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CORRELATION BETWEEN DIFFERENT MEASURES OF EXPOSURE IN A COHORT OF BAKERY WORKERS AND FLOUR MILLERS

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Abstract—This paper describes the relationship between continuous and ‘grouped’ variables for several measures of exposure in a longitudinal study of bakery workers and flour millers. Average shift and peak levels, both for dust and for flour aeroallergen were measured, duration of exposure obtained from questionnaire and cumulative exposure both for dust and for flour aeroallergen calculated. Neither for dust nor for flour aeroallergen was there a correlation between duration of exposure and intensity measures of exposure (peak and average). Moderate to good correlation existed between the various intensity measures of exposures both for dust and for flour aeroallergen. Good correlations existed between measures of exposure of dust and measures of exposure for flour aeroallergen. The degree of correlation was reflected by the fact that the number of workers changing categories depended on which measure of exposure was considered. The higher the correlation coefficient between various measures of exposure the fewer workers changed category. This information provides important information for a better understanding of the exposure–response relationship amongst bakery workers and flour millers.

INTRODUCTION

Exposure assessment for occupational epidemiological studies is becoming more refined. The use of quantitative measures of exposure has become more common (Love *et al.*, 1988; Huy *et al.*, 1991; Smid *et al.*, 1992; Wegman *et al.*, 1992; Gardiner *et al.*, 1993; Halpin *et al.*, 1994), partly because they allow a more elaborate exploration of the relationship between exposure and response. In general, the use of quantitative measures of exposure might lead to an increase in accuracy and precision resulting in a better estimation of risk (Blair and Stewart, 1992).

Occupational asthma, and bakers’ asthma in particular, is a common disease (Meredith *et al.*, 1991), but little is known about the intensity, duration and pattern of exposure related to its development. Therefore it might be necessary to obtain several quantitative measures of exposure such as duration of exposure, average concentration of exposure, peak exposure and cumulative exposure to explore exposure response relationships: the measures must be unrelated since otherwise they cannot be evaluated independently of each other. Few papers have reported correlation coefficients between different measures of exposure (Blair and Stewart, 1990; Armstrong *et al.*, 1990).

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We have carried out a longitudinal cohort study, with an extensive exposure assessment programme, of bakers and flour millers. The exposure assessment provided estimates of average shift exposure (Nieuwenhuijsen, 1993; Nieuwenhuijsen *et al.*, 1994) and of peak exposure (Nieuwenhuijsen *et al.*, 1995) for dust and flour aeroallergen for the subjects in the study. The first description of the relationship between exposure and response using full time-average concentrations of dust and flour aeroallergen has been reported elsewhere (Cullinan *et al.*, 1994). The prevalence of work-related symptoms and of positive skin-prick test responses increased with an increase in exposure. In this paper we describe the relationship between continuous and 'grouped' variables for full time dust and flour aeroallergen concentrations and for several other measures of exposure for this population.

METHOD

Exposure assessment

Detailed descriptions of the sites, exposure groups and exposure assessment have been reported elsewhere (Nieuwenhuijsen, 1993). Briefly, we surveyed three large modern British bakeries (between 200 and 450 employees each), three flour mills with flour-packing stations (60–200 employees each) and a flour-packing station (30 employees). Workers who started working at the sites for the first time after 1 January 1986 were included in the cohort. Workers with previous exposure to flour at other sites were excluded from the cohort analyses (Cullinan *et al.*, 1994). This left 265 workers, seen in 1990 and eligible for analysis in this paper. An occupational hygienist (M. J. Nieuwenhuijsen) visited each site and divided the employees into exposure groups, 11 in each flour mill and packing station and 15 in each bakery (Nieuwenhuijsen *et al.*, 1994). Three hygienists identified tasks that could lead to high exposure (Nieuwenhuijsen *et al.*, 1995). Workers in each exposure group and workers performing the identified tasks wore personal samplers (Casella AFC123, Casella London Ltd, Bedford, U.K.) sampling at 2 l. min^{-1} and connected to seven-hole sampling heads (Casella London Ltd, Bedford, U.K.) containing polytetrafluoroethylene (PTFE) filters ($1.2\text{ }\mu\text{m}$ pore size, 25 mm dia.; Sartorius Instruments Ltd, GB-Belmont, Surrey, U.K.). The filters were weighed before and after sampling to determine the dust concentration and were subsequently analysed in the laboratory for flour aeroallergen using the method described by Sandiford *et al.* (1994). The averages of the full-time and task measurements were assigned to every member in the exposure groups.

