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Evaluation of Peak Exposures in the Dutch Flour Processing Industry: Implications for Intervention Strategies

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Objectives: To effectively decrease occupational exposure to flour dust and related allergens, detailed information on exposure determinants and effectiveness of control measures is essential. In this paper, we use personal real-time exposure measurements to get more insight into the relationship between specific work characteristics, including the use of control measures, and (peak) exposure to flour dust. The study has three objectives: (i) identify tasks and activities related to peak exposure, (ii) identify control measures and other important exposure determinants and (iii) assess the potential impact of these control measures on the (peak) exposure to flour dust.

Methods: A data set containing 82 real-time exposure measurements in combination with information from detailed observations was used to study the association between peak exposures and different tasks, activities and other determinants such as control measures. Descriptive statistics of peak exposure on job level were generated as well as information on contribution of task-specific peak exposures to time-weighted average (TWA) exposure levels. Finally, we evaluated the efficacy of a variety of control measures on task exposure by comparing exposure levels of groups of workers with and without controls.

Results: In workers included in this study, >75% of TWA exposure is directly associated with peak exposures during a limited set of well-defined tasks/activities. The impact of a single task on population TWA exposure is generally limited (<40%). Worker behavior seems an important determinant in effective exposure control for many tasks.

Conclusions: Data from real-time measurements provide important detailed information with respect to exposure determinants and control measures, not obtainable from conventional measurement studies focusing at TWA exposure. This information is essential to perform prospective impact assessments of intervention strategies on the populations' exposure distribution.

Keywords: control measures; flour dust; peak exposure; real-time measurements

INTRODUCTION

Exposure to flour dust is among the most observed causes of occupational airway disease and asthma (Latza and Baur, 2005). Recent time trend studies do not show a decline in occupational exposure (Creely *et al.*, 2006), indicating that rigorous interventions are needed to reduce the disease burden in the flour-processing industry. To effectively decrease occupational exposure to flour dust and related allergens, detailed insight on exposure determinants, and especially effectiveness of control measures, is essential. Yet, although occupational exposure to flour dust has been studied extensively in a range of occupational industries, most studies evaluated average daily exposure in relation to descriptive variables such as sector or job (Nieuwenhuijsen *et al.*, 1994; Karpinski, 2003; Bulat *et al.*, 2004; Meijster *et al.*, 2007). Few studies also evaluated exposure determinants in a more detailed level.

A recent study in The Netherlands comprised >900 full-shift personal exposure measurements. The variability in exposure in this study could only

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to a limited extend be explained by job and tasks variables and only a few effective control measures were identified (Meijster *et al.*, 2007). In Canada, studies of Burstyn *et al.* (Burstyn *et al.*, 1997, 1998) also identified effective control measures in only a few activities. Likewise, only generic characteristics such as having appointed a safety representative were associated with lower exposure levels in the UK (Elms *et al.*, 2005).

A result of the findings in these studies is that a clear starting point for intervention strategies is absent. The question arises to what extent effects of existing control measures of exposure actually can be detected by statistical modeling of 8-h measurements. Workers may perform several tasks at different production lines, all with specific characteristics that might influence exposure during a shift. Production cycles are relatively short and tasks are preformed repeatedly over a workday. Generic questionnaires to monitor tasks performed and time spent on certain tasks may not be accurate enough. Hence, measurement error in these independent variables will very likely lead to underestimation of the effect of determinants on exposure. As a result, exposure assessment strategies based on 8-h exposure measurements [time-weighted average (TWA) exposure] may not always be sensitive enough to identify (task) specific determinants of exposure, including the effect of control measures.

Nieuwenhuijsen *et al.* (1995) showed that for bakery workers in the UK TWA exposure levels to a large extent are determined by peak exposures that can be associated with specific work activities. This suggests that it would be sensible to direct intervention strategies toward the conditions and tasks that contribute most to peak exposures. In this case, real-time exposure measurements are needed for allocating control measures in an optimal manner. Several examples from occupational settings are available where real-time measurements were used to characterize personal exposure (Eisen *et al.*, 1991; Wegman *et al.*, 1994; Edman *et al.*, 2003; Smit *et al.*, 2006).

