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Quantitative Self-Assessment of Exposure to Solvents Among Shoe Repair Men

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Self-assessment of exposure (SAE) refers to any exposure assessment methodology wherein the worker takes an active role in establishing his or her exposure status. The objective of this study was to investigate the reliability and feasibility of SAE approaches among shoe repair workers collecting exposure data over a 3 month period. This study was conducted in 26 Dutch shoe repair shops, which were divided into two groups of SAE with different levels of expert supervision. Participants in group 1 received only written instructions on sampling methods, whereas workers in group 2 were also instructed face-to-face by an occupational hygienist. Participants were asked to do 20 (group 1) or 14 (group 2) measurements by themselves. In group 2, an additional 6 measurements in each company were conducted under supervision of an expert. Organic solvents were measured by passive samplers (3M badges) and a sum score for volatile organic compounds (VOC score) was used in data analysis. Mixed effect models and principal component analysis were used to compare concentration levels and exposure variability between group 1 and group 2. Finally, 473 out of the 520 distributed samplers (91%) were available for analysis. Measurements in group 1 were not evenly spread over the 3 month period, whereas dispersal of measurements was much better if experts were more closely involved (group 2). No significant differences in average VOC scores were found between group 1 and group 2. The exposure variability in group 1 appeared to be significantly larger than that in group 2. However, analysis within group 2 showed that no differences exist in geometric means and exposure variability between 'expert' and 'self-assessment' measurements. Thus, the study results are ambiguous with respect to the reliability of SAE, and more research is needed to corroborate and refine the present results. This new methodology can, if proven reliable, be seen as a cost-effective way of collecting exposure data.

Keywords: exposure assessment; passive sampler; self-assessment

INTRODUCTION

Traditionally, exposure assessments have been conducted with a high degree of professional involvement with the occupational hygienist taking all the responsibility: i.e. designing the sampling strategy, performing the measurements and collecting contextual information. The role of the worker in this traditional type of exposure assessment is a passive one; the worker serves as the carrier of the sampling equipment. Self-assessment of exposure (SAE) refers to any exposure assessment methodology wherein the worker takes a more active role in establishing his or her exposure status. The worker is to various extents responsible for the sampling procedure, collection of contextual information and selection of measurement days. The occupational hygienist then becomes the person who focuses on interpretation of exposure data, whereas the physical process of collecting exposure information is transferred to the worker.

SAE requires the development of ready-to-use inexpensive devices that are suitable for use by non-professionals. Since measurement error is often small relative to the enormous exposure variability within and between workers (Nicas *et al.*, 1991), analytical precision should not be the principal

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concern in selecting user-friendly devices (Rappaport, 1991). Examples of user-friendly methods are passive diffusion samplers to measure exposure to solvents (Egeghy *et al.*, 2002) or badges to assess magnetic field exposure (Loomis *et al.*, 1994). Recently, a passive sampler has been developed for the assessment of dust exposure (Vinzents, 1996). Methods using a combination of pump and collector system seem less appropriate for SAE, although active sampling techniques have occasionally been successfully employed (Rappaport *et al.*, 1999).

To date, a limited number of studies have been published that specifically investigate the validity of quantitative SAE for inhalation exposure. The simplicity of measurement devices allowed for accurate measurements being obtainable from unsupervised workers with minimal or no training (Liljelind *et al.*, 2000, 2001; Egeghy *et al.*, 2002; Sunnesson *et al.*, 2002; Eriksson *et al.*, 2005). Hence, results have been promising and SAE may be seen as cost-effective means of obtaining large datasets (Nothstein *et al.*, 2000). However, it is unclear whether SAE also provides insight into long-term exposure, since Sunnesson *et al.* (2002) observed that enthusiasm of participants sometimes decreased after the first couple of measurement sessions.

In this paper, we will describe a study in which shoe repair men measured exposure to organic solvents using passive diffusive samplers. A large number of samplers were collected from each worker during a period of 3 months. The purpose of the study was to investigate the reliability and feasibility of such a demanding self-assessment study covering a relatively long time period. Different levels of self-assessment regimes were employed with varying degrees of professional supervision during the measurements. Estimates of central tendency and exposure variability are compared between the different approaches.