Measures of exposures

In this way four measures of intensity of exposure were obtained: estimates of average full-time dust and of average full-time flour aeroallergen and of task dust and of task flour aeroallergen (Table 1). Duration of exposure was obtained from work history questionnaires. Cumulative exposure was estimated by multiplying average full-time exposure estimates by duration of exposure (Table 1). Characteristics of the measures of exposure are given in Table 2.

Statistics

Descriptive statistics and correlation analysis were carried out using the statistical software package SAS (SAS Institute Inc., Cary, North Carolina, U.S.A.).

Table 1. Definitions of measures of exposure for occupational exposure to flour in bakeries, flour mills and packing stations

Exposure measures	Definition
Exposure duration	Length of exposure (month) in exposure groups with flour exposure
Average dust exposure	Average level of dust exposure for exposure groups over a workshift
Average allergen exposure	Average level of flour aeroallergen exposure for exposure groups over a workshift
Cumulative dust exposure	Sum of the products of average level of dust exposure for each exposure group multiplied by the length of time working in that exposure group
Cumulative allergen exposure	Sum of the products of average level of flour aeroallergen exposure for each exposure group multiplied by the length of time working in that exposure group
Dust peak exposure	Highest exposed task to dust within an exposure group
Allergen peak exposure	Highest exposed task to flour aeroallergen within an exposure group

Table 2. Characteristics of the measures of exposure

	Median	Minimum	Maximum
Employment duration (month)	26.0	1.0	70.0
Average dust level (mg m^{-3})	1.6	0.4	16.9
Average allergen level ($\mu\text{g m}^{-3}$)	169.8	45.5	1899.0
Cumulative dust level ($\text{mg} \cdot \text{month m}^{-3}$)	40.2	0.9	2119.0
Cumulative allergen level ($\mu\text{g} \cdot \text{month mm}^{-3}$)	5307.0	170.5	169 937.0
Peak dust level (mg m^{-3})	8.6	0.5	97.2
Peak allergen level ($\mu\text{g m}^{-3}$)	163.1	18.6	3808.0

RESULTS

Spearman correlation coefficients between the various measures of exposure are given in Table 3. Spearman correlation coefficients were used because the measures of exposure did not have a normal distribution and for our first analysis (Cullinan *et al.*, 1994) workers were ranked on exposure and the ranking then divided into three groups with equal numbers of workers. There was no correlation between exposure duration and the measured intensity of exposure (peak and average levels). Good correlation existed between average dust and average allergen levels, and between peak dust and peak allergen levels. Moderate correlation existed between the other measures of exposure except for both peak levels the correlations with the cumulative exposures were weak.

Pearson correlation coefficients were similar (less than 0.1 difference) except between peak dust levels and average dust, average allergen and cumulative dust, for which the coefficients were 0.34, 0.35 and 0.28, respectively. Also the Pearson correlation coefficients between duration of exposure and cumulative dust and average allergen exposure (both 0.43) and between peak allergen and average dust and peak dust concentrations (respectively, 0.56 and 0.70) were lower.