In the present paper, we analyzed data from personal real-time exposure measurements to get detailed understanding of the relationship between specific activities, work characteristics, including use of control measures, and (peak) exposure to flour dust. This study was conducted in the context of a sector-wide intervention program to reduce exposure and related occupational airway diseases among workers in the baking and flour processing industry in The Netherlands. The collection of the real-time measurements was part of a large occupational hygiene survey that is described elsewhere (Meijster *et al.*, 2007). The study has three main objectives: (i) identification of tasks and activities related to peak exposure within jobs and sectors, (ii) identification of control measures and other important exposure determinants and (iii) assessing the potential impact of these control measures on the (peak) exposure to flour dust.

METHODS

Exposure measurements

Real-time exposure measurements were performed in three cross-sectional exposure surveys. In total, 82 'real-time' measurements were obtained in different companies from 57 workers across different jobs in bakeries, flour mills and ingredient production plants. Measurements were performed using a DataRam (model pDR-1000, Thermo Electron Ltd). This device measures particle concentrations in air, moving through a detection chamber through ambient air movement, by means of light scattering (Thorpe, 2007). The DataRam has an effective measurement range of 0.001–400 mg m^{-3} and is calibrated for dust with particle sizes with aerodynamic diameters up to 10 µm. The DataRam was mounted in the breathing zone of the worker and was worn for a period of 4–8 h. Airborne concentration of flour dust was logged every 3 s to obtain a high resolution in exposure data.

Parallel to each DataRam measurement, a personal air measurement was performed using a PAS6 inhalable dust sampler. PAS6 samplers were located at the side of the preferred working hand (generally right side) and DataRam on the opposite side. Both samplers were placed on similar height in the breathing zone (around the collarbone) for each measurement. PAS6 samples were analyzed for dust, wheat allergens and fungal α-amylase, for this paper only dust results were used in comparisons with DataRam data. Details on PAS6 measurements and exposure levels for wheat allergens and fungal α-amylase, as well as processing of filters are described in a previous paper (Meijster *et al.*, 2007).

Classification of tasks, activities and control measures

During measurements, a trained occupational hygienist observed the worker and documented all main tasks performed. Within these tasks, performance of specific activities was also registered (e.g. shaking of bags, use of pressured air, etc.). Finally, detailed information was obtained on presence of control measures [e.g. use of local exhaust ventilation (LEV)]. A trained occupational hygienist conducted all surveys using a standardized checklist.

Based on checklist information, all 82 measurements were split up into tasks and activities in conjunction with control measures nested within tasks/activities. Tasks, activities and control measures taken into account were selected prior to the surveys based upon information from earlier studies. In incidental cases, this information was supplemented with additional situations observed on site.

Processing of data

Data from the DataRam device was uploaded to a computer and imported into Excel. Peak exposure

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plots were created for all DataRam measurement series to visually explore peak exposure patterns.

Peaks were identified using a peak detection limit, arbitrarily set at 1 mg m^{-3} of dust. This is approximately equal to the population average exposure level (Meijster *et al.*, 2007). This approach was earlier used by Preller *et al.* (2004). Several other studies used comparable concentration levels as peak detection levels for dust exposures (Edman *et al.*, 2003; Smit *et al.*, 2006). For each identified peak exposure, a variety of descriptive statistics (maximum peak concentration, average exposure concentration and peak duration) are calculated. Subsequently, a range of descriptive statistics was calculated for each measurement using a macro in Excel; i.e. arithmetic mean (AM), number of peaks, time between peaks, maximum peak concentration, total peak exposure, total peak exposure per task and activity.

Data from the real-time measurements were manually linked to the workplace survey information. All identified peaks were labeled with the task and/or activity a worker was performing. For each peak, the average exposure intensity (concentration) and the peak exposure duration (duration for which exposure was >1 mg m^{-3}) were calculated. We calculated a 'cumulative peak exposure' metric, by multiplying average peak exposure intensity with peak exposure duration. Within each measurement, cumulative peak exposures associated with a single task or activity were summed.

Since job and task profiles and exposure levels are fairly similar between traditional and industrial bakeries and between flour mills and ingredient production workers, measurements were grouped into two sectors: i.e. a bakery sector and the ingredient production sector. Bakery sector includes both traditional and industrial companies involved in bread and/or pastry production. Ingredient production sector includes companies involved in production of flour (milling) and premixes/bread improvers. A detailed description of job titles can be found in Meijster *et al.* (2007).