METHODS

Study design and population

Shoe repair shops were enrolled using databases from the Dutch branch organization. In total, 26 shops were recruited in Central/West Holland. To increase the comparability between shops, only the employee who accomplished most of the gluing activities was included in the study. Solvent vapours were sampled with a passive diffusion sampler and each participant was expected to use 20 samplers. Hence, 520 full-shift personal measurements were anticipated to be taken. In this study, two sampling strategies were compared: participants in group 1 received 20 badges by post with an extensive written instruction on how to use the badge, and to accomplish and plan the measurements. In group 2, we delivered 14 badges at the beginning of the study. Participants in group 2 received extensive oral instructions by an occupational hygienist and the same written instruction as workers in the group 1. Workers in both groups had to plan the measurements by themselves over a 3 month period (April–June 2005). In group 2, an additional six control measurements were conducted during the measurement period. These measurement days were randomly selected and measurements were conducted under supervision of an occupational hygienist. It was indicated to workers in both groups that the aim of the study was to determine whether workers could accurately measure exposure. Workers were randomly allocated to either group 1 or group 2.

Exposure assessment and chemical analyses

Full-shift personal exposure to organic solvents was measured with passive diffusive samplers (3M Badge, St Paul, MN, USA). The 3M badge (type 3500) consists of a charcoal pad (wafer), which is separated from the air by a diffusive membrane. An inventory of hazardous substances in the shoe repair branch showed that many different organic solvents are used (Le Feber *et al.*, 2003). All organic solvents listed in this earlier study that could be sampled on a diffusive badge were selected in the exposure assessment study: i.e. acetone, 2-propanol, methyl ethyl ketone, methylmetacrylate, ethyl acetate, hexane, *n*-butanol, cyclohexane, methyl isobutyl ketone, toluene, *n*-butylacetate, ethyl benzene, cyclohexanone, diacetonalcohol, naphtha and xylene.

On a measurement day, the participant opened the sampler at the start of a work shift and capped and stored the sampler in the fridge at the end of a shift. The participant registered date and time, and filled in a short form with questions about general ventilation, local exhaust ventilation, presence of co-workers in the same workplace, pairs of shoes repaired and volume of the workplace. In group 1, the badges were picked up by an occupational hygienist once a month; in group 2 badges were collected during a 'control' measurement day. 'Controlled' measurements in group 2 were done with the same diffusive samplers and followed the same procedures as during self-assessments, except that the occupational hygienist randomly selected the measurement day and was present at the start and end of the measurement. In a controlled measurement, the occupational hygienist opened, mounted and capped the samplers at the end of measurement, recorded start and end times, and transported the samplers to the laboratory. The form with questions on ventilation and tasks performed was cross checked by the occupational hygienist.

The solvents were adsorbed out of the wafer by adding 1.5 ml of CS_2. After 30 min, the solvent was removed from the badge and analysed by gas chromatography with flame ionization detection (GC-FID). Analyses were conducted with two columns (ZB-wax and CP-Sil-5-CB). Method validation consisted of determination of the limit of detection (LOD; average noise/background + 3 SD) and the limit of quantification (LOQ; average noise/background + 10 SD) using blank badges. The LOD was determined at 2 μg (*n*-butanol) and 0.6 μg (all other solvents) per badge. The LOQ was determined at 5.0 μg/badge (*n*-butanol) and 2.0 μg/badge (all other solvents). Concentrations below or equal to LOD were processed as LOD. Values between LOD and LOQ were replaced by 0.5 LOQ.

Statistical analysis

Microsoft Access 2002 was used to build a relational database, in which all exposure data and contextual information were digitalized. The final database was exported to SAS, version 8.02 (SAS Statistical Software, SAS Institute, Cary, NC), wherein the statistical analyses were performed. Measured results were combined in a volatile organic compounds (VOC) score in the form: $VOC = \Sigma C_a (a = 1, 2, \ldots, b)$, where C_a represents the concentration of the a-th substance and b the number of substances detected. The natural logarithm of VOC scores was taken to satisfy normal assumptions.

