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GROUPING STRATEGIES FOR EXPOSURE TO INHALABLE DUST, WHEAT ALLERGENS AND α -AMYLASE ALLERGENS IN BAKERIES

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Abstract—This paper describes repeated measurements of inhalable flour dust, wheat allergens and α -amylase allergens in the bakery industry. A total of 571 full-shift personal dust samples was collected. Wheat allergens and α -amylase allergens were measured in 449 and 507 samples, respectively, by the use of recently developed immunoassays. For all three measures of exposure, the main components of exposure variability were determined. Different grouping strategies for studying exposure–response relationships were compared. The specific job of a bakery worker was identified as the most important source of variability in inhalable flour dust concentrations. For exposure to wheat allergens, the job performed was also the most important source of variation, but type of bakery also explained some of the variability. For α -amylase allergen exposure, information on type of bakery was more important than job information. For exposure to inhalable dust and wheat allergens, a classification by job title would lead to sufficient contrast in average exposure levels. By contrast, a grouping strategy based on a combination of job and type of bakery appeared to be essential to obtain a useful classification of exposure to α -amylase allergens. © 1997 British Occupational Hygiene Society. Published by Elsevier Science Ltd

INTRODUCTION

The inhalation of cereal dusts and powdered baking additives may cause immunological sensitization and respiratory symptoms in bakers. It is clear that both host factors (atopy) and environmental factors (exposure) are important determinants of respiratory symptoms. Many epidemiological studies in the bakery industry have focused on host factors only (Järvinen *et al.*, 1979; Prichard *et al.*, 1984; Rosenberg *et al.*, 1991; De Zotti *et al.*, 1994). Recently conducted studies have attempted to relate dust or allergen exposure levels to specific sensitization, and respiratory symptoms (Hartmann, 1986; Musk *et al.*, 1989; Cullinan *et al.*, 1994) but very little is known about the levels of flour dust or specific allergen exposure that can cause allergic sensitization or lead to the development of respiratory symptoms.

The limited understanding of dose–response relationships in baker's allergy has two reasons. First, information on levels of exposure to inhalable dust or specific allergens is limited. In only a few studies have exposure data of inhalable dust been presented (Musk *et al.*, 1989; Lillienberg and Brisman, 1994; Nieuwenhuijsen *et al.*, 1994). Methods for quantifying personal allergen exposure levels in the baking

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industry have only recently been developed for wheat flour (Sandiford *et al.*, 1994; Houba *et al.*, 1996a) and fungal α -amylase (Houba *et al.*, 1996b). Second, in few studies was the exposure assessment strategy designed with the aim of studying exposure-response relationships. For studying such relationships, bakery workers have to be categorized into exposure groups in such a way that, within each group, workers are more or less 'uniformly' or 'homogeneously' exposed (Hawkins *et al.*, 1991; Rappaport, 1991). Moreover, contrast in exposure level between exposure groups is a prerequisite for detecting an exposure-response relationship (Prais and Aitchinson, 1954; Kromhout and Heederik, 1995). Large between-worker variation within exposure groups may bias the exposure-response relationship (Heederik and Miller, 1988; Armstrong *et al.*, 1992). For designing an optimal grouping strategy, components of exposure variability have to be determined. The relevant sources of variability of exposure can be studied when repeated measurements on individuals are available (Boleij *et al.*, 1995).

To date, only two studies have performed repeated measurements of flour dust of bakery workers (Burdorf *et al.*, 1994; Nieuwenhuijsen *et al.*, 1995). In both studies, the authors have classified workers into exposure groups based on estimated components of exposure variability in dust exposure. However, studying exposure-response relationships in the bakery industry based on dust exposure levels, has an important disadvantage. Dust levels may have only a moderate correlation with actual allergen concentrations (Houba *et al.*, 1996a,b), and it is questionable whether dust levels are a valid exposure measure in occupations where IgE-mediated allergies are being studied. Sources of variation of exposure to specific allergens may be different from variance components of dust exposure and as a result, optimal grouping strategies for allergen exposure may be different. Until now, however, repeated measurements of allergen exposure in the bakery industry have not been published and consequently, grouping strategies for allergen exposure (in particular wheat flour and α -amylase) have not been studied.

This paper describes results of analyses of variance of exposure to inhalable flour dust, wheat allergens, and fungal α -amylase allergens in the bakery industry. For each measure of exposure, some alternative grouping strategies will be compared. Differences in optimal grouping strategies for inhalable dust and both types of allergens are discussed.

