ORIGINAL ARTICLE

Annals of Agricultural and Environmental Medicine 2013, Vol 20, No 2, 307–311
www.aaem.pl

Chronic respiratory symptoms of poultry farmers and model-based estimates of long-term dust exposure

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Guillam MT, Pedrono G, Le Bouquin S, Huneau A, Gaudon J, Leborgne R, Dewitte JD, Segala C. Chronic respiratory symptoms of poultry farmers and model-based estimates of long-term dust exposure. Ann Agric Environ Med. 2013; 20(2): 307–311.

Abstract

Objectives. The airborne contaminant exposure levels experienced by poultry farmers have raised concerns about the possible health hazards associated with them. Thus, a longitudinal project was instituted in France to monitor these exposures in poultry workers and to evaluate the long-term effect on health.

Method. Sixty-three workers in two different poultry housing systems were included (33 from floor-based systems and 30 from cage-based systems). Personal dust concentrations (over 2 days) and activity patterns (over 14 days) were collected and then modeled to obtain average long-term estimates. Health data were collected by questionnaire.

Results. The mean daily time spent in the cage system was more than 2 hours longer than in the floor system. Two main common tasks accounted for ~70% of this time. Dust concentrations were higher in the floor system than in the cage system. The concentrations for the 14 days of known activity patterns estimated using the statistical model agreed well with the measured values. Several chronic respiratory symptoms were significantly associated with the high levels of long-term exposure estimated by the model. The highest risk was for chronic bronchitis symptoms (>4-fold higher for exposures of 0.1 mg/m^3 of respirable dust).

Conclusion. The presented modeling strategy can be used to estimate the long-term average personal exposure to respirable dust, and to study the association between dust exposure and chronic respiratory symptoms. This population of workers will be followed-up in subsequent examinations (3 years later) to determine whether the predictive model is valid, and whether long-term dust exposure is related to the incidence of respiratory symptoms and changes in pulmonary functions.

Key words
occupational exposure, respirable dust, task, environmental monitoring, chronic bronchitis

INTRODUCTION

France is the leading European producer for several types of poultry products. In recent years, the poor air quality in poultry housing facilities has raised concerns about the health and well-being of poultry workers. These individuals are exposed to airborne contaminants, including organic dusts, gases, fungi, bacteria and endotoxins [1]. In several previous studies, exposures to organic dust and endotoxins were measured comparatively for various types of livestock production environments and found to be highest in intensive poultry production [2, 3, 4, 5]. The dust levels produced by cage-housed poultry are lower than those produced by other housing systems [6, 7]. However, air contaminant levels are influenced by the characteristics of the buildings, the type of task and the type of poultry production [8, 9].

In France, more than 80% of all laying hens are still housed in cages. To improve animal welfare, the European Directive 1999/74/EC will require the prohibition of conventional cages for egg production from 2012 onwards. As a consequence, greater numbers of poultry workers stand to be exposed to the higher levels of airborne contaminants associated with floor-based housing systems. Thus, there is an urgent need to understand the relationships between dust exposure and the respiratory health of poultry workers.

The presented transversal study is the first part of an on-going cohort study of poultry workers in French egg production facilities employing conventional cages and floor rearing systems. The objectives of the study were to measure the personal exposure of workers in these different poultry-rearing systems, to estimate their long-term average dust exposure, and to measure how these estimated levels of exposure relate to respiratory symptoms and diseases.

MATERIALS AND METHODS

Population. Beginning in 2006, egg production workers from the region of Brittany in France were enrolled in the cohort study with the help of relevant producer organizations. Inclusion criteria were that the volunteers should still be working 3 years later, working at least 10 hours per week in egg production, not working in the production of food for the animals, and not working in broiler chicken, pullet or pig production.