The effect of SAE regime on estimates of mean exposure levels and variability were determined using mixed effects model, defined as follows:

$$Y_{g(ij)} = ln\left(X_{g(ij)}\right) = \mu_y + \alpha_g + \sum_{m=1}^{p} \alpha_m + \delta_{g(i)} + \varepsilon_{g(ij)}$$

for group (g) equals SAE level 1 and 2; for $m = 1, 2, \ldots, p$ potential determinants; for $i = 1,2, \ldots, k_g$ workers in the g-th group; and for $j = 1,2, \ldots, n_{g(i)}$ measurements of the i-th worker in the g-th group. X_{ij} represents the VOC score on the j-th day for the i-th worker and Y_{ij} is the natural logarithm of the individual measurement X_{ij}. In this model, μ_y represents the intercept; α_g represents the fixed effect of the g-th group (i.e. the self-assessment effect); α_m represents the fixed effect of the p determinants; $\delta_{g(i)}$ represents the random effect of the i-th worker; and $\varepsilon_{g(ij)}$ represents the random within-worker variability. It is assumed that $\delta_{g(i)}$ and $\varepsilon_{g(ij)}$ values are normally distributed with mean equal to 0 and variance of $\sigma^2_{B,g}$ and $\sigma^2_{W,g}$, respectively, representing the between-worker and within-worker variability components for both SAE groups. Since only one worker per workplace is selected, the between-worker variability component may reflect to a large extent differences between workplaces. Random effects are assumed to be statistically independent. A compound symmetry covariance structure was used to model the data. Graphical analyses of residuals were performed to evaluate assumptions of homoscedasticity. The likelihood ratio test was used to determine whether a reduced model with pooled components of variance could be fitted, using the model described in the equation as a reference. The significance of an interaction term for SAE group and time period was tested in order to evaluate whether different time trends exist among both self-assessment regimes. The relevance of the following exposure determinants was evaluated in the model: general ventilation, local exhaust ventilation, co-workers, number of pairs of shoes repaired and volume of the workplace. All tests were performed at a 5% level of confidence.

Next to the analyses on an aggregate VOC score, the individual substances were analysed using principal component analysis (PCA) in order to identify clusters of substances that occurred regularly in combination with each other during personal exposure. PCA was done using Matlab version 7.0.7 R14 (The Mathworks, INC) and PLS toolbox Version 3.0.4 (Eigenvector Research, INC). In this study, PCA was used as a tool in order to investigate whether different combinations of substances were used in group 1 and 2. Principal components were retained if eigenvalues were >1. Numerical indices representing each PC were generated as PC scores. Box plots were produced to compare PC scores between group 1 and 2.

RESULTS

Twenty six companies were initially involved in the study and a total of 520 measurements were anticipated to be collected. Eventually 473 sampling results could be used for further analysis (Table 1). About 9% of the measurements were lost as a result of various reasons: one company stopped its participation, some companies did not conduct all measurements and a few samplers were used incorrectly. Table 1 also shows the partitioning of measurements over the total sampling period of 3 months. It is shown in Table 1 that participants in group 1 (receiving only very limited expert supervision) did almost half of the measurements in June, whereas group 2 conducted more equal numbers of measurements in each month of the sampling period.

All companies completed a questionnaire with respect to generic characteristics of the company, and workers were also asked to register contextual information during the measurements. Table 2 shows that companies in group 1 were slightly larger than companies in group 2, based on number of employees and volume of the shop. Amount of pairs of shoes repaired on a measurement day ranged from 1 to 111 (average: 30) in group 1 and from 1 to 86 (average: 24) in group 2.

Scatter plots of the exposure data are presented in Figure 1. The range of VOC scores was large

Table 1. Number of samples available for analysis

	Group 1	Group 2	
		Self-assessment measurements	Expert measurements
Data availability			
Samples sent/delivered	260	182	78
Unused/lost samples	31[a]	12	0
Incorrect use of sampler	1	3	0
Eligible for analysis	228 (88%)	167 (92%)	78 (100%)
Partitioning of measurements			
April	51 (22%)	35 (21%)	27 (35%)
May	61 (27%)	69 (41%)	25 (32%)
June	110 (48%)	63 (38%)	26 (33%)
July	6 (3%)	1 (0.6%)	0 (0%)

[a]One company (20 samples) stopped participation.