METHODS

Sampling methods and strategy

Exposure levels were measured in five large industrialized and 16 small bakeries. Most of the large bakeries had several independent sections with autonomous production lines. In the analyses, each department was considered to be a separate bakery. Four types of large bakeries were distinguished with regard to the type of product: wheat bread production ($N=4$), production of confectionery ($N=4$), production of crispbakes or Dutch toast ($N=1$), and rye bread production ($N=1$). Workers of the large industrialized bakeries could be divided into six occupational groups according to job description, namely (1) doughmakers, (2) all-round staff, (3) oven staff, (4) slicers, packers and transport workers, (5) production managers, and

(6) maintenance and cleaning workers. Bakers in the 16 small bakeries were divided into three occupational groups according to whether they produced bread, pastry, or a mixture of the two. Within each occupational title, randomly selected bakers were asked to carry a personal air sampler. Participation was on a voluntary basis, but most of the bakery workers cooperated. In total, 230 workers in the bakeries were measured on 571 occasions during full-shifts. Most of the workers were measured on more than one occasion (with a maximum of six measurements per worker). However, for some workers only one measurement was available.

In all bakeries, personal dust samples were collected in the workers' breathing zone during full-shift periods of 6–8 h, using polytetrafluoroethylene (Teflon) filters (Millipore; pore size $1.0\ \mu\text{m}$) and inhalable dust (PAS-6) sampling heads at a flow rate of $2\ \text{l. min}^{-1}$ (ter Kuile, 1984). The PAS-6 sampler was recently assessed as accurate for exposure to inhalable dust in indoor situations with low wind speed (Kenny *et al.*, 1997). After sampling, filters were weighed in a preconditioned room of $18\text{--}22^\circ\text{C}$ with 45–55% humidity. Detection limit of this method was $0.17\ \text{mg m}^{-3}$, computed by dividing the mean + 3SD ($3\times$ standard deviations) of 24 blanks by the mean sampled volume. Forty-four dust samples (8%) were below the detection limit. Wheat flour and α -amylase allergens were recovered from the filters by extraction with 2.5 ml phosphate buffered saline, and the allergen concentrations were measured by inhibition enzyme immunoassay (EIA) for wheat flour (Houba *et al.*, 1996a), or sandwich EIA for fungal α -amylase (Houba *et al.*, 1996b). The assay for the measurement of wheat allergens had a reproducibility of 19.5%, and the detection limit for personal wheat allergen measurement was $50\ \text{ng m}^{-3}$. Seventy samples (16%) were below the detection limit. The detection limit for personal α -amylase allergen measurement was much lower ($0.25\ \text{ng m}^{-3}$), but 82% of all samples were below this limit. The reproducibility of the α -amylase assay was 22%, based on the duplicate analysis of 70 samples with detectable concentrations of α -amylase. In the analyses, values below the detection limit were considered as being two-thirds of this limit, as described by Helsel (1990).

Statistical analyses

All statistical analyses were performed using SAS software (version 6.09). For descriptive analyses PROC MEANS and PROC UNIVARIATE were used. Statistical analyses to estimate variance components were performed using PROC NESTED. Groups, workers within those groups, and their subsequent measurement periods were assumed to be selected at random and so random effect models were used. The structure of the exposure data was regarded as hierarchical (nested) (Samuels *et al.*, 1985). A one-way nested random effects ANOVA model was used to estimate the within-worker variance component (σ_{ww}^2) and the between-worker variance component (σ_{bw}^2), both for the total population and for each group separately. The estimates of variance components σ_{ww}^2 and σ_{bw}^2 will be designated as S_{ww}^2 and S_{bw}^2 , respectively, and were used to calculate the $\text{GSD}_{\text{ww}}[\exp(S_{\text{ww}})]$ and the $\text{GSD}_{\text{bw}}[\exp(S_{\text{bw}})]$. The variance components were also used for the calculation of the estimated within-worker to between-worker variance ratio: $\hat{\lambda} = S_{\text{ww}}^2/S_{\text{bw}}^2$ (Heederik *et al.*, 1991a), and the ratios of the 97.5th and 2.5th percentiles of the log-normally distributed exposures of each group of workers: ${}_{\text{bw}}R_{0.95} = \exp(3.92 \cdot S_{\text{bw}})$ (Rappaport, 1991). Both statistics ($\hat{\lambda}$ and ${}_{\text{bw}}R_{0.95}$) were used to evaluate the homogeneity of