Exposure categories were formed by ranking workers on exposure for the various measures of exposure and subsequently dividing them into three groups with similar numbers of workers. The only exception was the average dust concentration, which was divided on the basis of contrast in dust exposure (Cullinan *et al.*, 1994) and is in this

Table 3. Spearman correlation coefficients (*r*) between various measures of flour exposure in a population with occupational exposure to flour in bakeries, flour mills and flour packing stations

	Average dust level	Average allergen level	Cumulative dust exposure	Cumulative allergen exposure	Peak dust exposure	Peak allergen exposure
Exposure duration	0.05	0.07	0.59	0.64	-0.05	-0.07
Average dust level		0.86	0.73	0.60	0.73	0.73
Average allergen level			0.68	0.65	0.57	0.66
Cumulative dust exposure				0.93	0.46	0.49
Cumulative allergen exposure					0.39	0.47
Peak dust exposure						0.87

paper referred to as average dust concentration (1). Cut-offs for the various categories of exposure are given in Table 4. Table 5 shows a frequency table with the number of workers in the dust categories (1) against the number of workers in the allergen categories. The categories in which 53 workers (20.7%) fall depends on whether

Table 4. Cut-off for the categorization of measures of exposure

	Low	Medium	High
Employment duration (month)	≤ 17	$> 17-36$	> 36
Average dust level (mg m^{-3})	(1) < 1 (2) ≤ 0.7	$1-5$ $> 0.7-1.8$	> 5 > 1.8
Average allergen level ($\mu\text{g m}^{-3}$)	≤ 100.9	$101-215.3$	> 215.3
Cumulative dust level ($\text{mg} \cdot \text{month m}^{-3}$)	≤ 25.4	$> 25.4-73.5$	> 73.5
Cumulative allergen level ($\mu\text{g} \cdot \text{month mm}^{-3}$)	≤ 3186	$> 3186-8120.6$	> 8120.6
Peak dust level (mg m^{-3})	≤ 1.4	$> 1.4-\leq 12.9$	> 12.9
Peak allergen level ($\mu\text{g m}^{-3}$)	≤ 96	$> 96-415.9$	> 415.9

Table 5. Frequencies, row and column percentages for the dust category against the flour aeroallergen categories

Frequency Row pct Col pct	Flour aeroallergen categories			Total
	Low	Medium	High	
Dust categories (1)				
Low	90 86.54 100.00	14 13.46 16.87	0 0.00 0.00	104
Medium	0 0.00 0.00	60 66.67 72.29	30 33.33 36.14	90
High	0 0.00 0.00	9 14.52 10.84	53 85.48 63.86	62
Total	90	83	83	256

Row pct = row percentage.

Col pct = column percentage.

average allergen or average dust exposure is considered. Table 6 shows the percentage of workers that change category depending on which measure of exposure is looked at. Only a few workers (4.3%) change category between peak allergen and peak dust categories, but more than 50% change category between exposure duration and the intensity measures of exposure (peak and average concentrations of dust and allergen).

Figure 1 shows a plot of the Spearman correlation coefficient, taken from Table 3, against the percentage of workers changing category, taken from Table 6. The higher the correlation coefficient the fewer workers change category.

DISCUSSION

This paper has reported relationships between various measures of exposure in an epidemiological study of bakery workers and flour millers. There was no correlation between duration of exposure and measures of intensity of exposure (peak and average) either for dust or for allergen, but for both of these there was moderate to good correlation between the various measures of intensity of exposure. Good correlations existed both between the various measures of exposure to dust and between the measures of exposure to allergen. The degree of correlation was reflected in the number of workers for whom the category into which they fell depended on which measure of exposure was looked at. The higher the correlation coefficient between various measures of exposure the fewer workers changed category.

Although correlation between measures of exposure could provide important information for the design and analysis of epidemiological studies only a few reports have been published. This is in part due to the lack of exposure data in many studies, and where there is information it is limited to only one or only a few indices. Two previous studies have reported on correlation between various measures of exposure. Blair and Stewart (1990) found that measures of duration (employment and exposure) were highly correlated in a large cohort study of workers exposed to formaldehyde. Also average exposure and highest 8-h time-weighted average exposure were highly correlated.