Table 2. Descriptive statistics of the study population

Parameter	Group 1	Group 2
Number of companies	12	13
Pairs of shoes repaired (AM; range)	30 (1–111)	24 (1–86)
Employees per shop		
1	2	5
2	6	5
⩾3	4	3
Volume of shop (m^3)		
<100	2	6
100–200	8	6
>200	2	1
General ventilation		
yes	4	2
no	8	11
Local exhaust ventilation		
Yes	9	9
No	3	4

(i.e. between 2 and 2609 mg m^{-3}) and data show substantial variability between-worker and within-worker. The mixed effects model estimates are shown in Table 3 for the 'self-assessment' (group 1) and 'expert' group (group 2). The latter comprised both the expert and self-assessment measurements in group 2. Analyses were based on log transformed data and model results are back transformed. Geometric mean exposure in the self-assessment group was larger as compared with that in the expert group, although the difference was not statistically significant. Adjustment for potential confounders did not modify the outcome of this analysis. Exposure variability appeared to be significantly different for the two groups; i.e. the most appropriate mixed effects model appeared to include heterogeneous within-worker and between-worker variability components for group level. The exposure variability was larger among workers in group 1. Differences between workers are in both groups the main source of exposure variability.

Our mixed-effects models, taking exposure determinants into account, yielded three significant predictors of exposure: i.e. an open door during measurements appeared to reduce exposure (by a factor of 0.83), whereas number of pairs of shoes repaired and number of colleagues working with solvents during the measurement day increased exposure (by a factor of 1.19 for each additional 10 pairs and a factor of 1.20, respectively). Inclusion of these parameters in the model did not modify the conclusion of heterogeneous components of variance. Adding these parameters reduced the variability between workers by 32% (group 1) and 19% (group 2), whereas within-worker variability did not change much (group 1: 8%; group 2: 9%). A time trend could not be detected in the overall dataset and also an interaction term for group and time period was not significant. Including autocorrelation in the error structure of either of the two groups did not significantly improve the fit of the model.

Comparison of 'expert' measurements and 'self-assessment' measurements among workers in group 2 indicates that geometric mean exposures are equal (25.7 and 26.0 mg m^{-3}, respectively). Moreover, pooling of components of variance did not significantly reduce the fit of the model. Hence, patterns of exposure variability are comparable for the 'self-assessment' and 'expert' measurements among workers in group 2 (data not shown).

Principal component (PC) analysis among 16 measured organic solvent levels showed that three PCs accounted for ~85% of the multiple correlations among the measured solvents (Table 4). The first PC was positively associated with toluene (eigenvector = 0.643) and acetone (eigenvector = 0.430); the second PC was negatively associated with toluene (eigenvector = −0.505) and positively with cyclohexane

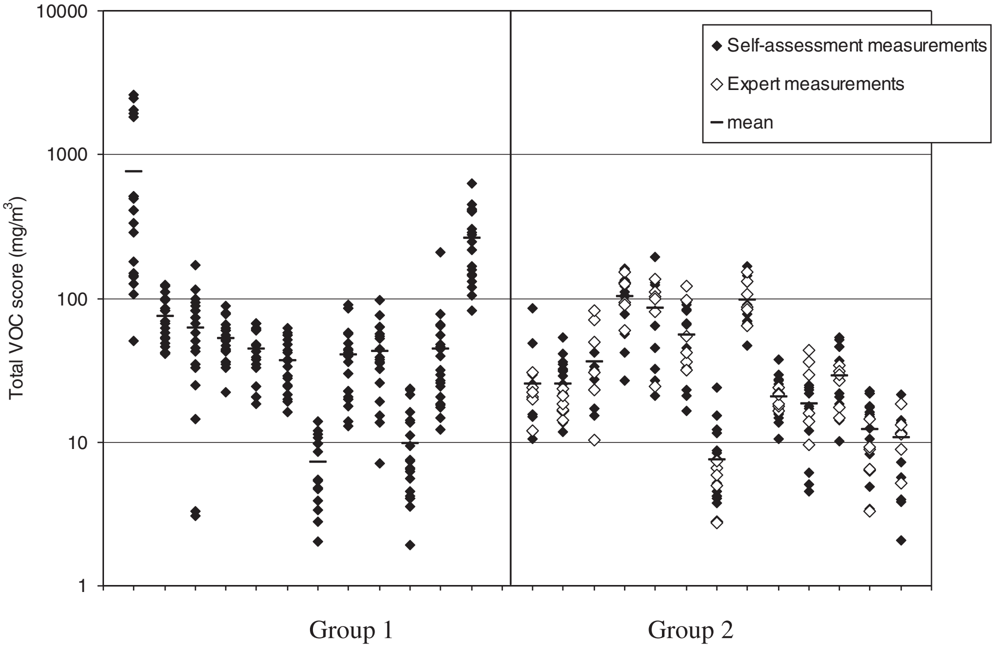

Fig. 1. Between-person and within-person exposure variability among group 1 and group 2.