exposure within occupational titles. A two-way nested random-effects ANOVA model was applied to estimate a between-group variance component (σ_{bg}^2), a within-group variance component (σ_{wg}^2) and a within-worker variance component (σ_{ww}^2) for different grouping schemes (Kromhout and Heederik, 1995). The estimates of the variance components σ_{bg}^2 , σ_{wg}^2 and σ_{ww}^2 will be designated as S_{bg}^2 , S_{wg}^2 and S_{ww}^2 , respectively. Using these variance components, the elasticity was calculated as a measure of contrast in exposure level between groups: $\text{elasticity} = S_{bg}^2 / (S_{bg}^2 + S_{wg}^2)$ (Kromhout and Heederik, 1995). The data used in the analysis of variance were the log-transformed estimates of inhalable dust and allergen exposure.

RESULTS

A total of 571 personal dust samples was collected. Wheat allergens and α -amylase allergens were measured in 449 and 507 samples respectively. Descriptive statistics and results of the one-way analyses of variance are presented in Tables 1, 2, and 3, for exposure to inhalable dust, wheat allergens and α -amylase allergens, respectively. In each table, exposure data are presented for the total population and for each of the 22 occupational titles separately. The definition of occupational title is based on job of the bakery worker and type of bakery where he or she is employed. For inhalable dust and wheat allergen exposure, the exposure data followed a log-normal distribution for nearly all occupational titles. For α -amylase allergen, however, a log-normal distribution of exposure data was only found in a few occupational titles. In most groups the exposure data were not log-normally distributed due to the high number of samples without detectable levels of α -amylase allergens.

For inhalable flour dust, the highest dust concentrations were found for doughmakers in large industrialized bakeries and for bakers involved in bread production in the small bakeries, and to a lesser extend for the all-round staff of the large bakeries. Overall, the between-worker exposure variability was greater than the within-worker variability ($\hat{\lambda} = 0.58$). After grouping, the within-worker variation appeared to be larger than the between-worker variation for 14 of the 22 occupational titles. For each group, the between-worker exposure variability was considerably lower compared with the whole population. For some groups, the number of samples was very small, and for these groups, no variance components were estimated. With the exception of doughmakers, only small differences in inhalable dust levels were found between several types of bakeries.

For wheat allergen exposure a similar pattern was found. For the total population the between-worker variability was large and was substantially lower for each occupational title separately. An important difference with inhalable dust exposure levels was that differences between bakery types within each job were larger. In each type of bakery, the proportion of the dust consisting of wheat flour was different, due to the use of ingredients other than wheat flour (Houba *et al.*, 1996a). Compared with dust exposure, the $_{bw}R_{0.95}$ of the total group of bakery workers was much higher (1578 vs 34).

For α -amylase allergen exposure the picture was remarkably different. For several occupational titles, all samples were below the detection limit. In fact, α -amylase exposure was limited to bakers involved in dough production in some types

Table 1. Characteristics of inhalable flour dust exposure by job and type of bakery

Occupational title	<i>N</i>	<i>k</i>	AM	GM	GSD _{bw}	GSD _{ww}	$\hat{\lambda}$	_{bw} <i>R</i> _{0.95}
Overall	571	230	2.0	1.0	2.5	2.0	0.6	34.2
<i>Large industrialized bakeries</i>								
Doughmakers								
Bread bakeries	37	15	6.8	4.5	2.1	1.7	0.5	18.2
Confectioneries	40	18	2.8	2.2	1.5	1.8	2.5	4.5
Crispbakes factory	40	16	3.2	2.8	1.3	1.5	2.2	3.1
Rye bread bakery*	7	3	1.0	0.9				
All-round staff								
Bread bakeries	37	16	1.4	0.9	2.0	2.3	1.5	13.8
Confectioneries*	4	2	7.5	1.2				
Crispbakes factory	29	12	1.3	1.1	1.2	1.8	16.8	1.8
Oven staff								
Bread bakeries	34	17	1.0	0.7	2.1	2.0	0.9	17.4
Confectioneries	21	10	0.9	0.6	1.0	2.4	∞	1.0
Crispbakes factory	24	11	0.8	0.7	1.4	1.4	0.7	4.2
Rye bread bakery*	5	3	0.4	0.4				
Slicers, packers, transport								
Bread bakeries	66	28	0.5	0.3	1.6	2.3	3.0	6.3
Confectioneries	26	11	0.5	0.4	1.6	2.1	2.6	5.8
Crispbakes factory	22	11	0.8	0.8	1.0	1.3	∞	1.0
Rye bread bakery	17	9	0.5	0.5	1.2	1.6	4.4	2.3
Production managers								
Bread bakeries	13	6	1.3	0.7	1.0	3.7	∞	1.0
Confectioneries*	3	1	0.5	0.5				
Crispbakes factory*	4	2	0.7	0.6				
Maintenance & cleaning workers								
	27	9	0.9	0.7	1.0	2.1	∞	1.0
<i>Small traditional bakeries</i>								
Bread bakers	36	18	3.8	3.3	1.6	1.3	0.5	5.7
Mixed bakers	57	27	2.7	2.0	1.9	1.8	0.8	11.3
Pastry cooks	22	9	1.0	0.7	1.0	2.3	∞	1.0

