplace spirometry monitoring, because of the considerable inherent variability in any one measure of lung function in an individual, a stable estimate of longitudinal change in lung function requires about 5-8 years of follow-up.(36) Nevertheless, as Hnizdo also noted, there is value in assessing early change over a shorter time period in occupational settings. Based on her analyses, a meaningful 'excessive' longitudinal decline would be about 10% over 1 year, and an additional 2% for each additional year of follow-up, for follow-up periods of 1-7 years. This is roughly similar to the 5.8% /year or greater cut-off found in our cohort to be linked to subsequent respiratory morbidity.

Few other studies have sufficient data to observe the outcomes associated with the new development of asthma or bronchial hyper-responsiveness in young adults without pre-existing asthma. Most studies are focused on asthma onset itself as the health outcome. However, our findings are consistent with studies that show that pre-existing asthma (or bronchial hyper-responsiveness) may lead to selection into jobs with lower exposures (hence potentially less work-related morbidity)(37) and that increased bronchial responsiveness among subjects without pre-existing asthma is a risk factor for subsequent chronic airflow obstruction.(38)

OBJECTIVE 2 results (MWF aerosol exposure impacts):

What is the impact, if any, of exposure to irritants and sensitizers found in metalworking fluid aerosols on respiratory morbidity in this inception cohort?

Table 18 shows lung function test results at the final follow-up, for machinists (current and former) and other trades people. There were no significant differences in FEV_1 or change in FEV_1 among the groups, although former machinists had a slightly lower average FEV_1 at follow-up than either current machinists or the rest of the cohort. Former machinists were significantly more likely than others to have hyper-responsive airways both at visit 2 and at the final follow-up.

Results of multivariable analysis to investigate exposure factors potentially related to FEV_1 at follow-up are shown in table 19. Potential explanatory variables considered in model building included demographic characteristics, indicator variables for quitting the trade either between visits 1 and 2, or between visits 2 and 3, and both continuous and categorical versions of all the exposure variables shown in tables 9 and 10. Also considered were duration variables for exposure to metalworking fluids between visits 2 and 3 (all types of fluids combined, but as noted above, this was mainly soluble fluid) and various types of metalworking fluids in the period between visits 1 and 2.

The final 'best model' for predictors of FEV_1 at visit 3 indicated a significant association between reduced FEV_1 and quitting the trade early (prior to visit 2) as well as early exposure to soluble metalworking fluids. In the population as a whole, exposures after visit 2 (either intensity or duration) did not appear to be linked significantly to visit 3 FEV_1; however, when the machinist population was stratified by current trade status (early quitters v. all others) it became apparent that cumulative exposure to metalworking fluid *was* associated with a significant decrease in visit 3 FEV_1 in both current and former machinists (see figure 3). Former machinists (those who quit the trade within the first 2 years of apprenticeship) had the lowest visit 3 FEV_1, but among those remaining in the trade (at least for 2 or more years), a clear ‘dose-response’ trend was seen with decreasing FEV_1 associated with increasing cumulative metalworking fluid exposure. This emphasizes a similar message with respect to the ‘healthy worker survivor effect’ as seen in the analyses aimed at objective 1.

A similar ‘healthy worker survivor effect’ was seen in models for predictors of bronchial responsiveness at visit 3 (table 20 and figure 4). However, in this case, increased bronchial responsiveness was associated with *current* metalworking fluid exposure, not cumulative exposure, and only among currently employed machinists exposed to estimated metalworking fluid concentrations above 0.4 mg/m^3. Machinists who had quit the trade prior to visit 2 had an intermediate level of bronchial responsiveness (higher than other trades people and than current machinists in the lowest 2 exposure categories), but lower than the most highly exposed current machinists.

Summary of results regarding objective 2

In summary, a dose-response relationship was seen between FEV_1 at visit 3 and *cumulative* metalworking fluid exposure among machinists who remained in their trade through the full study period, with higher cumulative exposure associated with decreased FEV_1. Machinists who quit the trade within the first 2 years of their apprenticeship had even lower FEV_1 values 16 years later than those currently employed machinists. A similar trend was seen for bronchial responsiveness in association with *current* metalworking fluid exposure levels; in this case the highest level of bronchial responsiveness was seen in the group with estimated current metalworking fluid aerosol exposure over 0.4 mg/m^3. For both FEV_1 and bronchial responsiveness outcomes, a strong ‘healthy worker survivor effect’ was seen.

Comparison of our objective 2 results regarding metalworking fluid aerosol exposures with other studies

Several other studies have also found exposure-responsive relationships between some aspect of metalworking fluid aerosol and increased prevalence of respiratory symptoms(13, 39-41) and acute (typically across-shift) declines in FEV_1 among exposed workers.(8-10, 19) However, other studies did not see similar results with respect to measures of short-term (12) or chronic lung function impairment.(42) In contrast we found clear exposure response relationships between cumulative and current exposure to MWF aerosol mass (primarily soluble and semi-synthetic fluids) and chronic airflow obstruction (with cumulative exposure) and bronchial hyper-responsiveness (with current exposure). In both cases morbidity was seen among workers exposed at levels below regulatory guidelines. We believe our study is the first longitudinal study designed to evaluate this chronic impact of exposure to metalworking fluids, while taking into account potential biases associated with the healthy worker effect.

Implications for future research on occupational health

We found that a dramatic reduction in lung function or increase in bronchial responsiveness early in the working life was predictive of later respiratory morbidity (measured using physiologic tests, and physician visits for asthma and bronchitis). Additional research is needed to confirm this finding and to evaluate the preventive role of aggressive early intervention (exposure control or treatment).

Second, although potential impact of the ‘healthy worker survivor’ effect in epidemiologic studies is well known, this research demonstrates the critical importance of taking it into account when analyzing results of occupational health cohort or prevalence studies. We advise WorkSafeBC to ensure that, wherever possible, funded studies are designed so that the impact of this effect can be evaluated or minimized.

With respect to metalworking fluid exposure, specifically, this research confirms that there is a potential for chronic respiratory impairment among machinists with continued exposure to metalworking fluid aerosols above the US National Institute of Occupational Safety and Health’s recommended exposure limit (0.4 mg/m^3). Further research directed at the impact of control measures, especially for CNC machining, is warranted.

Policy and prevention

Policy and prevention implications arising from this research

1. Our findings provide support for the implementation of lung function screening programs in the workplace (simple spirometry and detailed symptom assessment), provided they are accompanied by an aggressive policy of intervention for workers who develop significant lung function decline or new asthma symptoms.
2. Machine shop owners and managers should be made aware of the importance of metalworking fluid mist control, especially in relation to grinding and CNC machining tasks. It would appear that many machinists are aware of the high exposure potential from inadequately ducted CNC machines. This research provides concrete evidence to demonstrate this and emphasizes the potential lung harm associated with failure to control this source of exposure.
3. WorkSafeBC should consider adopting the US NIOSH recommended exposure limit for metalworking fluid mist aerosols.

Relevant user groups

- Occupational health physicians and nurses
- Managers of occupational health screening programs
- Managers and owners of machine shops and other workplaces with machining facilities
- Machinists

Dissemination / Knowledge Exchange

This project has generated 2 key knowledge transfer and exchange *research* outputs, both under the supervision of Dr. Anne Marie Nicol, who was first a post-doctoral fellow, working with Dr. Kennedy and then an assistant professor in the School of Environmental Health. Dr. Nicol's work was funded in part by CIHR and in part by this project grant. The results of these studies will inform the knowledge exchange strategy associated with this project and we currently engaged in implementing the recommendations that have been generated by the knowledge transfer and exchange research. ***Details are included in Appendix 3.***

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Tables and Figures

Table 1 - Visit 1 Results: Characteristics of participants at baseline

	Machinists	Controls	P
n	99	213	
Female, n (%)	3 (3%)	8 (4%)	ns
Non-white, n (%)	7 (7%)	13 (6%)	ns
History of childhood asthma	9 (9%)	18 (8%)	ns
Age, years, mean (sd)	24.3 (3.4)	24.4 (3.7)	ns
Smoking status			
Nonsmoker	56 (57%)	90 (42%)	
Ex-smokers	15 (15%)	35 (16%)	0.05
Current Smokers	28 (28%)	88 (41%)	
Positive skin test, n (%)	46 (46%)	91 (43%)	ns
Pulmonary function, mean (sd)			
FEV_1 : % predicted	100.2 (9.7)	102.2 (10.3)	ns
FVC : % predicted	103.5 (9.5)	105.7 (9.3)	ns
Bronchial reactivity			
Methacholine slope (ml FEV_1 per mg/ml), mean (sd)	-30.6 (63.9)	-27.1 (58.7)	ns
$PC_{20} \leq 8$ mg/ml, n (%)	9 (9%)	15 (7%)	ns

Table 2 - Visit 2 Results: Characteristics of participants at year 2 follow-up

	Machinists	Controls	p
eligible, n	99	213	
participated, n (%)	91 (92%)	188 (88%)	
Age, years, mean (sd)	24.3 (4.0)	24.2 (3.9)	ns
Years between tests, mean (sd)	2.06 (.56)	2.06 (.54)	ns
Quit trade between tests, n (%)	13 (16%)	5 (3%)	<.001
Pulmonary function, mean (sd)			
FEV_1 : % predicted	98.5 (11.0)	100.8 (10.5)	ns
FVC : % predicted	103.0 (10.3)	106.0 (9.9)	<.05
Δ FEV_1 (ml/yr), mean (sd)	-61.9 (87.3)	-65.3 (105.5)	ns
Bronchial responsiveness:			
Methacholine slope, mean (sd) (ml FEV_1 per mg/ml methacholine),	-35.4 (87.7)	-18.5 (28.4)	<.10
$PC_{20} < 8$ mg/ml, n (%)	8 (10%)	6 (4%)	<.10
Change in methacholine slope, mean (sd) (slope at follow-up - slope at baseline, ml/mg/ml)	-17.1 (78.8)	+1.2 (31.1)	<.05
Incident asthma[1], n (%)	6 (7%)	3 (2%)	<.05

1. Doubling dose decrease in PC_{20}, plus asthma-like symptoms at follow-up

Table 3 - Visit 2 Results: Linear regression analysis of methacholine slope at follow-up