Table 3. Restricted maximum likelihood estimates of geometric mean exposure to VOCs and exposure variability in group 1 and group 2

Group	Geometric mean exposure				Components of exposure variability		
	Estimate	Lower 95% CI	Upper 95% CI	t-test P-value	$\hat{\sigma}_B^2$	$\hat{\sigma}_W^2$	LR P-value
1	42.9	20.5	90.0		1.33	0.47	<0.0001
2	25.8	15.3	43.4	0.23	0.72	0.27	

$\hat{\sigma}_B^2$: Between person component of variance; $\hat{\sigma}_W^2$: Within person component of variance; LR: likelihood ratio.

(eigenvector = 0.592) and methyl ethyl ketone (eigenvector = 0.409); the third PC was positively associated with acetone (eigenvector = 0.619) and negatively with ethyl acetate (eigenvector = −0.595). Box plots show that PC scores do not differ to a large extent between workers in group 1 and 2 (Fig. 2).

DISCUSSION

Quantitative self-assessment is a relatively recent development and is the term used to describe an exposure assessment method where the worker performs at least the sampling himself. Research groups that have applied quantitative self-assessment approaches are not numerous (Loomis *et al.*, 1994; Saarinen *et al.*, 1998; Rappaport *et al.*, 1999; Tielemans *et al.*, 1999; Liljelind *et al.*, 2000, 2001; Egeghy *et al.*, 2002; Sunesson *et al.*, 2002). Results so far have been promising and suggest that it is feasible for workers to conduct exposure measurements themselves. Likewise, our study shows that workers are capable of conducting measurements in the absence of expert supervision. Only a small percentage of distributed samplers could, for various reasons, not be used in the data analysis.

On the other hand, planning of individual measurements over a longer time period seems to be a more difficult point in our self-assessment study. Participants were instructed to spread there measurements equally over a 3 month period. Yet, in group 1, most measurements were conducted in the last month, whereas partitioning of measurements was much better if experts were more closely involved in the exposure assessment process (group 2). Hence, the results indicate that an unrestricted SAE approach in which only written instruction is given is not feasible when a specific sampling regime and timing is desired. Some supervision of the exposure assessment process seems warranted in these cases. However, the inequality of measurements over the sampling period had no impact on the present exposure assessments, as no time trend or interaction between time and group could be detected.

The present study did not include an assessment of the ability of workers to reliably collect appropriate contextual information. However, all items in the

Table 4. Results of PCA of multiple correlations among personal exposures to organic solvents (transformed by the natural logarithm)

Organic compound	Eigenvector		
	PC1	PC2	PC3
Acetone	0.430	0.168	0.619
2-Propanol	0.197	−0.004	0.141
Methyl ethyl ketone	0.181	0.409	0.254
Methylmetacrylate	0.060	0.015	0.017
Ethyl acetate	0.146	0.325	−0.595
Hexane	0.202	0.275	−0.101
N-butanol	0.003	−0.009	0.013
Cyclohexane	0.143	0.592	−0.235
Methyl isobutyl ketone	−0.005	−0.005	−0.004
Toluene	0.643	−0.505	−0.310
N-butylacetate	0.033	0.005	0.070
Ethyl benzene	0.195	−0.059	−0.033
Cyclohexanone	−0.005	−0.004	−0.004
Diacetonalcohol	0.099	−0.075	0.104
Naphtha	0.312	0.076	0.004
Xylene	0.314	−0.046	−0.025
Eigenvalue (variance explained)	11.4 (53.3%)	5.2 (24.5%)	1.6 (7.4%)

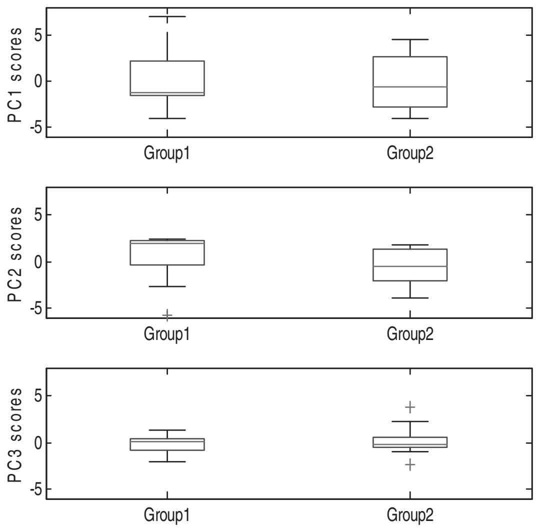

Fig. 2. Box plots of principal components for group 1 and group 2.

self-administered questionnaire were filled in by the participants and the questionnaire appeared to have no impact on the willingness to participate in the study. Several parameters collected in the questionnaire appeared to be significantly related with exposure levels, implicitly suggesting that questionnaires were filled in appropriately by the workers.