N, number of measurements in a group; *k*, number of workers in a group; AM, arithmetic mean (mg m^{-3}); GM, geometric mean (mg m^{-3}); GSD_{bw}, between-worker geometric standard deviation; GSD_{ww}, within-worker geometric standard deviation; $\hat{\lambda}$, variance ratio of within- and between-worker variance ($= \sigma_{ww}^2 / \sigma_{bw}^2$); _{bw}*R*_{0.95}, ratio of the 97.5th and 2.5th percentiles of the between-worker distribution.

*The number of samples was too small to estimate variance components.

of bakeries (bread production and production of crispbakes). Between those groups, however, large differences in α -amylase allergen exposure were found. Allergen exposure in the crispbakes factory was much higher compared with bread producing bakeries. The α -amylase exposure in large bread-producing bakeries was considerably higher compared with bread bakers in the small traditional bakeries. For most occupational titles, the between-worker variation was smaller compared with the whole population, which implies that the occupational title mean exposures were an acceptable exposure estimate for each member of that group. An exception was the group of doughmakers from the bread factories, where a high between-worker variation was found.

In Table 4 three alternative grouping strategies were compared for each measure of exposure. For each grouping strategy, the total variability of exposure was

Table 2. Characteristics of wheat allergen exposure by job and type of bakery

Occupational title	<i>N</i>	<i>k</i>	AM	GM	GSD _{bw}	GSD _{ww}	$\hat{\lambda}$	_{bw} <i>R</i> _{0.95}
Overall	449	206	5360	684	6.5	3.1	0.4	1578
<i>Large industrialized bakeries</i>								
Doughmakers								
Bread bakeries	32	14	35068	16 511	2.7	2.3	0.7	52.2
Confectioneries	25	13	3571	1969	2.8	2.4	0.7	59.6
Crispbakes factory	15	9	5853	5104	1.0	2.1	∞	1.0
Rye bread bakery*	4	2	503	364				
All-round staff								
Bread bakeries	35	16	4377	997	3.3	4.1	1.4	102
Confectioneries*	4	2	18 505	2487				
Crispbakes factory	16	9	2305	876	1.0	5.4	∞	1.0
Oven staff								
Bread bakeries	30	17	3653	771	6.4	2.6	0.3	1400
Confectioneries	21	10	720	302	1.6	4.6	10.4	6.5
Crispbakes factory	15	8	152	128	1.5	1.6	1.1	5.0
Rye bread bakery*	5	3	37	36				
Slicers, packers, transport								
Bread bakeries	56	26	173	74	2.2	2.3	1.1	21.2
Confectioneries	22	9	102	62	1.7	2.1	1.9	7.6
Crispbakes factory	17	10	599	150	1.0	4.4	∞	1.0
Rye bread bakery	13	9	40	38	1.0	1.4	∞	1.0
Production managers								
Bread bakeries	13	6	7745	859	2.4	7.2	5.0	31.5
Confectioneries*	3	1	79	60				
Crispbakes factory*	1	1	304	304				
Maintenance & cleaning workers								
	20	8	528	242	1.3	3.8	28.5	2.7
<i>Small traditional bakeries</i>								
Bread bakers	31	17	8687	5989	2.0	1.7	0.6	14.6
Mixed bakers	55	26	5298	2729	2.1	2.3	1.3	17.4
Pastry cooks	16	7	1183	614	2.4	3.4	1.9	32.9

N, number of measurements in a group; *k*, number of workers in a group; AM, arithmetic mean (ng m⁻³); GM, geometric mean (ng m⁻³); GSD_{bw}, between-worker geometric standard deviation; GSD_{ww}, within-worker geometric standard deviation; $\hat{\lambda}$, variance ratio of within- and between-worker variance ($=\sigma_{ww}^2/\sigma_{bw}^2$); _{bw}*R*_{0.95}, ratio of the 97.5th and 2.5th percentiles of the between-worker distribution.