Statistical analyses

The final Excel database was imported into SAS v9.1 for statistical analyses. Correlation between average exposure values of DataRam and PAS6 measurements were explored per sector using PROC CORR and scatter plots. A ratio of the DataRam versus PAS6 results was calculated for each measurement to evaluate (structural) differences between both methods. To correct the DataRam measurements for structural underestimation of the inhalable dust concentration, the median of the ratios of the individual measurements was used as a correction factor before further analysis. For each job within each sector, an overview was made of the descriptive statistics with respect to peak exposure (i.e. number of peaks per hour, maximum peak intensity, median peak duration, maximum peak duration). The effect of exposure control technologies were evaluated by stratified analysis, comparing average cumulative peak exposure related to tasks and activities among workers with and without a particular control measure. A reduction factor was calculated as percentage difference of average cumulative peak exposure with and without control measure.

Scenario analysis

To get insight into the impact of task-based interventions on TWA exposure, we evaluated two hypothetical examples. First, we evaluated the impact of eliminating the peak exposure during sprinkling of flour for an individual worker. The peak exposure periods were eliminated from the exposure measurement and descriptive statistics were recalculated to evaluate the impact on the TWA exposure.

In the second example, we evaluated the effect of a hypothetical control strategy in the whole set of bakery workers in our study population (n = 59). The strategy comprised implementing the state of the art with respect to control measures upon this population. In other words, we looked at the work practice of all 59 bakery workers and, where not present, assumed implementation of the control measures as listed in this paper. Exposure levels were then reduced according to the corresponding average reduction factors and TWAs recalculated.

RESULTS

The correlation between inhalable dust and real-time measurements is high (correlation coefficient = 0.79, Fig. 1a). Nevertheless, the DataRam significantly underestimates the concentration of dust in air compared to the PAS6 inhalable dust sampler. Overall, the median exposure measured with the DataRam sampler was 0.21 and 1.63 mg m^{-3} for PAS6 measurements. Figure 1b shows box plots of the ratios of PAS6 and DataRam results per sector, with median ratios and outliers indicated. Generally, the ratio was fairly similar across sectors and measurements. The median ratio between DataRam and PAS6 results for all measurements was approximately a factor 0.12 (DataRam underestimates exposure with a factor 8 compared to PAS6).

Figure 2a,b gives a typical selection of real-time measurement plots with labeled peaks. Peaks are generally relatively short exposure moments of seconds to minutes, sometimes occurring with a high frequency. Highest levels are in excess of 100 mg m^{-3}. The plots indicate that the concentration of dust in air between peaks is in most cases negligible. In these periods, workers generally perform tasks that are associated with low exposures, such as wrapping or administrative work. Alternatively, tasks with "high" exposure

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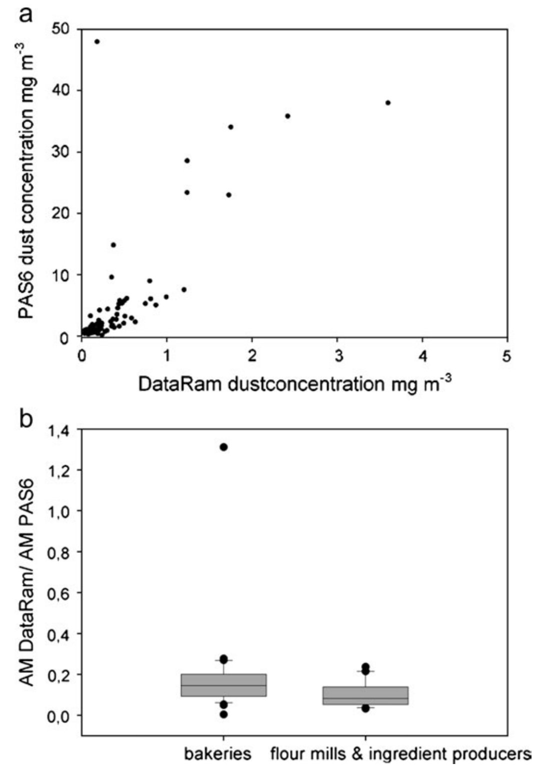

Fig. 1. (a) Scatter plot of correlation between dust concentrations measured with DataRam versus dust concentration measured with PAS6. (b) Box plots of the ratio between the arithmetic mean of the DataRam measurement versus the PAS6 measurement for both bakeries and ingredient producers (box plot shows median, 10–90 percentiles and outliers).