Duration of exposure to metalworking fluid (type, task)	coefficient (se)[1]	p
soluble metalworking fluid (hrs), log transformed	0.027 (.013)	.04
synthetic metalworking fluid (hrs), log transformed	0.034 (.013)	.008
straight metalworking fluid (hrs), log transformed	-0.025 (.018)	.16
tool or cutter grinding (hrs), log transformed	-0.017 (.019)	.40

1 dependent variable: ln (20-methacholine slope); also in model: age, positive skin prick test (yes/no), FEV1/FVC%, (all at time of test); history of childhood asthma, quit smoking between tests (yes/no), and baseline methacholine slope (log transformed)

Table 4 - Determinants of exposure to 'total' metalworking fluid aerosol

	B[1]	SE
Factors associated with increased exposure		
Proportion of shift grinding	1.460	0.360
Operated enclosed CNC machine tool (y/n)	0.234	0.124
Welding in shop (y/n)	0.970	0.108
Factors associated with reduced exposure		
Proportion of shift machining aluminum	-0.461	0.188
Proportion of shift at a vertical mill	-0.333	0.117
Shop with peaked roof (y/n)	-0.450	0.158
Shop with mechanical ventilation (y/n)	-0.283	0.136
Height of shop (meters)	-0.069	0.020
Intercept	-1.174	0.176

1. from multiple linear regression model with ln “total“ aerosol as the dependent variable, with "total" defined as aerosol sampled using a 37-mm cassette, and therefore not deliberately designed to capture aerosol in specific size fractions, yet under-sampling the inhalable fraction that is captured in the nasal passages and upper respiratory tract;
β= regression coefficient, SE = standard error of regression coefficient

Figure 1 - Prevalence of moderately increased bronchial responsiveness at visit 2 in relation to fluid and machine type

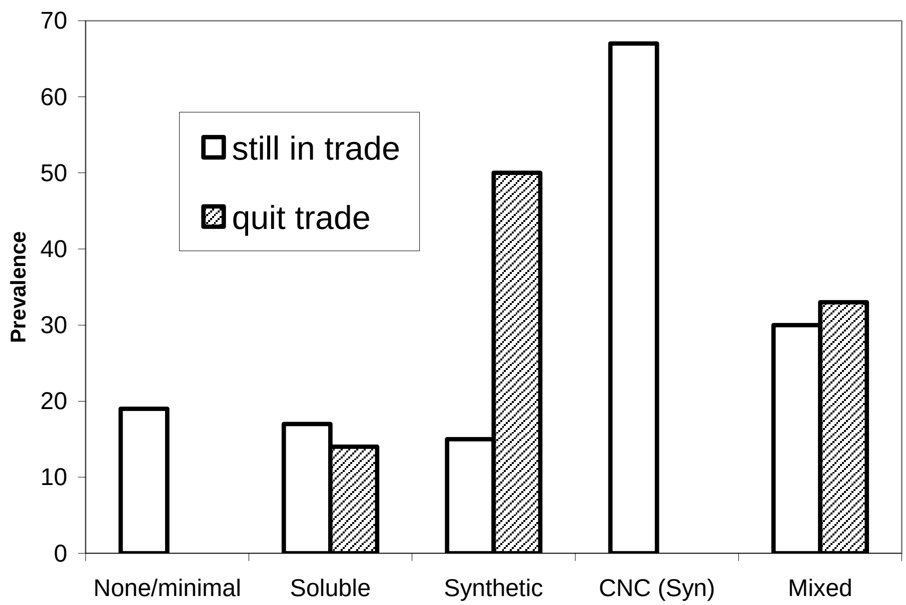

Table 5 - Visit 3 total participation status

	group (based on apprenticeship program, v1)				Total
	machinists	painters	insulators	electricians	
original n	116	82	53	105	356
tested visit 3	77	38	35	59	209 (59%)
deceased	1	5	1	0	7 (2%)
no contact	13	21	8	26	68 (19%)
sick, disabled	1	0	2	1	4 (1%)
refused*	19	10	5	10	44 (12%)
contacted, unable to schedule+	5	8	2	9	24 (7%)

*includes cohort members who have not refused outright, but who have failed to show up repeatedly for scheduled testing appointments

Table 6 - Comparison of visit 3 participants and non-participants

	tested visit 3 n=209	located, but not tested visit3*	lost to follow-up	p
n	209	79	68	
age visit 1, mean (sd)	24.4 (3.9)	24.3 (4.2)	24.5 (3.9)	0.3
female	4.3%	1.3%	1.5%	0.3
nonwhite	5.3%	3.8%	11.8%	0.1
atopic, visit 1	45.0%	40.5%	44.1%	0.8
history of childhood asthma, visit 1	8.1%	6.3%	7.4%	0.9
smoking status, visit 1				
non-smoker	51.7%	36.7%	33.8%	
ex-smoker	16.3%	19.0%	20.6%	0.05
current smoker	32.1%	44.3%	45.6%	
quit trade between visits 1 and 2	6.6%	14.7%	7.4%	0.1
pulmonary function, mean (sd)				
FEV_1 % predicted, visit 1	100.7 (11.1)	102.5 (10.8)	102.2 (11.9)	0.2
Δ FEV_1 (visit 2 to 1), ml/yr	-65.1 (100.9)	-66.9 (90.5)	-68.9 (110.9)	0.8
bronchial responsiveness (%)				
PC_{20} < 8 mg/ml, visit 1	7.0%	9.3%	10.6%	0.7

*including the 7 deceased cohort members

Table 7 - Demographic characteristics of eligible visit 3 participants by current trade status

	Still Machinists	Still Painters	Still Insulators	Still Electricians	Currently other job	P
n	39	29	23	39	58	
Female (%)	0	7	4	3	9	0.3
Non-white (%)	8	3	0	10	3	0.4
Atopic, visit 3 (%)	64	62	48	62	47	0.3
Current smoker (%)	10	24	43	10	31	<0.01
Age, visit 3 (mean)	40.6	41.1	40.7	39.9	40.3	0.6

* eligible, defined as: age 35 or younger and less than 5 yrs in current trade at first visit

Table 8 - Machinists' current job – machines used

Machine type	Number (total)	CNC machines
Mill or milling machine	30	11
Lathe	33	12
Machining center	5	5
Grinder	15	0
Drill	12	2
Saw	6	1
Other	5	3
Total	106	34

Table 9 - Work and exposure characteristics of visit 3 machinists and former machinists

	Still Machinists		Former Machinists	
	Mean (sd)	range	Mean (sd)	Range
N	39		30	
Yrs of machining, since visit 1	6.8 (5.2)	4, 16	4.6 (4.9)	0, 12
Yrs of machining, before visit 1	1.6 (1.1)	0, 5	1.3 (1.1)	0, 4
Current job metalworking fluid expos (mg/m3)[1]	0.25 (0.18)	0.05, 0.8	-	
Current job, percent of time machining with soluble metalworking fluid	18 (32)	0, 100	-	
Cumulative metalworking fluid exposure, mg/m^3-yrs	2.2 (2.7)	0.2, 14.4	2.4 (4.5)	0, 23.7
Enclosed CNC machining[2]				
200-10,000 hrs	28%		3%	
> 10,000 yrs	10%		3%	
Enclosed CNC machining current job > 10% of time	18%		-	
Machining using metalworking fluids[3]				
< 1900 hrs	31%		57%	
1900-11,500 hrs	36%		27%	
> 11,500 yrs	32%		17%	
Exposure monitoring	n=22			
metalworking fluid aerosol, measured (mg/m^3)[4]	0.14 (0.17)	0.02, 0.7		

1 ‘total’ aerosol concentration, estimated from detailed task analysis and empirical models, see text for details
2 computer numeric controlled machine, at least partly enclosed but not ducted
3 hours computed from detailed job histories and task duration questionnaire
4 ‘total’ aerosol concentration, measured 1 day only for model evaluation purposes, see text for details

Table 10 - Work and exposure characteristics of visit 3 eligible participants

Prevalence (%) of participants reporting each exposure

	Still Machinists	Still Painters	Still Insulators	Still Electricians	Currently other job
n	39	29	23	39	58
History of: (%)					
Isocyanate expos.					
1-500 hours	0	48	13	0	9
500+ hours	0	24	9	0	2
Industrial electrical const/maint					
1-50 wks	0	0	0	36	3
50+ wks	0	0	0	28	10
Abrasive blast cleaning					
1-500 hours	0	28	0	0	2
500+ hours	0	28	0	0	2
Welding, current job					
≥ 1 day/week	5	3	4	3	9
Disinfectant expos, current job					
≥4d/wk *or* ≥4h/day	5	3	0	0	5
Gassing incident, since V1	3	7	17	3	0

Table 11 – Trade 'drop-out' status after 15 years of follow-up

	Other Trades	Machinists	P
N	132	77	
Quit trade:			
between visits 1 & 2	1.5%	14.3%	<0.001
between visits 2 & 3	20.4%	29.9%	0.1
Changed job(s) for health reasons	6.8%	6.5%	0.9

Table 12 - Predictors of changing jobs for health reasons or health concerns[1]

	Odds ratio	95% CI
Cumulative metalworking fluid exposure category[2]	2.0	(1.1, 3.5)
Other asthmagen exposure[3]	5.2	(1.3, 20.5)

1 multi-variable logistic regression model with job change (yes/no) as the dependent variable (excluding changing jobs because of injury)

2 cumulative exposure categories: 0, < 2, 2-4, ≥4 mg/m^3*yrs

3 high exposure to isocyanates, abrasive cleaners, jobs at high risk for 'gassing'

