Ann. Occup. Hyg., Vol. 56, No. 3, pp. 292–304, 2012

doi:10.1093/annhyg/mer112

Effect of Training, Education, Professional Experience, and Need for Cognition on Accuracy of Exposure Assessment Decision-Making

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Received 9 May 2011; in final form 24 October 2011; published online 19 December 2011

Results are presented from a study that investigated the effect of characteristics of occupational hygienists relating to educational and professional experience and task-specific experience on the accuracy of occupational exposure judgments. A total of 49 occupational hygienists from six companies participated in the study and 22 tasks were evaluated. Participating companies provided monitoring data on specific tasks. Information on nine educational and professional experience determinants (e.g. educational background, years of occupational hygiene and exposure assessment experience, professional certifications, statistical training and experience, and the 'need for cognition (NFC)', which is a measure of an individual's motivation for thinking) and four task-specific determinants was also collected from each occupational hygienist. Hygienists had a wide range of educational and professional backgrounds for tasks across a range of industries with different workplace and task characteristics. The American Industrial Hygiene Association exposure assessment strategy was used to make exposure judgments on the probability of the 95th percentile of the underlying exposure distribution being located in one of four exposure categories relative to the occupational exposure limit. After reviewing all available job/task/chemical information, hygienists were asked to provide their judgment in probabilistic terms. Both qualitative (judgments without monitoring data) and quantitative judgments (judgments with monitoring data) were recorded. Ninety-three qualitative judgments and 2142 quantitative judgments were obtained. Data interpretation training, with simple rules of thumb for estimating the 95th percentiles of lognormal distributions, was provided to all hygienists. A data interpretation test (DIT) was also administered and judgments were elicited before and after training. General linear models and cumulative logit models were used to analyze the relationship between accuracy of judgments and the various characteristics describing the participants. Data interpretation training (P < 0.0001), the company that the hygienist worked for (P < 0.0001), the total number of years hygienists had experience doing exposure assessments (P < 0.0001), and professional certifications (P < 0.0001) held by hygienists were found to be significant determinants of accurately predicting the correct exposure category for DITs as well as for task-specific judgment accuracy. Years of experience with a particular task (P < 0.0001), task evaluated, and the number of datapoints used for making judgments were found to be significant predictors of task-specific judgment accuracy. The NFC score was a predictor of the improvement in task judgment accuracy after training. The NFC score was itself predicted by determinants, such as company, years on current job, years of exposure assessment experience, and professional certifications. The results of this study are relevant not only for the case of industrial hygienists making exposure judgments prospectively but also possibly for those hygienists engaged in retrospective exposure assessments for epidemiological studies.

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Keywords: accuracy of decision-making; experience and education; exposure decisions; need for cognition

INTRODUCTION

Accurate exposure measurements by hygienists are at the heart of occupational hygiene practice. The accuracy of their judgments determines if the workers under their care receive the appropriate level of exposure controls, i.e. administrative, engineering controls, and personal protective equipment. Most exposure assessment strategies require the workforce to be categorized into similar exposure groups or SEGs as suggested by Corn and Esmen (1979), Mulhausen and Damiano (1998), and Ignacio and Bullock (2006). Most commonly, occupational hygienists use a combination of personal experience with a given type of operation, review of exposures from similar operations, similar tasks or chemicals, and/or exposure predictions developed using physical/chemical exposure modeling techniques to assign an initial 'exposure rating' and prioritize their SEGs for further actions. Based on this prioritization, a baseline monitoring campaign is carried out for some SEGs and the measurement data collected are used to refine the initial rating and determine if the exposure distribution is acceptable. Acceptability is commonly evaluated by comparing an upper percentile, such as the true group 95th percentile to the occupational exposure limit (OEL). In the American Industrial Hygiene Association (AIHA) strategy, the 95th percentile of the exposure distribution is estimated along with its upper confidence limit (UCL). Based on the magnitude of the group 95th percentile and its UCL relative to the OEL, the exposure is classified into one of four categories: Category 1 or 'highly controlled', Category 2 or 'well controlled', Category 3 or 'controlled', and Category 4 or 'poorly controlled' (Mulhausen and Damiano, 1998; Ignacio and Bullock, 2006). This classification becomes the basis for decisions regarding exposure management (Hewett *et al.*, 2006; Logan *et al.*, 2009; Vadali *et al.*, 2009).

The AIHA strategy (Mulhausen and Damiano, 1998; Ignacio and Bullock, 2006) calls for collecting 6–10 measurements for most SEGs that are to be evaluated using exposure monitoring. Obtaining such data can be expensive and time consuming. In reality, most exposure assessments are made with either fewer than six monitoring data or no data at all due to resource constraints. Often, in the absence of sufficient data, hygienists interpret the available workplace information using their professional judgment and make decisions regarding appropriate controls. Therefore, there is a heavy reliance on the accuracy of professional judgments and the ability of occupational hygienists to correctly integrate them with monitoring data to make accurate exposure decisions. Professional judgment is the aptitude of an experienced professional to make correct inferences using incomplete data (Ignacio and Bullock, 2006). However, there is evidence that professional judgments of experts may be dependent on determinants, such as educational background, years and type of experience (Simon and Chase, 1973; Ericsson *et al.*, 1993; de Cock *et al.*, 1996), and psychological factors (Kahneman *et al.*, 1982; Gilovich *et al.*, 2002; Logan *et al.*, 2009). This article presents the results of a study of the effects of these determinants on the accuracy of exposure judgments made by occupational hygienists.