might be performed with use of effective control measures. The latter is illustrated by the graphs in Fig. 3a–c. Here, some specific examples are given of reduced exposures as a result of implementation of specific control measures. Figure 3a shows the effect of replacing flour sprinkling by use of oil; nevertheless, high peak exposures still occur during the sprinkling of flour where substitution with oil is not possible. Figure 3b represents a situation where weighing of ingredient was performed in a laminar flow cabinet. Dust exposure under these circumstances is negligible, contrary to the examples in Fig. 2 where high peak exposures occurred during weighing without control measures. Finally, Fig. 3c shows an example of a worker using a vacuum cleaner instead of a broom or pressured air during cleaning (see Fig. 2).

Table 1 gives the number of peaks per hour as well as peak intensity and duration, which varies substantially between jobs. In some cases, many peaks are observed, >20 peaks per hour sometimes in combination with very high concentrations, in excess of 100 mg m^{-3}. For all jobs, extensive periods of peak exposure are identified, often peak exposures have a duration of >10 min and occasionally periods over 1 h are observed.

Table 2 shows the number of measurements where peak exposure was observed during a specific task, as well as the relative contribution of this task peak exposure to the TWA exposure. Contribution of peak exposure during individual tasks to TWA exposure in bakeries is substantial for dough making, dough processing and to lesser extent cleaning and limited for the other tasks. In individual cases, the contribution of peak exposures during most tasks and activities can be substantial, up to 100%. In bakery workers, on average approximately 76% of TWA exposure could be assigned to peak exposures associated with specific tasks.

For ingredient producers, contribution of the different tasks to TWA exposure was more evenly distributed. Weighing of ingredients, dumping of ingredients and cleaning were activities that caused most peak exposure. On average, 78% of TWA exposure was related to peak exposure during the defined tasks.

Potential control measures identified were enclosure of mixing tub at silo, no shaking of bags and silo hose when dumping or weighing ingredients, use of LEV at different tasks, elimination of use of sprinkling flour and performing wet cleaning instead of sweeping or pressured air use.

Average and ranges of cumulative peak exposure vary substantially between tasks as does the effectiveness of the different control measures (Table 3). In general, reduction of exposure in both sectors were in most cases >50% (between 22 and 100%), except for partial substitution of sprinkling flour with oil where no reduction on task level was observed. Most effective control measures (with respect to percentage reduction) in bakeries were no shaking of cotton hose attached to flour silo, no flour dusting and perform only wet cleaning. For ingredient production sector, the elimination of use of pressured air, installation of LEV when bagging and not shaking bags when dumping ingredients were most effective control measures.

The above data show that significant reductions in exposure can be achieved on a task level. For an individual worker, the impact on exposure depends on the time spend on the task and performance of other activities. In a hypothetical example, we eliminate the peak exposures during sprinkling of flour from the exposure pattern shown in Fig. 3a, the TWA exposure of this individual decreases from 4.2 mg m^{-3} to 1.6 mg m^{-3}. This represents a reduction of 62%.

The information on efficacy of control measures can also be used to prospectively evaluate the impact of intervention strategies. A hypothetical intervention strategy that beheld structural implementation of best practices (as presented in Table 3) for all bakery workers in our study population was evaluated. At individual level, reductions in flour dust exposure