Table 13 - Lung function test results, visit 3 participants

	Still Machinists	Still Painters	Still Insulators	Still Electricians	Currently other job
n	39	29	23	39	58
FEV_1 (% predicted)					
visit 1 (1988-90)	100.6 (11.1)	100.1 (13.1)	102.0 (10.8)	103.4 (10.0)	98.9 (10.8)
visit 2 (1990-93)	99.4 (11.5)	99.4 (13.1)	99.4 (11.4)	102.6 (9.8)	95.5(10.2)
visit 3 (2004-7)	99.3 (11.3)	98.3 (13.5)	98.1 (9.3)	99.3 (11.3)	96.9 (12.3)
Δ FEV_1 (visit 2- 1), ml/y	-63.8 (93.1)	-75.2 (148.5)	-87.8 (151.8)	-27.3 (74.3)	-77.0 (98.7)
Δ FEV_1 (visit 3- 1), ml/y	-28.5 (15.8)	-30.4 (12.2)	-34.4 (19.0)	-25.9 (15.4)	-29.3 (19.1)
% with FEV1 decline > 100 ml/yr, visit 2-1	31%	42%	52%	20%	32%
% with FEV_1 decline > lower 95% Conf limit, visit 2-1[1]	3%	12%	9%	0	2%
Hyper-responsive airways[2]					
Baseline	8%	0%	5%	8%	7%
2 y. follow-up	14%	8%	0%	8%	11%
16 y. follow-up	9%	11%	5%	14%	10%

1 Based on lower 95% Confidence limit of -5.8% decline per year (annual decline as a percentage of baseline percent predicted value)

2 PC_{20} < 8 mg/ml

Table 14 - Predictors of FEV_1 (% predicted) at year 16 (visit 3)

	Model 1		Model 2	
	Coefficient (se)	P	Coefficient (se)	P
Intercept	64.2 (16.0)		36.9 (12.9)	
Smoking amt[1] (visit 3)				
current smokers	-0.07 (.07)	0.4	-0.07 (.07)	0.4
former smoker	-0.22 (.17)	0.06	-0.16 (.11)	0.1
Weight (kg), at visit 3	-0.05 (.06)	0.4	-0.05 (.05)	0.4
Visit 1 obstruction (FEV_1/FVC %)	+0.66 (.15)	<0.001	+0.84 (.13)	<0.001
Baseline bronchial responsiveness[2]	**- 3.5 (1.6)**	**0.03**	not in model	
Clinically relevant increase in bronchial responsiveness[3]				
visit 1 to 2	**-6.4 (3.3)**	**0.05**	not in model	
visit 1 to 3	**+0.3 (2.0)**	**0.8**	not in model	
FEV_1 change < lower 95%CL, visit 2 - 1[2] (yes/no)	not in model		**-10.4 (4.2)**	**0.01**

1 packs/day x years of smoking
2 ln (20 – methacholine slope, in ml/mg) at visit 1
3 more than one doubling dose decrease in PC_{20} between visits

Table 15 - Predictors of bronchial hyper-responsiveness (lnslope3) at year 16 (visit 3)

	Coefficient (se)	P
Intercept	2.2 (0.4)	
Female	0.64 (0.3)	0.04
Baseline bronchial responsiveness[1]	0.41 (.09)	<0.001
Clinically relevant increase in bronchial responsiveness, visit 1 to visit 2[2]	1.3 (.19)	<0.001

1 ln (20 – methacholine slope, in ml/mg) at visit 1
2 more than one doubling dose decrease in PC_{20} between visits

Table 16 - Correlations between lung function changes from visits 1 to 2, 2 to 3, and 1 to 3

	Δ FEV_1 visit 1 - 2	Δ FEV_1 visit 2 - 3	Δ FEV_1 visit 1 - 3
Δ FEV_1 visit 1 - 2	1	-0.26	+0.45
Δ FEV_1 visit 2 - 3		1	+0.71
Δ FEV_1 visit 1 - 3			1

Figure 2 - FEV_1 decline over the study period – by degree of decline from visits 1 to 2

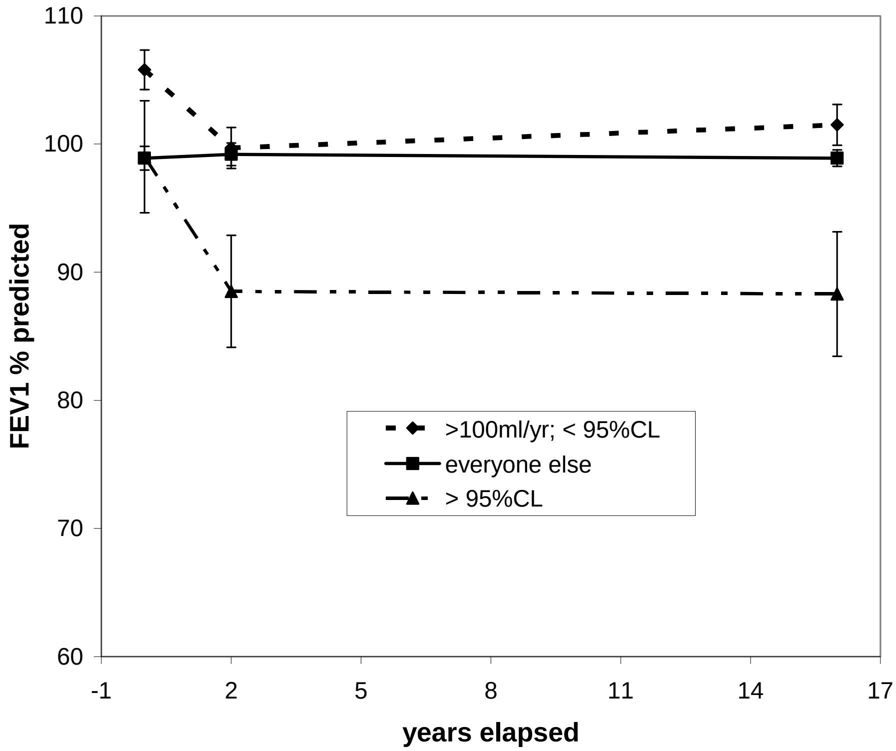

Table 17 – Early lung function predictors of physician visits for asthma or 'bronchitis' symptoms[1] during the follow-up period (visit 2 to visit 3)

	Odds Ratios (95% CI)			
	Asthma (case)	**Asthma (visit rate)**	**Bronchitis (case)**	**Bronchitis (visit rate)**
Symptom models				
Bronchitis symptoms				
Visit 1	1.7 (0.4, 7.2)	3.5 (0.8, 15.2)	**4.4 (1.6, 11.9)**	**2.1 (1.4, 3.3)**
Visit 2	1.5 (0.4, 5.9)	1.5 (0.5, 4.8)	0.6 (0.2, 2.2)	1.2 (0.8, 1.9)
Asthma like symptoms				
Visit 1	1.1 (0.3, 3.6)	1.1 (0.4, 3.6)	1.0 (0.4, 3.0)	1.5 (1.0, 2.3)
Visit 2	**5.9 (1.9, 18.8)**	**5.7 (2.1, 15.7)**	2.0 (0.7, 5.3)	1.4 (1.0, 2.0)
Spirometry models				
FEV_1 decile, visit 1	0.8 (0.5, 1.2)	0.9 (0.5, 1.4)	0.8 (0.5, 1.2)	1.0 (0.8, 1.1)
PC_{20} < 8 mg/ml, visit 1	2.5 (0.7, 9.4)	**4.5 (1.3, 14.9)**	2.5 (0.9, 6.8)	1.5 (0.9, 2.4)
Clinically relevant increase in bronchial responsiveness, visit 1-2	**5.5 (1.5, 16.1)**	**6.5 (1.7, 24.9)**	2.9 (0.6, 13.4)	2.2 (1.3, 3.8)
Or				
FEV_1 decline, visit 1-2, > 95% CL	3.2 (0.8, 12.1)	2.8 (0.5, 15.3)	1.9 (0.2, 15.2)	1.0 (0.5, 2.1)

1 Odds ratios derived from log binomial (case) or log linear (rate) regression models with smoking status (visit 1 and visit 3) and an indicator variable for high physician utilization overall also included in models

Table 18 - Lung function test results at 16 years of follow-up, by machining trade status

	Other Trades	Former machinists	Current Machinists	P
N	132	34	43	
FEV_1 (% predicted)				
baseline	101.4 (11.3)	97.1 (10.0)	101.0 (11.1)	0.20
16 y. follow-up	99.0 (12.5)	93.9 (12.4)	99.2 (11.9)	0.1
change in FEV_1 (ml/y)				
Visits 1 to 2	-64.0 (118.8)	-68.4 (85.7)	-67.2 (94.8)	0.9
Visits 2 to 3	-27.7 (19.2)	-27.2 (24.4)	-25.4 (17.5)	0.8
Hyper-responsive airways[1]				
baseline	5.6%	11.8%	6.9%	0.5
2 y. follow-up	5.9%	21.2%	12.5%	0.03
16 y. follow-up	8.5%	26.1%	8.6%	0.04

1. $PC_{20} < 8$

Table 19 - Exposure Predictors of FEV_1 at year 16 (Visit 3):

	Coefficient (se)	P
Intercept	117.8 (5.3)	
Cumulative smoking amt* (visit 3)		
current smokers	-0.09 (0.7)	0.3
former smoker	-0.27 (1.1)	0.01
Weight (kg)	-0.17 (.06)	0.004
History of childhood asthma	-9.3 (3.2)	0.004
Quit machining trade between visits 1 and 2	-10.4 (3.6)	0.005
Early soluble metalworking fluid exposure (hours before visit 2)	-0.004 (.001)	0.02
Cumulative metalworking fluid exposure category (up to visit 3)	-1.4 (1.0)	0.2

Figure 3 – FEV_1 (% predicted)[1] by cumulative metalworking fluid exposure and 'quit trade' status