Experts and decision-making

In recent years, cognitive psychologists have investigated human performance involving skills that are acquired over long periods of learning and experience. These studies have contrasted the knowledge and skill of experts with that of novices. Glaser (1987, 1992, 1996) proposed that the process of organizing knowledge in sophisticated patterns enables people to become experts. His studies focused on understanding the performance differences between experts and relative novices in a given field when they use their knowledge on the subject to solve problems. Experts recognize larger patterns in problems when compared to novices. A novice's knowledge is much more fragmented and less integrated.

DeGroot (1965), Chase and Simon (1973) and Reynolds (1982), in studies of world-class chess masters, concluded that the same stimulus is perceived and understood differently depending on the knowledge that a person brings to the situation. Meaningful patterns seemed more readily apparent to the masters than less experienced players. Skills similar to those of master chess players have been demonstrated by experts in other domains, including electronic circuitry (Egan and Schwartz, 1979), radiology (Lesgold *et al.*, 1988), mathematical solutions (Hinsley *et al.*, 1977; Robinson and Hayes, 1978), and computer programming (Ehrlich and Soloway, 1984). In each case, expertise in a domain helps people develop sensitivity to patterns of meaningful information that are not apparent to novices. For example, electronics technicians were able to reproduce large portions of complex circuit diagrams after only a few seconds of viewing while novices could not. The expert knowledge that underlies the ability to recognize problem types has been characterized as involving the development of organized conceptual structures or schemas, which guide how problems are represented and understood (Glaser and Chi, 1988). No strong correlation was found between good memory and being an expert.

Determinants related to education and experience are investigated in this paper. These could have a significant impact on the hygienists making correct decisions as they are a measure of their substantive knowledge. Zeitz and Glaser (1994) found that when incomplete information was available, experts rely more on their knowledge to make justifiable decisions. This could be an important determinant of how hygienists use their existing knowledge and background as well as experience acquired on specific tasks and apply it to their decision-making.

Learning from past experience also helps to make complex decisions based on uncertain information. Research has also shown that experience helps experts to make better decisions and that a minimum of 10 years of experience is required to achieve mastery at the level of an expert (Simon and Chase, 1973; Ericsson *et al.*, 1993).

Need for cognition

Individual occupational hygienists may process information regarding a given task differently that may lead to different exposure judgments. Whether hygienists process information about a task more or less actively may be related to their interest in really understanding it. This is distinct from the determinants related to education and experience and is a cognitive trait. Thus, the level of active processing of information can be construed as an individual tendency. Cacioppo and Petty (1982) used the term 'need for cognition (NFC)' to denote the individual differences in the tendency to seek and enjoy effortful thinking.

NFC is defined as intrinsic motivation for, and enjoyment of, thinking (Cacioppo and Petty, 1982; Cacioppo *et al.*, 1996). It is commonly measured using a 34-item questionnaire. In this study, an 18-item short version of the NFC scale was used (Cacioppo *et al.*, 1984). Participants indicate that, on five-point rating scales, the degree to which each statement characterizes them. The statements refer to how much or how little a person enjoys cognitive activities. For example, 'I prefer complex to simple problems' or 'Thinking is not my idea of fun'. The score is called the NFC score. Previous research on relationships between NFC and other individual difference constructs suggest heightened involvement in cognitive activities for high-NFC people. For example, NFC is related to an individual's tendency to formulate complex attributions as well as to the tendency to sustain attention to an ongoing cognitively challenging task (Fletcher *et al.*, 1986; Osberg, 1987).

NFC is thought to be a relatively stable aspect of personality to judge information-processing style (Kihlstrom and Cantor, 2000). However, it is weakly correlated with verbal analysis, college grade point average, and level of education (Cacioppo *et al.*, 1996). It is also unrelated to abstract reasoning ability (Cacioppo *et al.*, 1983). Together, these findings lend support for the idea that NFC taps motivation to think rather than ability.

When making subjective judgments, hygienists are expected to process different aspects of task-related information, such as monitoring data and various workplace variables. The NFC score was hypothesized as being related to accuracy of the judgments. A statistical training was provided to all hygienists as part of the study and it is hypothesized that the NFC score would also predict the effect of the training on judgment accuracy. In other words, the effect of training would be greater for those with higher NFC scores.

METHODS

This paper studies the relationship between exposure judgment accuracy and characteristics that describe the occupational hygienists in terms of their educational background and knowledge of various domains, cumulative professional experience, as well as experience characteristics specific to the task being evaluated and the NFC as a psychological trait that may be relevant. Statistical data interpretation training has also been investigated as a predictor of judgment accuracy.