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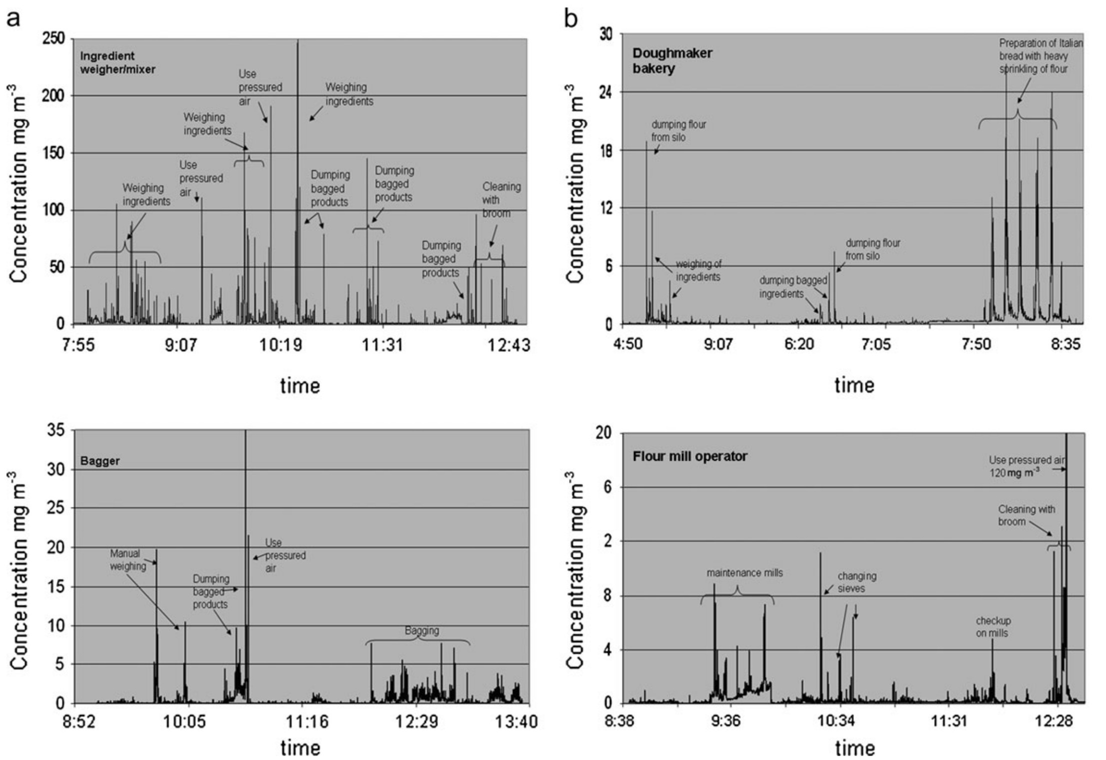

Fig. 2. (a and b) Plots from (partial) real-time measurements showing specific labeling of type of peak exposure for different jobs.

ranged between 0 and 80%. As expected, relatively low reductions were observed in individuals with TWA exposures already <1 mg m^{-3}; on average 17% exposure reduction was observed in this group. These workers generally performed less of the high exposure tasks or already implemented control measures in their daily work practice. For workers with exposures between 1 and 3 mg m^{-3}, the average exposure reduction was 36% and for workers with exposure >3 mg m^{-3} average reduction was 47%.

The median TWA group exposure decreased from 1.45 mg m^{-3} before to 0.88 mg m^{-3} after the hypothetical interventions. The geometric standard deviation decreased from 2.10 to 1.98.

DISCUSSION

This paper describes the use of real-time exposure measurements to associate tasks/activities and related control measures to (reduction in) peak exposure. This study shows that the real-time measurement data combined with detailed observational information on worker performance can provide quantitative information on the influence of determinants on TWA exposure levels. It also gives information on effectiveness of specific control measures in reducing task-based peak exposures.

In general, the results show that contribution of one or a few specific task exposures and associated control measures can be large on an individual level but that a broader range of tasks is important for the overall population TWA exposure. Hence, interventions in this sector should cover a range of tasks to have substantial impact on the population exposure distribution.

The control measures identified in this study show that worker behavior during several of the tasks/activities has a large impact on exposure. The importance of worker behavior, skills and hygiene on exposure is generally acknowledged in studies on exposure control and interventions (Lumens *et al.*, 1993; Lazovich *et al.*, 2002; Elms *et al.*, 2005). Quantitative information on impact of interventions specifically focusing on worker behavior related to the tasks and activities observed in our study is, to our knowledge, not available from scientific literature. Some comparison data are available for specific control measures. For cleaning, one study evaluated the effect of wet cleaning (sweeping) instead of dry sweeping and found reductions up to 99% (Tjoe Nij *et al.*, 2003). This is comparable to the reduction figures found in our study for substituting sweeping with wet cleaning. Several studies showed that use of pressured air (significantly) increased exposure, but none quantified exposure reductions when eliminating this task (Brosseau *et al.*, 2001; Mikkelsen *et al.*, 2002; Daroowalla *et al.*, 2005). For substitution of sprinkling flour with oil, Burstyn *et al.*