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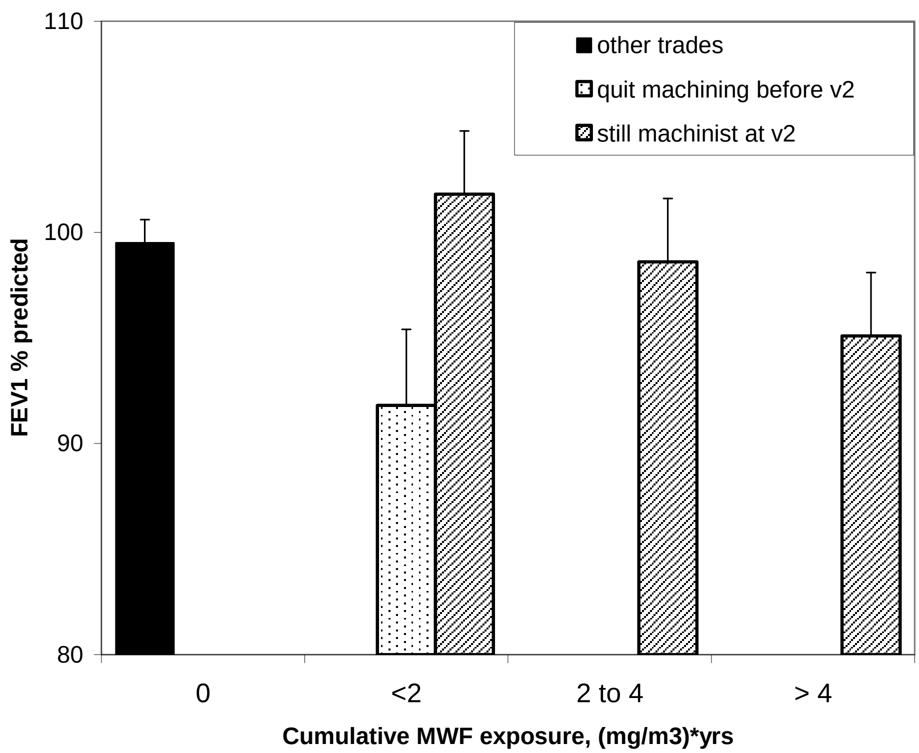
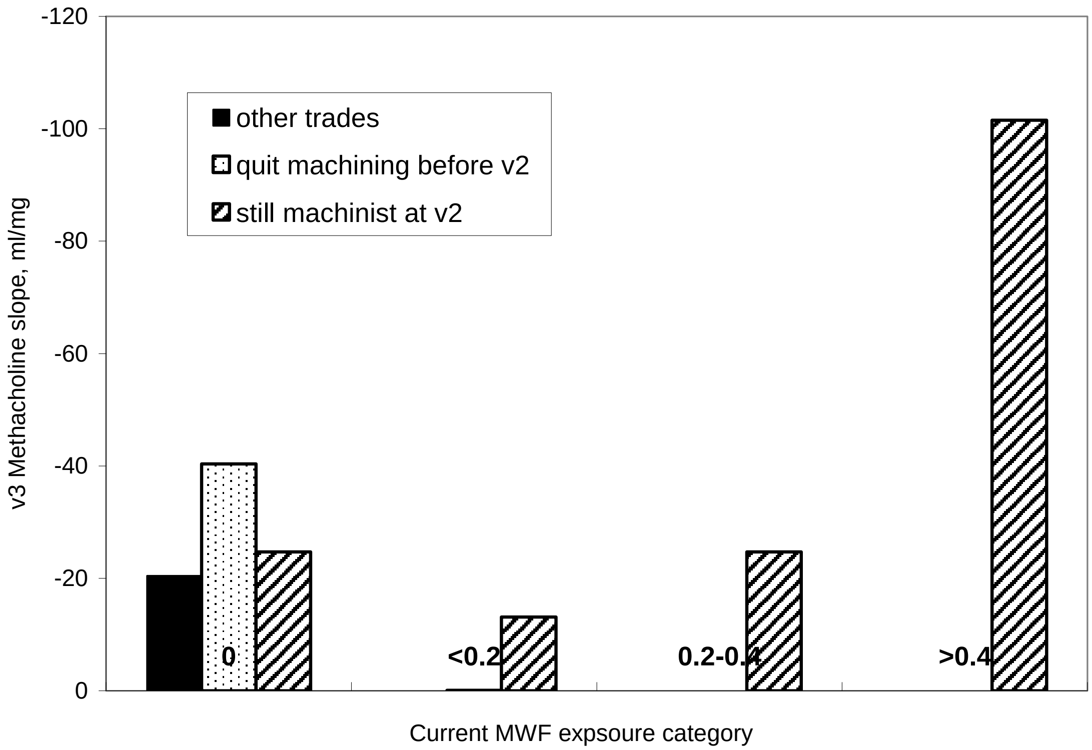


1 FEV_1 % predicted, adjusted for other variables in model (see Table 19). Bars show average values ± SEM

Table 20 - Exposure predictors of bronchial hyper-responsiveness (lnslope3) at year 16:

	Coefficient (se)	P
Intercept	3.2 (1.0)	
Baseline bronchial responsiveness (lnslope1)	0.41 (.12)	0.007
Atopic (yes/no)	0.19 (.12)	0.1
Visit 1 obstruction (FEV_1/FVC %)	-0.01 (.01)	0.1
Quit machining trade between visits 1 and 2	0.43 (0.3)	0.1
Current metalworking fluid exposure category	0.16 (.08)	0.05

Figure 4 - Bronchial responsiveness (methacholine slope) at visit 3, by current metalworking fluid exposure and 'quit trade' status



1. $p<0.05$ comparing machinists in the highest exposure category to all others

APPENDIX 1 – Results from determinants of exposure model evaluation sub-study

Of the 44 machinists still employed in the machining trade, 31 collected several bulk metalworking fluid samples each (112 useable samples) and 30 collected air samples. Several participants who are classed as 'machinists' for this study were shop supervisors or working at a job only indirectly related to machining; seven of these did not collect air samples; some did collect bulk samples. Seven machinist participants declined to take air samples for a variety of reasons. Two air samples were unusable because of technical pump failure.

Metalworking fluid bulk samples

The bulk fluid samples consisted of 46 samples labeled as unused fluids (supposedly taken directly from the original container, undiluted, called 'clean' in this report) and 68 samples taken from working machines (either from the sump or from the application nozzle, called 'used' in this report).

Fluid density values ranged from 0.81 to 1.08 g/ml (mean 0.98); viscosity values ranged from 30.6 to 681cP (mean 62) for used fluids and from 30.6 to 1616 cP (mean 360) for clean fluids.

Material safety data sheets were obtained for all fluids and samples were classified as soluble fluids (72 samples), synthetic fluids (3 samples), semi-synthetic fluids (24 samples), or straight oils (8 samples). It was not possible to classify 7 samples as the machinists involved could not provide reliable information about the fluid name or type.

The main tool types represented were milling machine (23 used samples) and lathes (22 used samples). Both these tool types used primarily soluble fluids (74% of mills and 77% of lathes) with the remainder using semi-synthetic fluids. The other tools types included drills (5 used samples), grinders (5 used samples), saws (4 used samples), other types with 1 or 2 samples each (total of 10 used samples). The straight oil samples all came from hones, the synthetic samples from a boring machine, and the unknown sample types were from a deburring machine and a beam roll forming machine.

A total of 87 samples provided reliable endotoxin data.[2] Endotoxin values ranged from below detection (6 samples; 1/2 detection limit was substituted) to 3.45×10^6 EU per ml. The distribution of values was highly skewed so values were log transformed (natural log) prior to analysis.

Table 1 shows geometric mean endotoxin values by fluid type and by clean v. 'used' fluids. As expected, endotoxin levels were low in 'clean' fluids but among the soluble fluid samples of so-called clean fluid, endotoxin concentrations above 200 EU/ml were found in 6 samples (from different fluids), suggesting either contamination of the fluid containers or mislabeling of samples or a combination of both.

Also, as seen by other investigators, soluble fluids had the highest endotoxin values. The one sample from a synthetic fluid was higher, but no conclusions can be drawn from this single sample. Straight fluids had very low values; semi-synthetic fluids had intermediate results.

Detailed multivariable analyses of potential determinants of endotoxin levels in 'used' bulk fluids, including variables suggested by other investigators as being potentially predictive of endotoxin levels (e.g. proportion of tramp oil, pH, use of biocides, frequency of changing the

[2] After carrying out the laboratory analyses we detected a contamination event in our laboratory that rendered 25 bulk samples and 6 filter samples invalid.

fluid in the sump, frequency of checking fluid concentration) did not reveal any significant predictors in addition to fluid type.

Air sample analysis

A total of 22 air sample filters provided useable data. Concentration of 'total' aerosol ranged from below the limit of detection (1 sample) to 0.72 mg/m^3 (mean 0.14; median 0.09 mg/m^3).

As a first step in evaluating the predictive model for total aerosol concentration developed previously by us (28), we compared actual concentration values for these 22 filters to predicted values created using the variables that were statistically significant in the predictive model. ***These variables were: proportion of shift spent doing grinding, milling, and machining aluminum (3 variables), working at an enclosed or partially enclosed CNC machine, welding being carried out in the shop, presence of a room ventilation system, shop ceiling height, and presence of a peaked roof.***

Plots comparing actual values (on the vertical axis) and predicted values (on the horizontal axis) are shown in figures 1a and b, for log transformed values and original values. The mean difference between predicted and actual values was 0.08 mg/m^3 (sd 0.17). These plots indicate that metalworking fluid exposure concentrations measured in this evaluation sub study were within a reasonable range of the values that would have been predicted by the empirical model.

To further evaluate the previous predictive model, we created a new "determinants of exposure model" from the data collected in the current study, using the same methods as previously described.(28) Briefly, multivariable regression analyses were carried out with the total aerosol values (natural log transformed) as the dependent variable and the same potential predictor variables.

The best model for the new data (from this study) contained 4 of the same variables found previously (and no new variables): proportion of shift spent milling and machining aluminum (associated with lower concentrations), and the proportion of the shift spent grinding and the fact of working (at any time) with an enclosed or partially enclosed CNC machine (both associated with higher concentrations). We considered using this simpler model to estimate exposures for the full dataset, but discovered that the estimates produced were highly skewed, with a small number of unreasonably high values (related to time spent grinding).

Together these findings supported our initial plan to create estimates of total metalworking fluid aerosol exposure using the original empirical model we developed in preparation for this project.