Presentations were made at the Professional Conference on Industrial Hygiene in 2005 and at the American Industrial Hygiene Conference and Exposition in 2006 to recruit hygienists from companies from several industry sectors. The presentations emphasized the need for understanding and improving professional judgments and using Bayesian methods for decision-making. Interested companies were contacted and invited to participate. Within each company, one person served as the principal contact with the research team. This person was not involved in making task judgments but recruited the hygienists who participated from that company, selected the tasks for which monitoring data were collected, and provided all the necessary task process details to the participating hygienists and the research team. The hygienists were recruited based solely on their availability and consent to participate in this exercise. Informed consent forms were signed by each participating hygienist. The study had a total of 49 hygienists from six companies.

The tasks that were evaluated were chosen by the company personnel, such that their exposures spanned the range of the four exposure categories. Each task was to be clearly defined with details of what the worker does on the job. Each company was asked to provide a minimum of 10 hygiene–task combinations. Each task was to have 8–10 exposure measurements from personal samples. A total of 22 tasks from six companies were evaluated. Hygienists from each company provided judgments for tasks selected from their company only. Table 1 summarizes the number of hygienists and tasks evaluated from each company.

Each company provided monitoring data for specific tasks that were chosen for judgment elicitation in this study. The participating hygienists were asked to review all available information for each task that they evaluated, including the chemicals used in the task, Material Safety Data Sheets, personal protective equipment worn by the workers, duration of the task, and task environment specifics such as the general room ventilation. The hygienists were also encouraged to personally observe the facility and talk to the plant personnel regarding the tasks. All the available information on workplace processes, equipment, controls, and materials for the tasks for which judgments were provided were made accessible to the hygienists. The hygienists were asked to give their initial judgment based on their knowledge of the task alone, without looking at any of the monitoring data. The first monitoring datapoint was then revealed to them and they were allowed to modify their initial judgment on the basis of this new information. Subsequent datapoints were revealed, one at a time, and the hygienists were allowed to modify their judgment after each datapoint was revealed. Thus, for each task, a series of exposure judgments were obtained from each hygienist who evaluated that task.

In order to assess the accuracy of hygienists' judgments, the correct exposure category or 'reference' judgment category was defined for each task based solely on the monitoring datapoints provided by the company. The reference exposure category is defined as the category that is estimated to have the greatest likelihood of containing the 95th percentile of the exposure distribution based on the complete set of monitoring datapoints, given all combinations of geometric mean and geometric standard deviation that are possible for that category (Hewett *et al.*, 2006).

Table 1. Summary of number of participating hygienists and number of tasks in each company.

Company	Number of hygienists	Number of tasks
A	3	5
B	10	2
C	7	3
D	3	6
E	7	5
F	19	1
Total	49	22

A total of 22 tasks were evaluated across the six companies. The number of monitoring datapoints for each task varied from 5 to 24. A total of 2142 task judgments were collected from all hygienists, before and after training. The judgments elicited were in the form of the probability of the 95th percentile lying in each of the four AIHA categories.

The probabilities were expressed on a scale of 1–100 for each of the four categories (in whole number values). No category could have a probability of zero, the sum of the probabilities in the four categories had to add up to 100%, and one of the four categories had to have the highest probability. This reflects the category that the hygienist thinks is the most probable category in which the 95th percentile of the exposure distribution is located for that particular task.

Data interpretation training was provided to the participants after all the judgments were made for all the tasks. This training covered basic statistics and properties of lognormal distributions. Participating hygienists were taught some simple rules of thumb to estimate the 95th percentile rapidly. The hygienists were then given data interpretation tests (DITs) on small simulated monitoring data sets before and after the training. Each DIT had eight data sets with the number of simulated monitoring datapoints varying between 1 and 8. The OEL for all data sets was assumed to be 100. Hygienists were asked to predict the probabilities of the 95th percentile being located in each of the four exposure categories for each data set. The entire exercise was performed again, post-training, for all hygienists.

Determinant information relating to personal, educational, and cumulative experience as well as task-specific experience was collected from the participants (Tables 2 and 3). Information about educational and professional experience included the field of advanced educational degrees, professional certifications, years of experience in exposure assessment, air sampling experience (although we did not distinguish between hygienists personally obtaining samples and those supervising the sampling process), years since the hygienist last engaged in an exposure assessment exercise, cumulative

Table 2. Data sheet for collecting personal and professional determinant information from all participating hygienists from all companies.