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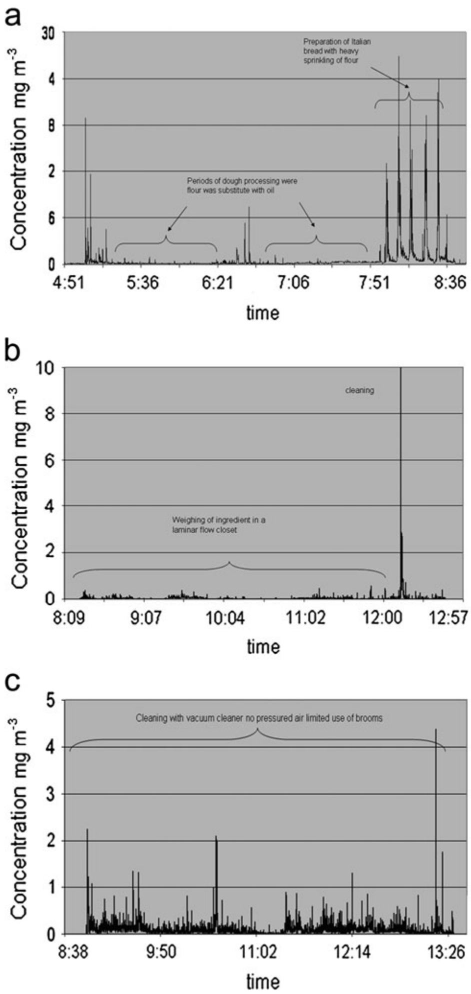

Fig. 3. (a) The potential effect of substitution of flour sprinkling with use of oil when processing dough. (b) Elimination of peak exposures when weighing ingredients by performing weighing activities in a laminar flow closet. (c) Limited peak exposure when cleaning flour spill in a flour mill with vacuum cleaner instead of broom.

(1997) found significant reduction in exposure while the present study found no effect on task level. This is primarily caused by the fact that substitution is in most cases only partial in Dutch bakeries, as Fig. 2 also shows, having only limited effect on task level. Where sprinkling flour was eliminated, substantial reductions in exposure were observed.

LEV is by far the most studied exposure control technology. Effectiveness ranges substantially, depending on type of LEV (integrated in process, mobile, etc.), process characteristics and worker behavior (e.g. working exactly below the LEV or at a distance). For efficacy of integrated LEV when dumping bagged product, one study in mining was identified. This study showed reductions in exposure of 80–90% during bag filling (Cecala *et al.*, 2000), comparable to the reduction observed in ingredient factories. A Dutch study on evaluation of effectiveness of LEV during dumping of powders found exposure reductions between 55 and 99%, all >75% except for one situation with poor design (Marquart *et al.*, 2004). This is a little higher than the 65% reduction found in the ingredient sector, where LEV was generally limited to a flow hood above the dumping site. For weighing of ingredients, Heinonen *et al.* (1996) found exposure reductions of LEV up to almost 100% depending on the design and flow rate, considerably higher than the figures we found in our study. In general, the use of LEV and therefore the effectiveness at the processes observed in both bakeries and ingredient sector were in many cases not optimal. Ineffective design and use (i.e. large distance from the source, relative position of worker and LEV system, weak airflow, poor maintenance) was the most observed reason for LEV not to be very effective in controlling exposure.

This study identified a large variety of tasks, activities and control measures associated with peak exposures that were not identified in an earlier study among the same population, focusing at determinants of full-shift TWA exposure (Meijster *et al.*, 2007). This is likely caused by the limitations of the contextual data and measurement error in the previous study. The time series presented in this paper in combination with detailed observations show that exposure to flour dust in the studied sectors is a complex phenomenon; workers perform many tasks often for very short time periods and have a large mobility within the production facility. The use of control measures can be very fragmented, being implemented for one task, but not for another task conducted during the same shift. Furthermore, as our study shows, on a population level the influence of a single task or control measure on the TWA exposure is limited. The use of general, often post-measurement interview-based questionnaires results in crude generalizations about tasks performance and the presence of specific determinants (i.e. control measures). This limited contextual information leads to misclassification error in these variables. Consequently, although 8-h TWA exposure measurements provide invaluable information on variability and major determinants of exposure (Kromhout, 2002), they lack sensitivity (in these situations) to evaluate effectiveness of (task) specific control measures.