Discussion

We note that the most recent metalworking fluid aerosol concentrations were slightly lower than those measured by us previously for the development of the empirical models. This could be due to several factors including exposures in general declining in more recent years and exposures in the shops where these machinists work being lower than in other machine shops due to the influence of participation in our study over the years. The trend towards lower exposure levels in recent decades is consistent with those reported by two recent comprehensive reviews of metalworking fluid exposures and their determinants.(43, 44) More important is that the same task related variables remained predictive of exposure in this small evaluation study as were seen previously, namely higher exposure associated with grinding and with enclosed or partially enclosed CNC machining. Higher exposures associated with grinding have also been reported in the recent reviews of this subject.(43, 44) Although it may appear counterintuitive that working with an enclosed CNC machine should result in higher exposures (as enclosure is typically seen as a control measure), it should be noted that only two of the ‘enclosed’ CNC machines used by machinists in this study were also equipped with a mist collection device. CNC machines operate at very high speeds and use large quantities of metalworking fluid. Hence they generate very high peak mist concentrations to which machinists are exposed when they open the enclosure or if they prop open the enclosure doors – as is done on occasion. Appendix 2 contains sample quotes from machinists who were interviewed for a companion study. These quotes reveal that although some machinists perceive CNC machining to be ‘cleaner’, in practice they often generate the highest exposures.

Table 1 - Endotoxin concentration (EU/ml fluid) in bulk metalworking fluid samples

	soluble	semi-synthetic	synthetic	straight	unknown
Clean fluid					
n	19	5	1	4	3
mean (sd)	53 (71.4)	1.2 (10.5)	0.14	1.4 (1.9)	1.4 (1.6)
Used fluid					
n	33	15	1	2	4
mean (sd)	817 (108)	167 (53)	2336	1.2 (2.8)	30 (17.6)

$p<0.01$ ANOVA, difference between clean and in use fluid; and differences among fluid types

Figure 1a - Exposure model evaluation sub study: actual total metalworking fluid aerosol concentrations, mg/m^3 (vertical axis) *v*. predicted aerosol concentration, mg/m^3 (horizontal axis)

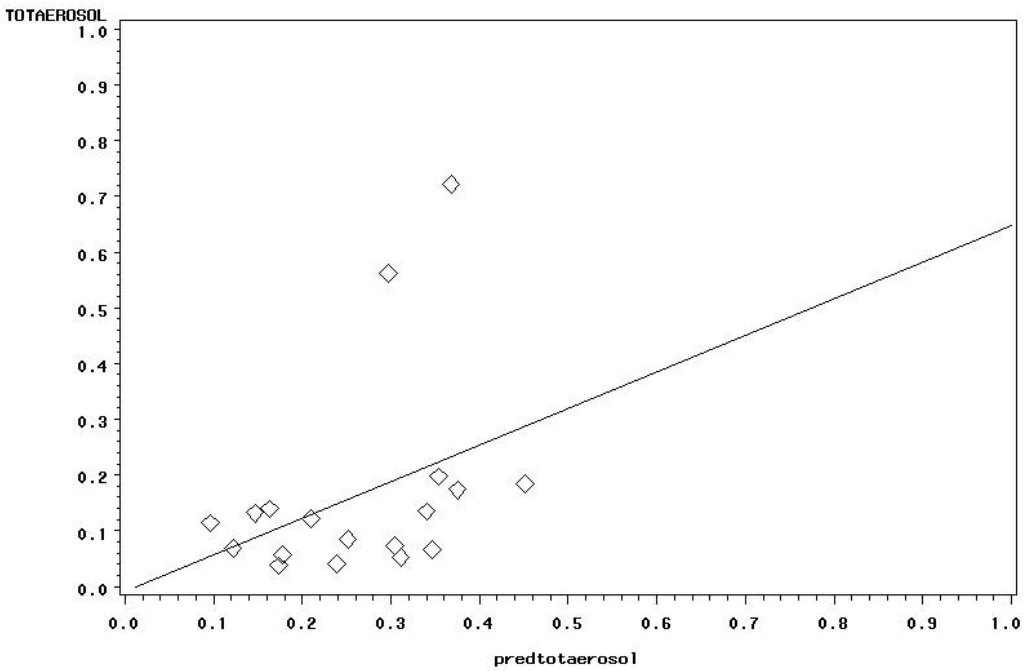
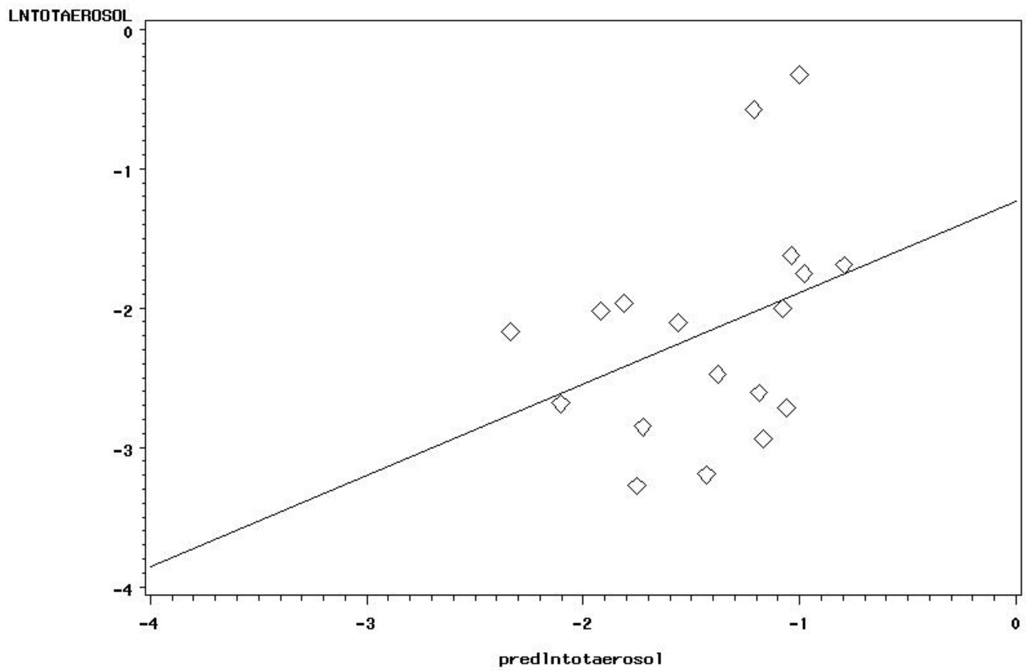


Figure 1b - Exposure model evaluation sub study: log transformed actual metalworking fluid total aerosol concentrations, mg/m^3 (vertical axis) *v*. log transformed predicted aerosol concentrations, mg/m^3 (horizontal axis)



APPENDIX 2 – Quotes related to CNC machining

(from companion study: AM Nicol and C Hurrell (2008), see appendix 3)

metalworking fluid27: Well each individual has certain characteristics or traits – there are situations where they will have a door open on a CNC where they are just running a proofing cycle on a part – so they'll hit the override to keep the door open and actually might be right there where the part is running coolant and so on, but most of the machinery that we have where we are running coolants tends to be running at a reasonable pressure and it's not advantageous to have the door open because it gets pretty messy, pretty quickly.

****

metalworking fluid21a: But you can...I mean, you get certain amount of spray off the tools. With CNC you get a lot of spray off the tools, but it's covered in, but it's still...I mean, it's covered in, but you're still getting it.

INT: Why?

metalworking fluid21a: Because, well, it's not really ventilated. It's still coming out.

****

metalworking fluid21a: Um...like if each machine had a hood, and was totally ventilated, that would help. Enclosed machines. Like if everything was a CNC machine, which is not practical for a lot of things, but that would cut it down a lot.

****

INT: So it was kind of like poor hygiene in general which probably translated.

metalworking fluid4: Yeah poor hygiene. When we were apprentices we were taught that, and I instill that into my guys today. I mean, we do, we spend an awful lot of hours a year cleaning, keeping the place, keeping the shop clean, and primarily we are a CNC shop, so it’s a lot easier to keep the place clean ‘cus the machines are contained, whereas, in the older machine shops, they were all open and everything was open and the stuff would go everywhere, right?

****

metalworking fluid1: I see this on a regular basis in our shop because our shop is sort of a mix up of older machinery and newer machinery. The new machinery is all enclosed and self contained but the older machinery is generally very open, there is no guarding on it and some of the guys are pretty lax about taking their air wand out and cleaning off their work tables of their machine; blowing the chips which are saturated in the coolant, the metalworking fluids and that tends to put a bit of a haze into the air; you can see it once in a while. Generally, when the guys are cleaning down at the end of their shifts. So, that’s when other people are exposed to it. Again, there are fewer and fewer of these machines so it’s less and less of an issue.

****

metalworking fluid13: I would say so. With the CNC you tend to be more specialized, and all of the ways are enclosed, so you don’t have way oil dripping into your coolant, everything is enclosed and self lubricating.

****

metalworking fluid2: Well, all the CNC equipment now has reduced exposure hugely because it is all in an enclosed cabinet. So you run the machine and you are not in contact with anything. You are looking through a window watching the machine do the work.

****

metalworking fluid23: Well we have one guy, he has multiple sclerosis, and he's old eh, he's 58, so we just let him operate the one CNC by himself. That's his; no one else ever uses it. And that's one where he gets a face full of coolant or mist every once in a while. Like he's easily getting a hundred times or two hundred times what I'm getting.

****

metalworking fluid23: What we've done is- the biggest thing is we bought a second CNC lathe, and we noticed that it was loosing a lot of coolant into the atmosphere, let's say 20 litres a day, which is a lot. So we put in, we call it a mist collector, and it's just like a bit vacuum pump, and this CNC lathe is pretty much enclosed, and the vacuum pump will suck all of the air and the coolant mist into a- through a filter, and it will throw out clean air and it will separate the coolant and it will run down the tube back into the lathe.

INT: Oh, okay.

metalworking fluid23: It's called a mist collector. That's what we call it.

INT: And have you found that it's been quite effective?

metalworking fluid23: Yes, it works. Yep, for sure. Yep, there's talk of getting a second one for another lathe, another CNC lathe.

****

INT: Okay. So do you find with the new enclosed machines you're still getting as much exposure?

metalworking fluid14: Well, they're enclosed in the front, whereas the operator's not right, directly...he's looking through a window, basically looking at it, but they're basically open at the top, so depending on the type of machine that's happening, the coolant can still rise and precipitate out of the air.

INT: Yeah.

metalworking fluid14: And that's where...you know with the semi-CNC lathes that we have they still have a door that closes and it still falls along with the carriage, but because of the configuration of the machine, they're longer and they're open at the back end. So, when that chucks – screaming around at 3,000 rpm, the coolant just...it "mistifies" it, I guess, for lack of a better word. I just makes a big....you can feel it in the air.