Name of company				Date	
Hygienists ID (either name or some sort of number)					
Years in current job type					
Undergraduate degree field	(Ex—BS Chemistry)				
Masters degree field					
Advanced degree field					
List professional certifications (CIH, CSP, IHIT, PE, or other)					
	Please circle box that best applies and enter actual estimate				
Number of years making exposure judgments	<1 year	1–3	3–5	5–10	>10
Number of years since actively engaged in doing exposure assessments	<1 year	1–3	3–5	5–10	>10
Estimate the total number of job tasks documented using AIHA strategy	<10	10–100	100–1000	1000–5000	>5000
Career air sampling experience[a]	Collected less than three air sampling surveys	Collected 3–20 air sampling surveys	Collected 20–100 air sampling surveys	Collected 100–200 sampling surveys	Collected >200 air sampling surveys
Statistics experience	Do not have a good understanding of normal and lognormal stats	Can do basic lognormal stats calcs (GM and GSD)	Familiar with calculating point estimate of 95% tiles or exceedance fractions	Familiar with calculating confidence intervals or tolerance limits for 95% tiles	

[a]The term air sampling survey refers to any kind of air sampling (active/grab/passive) that the hygienist has been involved with.
GM, geometric mean; GSD, geometric standard deviation; PE, Professional Engineer.

Table 3. Task-specific determinant data collected from all participating hygienists from all companies.

Task experience information data sheet					
Task 1 name of task	Please circle box that best applies for each row				
Years experience with exposure assessments on this type of task	Never	1–2	3–5	5–10	>10
Approximate number of exposure assessments on this chemical	Never assessed exposure to this chemical	1–2	3–5	5–10	>10
Number of air sampling surveys[a] performed on this chemical	Never sampled it	Observed sampling	Collected <3 surveys on agent	Collected 3–10 surveys on agent	>10 surveys on agent
Do you recall reviewing sampling data on this type of chemical task?	No	Vaguely	Yes	Yes—on this exact task	

[a]The term air sampling survey refers to any kind of air sampling (active/grab/passive) that the hygienist has been involved with.

experience in assessing exposures using the AIHA strategy, experience using physical–chemical mathematical models, and statistical experience. Task-specific questions included experience with similar tasks, experience with similar chemicals, and review of previous monitoring data on the task.

The following null hypotheses were tested:

1. The educational and cumulative experience characteristics of hygienists are not associated with the DIT judgment accuracy.
2. The educational and cumulative experience characteristics of a hygienist as well as task-specific experience determinants are not associated with the accuracy of task exposure judgments.

3. The NFC test scores are not associated with improvements in task judgment accuracy after data interpretation training.
4. The NFC scores are not associated with any task-specific experience determinants.

Several measures were used as dependent variables. For the DITs and the task judgments, the absolute accuracy of each judgment for a given task for each hygienist was calculated using the formula:

$$\text{Absolute accuracy} = 1 - \frac{\sqrt{\sum_{i=1}^{4} (\text{Tr}_i - \text{IH}_i)^2}}{(96\sqrt{2} - 0)}, \quad (1)$$

where Tr_i = true probability assignment for the ith category based on complete monitoring data set (reference judgment); IH_i = hygienists probability assessment for ith category; $96\sqrt{2}$ = maximum possible difference between a hygienist's judgment and the reference judgment; 0 = minimum possible difference between a hygienist's judgment and the reference category.

The sum of all four categories should add up to 100 and the maximum probability in any one category cannot exceed 97. For example, if the reference judgment is a Category 4 exposure with 97% probability, but the hygienist predicts Category 1 with 97% probability, then the numerator of equation (1) would represent the maximum difference, which equals $96\sqrt{2}$. The minimum difference between any hygienist judgment and the reference is 0, in which case, the absolute accuracy is 1.

Categorical accuracy was also calculated for both DITs as well as task judgments. The categorical accuracy was based on the deviation from the reference category. If the hygienist predicted the same category as the reference exposure category, then the categorical accuracy was assigned a value of 1. If the hygienist predicted a category that was higher than the reference (could be 1, 2, or 3 categories higher), the categorical accuracy was assigned a value of 2 for that judgment. If the hygienist predicted a category lower than the reference (could be 1, 2, or 3 categories lower), the categorical accuracy was assigned a value of 3. The assignment of the numbers 1, 2, and 3 for categorical accuracy is only nominal values and not ordinal. They are not ranked in any way, but the numbers are assigned only to identify the category over or under prediction.

1 = correct prediction.
2 = over prediction.
3 = under prediction.

General linear regression models were used for DIT and task absolute accuracy models and cumulative logit models were used for DIT and task categorical accuracy models.

RESULTS AND DISCUSSION

Table 4 shows the summary statistics of the hygienists' characteristics relating to their educational and work experience backgrounds. There is a wide variation, from 4 months to 26 years, in the cumulative experience that participants had in their current job. This represents a good cross-section of practitioners from several industry sectors. Eighty-four percent of the participants had a Master's degree in industrial hygiene, environmental health, or a related science field, which is typical of hygienists working in large companies. There was no one with a doctoral degree. Almost all hygienists had some professional certification, with 24% of them being Certified Industrial Hygienists (CIHs) and another 24% having both CIH and Certified Safety Professional (CSP) certification, again typical of hygienists working in large companies. Thirty-nine percent of hygienists had >10 years of experience in making exposure judgments and 94% of hygienists had actively engaged in exposure assessments within the last year. All participants had used the AIHA strategy for documenting job tasks to some extent and had at least three or more air sampling experiences during their career. All hygienists reported some knowledge of statistics, with 41% of them professing only a basic understanding of lognormal statistics. The NFC scores ranged from 52 to 79 with an average score of 67 (minimum possible score is 18 and maximum possible score is 90).