The results of the study indicate that no statistically significant differences exist in estimates of central tendency (geometric mean exposure), whereas exposure variability is not homogeneous for both groups. The between-worker and within-worker components of variability were larger in group 1 as compared with those in group 2. Hence, exposure variability was larger among workers receiving no expert supervision during the exposure assessment process. This observed difference may be due to several reasons. This may be a random effect due to small sample size. The overall number of exposure measurements is rather large but represents only 25 shoe repair shops. Adjustment for potential confounders reduced the differences in exposure variability between group 1 and 2 to some extent. It cannot be ruled out that residual confounding due to unknown determinants is responsible for the remaining differences in exposure variability between both groups.

Discrepancies in exposure variability patterns may also be due to self-assessment bias in group 1 or, alternatively, due to the fact that workers in group 2 depart from their normal behaviour while they are observed by an expert (Goldenhar and Schulte, 1994). However, internal analysis specifically focusing on data from group 2 did not reveal any differences in exposure pattern between 'expert' and 'self-assessment' measurements. The latter observation is reassuring and suggests that a self-assessment strategy as applied in this study produces unbiased results. This heterogeneity in study results makes it difficult to draw firm conclusions with respect to reliability of self-assessment as applied in this study. More research on this topic should be conducted to increase the current state of knowledge on reliability of SAE and required boundary conditions.

In each company, only the worker was selected who conducted most of the gluing activities. This probably resulted in overall biased exposure assessments, in that estimates of central tendency may be increased and exposure variability decreased due to overrepresentation of 'highly' exposed workers. However, it is very unlikely that this bias interfered with the comparison of self-assessment strategies, since selection of workers was done in a comparable manner for both groups.

We used principal component analyses to evaluate whether different solvents were used among group 1 and group 2. Results of the PCA indicate that workers in group 1 and group 2 are exposed to the same combination of solvents. Hence, the self-assessment regime has no impact on the type of product used by the worker during the measurement period.

Like others (Liljelind *et al.*, 2001; Eriksson *et al.*, 2005), we envisage that SAE is an important new development in modern occupational hygiene. Monetary costs are substantially reduced in self-assessment studies so that larger sample sizes can be obtained as compared with traditional approaches. This cost-effectiveness facilitates exposure measurements to be collected over long time periods and to conduct multiple measurements per worker. These features are prerequisites for testing compliance with regulatory exposure limits (Rappaport *et al*., 1995) or for determination of exposure estimates in epidemiological studies (Tielemans *et al*., 1998; Loomis and Kromhout, 2004). Moreover, self-assessments may be very suitable for hazard surveillance programmes, since these approaches enable the coverage of a broad range of workplaces including SMEs.

The introduction of self-assessment techniques may change the occupational hygiene profession, in that the focus shifts from actual collection of data to interpretation of data and making decisions on appropriate interventions. This less hands-on role of occupational hygienists seems to be a logical development that enables more involvement of professionals in the more complex risk assessment and management problems. Nonetheless, more research is warranted in the area of SAE. First, continued development of user-friendly equipment and the assessment of its suitability to quantitative self-assessment are needed. In this context, recent advances in the development of passive dust samplers are very promising (Vinzents, 1996). We are currently exploring the possibilities of this passive dust sampler in self-assessment studies among workers in the woodworking and bakery industry. Second, psychosocial elements in self-assessment studies need more attention, focusing on how to optimize company and worker involvement in exposure-assessment processes. Advances in these areas will certainly improve the feasibility of self-assessment studies in the future.

In conclusion, our study shows that it is feasible to conduct measurements in the absence of expert supervision, although some expert guidance seems necessary when timing of measurements over a defined period is important. The results of the present study are ambiguous with respect to reliability of SAE. More research is needed to corroborate and refine the present results.

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