APPENDIX 3 - Research on dissemination and knowledge exchange

Project 1: Exploring knowledge translation in occupational health using the mental models approach: a case study of machine shops

This project was funded by the Canadian Institutes of Health Research and led by Dr. Nicol.

We collected data through a series of 40 interviews with scientists, policy makers, product suppliers and workers who are involved in working with or researching metal working fluids. The results of these interviews were "mapped" for each group (scientists, workers) using Mental Models methodology (Morgan 2002) to explore how new research and information about metalworking fluids are communicated between groups. These maps, also known as Influence Diagrams, were compared and contrasted, the results of which illustrated a number of key points regarding metalworking fluids knowledge transfer and exchange.

The interviews for machinists covered their work history, their knowledge of metalworking fluid exposure and protective practices, and their understanding of the health risks of their job.

The results, which have been published elsewhere (Nicol 2008), offer insight into the information needs and risk perception of machinists.

In general, we found that communication between scientists, policy makers and workers on metalworking fluid hazards is poor.   Overall, most workers did not consider metalworking fluids to be hazardous to their health and many were unaware of the potential health effects associated with these products. Many of the scientists described being frustrated by their attempts to convey their research beyond the academic realm.

When asked open-ended questions about where they received information about the health effects of metalworking fluids, the majority of machinists said that metalworking fluid suppliers were the most common source of this information (this category of information source was not included in the risk communication survey). However, machinists did not trust the information they received from suppliers. As one machinist said:

> "They're [the suppliers] just trying to sell you something."

Machinists indicated that they did trust governments and occupational health and safety agencies, but that they did not often receive information from these sources.

Results from the health effects portion of the interviews showed that few machinists could provide any detail about the respiratory health effects of metalworking fluids. They did not link symptoms such as cough, difficulties breathing, phlegm, asthma, or bronchitis to metalworking fluid exposure. Workers much more frequently linked dermal health effects such as dermatitis to metalworking fluid exposure, although they weren't considered serious, even though they were eligible for compensation. When asked about the effects of short-term exposure, one worker replied:

> "As far as sick . . . I wouldn't call what I had being sick. It's just, you know, you have a rash on your hand and I did have time off because of that."

This result is consistent with other studies that have found that workers tend to talk more easily and automatically about more common health problems rather than those that are considered more serious (Sadhra, 2002).

This study illuminated a number of important disconnects between how workers receive information as opposed to how they would like to receive information, an important distinction that may be impeding the awareness and management of workplace risks. Results from this study also suggest that more attention needs to be paid to providing workers with a more comprehensive understanding of the effects of metalworking fluid on the respiratory tract.

Project 2: Occupational health risk communication survey

Introduction

A new occupational health risk communication survey was developed by Dr. Nicol and was included as part of our original study protocol. In addition to its use in this group of former apprentices, it was also used by us in a large survey of marine workers; using identical methods. The purpose of this survey was to explore how workers receive health and safety information currently, would like to receive this type of information in the future and who they trusted to provide them with this information. Studies have shown that in order for communication to be effective, workers must receive information from a trusted source, and in a format that is useful to them (Kasperson 1992, Schulte 2003).

The survey was also designed to better understand how workers perceive the risks encountered in their own workplaces. Understanding occupational risk perception is useful for designing appropriate safety messages and for understanding protective equipment use and behaviors. The survey also assessed workers' current knowledge base about occupational health effects, with an emphasis on determining what workers know about work-related lung diseases. A number of research studies have shown that a lack of awareness of the association between symptoms and workplace exposures can hamper proper diagnosis and treatment of occupational respiratory diseases (Gupta 2006, Nowak 2007, Santos 2007).

Methods

Survey questions were a mix of closed and open-ended questions. Participants were asked to choose, from a list, their sources and preferred formats for receiving occupational health and safety (OHS) information. They also indicated their level of trust (on a 10-point scale) in various information sources. The same 10-point scale was also used to assess job satisfaction.

Decisions about risk require information about the nature and likelihood of occupational hazards and health outcomes (Weinstein, 1999). Thus, open-ended questions required participants to list, without prompts, the main hazards and related health effects associated with their job. Then they were asked (using a percent chance scale) about the probability of personally experiencing an occupational injury or illness. They were also asked to describe similar probabilities for a co-worker with the same job, because research has shown that most people tend to believe that their own risks are less than those of others (Hoorens, 1994). The probability scale used in this survey was adapted from those used by Fischoff and colleagues (Fischhoff, 1999).

The survey was administered by a trained interviewer following the main questionnaire.   Data were entered and checked as described above for the main questionnaire; results were analyzed using SPSS and MS-Excel with comparison being conducted between the former apprentices' survey and the marine workers' responses. The former apprentice group was also broken down in five categories for analysis; still employed as a painter, still employed as a machinist, sill employed as an electrician, still employed as an insulator and no longer employed original trade. Analyses conducted included frequencies, comparison of means using ANOVA and chi-square.

Results

A total of 209 former apprentices participated in the survey. Results are shown here, comparing responses for the former apprentices (this project) to those given by the BC marine workers (n=255). Stratification by current occupation is also shown where possible.

Of the 209 respondents, only 11 (5.2%) people were not self-identified Caucasian and only 9 (4.3%) were women. As a result, it was not possible to stratify many of the health risk information by these variables due to their small sample size.

a) Occupational health and safety (OHS) information – preferred formats

Participants were asked their top three preferred formats for receiving occupational health and safety information. Among the former apprentices, the highest ranked choices were "in-person" or face to face communication, brochures or leaflets, and video or CD-ROM. Email was preferred slightly more often than video as a first choice, but overall, video and CD ROMs had a higher rating when considering all three choices. See Chart 1 below.

These results were fairly similar between the former apprentices and the marine workers (see Chart 2). However the former apprentices were more interested in the video/CD-ROM format than the marine workers. This may be related to the age difference between the groups (former apprentices' average age, 40.0; marine workers average age, 56.6). *Notably, websites scored low as preferred choices by both groups.*

b) OCCH information: sources – frequency

Participants were asked how often they came in contact with specific agencies or persons.

Over 25% of both groups (former apprentices and marine workers) responded they did not have any contact with any group or agency for occupational health and safety information or training. However, this lack of contact was *least* common among current machinists (16%).

Findings for the remainder are shown in table 1. Overall, the most frequent sources for receiving health and safety information were the workplace Occupational Health and Safety (OHS) committee, and the employer. Unions and WorkSafeBC were less frequent points of contact for OHS information or training.   Compared to marine workers (who all have the same employer), former apprentices received OHS information less frequently from their employer and slightly more frequently from WorkSafeBC.

Examining this question by trade (among former apprentices) showed that those workers who were still working as machinists had less contact, on average, with union representatives than other occupations (p=0.08, ANOVA) This is most likely related to the fact that construction trades are more highly unionized in BC than machinists working in small machine shops.

c) OHS information: sources – trust

Respondents were asked to rate (from 0 not trusted to 10 more trusted) how much they trusted various agencies to provide OHS information. Results are shown in Table 2 (values converted to %). Findings show that both the former apprentices and the marine workers trusted medical professionals and university researchers the most.   The BC Lung Association was also ranked highly by both groups.

There were some differences between the cohorts, with the former apprentices trusting their employer and the government significantly more than the marine workers. Conversely, the marine workers trusted their OHS committees and union representative more than the former apprentices.

Significant differences were also found between current occupations within the former apprentices group. Table 4 shows that those still employed as insulators trusted their employers, union representatives, and health and safety committees more and the government less than the other trades. Those who were still working as machinists had the least amount of trust in union representatives, again, possibly due to lower rates of unionization in this group compared to construction workers.

d) Perception of hazards at work

Participants were asked an open ended about what they felt were the most serious hazards that they faced in their own workplace, for their current job. Almost one half (42%) of all participants were concerned mainly about respiratory health hazards such as fumes, dust and fibres, with the next most common category being physical hazards.

However, when the results were stratified by occupation (using initial trade for the apprentices cohort), the results varied considerably (see chart 3 below). Marine workers and insulators were significantly more concerned about respiratory hazards than any other type of hazard ($p<0.001$). Painters and electricians were also highly concerned about physical hazards, with concern about chemical hazards being highest among painters.

Among current machinists only 14 (33%) made specific mention of metalworking fluid mist (or components) as a hazard of concern (all 14 did associate this exposure with respiratory health).

In contrast, 15 of 23 current insulators (65%) mentioned fibres (asbestos or glass fiber) as a hazard of concern.

Respondents were also asked an open-ended question about what health effects they perceived could occur from exposures to these hazards in their workplace. Eighty percent of respondents were able to provide at least one answer to this question. The most common response was breathing or lung related problems. Workers described these problems in the following ways:

- "hard to breathe"
- "difficulty breathing"
- "clogging of lungs"

A number of workers were only able to state that the lungs in general would be affected by their exposures at work, although they did not know what kinds of conditions these could cause. Three respondents (all current painters) in the former apprentices study noted that asthma was a potential health outcome from their work and four people (two of them machinists) responded specifically with "lung cancer".

Other health effects that were mentioned by the respondents included "death" (9%), broken bones, sprains or muscle problems (7%) and burns or electrocution (4%).

e) Perception of "riskiness" of current job

Respondents were asked how likely it was that they would have either a minor or serious accident at work, develop an occupational disease, or die from a workplace cause. They were also asked the same questions with respect to a co-worker.

The former apprentices considered minor accidents to be the most likely health problem to occur while on the job (Chart 4), followed by developing an occupational disease and then having a serious disabling injury. Workers perceptions of risks for themselves versus their colleagues followed the same patterns and elicited a similar magnitude of risk perception. Table 5 illustrates these results for perception of risk of having a minor accident at work for the former apprentices.