The effect of various determinants on judgment accuracy was assessed by developing a statistical model with the determinants as the independent variable and absolute or categorical accuracy as the dependent variable. The comprehensive list of variables initially considered for DIT accuracy were training, company, years in current job, highest educational degree, professional certifications possessed, number of years making exposure assessments, number of years since actively engaged in doing exposure assessments, total number of job tasks documented using the AIHA strategy, career air sampling experience, self-reported statistical experience, and NFC score. For task judgment accuracy, in addition to the above list of variables, task-specific determinants such as task,

Table 4. Summary statistics of educational and professional experience and NFC score determinants for all 49 hygienists. GM, geometric mean; GSD, geometric standard deviation.

Years in current job	<1 2%	1–5 34%	6–10 28%	>10 36%	
Highest educational degree	Associate degree in EHS or science	BS degree in EHS or science	MS degree in EHS or science	Doctoral degree in EHS or science	
	2%	14%	84%	0%	
Certifications	CIH only	CSP only	IHIT only	CIH and CSP	No certification
	24%	2%	2%	24%	47%
Number of years making exposure judgments	<1 6%	1–3 16%	3–5 14%	5–10 24%	>10 39%
Number of years since actively engaged in doing exposure assessments	<1 94%	1–3 4%	3–5 2%	5–10 0%	>10 0%
Estimate of total number of job tasks documented using AIHA strategy	<10 20%	10–100 31%	100–1000. 24%	1000–5000 16%	>5000 8%
Career air sampling experience	Less than three air sampling surveys	3–20 air sampling surveys	20–100 air sampling surveys	100–200 air sampling surveys	>200 air sampling surveys
	0%	8%	29%	29%	35%
Statistical experience	No understanding of normal and lognormal stats	Can do basic lognormal stat calculations (GM and GSD)	Familiar with calculating point estimate of 95% tiles or exceedance fractions	Familiar with calculating confidence intervals or tolerance limits for 95% tiles	
	0%	41%	33%	27%	
NFC score	18–36	37–54	55–72	73–90	
	0%	5%	71%	24%	

BS, Bachelor of Science; EHS, Environmental Health and Safety; MS, Master of Science.

datapoint (i.e. the number of datapoints revealed to the hygienist before obtaining the judgment), years of experience with exposure assessments on that type of task, number of years exposure assessment experience on that specific chemical, number of air sampling surveys performed on that specific chemical, and review of sampling data on that specific type of chemical–task combination were considered. To arrive at the list of variables to include in the models that will not result in collinearity problems, correlations between pairs of the various experience variables were first tested using the frequency procedure and using the Chi-square test values in SAS version 9.1 (SAS Inc., Cary, NC, USA). The number of years of making exposure judgments, number of years since actively engaged in exposure assessments, total number of job tasks documented using the AIHA strategy, and career air sampling experience were found to be correlated with each other. Therefore, of these variables, only the total number of years hygienists spent making exposure judgments was retained as a cumulative experience determinant. Similarly, for task accuracy, all pairs of the four task-specific determinants were found to be correlated with each other. Therefore, only the number of years a hygienist had experience with the particular task that they evaluated was retained as the task-specific experience determinant. The other determinants were professional certification [CIH/CSP/Industrial Hygienist in Training (IHIT)], years in current job, NFC score, the company that the hygienist worked for, and training (Table 5). Since the relationship between the hygienist-specific determinants and judgment accuracy could be confounded by the company that the hygienists are from and the data interpretation training that they receive, these two variables were also included in the models to control for confounding.

To test for confounding, a baseline model was first fitted with all the independent variables shown in Table 5. Since company and training were found to have a significant impact on accuracy, these two variables were retained while testing for confounding with the other variables. Regression models were fitted with one variable at a time, and the effect on the estimate of company and training was investigated. Since there was no confounding effect observed, the baseline model was retained (Kleinbaum *et al.*, 1982).

DIT judgments and effect of determinants

The effect of various determinants on DIT judgment absolute accuracy and DIT judgment categorical accuracy was analyzed statistically. To test Hypothesis 1, a general linear model (GLM) was fit with DIT judgment absolute accuracy as the dependent variable and list of determinants (Table 5) as the independent variables (Model 1). A cumulative logit model was fit with DIT judgment categorical accuracy as the dependent variable and all the determinants in Table 5 as the independent variables (Model 2). The absolute accuracy model (Model 1) was found to be significant ($P < 0.0001$) with an F value of 6.79. Table 6 shows the significant results for Model 1 that has absolute accuracy for DITs as the dependent variable and educational and experience characteristics as the independent variables. The significant variables were training ($P = 0.0012$), company ($P = 0.0191$), years of experience doing exposure assessments ($P = 0.0099$), and professional certifications possessed by the hygienists ($P < 0.0001$). Other variables including years in current job and the NFC scores were not significant.

Table 5. List of dependent and independent variables for DIT and task judgment accuracy models.