*The number of samples was too small to estimate variance components.

partitioned into a between-group component, a between-worker component, and a within-worker component. For inhalable dust and wheat allergens all available samples were used. For α -amylase, the analysis of variance was restricted to those occupational titles with detectable levels of α -amylase allergens. For inhalable dust exposure, the job of a bakery worker explained approximately 50% of the exposure variability. Grouping workers based on type of bakery was not meaningful for exposure to inhalable dust. For wheat allergen exposure, job was also the main explanatory variable, although bakery type also explained variability in wheat allergen exposure. However, the increase in contrast was limited when workers were grouped by the combination of job and type of bakery. In contrast, for exposure to α -amylase allergens type of bakery was the most important source of exposure variability.

Table 3. Characteristics of fungal α -amylase allergen exposure by job and type of bakery

Occupational title	N	k	AM	GM	GSD_{bw}	GSD_{ww}	$\hat{\lambda}$	$_{\text{bw}}R_{0.95}$
Overall	507	214	3.3	0.3	3.1	2.4	0.6	85.7
<i>Large industrialized bakeries</i>								
Doughmakers								
Bread bakeries	32	14	3.2	0.8	4.6	2.0	0.2	403
Confectioneries	32	16	all < detection limit					
Crispbakes factory	27	11	39.4	18.1	2.6	3.3	1.5	44.9
Rye bread bakery*	7	3	0.2	0.2				
All-round staff								
Bread bakeries	35	16	0.6	0.2	2.1	1.5	0.3	19.7
Confectioneries	4	2	all < detection limit					
Crispbakes factory	26	11	14.5	1.3	3.1	8.5	3.7	80.8
All other jobs in large bakeries	243	111	0.2	0.2	1.0	1.4	∞	1.0
<i>Small traditional bakeries</i>								
Bread bakers	31	17	0.8	0.3	2.4	2.1	0.8	29.3
Mixed bakers	54	26	0.3	0.2	1.0	1.9	∞	1.0
Pastry cooks	16	7	all < detection limit					

N, number of measurements in a group; *k*, number of workers in a group; AM, arithmetic mean (ng m⁻³); GM, geometric mean (ng m⁻³); GSD_{bw}, between-worker geometric standard deviation; GSD_{ww}, within-worker geometric standard deviation; $\hat{\lambda}$, variance ratio of within- and between-worker variance ($= \sigma_{ww}^2 / \sigma_{bw}^2$); _{bw}*R*_{0.95}, ratio of the 97.5th and 2.5th percentiles of the between-worker distribution.

*The number of samples was too small to estimate variance components.

Table 4. Between- and within-group exposure variability for several grouping schemes

Grouping variables	<i>g</i>	<i>k</i>	<i>S</i> _{bg} ²	<i>S</i> _{wg} ²	<i>S</i> _{ww} ²	Elasticity
<i>Flour dust exposure (N = 571)</i>						
Job	9	253	0.69	0.27	0.43	0.72
Type of bakery	4	230	0.02	0.79	0.48	0.03
Combination	22	253	0.67	0.22	0.43	0.75
<i>Wheat allergen exposure (N = 449)</i>						
Job	9	222	2.98	1.10	1.14	0.73
Type of bakery	4	206	0.88	2.99	1.26	0.23
Combination	22	222	3.11	0.73	1.14	0.81
<i>Fungal amylase exposure (N = 205)</i>						
Job	4	95	1.50	1.76	1.12	0.46
Type of bakery	2	85	3.92	1.41	1.06	0.73
Combination	6	95	2.53	0.77	1.12	0.77

g, number of groups; *k*, number of workers; *S*_{bg}², estimated variance component due to groups; *S*_{wg}², estimated variance component due to workers (between workers within groups); *S*_{ww}², estimated variance component due to days (between days within workers); elasticity, *S*_{bg}²/(*S*_{bg}² + *S*_{wg}²).