Differences were found between the marine workers and the former apprentices. In particular, the marine workers were significantly more concerned about developing an occupational disease, both for themselves and their coworkers, than the former apprentices (p=0.001 ANOVA, see Chart 5). Similar differences were found between marine workers and former apprentices perceptions of serious injuries (p=0.01),

Although fewer respondents felt it was likely that they would be fatally injured on the job, the percentage for the formers apprentices was still 18%. The marine workers results were the same.

f) Perceived Health Status

Perceived health status varied by occupational group, but the differences were not statistically significant. The majority of workers considered their own health to be "good" on a five point scale. Only those who had switched to other trades (n=66) had responses in the "fair" or "poor health" categories, but overall this was low (n=4) see Chart 6. Interestingly, among former apprentices, there was no association between perceived health status and the perception of riskiness of the current job. In fact, persons who rated their own health as only fair or worse rated the riskiness of their job (to themselves or to a co-worker) slightly lower than did those who rated their own health good or excellent.

g) Perception of workplace satisfaction

Respondents were asked to rate how satisfied they felt most workers in their current workplace were with their job on a scale of 1-100, with 100 being excellent. This scale was also used to assess perception of employer/employee relations in the workplace. For perceived job satisfaction, no significant differences were found amongst the former apprentices' trades, with the average job satisfaction ranging between 63-67%. However, there were significant differences between this cohort and the marine workers, whose average job satisfaction score was lower at 60% ($p=0.001$, ANOVA).

Employer/employee relations followed a similar pattern. Average perception of employee relations were similar for the former apprentices (between 61-69% for each of the original trades); it was much lower for the marine workers (48.4%, $p=0.001$ ANOVA).

However, as found for perceived health status, among former apprentices there was no association between perception of job satisfaction or employee-employer relationships and perception of the riskiness of the current job (either for self or coworkers).

Discussion

The results of this research provide some key pieces of information for how study results could be more effectively disseminated back to the participants. Information communicated in-person by doctors, university researchers, or OHS committees, using leaflets appears to be the preferred approach to communicating health and safety information for both the study and the comparison groups. Websites, despite their current attraction among researchers as potential knowledge transfer avenues, appear to be less favoured by workers as sources of information about OHS concerns.

It is important also to note that simply relying on OHS committees as the only source of information dissemination may not be effective. Utilizing doctors or researchers may be important, particularly for the 20% of this study population who had no routine contact with health and safety personnel. Tailoring information in this manner and using trusted sources may increase overall awareness about the study, and may also increase the probability that the messages are seen as credible.

The importance of trust, as discussed previously is not only important for increasing information uptake, but also, as Frewer (2003) notes, important for ensuing that risk messages don't overly alarm people, contributing to a process known as the "social amplification of risk". This process, once initiated, can sensitize populations to either disregarding or being hyper-attentive to future attempts at communicating risks and both of these avenues can reduce absorption of risk messages (Frewer 2003).

This study found that workers perceived themselves and their coworkers to have risks of similar magnitude and that this perception is not related to their sense of their own health status, nor is it tempered by their perception of job satisfaction or employee employer relationships in the work environment. This result is interesting given that, in general, people tend to consider themselves less at risk from exposures than others around them (for example, most people believe their marriage will last, even though divorce statistics are very high). This phenomenon is referred to as "optimistic bias" (Weinstein, 1980). However, this bias was not reflected in the results from this study. This lack of optimistic bias may be due to the fact that respondents were part of the UBC Lung Health Study, and had had multiple points of contact with researchers who were assessing their lung function. Indeed this survey was administered in the same session as lung function testing, so issues about lung health would be very much in the forefront of workers' minds. Similar results were found for the comparison group, using the same study protocol.

Alternatively, Weinstein (2004) notes that optimistic bias "decreases with perceived frequency and personal experience". We know that many of these workers are exposed frequently to lung irritants and it is possible that a number of them have experienced acute incidents that may influence their perception about risks. Research has found that people who work directly with dangerous chemicals worry about the risks associated with these compounds (Baugher 1999) and as such, continuous contact with compounds known to be toxic may also serve to decrease optimism about exposure. Most of the work on optimistic bias has been done in non-occupational settings where chemical exposures may be very different (e.g. living near a waste facility) and may, as a result, generate different cognitive outcomes when considering risks. The lowering of optimistic bias has been noted as a factor for the communication of protective behaviors. As Weinstein states (2004), "…acceptance of personal vulnerability is an important aspect of progress towards precaution adoption". In occupational settings, increasing precaution adoption, in the form of protective behaviors, would be beneficial. As such, more research on this phenomenon may be productive for health and safety communication.

While workers in this study were aware that their lungs *may* be at risk, a majority still were not able to explain the health outcomes associated with exposures. In particular, less than half of current machinists were able to identify metalworking fluids as a hazard, despite the fact that they were enrolled in a study specifically aimed at evaluating the potential hazards of metalworking fluid exposures.

This has implications for exposure control (if you don't know what the actual hazards are you won't target control measures towards them) and also for the identification of work-relatedness of disease and possible workers compensation claims. The latter both require that both doctors and patients can accurately link workplace exposures to health outcomes (Gupta 2006). More efforts to educate workers about the symptoms of occupational lung disease may improve doctors' ability to determine links between patients' occupation and disease.

Significant differences were found between perceptions of risk of serious injury and disease between the marine workers and the apprentices. These distinctions may reflect both differences in chemical exposures across industries as well as differences in workplace safety culture. Perceptions of risk tend to be higher when workplace stressors are more severe, even when exposures are the same (Baugher 2002). The marine workers reported lower job satisfaction and poorer employer/employee relations, a factor which may play a role in increasing their perception of risks in their workplace.

Conclusion

In summary, this study suggests that the "optimal" format for providing research results, which may increase the success of communication about occupational lung exposures and disease would include:

- authoring one or more leaflets or brochures from UBC that provide a summary of the UBC Lung Health Study results
- mailing leaflets directly to study participants
- investigating cross promotion of the leaflets with WorkSafeBC and other agencies such as the Canadian Centre for Occupational Health and Safety (CCOHS)
- communicating key study findings to respiratory and occupational physicians and providing them with leaflets to distribute

- contacting unions and employers to explore the possibilities for distribution through OHS committees.

This research also points out that the use of a website is not likely to be an effective ‘first avenue’ for knowledge translation related to this or perhaps even to other occupational health studies.

This research also explored workers’ knowledge and perception of risks associated with their work. It emphasized that many machinists are still unaware of the specific hazard associated with metalworking fluid mists. It also showed that concern about risks varies by type of effect (accident versus disease), although perceived risk did not reflect the “optimistic bias” often seen in other non-occupational studies. More research on workplace exposure and safety cultures may further our understanding of occupational risk perception.

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Tables and Figures

Chart 1. Apprentice Study preferred formats for receiving health and safety information

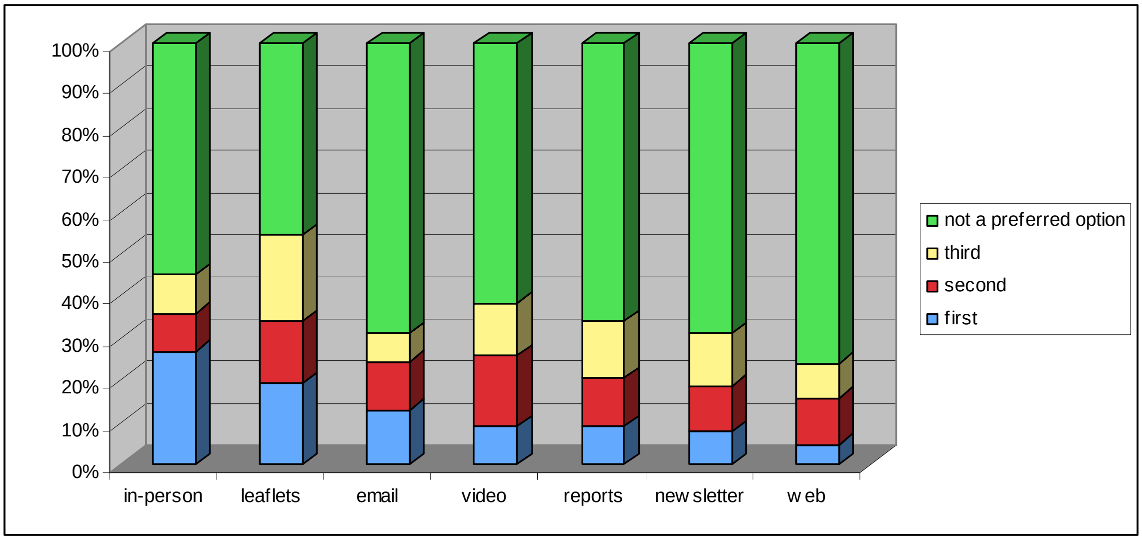

Chart 2 Comparison of preferred formats, apprentice study versus comparison group

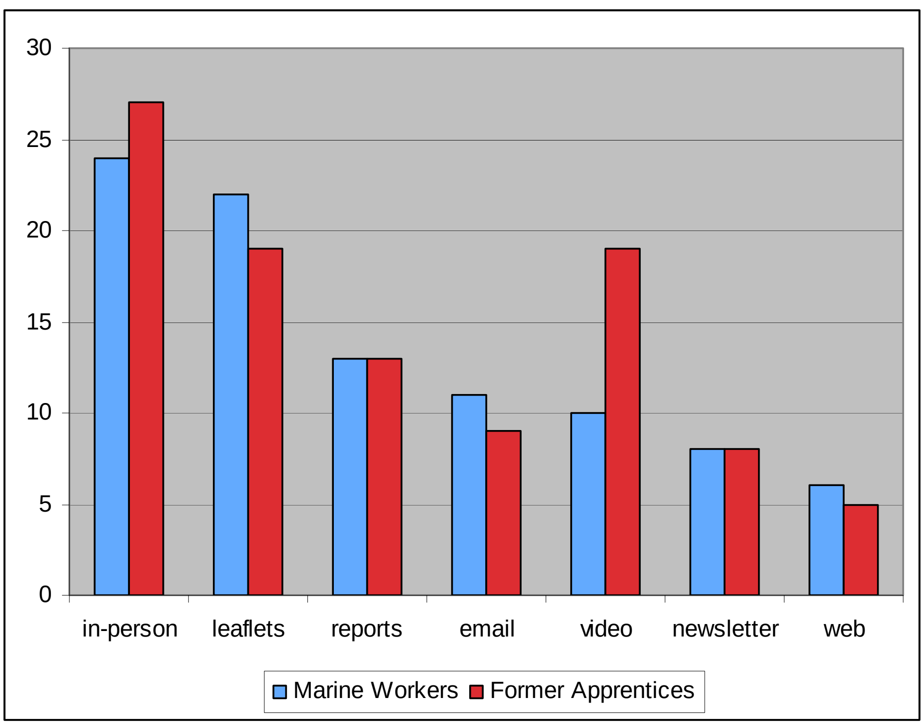

Table 1 Mean number of time per year respondents had contact with agencies or groups for health and safety information or training