Dependent variable	Independent variables
DIT judgment absolute accuracy and categorical accuracy	Company
	Training
	Years in current job
	NFC score
	Years of experience doing exposure assessments
	Professional certification
Task judgment absolute accuracy and categorical accuracy	Company
	Training
	Datapoint
	Task
	Years in current job
	NFC score
	Years of experience doing exposure assessments
	Professional certification
	Years of experience on task evaluated

Table 6. Model 1: significant independent variables* from model fitted with DIT judgment absolute accuracy as the dependent.

Variable	F value	$P > F$
Training	10.54	0.0012*
Company	2.72	0.0191*
Years of experience doing exposure assessments	3.35	0.0099*
Professional certifications	38.74	<0.0001*

*The model is significant ($P < 0.0001$) with an F value of 6.79.

Model 2 used DIT judgment categorical accuracy as the dependent variable and experience and educational characteristics (shown in Table 5) as the independent variables. The results were similar to those for Model 1 and are, therefore, not shown in a separate table.

Models 1 and 2 deal with the education and experience of hygienists and how they are related to accuracy of judgments based on small simulated data sets (DITs). Since the DITs contain simulated data from a lognormal distribution, studying the accuracy of prediction on these tests helps us understand how hygienists interpret monitoring data and how they are able to apply it to the categorical predictions. Overall, it was found that training had an effect on accuracy, i.e. hygienists are able to apply the rules of thumb easily and predict correctly the exposure category, post-training. Whether or not the hygienists possessed CIH/CSP/IHIT certifications was also a significant predictor of judgment accuracy. The number of years a hygienist spent making exposure assessments was a predictor of absolute accuracy but not categorical accuracy. Since some educational and cumulative experience characteristics were found to be significant, Hypothesis 1 is rejected.

Apart from educational and experience information, determinant information, referred to as task-specific determinant information, was also collected from each hygienist, which reflected their experience of the specific task or chemical (Table 7). These determinants refer to an individual hygienists-specific experience on the real tasks that they provided judgments for, from their own company. Forty-three percent of hygienists had no previous experience on the type of task that they provide judgments for and 34% of hygienists had no exposure assessment experience with the chemical used for the task. Forty-eight percent of hygienists had never performed previous air sampling surveys on the particular chemical and 54% of them did not recall reviewing sampling data on the task. This shows that some of the hygienists were familiar with either the task or the chemicals used for the task for which they provided judgments.

Task judgments and effect of determinants

To test Hypothesis 2, task judgment accuracy (on real tasks in the six participating companies as opposed to the simulated data sets used previously) was investigated as the dependent variable with the determinants in Table 5 as the independent variables. Task judgment absolute accuracy was modeled using a GLM with the determinants presented in Table 5 (Model 3). Task judgment categorical accuracy was modeled using a cumulative logit model with determinants in Table 5 (Model 4).

Models 3 and 4 were found to have the same results, and therefore, only results for Model 3 are shown in Table 8.

Models 3 and 4 looked at task-specific determinants in addition to education and experience. Unlike Models 1 and 2 that considered judgments based on small simulated data sets, these models considered accuracy of judgments of actual tasks in workplaces at the participating companies. As in the case of the DIT accuracy models (Models 1 and 2), training was found to be significant here as well. This indicated that training improved accuracy not only for simulated data sets but also for actual workplace tasks.

Company effect was found to be significant ($P < 0.0001$) indicating that hygienists from certain companies were able to more accurately judge exposures than others. This could be because of the training provided in the company or the exposure assessment strategy in place at the company. If a company has a good exposure strategy in place and if hygienists are routinely trained with exposure assessment strategies, they may perform better than hygienists working in from companies that do not have any such strategy in place. Another possible reason could be that since the companies had the choice of picking the tasks they would be evaluating for the study, hygienists from certain companies might have had more experience with those particular tasks chosen. However, we do not have the information to definitely attribute a cause for this finding.

The task and datapoint were found to be significant along with the years of experience on the task that each hygienist evaluated. This indicates that hygienists experienced with a particular task were able to predict the exposure category with more accuracy that other hygienists who do not have previous experience on the task. The task variable was found to be significant indicating that a hygienist with even a little experience on a particular task is able to make accurate exposure decisions. This coupled with the fact that years of experience on a task was significant indicates that if a hygienist had previous exposure assessment experience on a particular task, they were more likely to remember the task and hence predict the exposure category more accurately. The datapoint variable was found to be significant indicating that as more datapoints were revealed, the hygienists were more accurate at predicting the correct exposure category.

Professional certifications possessed by the hygienists and the total years of exposure assessment experience were also significant. Since several educational and cumulative experience characteristics were found to be significant predictors of task-specific judgment accuracy, Hypothesis 2 is rejected.

Table 8. Model 3: significant independent variables* from model fitted with task judgment absolute accuracy as the dependent variable.

Variable	*F* value	$P > F$
Training	216.24	<0.0001*
Company	82.83	<0.0001*
Datapoint	64.59	<0.0001*
Task	316.66	<0.0001*
Years of experience doing exposure assessments	6.74	0.0004*
Certification	37.19	<0.0001*
Years experience on task evaluated	7.60	<0.0001*

*Model was significant with ($P < 0.0001$) and an *F* value of 48.87.