The opposite placement of the samplers on the worker might have been a potential source of bias in our comparisons (Mark *et al.*, 2003). Nevertheless, two recent studies show that the difference of measured concentration between parallel samplers placed on the left and right side of a worker is minimal. For styrene, a recent study did not find any significant difference in sampled concentration (Eriksson *et al.*, 2005). A study performed in the rubber industry, looking at exposure to dust and rubber fumes, found a small difference of 30% between measured concentration with PAS6 samplers placed on the left and right

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Table 1. Descriptive peak exposure statistics and average exposure levels (PAS6) per sector and job

Sector	Job	*n*	PAS6 AM ($mg\ m^{-3}$)	Descriptive peak statistics			
				Average number of peaks per hour	Maximum peak intensity ($mg\ m^{-3}$)[a]	Median duration (s)[b]	Maximum peak duration (s)[c]
Bakeries	Breadbaker	30	4.49	26	371	53	9441
	Pastrybaker	4	0.49	27	117	34	2478
	Dough maker	16	1.82	33	203	29	2637
	All baker	8	2.02	30	400	54	4890
	Storage worker	1	2.32	18	400	179	5883
Ingredient producers	Weigher/mixer	7	14.9	20	317	172	8700
	Bagging operator	1	0.65	17	20	39	939
	Mill operator	5	10.60	29	258	32	1971
	General operator	1	1.19	30	28	44	1449
	Dumper ingredients	2	19.47	18	231	180	2459
	Cleaner	3	10.23	42	165	71	1368
	Foreman/boss	1	1.64	13	222	88	1749
	Storage worker	3	0.78	8	161	16	6542

AM, arithmetic mean.
[a]Maximum peak intensity observed within that job over all measurements.
[b]Median duration of the peak exposures averaged over all observed peaks in all measurements for that job.
[c]Maximum peak duration, longest single peak exposure observed over all measurements for this job.

Table 2. Relative contribution of task/activity peak exposure to total TWA exposure

Sector	Activities and main tasks	*K*[a]	Contribution to TWA exposure (%)	
			AM	Range
Bakeries	Preparing dough	48	39	0–100
	Processing dough	45	24	0–99
	Cleaning	34	6	0–43
	Pastry work	8	1	0–18
	Wrapping	6	1	0–31
	Storage work	14	1	0–7
	Maintenance	11	1	0–15
	Control work	28	3	0–33
	Total peak exposure	59	76	32–100
Ingredient producers	Bagging	6	6	0–58
	Dumping	14	13	0–49
	Cleaning	17	16	0–95
	Maintenance work	6	4	0–53
	Weighing of ingredients	15	26	0–98
	Control work	16	4	0–2
	Storage work	19	9	0–100
	Total peak exposure	23	78	8–100

AM, arithmetic mean.
[a]Number of measurements where peak exposures occurred during this task.

shoulder (de Vocht *et al.*, 2006). Although no comparisons results are available specifically for bakery workers, we believe these results indicate the effect of opposite placement has been limited.

Our results allow calculation of the effect of control measures on peak exposures into so-called reduction factors. The presented reduction factors give an indication of the average potential impact on task/activity exposure. Actual reduction varies substantially between companies and individual work areas. In the occupational hygiene literature, large variations are observed in effectiveness of control measures across studies (Fransman *et al.*, 2008).

In this study, information on the evaluated control measures is based on small numbers of observation and might change substantially if more data would

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Table 3. Impact of control measures on task/activity peak exposure in bakeries and ingredient production facilities