DISCUSSION

When studying the relationship between exposure and response, an accurate quantitative estimate of exposure is needed for each study subject. Basically, two quantitative exposure assessment strategies can be distinguished. First, each worker of the population under study can be measured repeatedly, and an average exposure estimate is calculated for each worker. In the second approach, subgroups of

workers are defined based on work characteristics, and a random sample of workers in each group is monitored. Exposure assessment strategies in occupational epidemiology are almost always based on grouping strategies, rather than on individual-based strategies. Desirable goals in grouping strategies would be division of workers into groups that are more or less uniformly exposed, and exposure groups with clearly distinguishable levels of exposure. Insight into exposure variability is crucial when designing an appropriate exposure assessment strategy. In this study, the variability of exposure to inhalable flour dust, to wheat allergens and to α -amylase allergens was studied using nested random effects ANOVA models. Exposure variability of inhalable flour dust was described before (Burdorf *et al.*, 1994; Nieuwenhuijsen *et al.*, 1995). However, variability of allergen exposure levels has not been described before.

An underlying assumption of the grouping strategy is that the average exposure of an individual worker is supposed to be indistinguishable from the average exposure of the total group (Boleij *et al.*, 1995). For epidemiological research, no strict criteria can be given for a required level of homogeneity. The inhomogeneity which is acceptable is determined by the magnitude of the variation in exposure in the whole population and the variation within the exposure groups (Heederik *et al.*, 1991a). For compliance strategy purposes, Rappaport (1991) has suggested that the difference between the highest and lowest exposed worker in a group should be below a factor 2, as reflected by a $_{bw}R_{0.95} < 2$. According to this strict definition, few occupational titles in our study could be considered as uniform exposed groups. However, several studies in other industries have shown that few exposure groups can meet this rather strict criterion (Spear *et al.*, 1987; Heederik *et al.*, 1991a; Rappaport *et al.*, 1993; Kromhout *et al.*, 1993). For inhalable dust and both types of allergens, the $_{bw}R_{0.95}$ for most occupational titles was considerably smaller than for the total group, which implies that the mean exposure of the occupational title was an acceptable exposure estimate for each member of that group. Besides, there was no information available for further subdivision of workers into smaller groups.

The formation of uniform exposed groups is helpful in making an optimal estimate of the exposure for each individual. As a result, the estimates of the relationship between exposure and response will be more precise, due to the reduction of random exposure measurement error. However, a strict definition of a uniformly exposed group is not a prerequisite for identifying a relationship between an exposure and a health outcome. Large within-group variation is acceptable as long as there is limited overlap (Heederik *et al.*, 1991b). Therefore, the variability in exposure between groups has to be substantially larger than the exposure variability within exposure groups. In our study, the between-group variance was the most important source of variability of exposure for all three measures of exposure. A grouping strategy in which bakery workers were grouped based on a combination of job and type of bakery resulted in a high contrast in exposure with elasticity of 0.75, 0.81 and 0.77 for inhalable flour dust, wheat allergen and α -amylase allergen, respectively. However, for exposure to inhalable dust and wheat allergens, a classification by job title alone would lead to a comparable contrast in average exposure levels. For α -amylase allergen exposure, information on type of bakery was the main explanatory variable found in our analysis of variance. However, the samples of many occupational titles had to be excluded from the analyses, because

all samples were below the detection limit of the α -amylase assay. As a result, the estimated components of exposure variability are probably only applicable for a small number of jobs in the bakery industry, and job should also be considered as an important explanatory variable of α -amylase allergen exposure. Therefore, a grouping strategy based on a combination of job and type of bakery is probably essential for a meaningful classification of exposure to α -amylase allergens. The elasticity for the different grouping strategies described in Table 4 is high compared with the elasticity found in other industries (Heederik *et al.*, 1991a; Kromhout and Heederik, 1995; Kromhout *et al.*, 1996).

In total, 21 bakeries were included in the study, and most were small traditional bakeries. Only a limited number of large industrialized bakeries was studied, and although some included several types of separate bakeries, only one plant was available for some types of bakeries (crispbakes factory and rye bread factory). For these types of bakeries we are in fact unable to give any information about possible differences between bakeries. For other types of bakeries, however, several were included in the study and only small differences in exposure levels between bakeries were found.

As mentioned, two other studies have performed repeated exposure measurements in bakery workers (Burdorf *et al.*, 1994; Nieuwenhuijsen *et al.*, 1995). In both, the specific job of the bakery workers was also identified as the most important source of variance of inhalable dust exposure, and a similar elasticity for this grouping strategy was found (approximately 0.75 in both studies). However, no variability of allergen exposure was described in these studies. Our study showed that for exposure to wheat allergens, the job of a bakery worker was by far the most important source of variation, and contrast in exposure levels could only be slightly increased when information on type of bakery was incorporated in the grouping strategy. For exposure to α -amylase allergens, however, information of the type of bakery was essential, and using information on jobs in the grouping strategies as well, led to similar estimates of contrast.

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