Table 7. Summary statistics for task-specific experience characteristics for all 49 hygienists.

Years experience with exposure assessment on the type of task	Never 43%	1–2 22%	3–5 18%	5–10 11%	>10 6%
Approximate number of exposure assessment on this chemical	Never 34%	1–2 27%	3–5 15%	5–10 11%	>10 13%
Number of air sampling surveys performed on this chemical	Never 48%	Observed sampling 4%	Collected less than three surveys on agent 14%	Collected 3–10 surveys on agent 17%	Collected >10 surveys on agent 16%
Do you recall reviewing sampling data on this type of chemical task	No 54%	Vaguely 19%	Yes 14%	Yes—on this exact task 13%	

Effect of judgment accuracy, determinants, and training on NFC scores

In trying to understand the accuracy and the determinants that help to predict accuracy, NFC was thought to be one of the relevant cognitive determinants and hence, models were fit to understand this variable better. Making exposure judgments require a good understanding of the process and knowledge of task. When presented with limited monitoring data or no data at all, hygienists have to think about the process before making judgments on exposures. It was hypothesized that hygienists with a higher NFC score would be able to more accurately predict exposures. We also hypothesized that improvements in accuracy would be greater for hygienists with higher NFC scores. To test Hypothesis 3, the effect of the NFC score on improvements in task judgment accuracy was studied. The improvement in accuracy was calculated for task judgment categorical accuracy as the difference between post-training task judgment accuracy and pre-training task judgment accuracy.

A cumulative logit model was used with the difference in task judgment categorical accuracy as the dependent variable and NFC score as the independent variable (Model 5, Table 9). The model was found to be significant ($P = 0.0085$). This means that hygienists with a higher NFC score showed greater improvement in predicting the correct category for task judgments post-training. Since hygienists were provided with task-specific information as well as monitoring data, hygienists with higher NFC scores were able to apply this additional information and make correct category judgments with greater frequency after the DIT training. Since NFC scores have an effect on improvement in task judgment categorical accuracy, Hypothesis 3 is rejected.

To test Hypothesis 4, NFC was also modeled with task-specific determinants as independent variables to identify key predictors (Model 6, Table 10). The model was found to be significant ($P < 0.0001$) with an F value of 58.38 and an R^2 value of 0.34. The company, the number of years a hygienist has been working in the current job, years of experience doing exposure assessments, professional certifications possessed by the hygienist, task, and years of experience on the task were found to be significantly associated with NFC score. Hence, Hypothesis 4 is rejected. As mentioned earlier, the NFC scale is a personality variable reflecting the extent to which people engage in and enjoy effortful cognitive activities (Cacioppo *et al.*, 1996). People high in the NFC score are more likely to form their judgments by paying close attention to relevant arguments (in this case, information available on a task from various sources like, basic characterization, monitoring data, etc.). These traits are likely to be similar to the traits needed to obtain professional certification and could also be associated with experience. Some companies may be hiring employees using criteria that may be related to NFC scores; hence, company was also found to be a significant variable.

In Model 5, it was found that the improvement in categorical accuracy for task judgments is higher for hygienists with higher NFC scores. This indicates that hygienists with higher NFC scores are better able to integrate the data interpretation training and take into account the monitoring data provided for each task and incorporate them into the final exposure judgment. Model 6 indicates that NFC score itself may be associated with some variables associated with accuracy in DITs and task judgment accuracy. In other words, the variability in the accuracy of DIT and task judgment accuracy scores that are explained by determinants that are correlated with NFC. Thus, including the NFC as well as these determinants in the same model is redundant and the NFC would not provide any additional explanation of the variability. This could explain why the NFC score was not a significant variable in models predicting accuracy in DITs and task judgments. Table 11 lists the models and the dependent and independent variables used for each model.

CONCLUSIONS

Exposure judgments made by hygienists drive the decisions regarding controls that impact health risk

Table 9. Model 5: results for model fitted with NFC score as the independent variable and increase in task judgment categorical accuracy as the dependent variable.

Increase in categorical accuracy for task judgment		
Variable	Wald Chi square	$P >$ Chi square
NFC score	6.92	0.0085

Table 10. Model 6: significant independent variables from model fitted with NFC score as the dependent variable. The model was found to be significant ($P < 0.0001$) with an F value = 12.60 and a $R^2 = 0.16$.

Variables	F value	$P > F$
Company	73.75	<0.0001
Years on current job	26.69	<0.0001
Year of experience doing exposure assessments	19.78	<0.0001
Professional certifications	18.23	<0.0001
Task evaluated	7.84	0.0052
Years of experience on task evaluated	117.56	<0.0001

Table 11. Statistical models used for analyzing effects of various determinants on accuracy.