Control measure	Sector	Short description of control measure	Task/activity	No control measure			Control measure[a]			Average reduction in peak exposure (%)
				n[b]	Cumulative peak exposure		n[b]	Cumulative peak exposure		
					Average[c]	Range		Average[c]	Range	
A	Bakery	No shaking of cotton hose attached to flour silo	Dumping flour from silo	10	3389	0–9154	7	518	0–2689	85
B		Closed tub and LEV	Dumping flour from silo	7	518	0–2689	16	405	0–2089	22
C		No shaking of bags when dumping bagged ingredients in mixing tub	Dumping bagged flour	28	3373	0–17590	22	2071	0–10303	39
D		No shaking of bags	Weighing ingredients	28	4568	0–21971	22	1456	0–12365	68
E		Substitute normal flour with dust free flour when dusting	Flour sprinkling	28[d]	6459	0–46827	6[d]	2921	0–14897	55
F		Partially substitute flour dusting with oil	Processing dough	28[e]	14105	0–65274	3	22109	9591–46986	NR[f]
G		No flour dusting	Processing dough	28[e]	14015	0–65274	10	2823	0–12032	80
H		Eliminate use of pressured air	Cleaning	8	4979	10–14995	23	2173	0–10801	56
I		Use vacuum cleaner where possible	Cleaning	23	2173	0–10801	5	1666	477–1324	30
J		Only perform wet cleaning activities	Cleaning	5	1666	477–1324	6	140	0–676	92
K	Ingredient producers	Use of LEV	Bagging	3	58038	0–174115	5	6034	0–28720	90
L		Use of LEV	Dumping	3	66827	0–112799	6	23246	0–94467	65
M		No shaking of bags	Dumping	3	66827	0–112799	6	3069	9–6877	95
N		Eliminate use of pressured air	Cleaning	10	27129	79–180497	10	1344	0–7141	95
O		Eliminate use of pressured air	Maintenance	4	10042	0–20867	3	9	0–26	100
P		Use of LEV	Weighing ingredients	3	127545	4100–222244	6	64009	2944–333707	50
Q		No shaking of bags	Weighing ingredients	6	64009	2944–333707	6	38845	145–173575	39

[a]Indicated in the first column (e.g. A, B, C, etc.).
[b]n = number of measurements in this group.
[c]Arithmetic mean.
[d]Not including workers that partially substitute sprinkling flour with oil.
[e]Only workers that sprinkle with normal flour.
[f]NR, no reduction.

become available. Especially for ingredient production industry, numbers are very small and therefore results should be interpreted with caution. Although the number of workers included in the study is limited, we do believe our sample provides a good representation of the work performed in the different branches.

More than in experimental or intervention studies, in observational studies, environmental factors that can have an impact on exposure might differ between groups of workers that are compared, in our caseworkers with and without control measures. (Fransman *et al.*, 2008). This might have lead to bias in our estimated reduction factors. By defining and describing very specific tasks and activities, we have tried to minimize such error in our study.

It was not possible to correct the cumulative peak exposure of the activities for differences in total time an activity was performed between groups of workers with and without control measure. Information on performance time was obtained from the survey

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questionnaire and was only available for the main tasks and not for the more detailed activities. As a result, we might have over- or underestimated specific reduction factors. However, adjusting for the main task time did not reveal substantial changes in reduction factors. This suggests that the potential confounding effect is limited.

Although the information from real-time measurements provides valuable data, there are some drawbacks of the used measurement methodology. The DataRam device used in this study is primarily designed to sample dust that contains particles with an aerodynamic diameter <10 μm. Earlier studies have shown that flour particles are relatively large with a substantial amount of particles >10 μm (Sandiford *et al.*, 1994; Thorpe and Walsh, 2002; de Pater *et al.*, 2003). Particle sizes above the respirable range may not be detected by direct reading devices. This can lead to underestimation of the dust concentration with a constant factor not depending on the measured concentration (Thorpe, 2007). This indicates that the use of an overall calibration factor related to the mass median aerodynamic particle diameter of the dust measured is justified. Thorpe (2007) presents comparable correction factors for dusts with similar characteristics to flour dust. Smit *et al.* in a study looking at seed dust also presented comparable reduction factors (Smit *et al.*, 2006).

In conclusion, this study shows that exposure to flour dust in The Netherlands is primarily caused by short-term, sometimes very intensive, peak exposure moments. The impact that exposure during a specific task or activity has on TWA exposure can be substantial for an individual worker. This information is important to get a better understanding why workers have (sometimes very) high exposures and eventually to design efficient control strategies focusing on a limited set of relevant tasks. This information on peak exposure patterns will also help in explaining to workers why and how they have to change their work practice. The presented hypothetical examples show how the information from this study might be used to get insight in the potential impact of specific intervention strategies.

Nevertheless, the reduction factors have to be interpreted with caution since for some interventions the number of measurements was minimal. In the near future, the information from this study will be used as input for scenario analysis to predict post-intervention population distributions of exposure. This will be done in the context of a health impact assessment study among bakeries, predicting shifts in burden of disease due to branch-specific interventions at the workplace.

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