	Former apprentices	SD	Marine Workers	SD
OHS Committee	5.7	8.3	7	12.8
Employer	3.8**	6.4	6.3	12.5
Union Rep	1.6	4.7	2.2	7.4
WorkSafeBC	1.6*	5.0	0.9	2.4
Other	1.0	2.6	1.1	6.2

*p<0.05 and **p<0.01; between former apprentices and marine workers

Table 2 Trusted sources, formers apprentices and marine workers

	Former Apprentices (%)	SD	Marine Workers (%)	SD	p
Medical Professional	84	18	84	19	0.8
University Research	81	23	82	20	0.6
WorkSafeBC	78	88	68	25	0.09
BC Lung Assoc.	76	75	78	24	0.3
employer	63	31	54	26	0.001
coworkers	62	27	62	24	1.0
health and safety committee	57	40	71	22	0.000
government	50	30	44	28	0.04
union rep	42	38	62	24	0.000

Table 3 Trusted sources, by current occupation (%)

	Not in original trade	Still a Painter	Still an Insulator	Still a Machinist	Still an Electrician	P
Medical Professional	85	79	86	82	87	0.8
University Research	80	68	87	82	88	0.7
WorkSafeBC	97	73	59	68	73	0.09
BC lung	76	64	77	78	81	0.3
employer	60	63	75	63	62	0.001
coworkers	60	58	75	59	66	1.0
health and safety committee	56	55	75	44	65	0.000
government	45	48	40	58	53	0.04
union rep	40	51	67	20	42	0.000

Chart 3 Main hazard of concern at work

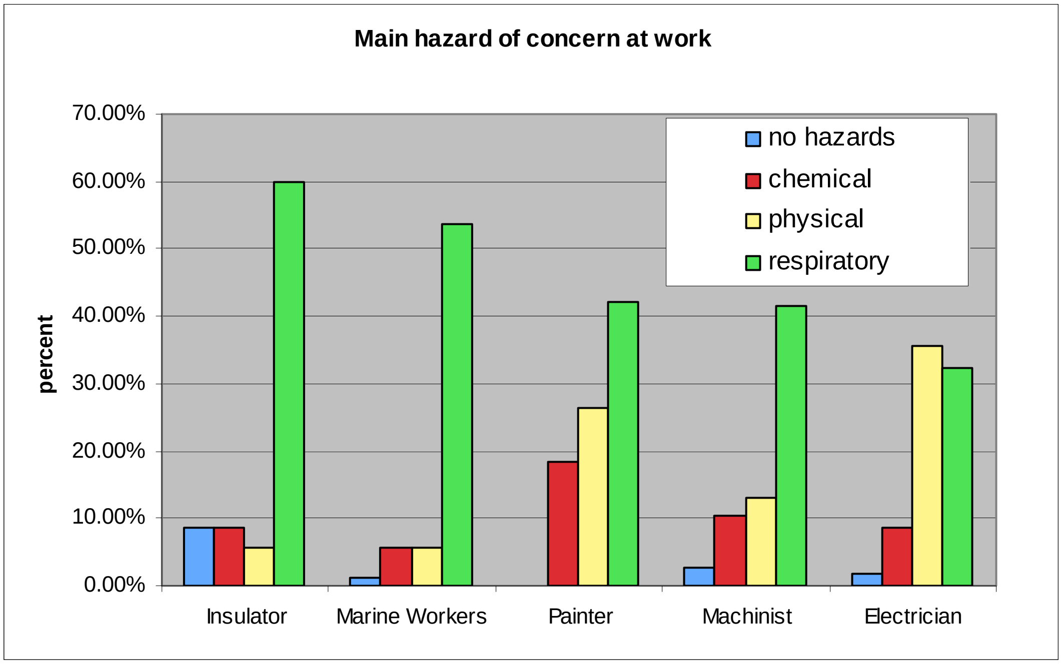

Chart 4 Perception of Risk of minor accident, former apprentices only (%)

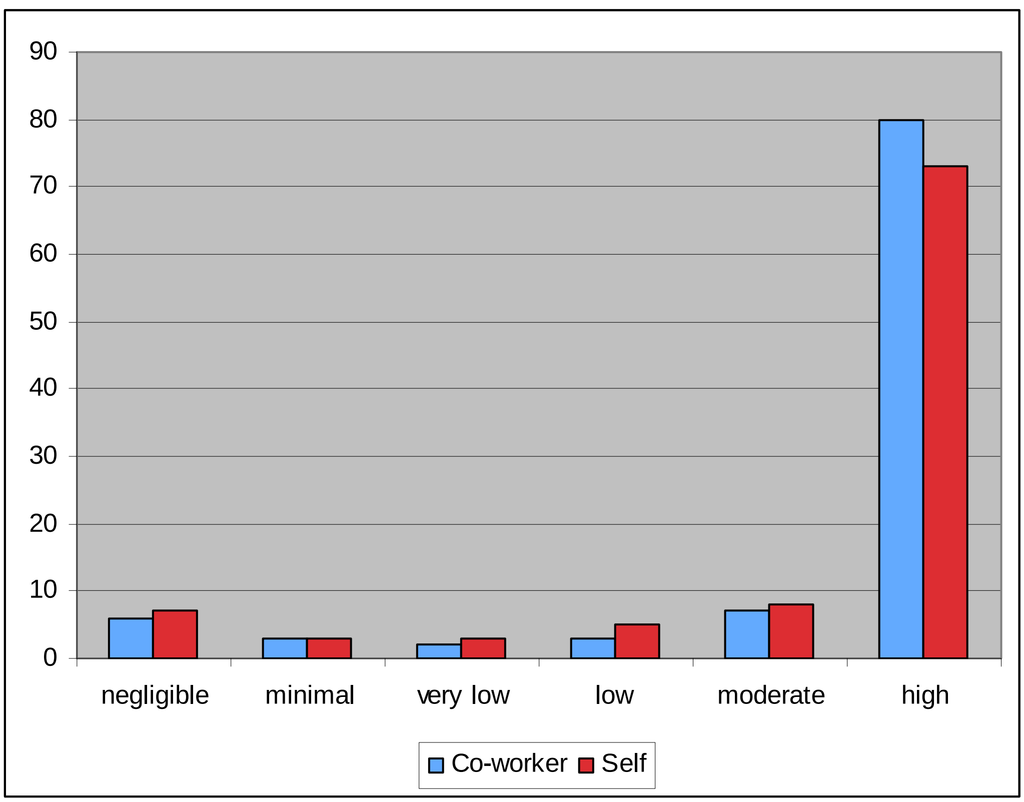

Table 4 Former apprentices perceptions of risks at work (probabilities in %)

Minor accident (%)

	negligible	minimal	very low	low	moderate	high
Co-worker	6	3	2	3	7	80
Self	7	3	3	5	8	73

Serious accident (%)

	negligible	minimal	very low	low	moderate	high
Co-worker	17	12	7	8	16	40
Self	25	16	10	8	12	29

Occupational disease (%)

	negligible	minimal	very low	low	moderate	high
Co-worker	23	13	7	11	13	34
Self	29	13	9	11	10	28

Dying on the job (%)

	negligible	minimal	very low	low	moderate	high
Co-worker	37	19	12	8	8	17
Self	43	21	10	3	4	18

Chart 5 Perception of developing occupational disease (%)

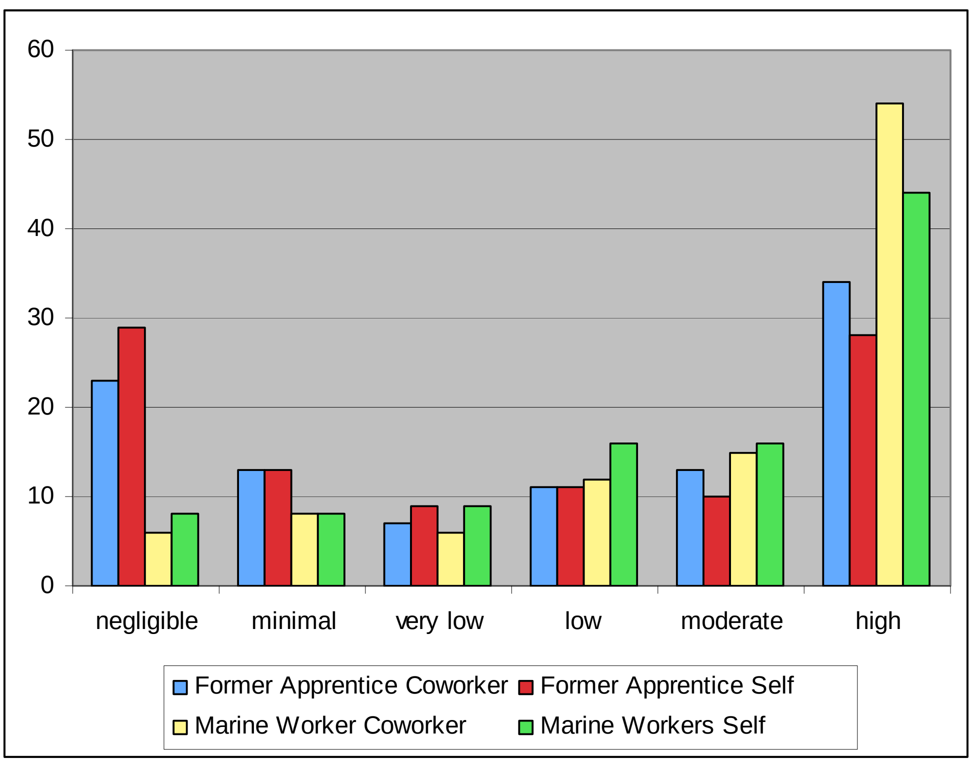

Chart 6 Current health status, by current occupation