Moderate correlations were seen between cumulative exposure and either average exposure, or highest 8-h time-weighted average exposure, or duration of exposure, between average exposure and peak exposure, and between highest job exposure and peak exposure. Average exposure showed little correlation with duration of exposure, duration of employment or peak exposure. The degree of similarity of these estimates of exposure varied between the different plants. Armstrong *et al.* (1990) found good correlations between time-weighted arithmetic means and indices that explicitly emphasize short but highly intense exposures, such as peak values and time above thresholds among electrical utility workers. Correlations between electric-field strength and magnetic-field strength density were generally quite weak as were correlations of either with high-frequency transients.

In the first analyses of the epidemiological study we reported an increase of the prevalence of work-related symptoms and sensitization with an increase in average exposure over shift for both allergen and dust exposure. Since there is a moderate to good correlation between these two measures and peak and cumulative exposure measures it is hard to demonstrate an independent effect of any of them. An increase in health outcome with increasing average exposure might be caused by the peak

Table 6. Percentage (%) of the workers that changes exposure category when different measures of exposure are used in a population with occupational exposure to flour in bakeries, flour mills and flour packing stations

	Average dust level (1)	Average dust level (2)	Average allergen level	Cumulative dust exposure	Cumulative allergen exposure	Peak dust exposure	Peak allergen exposure
Exposure duration	63.4	59.8	63.8	42.6	36.7	63.4	64.0
Average dust level (2)		25.6	30.3	32.3	40.1	38.6	43.1
Average dust level (1)			20.7	39.2	47.5	35.2	33.3
Average allergen level				40.8	45.1	34.0	29.4
Cumulative dust exposure					21.4	43.9	44.1
Cumulative allergen exposure						47.8	46.9
Peak dust exposure							4.3

Average dust level (1) = after Cullinan *et al.* (1994).

Average dust level (2) = tertiles based on ranked exposure.

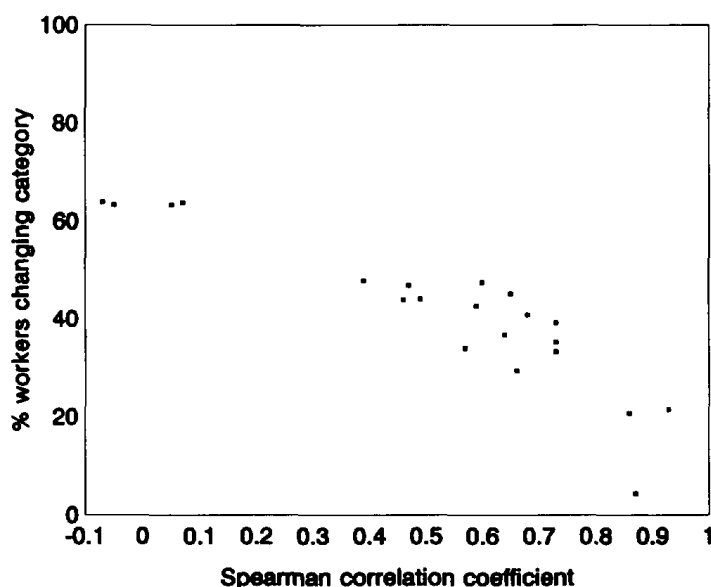


Fig. 1. Plot of the percentage of workers that change categories against the Spearman correlation coefficient.

exposure which correlates with average exposure. Duration of exposure was not correlated with intensity of exposure and independent effects can be established. Duration of exposure was moderately correlated with cumulative exposure both for allergen and for dust. This might be due to the fact that cumulative exposure is a product of duration of exposure and average exposure with the former the driving force.

The analysis of correlation between different measures of exposure is important for a better understanding of exposure-response relationships. It provides information for data analysis and in relation to its limitations and strengths. It provides a stronger scientific base from which to draw the right conclusions of what causes the health effect. Many epidemiological studies have no measure of exposure, or only one. In a time where more and more the health effects of exposures are weak more refined exposure assessments with various quantitative measures of exposure are necessary.

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