Models	Dependent variables	Independent variables	Model used	Significance
Model 1	DIT judgment absolute accuracy	Determinants listed in Table 5	GLM	Significant model
Model 2	DIT judgment categorical accuracy	Determinants listed in Table 5	Cumulative logit model	Significant model
Model 3	Task judgment absolute accuracy	Determinants listed in Table 5	GLM	Significant model
Model 4	Task judgment categorical accuracy	Determinants listed in Table 5	Cumulative logit model	Significant model
Model 5	Difference in task judgment categorical accuracy	NFC score	Cumulative logit model	Significant model
Model 6	NFC score	Determinants listed in Table 5	GLM	Significant model

reduction. This paper investigated four sets of factors that might be related to the ability to make accurate exposure judgments based on limited number of monitoring data: (i) factors relating to the personal background of the occupational hygienist, e.g. education, professional experience, competence in specific relevant skills, (ii) task-specific factors, (iii) the effect of NFC scores on the improvement in judgment accuracy, and (4) the effect on NFC scores on task-specific factors.

The study found that cumulative years of exposure assessment experience and professional certifications possessed by the individual hygienist were the key hygienist-specific determinants that were associated with accurate judgments. It was also found that data interpretation training had a significant effect, which indicated that irrespective of personal background, when provided with a standard training, hygienists show significant improvement in judgment accuracy.

When task-specific determinants were investigated for accuracy, in addition to the IH-specific determinants, it was found that company, task, datapoint, and years of experience on a particular task were significant predictors of accuracy. A significant company effect might indicate that there could be significant differences between companies in terms of work cultures that affect the way that hygienists assess exposures. Companies can be either compliance-driven or performance-driven (i.e. more emphasis on actual worker protection versus complying with the letter of the law). Some companies might have a more rigorous training program or a clear and transparent exposure assessment strategy in place that can help hygienists from those companies perform better. Since information relating to work culture and practices in companies was not collected, no conclusive explanation of company effect can be offered in this paper. The task being evaluated was found to be a significant predictor of accuracy. The study was designed such that the hygienists only evaluated tasks from their own companies, and therefore, this finding could be a manifestation of the company effect. It is also likely that the nature of the various tasks in our study lent themselves to inherently lower or higher accuracy due to their variability. The tasks selected came from a variety of settings including general manufacturing, chemical manufacturing, and pharmaceutical industries that tolerate different levels of process and exposure variability. The datapoint variable was significant indicating that as more monitoring data were provided, more hygienists were able to make accurate judgments. The years of experience on a particular task and exposure assessment on the chemical were significantly associated with accuracy, suggesting that cumulative experience improves accuracy.

The NFC scores were significantly associated with the level of improvement in judgment accuracy scores after training, indicating that the effectiveness of training was, at least in part, a function of cognitive openness to learning as opposed to innate ability to learn. At the same time, the NFC score was associated with several hygienist- and task-specific determinants of judgment accuracy suggesting that the score might not just be a reflection of an innate quality but something that can change with experience and context.

While training was found to improve accuracy of hygienists to a significant degree, it is possible that hygienists who routinely do not conduct exposure assessments might not benefit from just a one-time training and might need periodic reinforcement. It is reasonable to assume that periodic refresher training of occupational hygienists in relevant statistics, especially relating to lognormal distributions and estimations of upper percentiles of such distributions will likely improve the accuracy of their exposure judgments on a more sustained basis. It was also found that years of exposure assessment experience and having a professional certification (CIH/CSP/IHIT) were associated with increased accuracy of judgments. One possible recommendation from a company perspective could be to institute a mentorship program that would allow junior hygienists within the company to get guidance from more experienced hygienists until they have reached a certain level of expertise and experience (and obtained professional certification) to make independent exposure assessments. The finding that experience with a specific task increased accuracy leads to the common sense recommendation that more experience and active engagement in exposure sampling and assessment with chemicals/tasks used at a facility will only improve judgment accuracy. It is well known from studies of human expertise in other fields that high-level performance requires three ingredients—focused training, practice, and accurate feedback. This study indicates that the same holds true for expertise in the area of occupational exposure assessment.

This study has identified several characteristics of hygienists that could form the basis of a performance metric, including certification, to track the performance of industrial hygienists over their career. However, the study is only a first step to understanding the varied characteristics that lead to the development of a skilled industrial hygienist, in that, it focused on the ability of hygienists to interpret small sets of exposure data and the effect of training in improving this skill. It seems reasonable to assume that other skills, e.g. using rules of thumb to make exposure judgments during walkthroughs (without reference to any measurements), synthesizing information from the basic characterization of the workplace, ventilation surveys, and other sources to make judgments, and the use of exposure models would also depend on hygienist characteristics and would also be amenable to improvement via targeted training. This indeed the focus of our future work.

Finally, this paper is focused on evaluating judgments made by hygienists for prospective decision-making, i.e judgments related to compliance, identification of appropriate engineering and administrative controls, the assignment of appropriate personal protective equipment, and administration of appropriate levels of training. However, the findings reported here may also be relevant for those hygienists performing retrospective exposure assessments related to epidemiology studies, health surveillance, and illness cluster investigations.

FUNDING

National Institute for Occupational Safety and Health of the Centers of Disease Control and Prevention (1RO1 OH008513).

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