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Received: 16 April 2012; accepted: 18 January 2013

Health data. Physicians of the farmer's health insurance performed the medical examinations. The examination included: a questionnaire (derived from the standardized questionnaire of the European Community Health Respiratory Survey) regarding their socio-economic characteristics, past professional activities, smoking status, respiratory symptoms and respiratory diseases; prick tests for common allergens (mite, cat, dog, grass pollens, *Aspergillus*, *Alternaria alternata*, *Cladosporium*) and pulmonary function tests (all physicians received training and used the same Spirolyser 10 instrument [FIM Medical]). The pulmonary functions of the subjects were tested while they were wearing a nose clip and in a seated position. According to the ATS criteria, the largest value among 3 technically acceptable measurements was chosen.

Exposure measurement. First, the volunteer and two technicians completed a questionnaire on the farm's characteristics, including the type of rearing system used (cage or floor), characteristics of the building (age, ventilation, type of floor), and the farm's cleaning practices. Exposure to respirable dust (<4 µm in diameter) in the breathing zone was assessed for each participant using a personal dust sampler (CIP 10, – ARELCO) on 2 occasions: once in a cold season work shift and once in a warm season work shift. Outside temperature was obtained from the meteorological station nearest each building (less than 25 km away).

Participants were requested to complete a diary on the places visited and the time spent during their different professional activities (elapsed time, every 5 minutes). Diaries were kept for the 2 days of the exposure sampling and the following six days of the week. All these data were entered into an ACCESS® database.

Statistical methods. Associations between qualitative variables were analyzed by Chi-squared test, or by a Fisher's exact test if the hypotheses of Chi-squared test were not satisfied. Associations with exposure levels were based on log-transformed concentrations to obtain normally distributed residuals, and were tested with Student's *t*-test or the Wilcoxon test. The paired-Student's *t*-test was used for repeated data.

The long-term average exposure to respirable dust was estimated as previously described [10], but was conducted using multiple steps.

First, associations between the log-transformed exposure for the 2-day period (2-d) and predictive factors (i.e. type of rearing system, characteristics of the building, times spent in different activities, outdoor daily temperature and season) were conducted using mixed regression models with auto-correlation taken into account by random effect. Independent variables with a significance level of at least 0.4 in univariate analyses were selected for the stepwise multivariate regression analysis. The variables were kept in the stepwise model if their significance levels were at least 0.2; except for temperature, which was forced in the model. Significant interactions between time spent on different activities and rearing system type were tested and, if significant, were taken into account in the models.

Secondly, the derived regression model was used to estimate the exposure (ln[exposure]) during each of the 14 days with a known activity pattern. To determine the reliability of the model and the estimated dust concentrations, a correlation coefficient from the measured values and the estimated values was calculated. A coefficient close to 1 indicated that the dust concentration estimated by the model was close to the measured value. This coefficient and the Bland-Altman graphical approach were used as criteria for choosing the final model [11]. The averages of the 14-day estimated exposures were used as estimates for the long-term average exposure of each participant in subsequent analyses.

Logistic regression models were used to study the associations between the long-term average exposures and respiratory symptoms and diseases; and between the exposure estimates and pulmonary functions. Variables with a significant level of 0.2 in univariate models were introduced in the stepwise multivariate models. Interactions between exposures and some possible predictor variables were tested, and if necessary, entered into the model.

All the statistic analysis were performed with the programmes ACCESS®, Excel® and SAS® v9.2 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Sixty-three egg production workers were recruited for the study, of whom 33 worked in floor-based rearing systems (mean number of laying hens: 9,000), and 30 worked in cage-based rearing systems (mean number of laying hens: 79,000). The general characteristics of the workers are presented in Table 1. Women were more numerous and total employees were less numerous in floor-based rearing systems than in cage-based systems. The numbers of current smokers were similar for the 2 groups, but ex-smokers were more numerous in the floor system group. Most of the workers had spent their childhood on a farm. Time spent in farming was significantly longer for the workers in cage-housed systems than for those in floor-based rearing systems.

Table 1. Personal characteristics of the poultry workers

	Total 63 (100)	Cage-housed 30 (47.6)	Floor-housed 33 (52.4)
Sex, n (%)			
Women	25 (39.7)	6 (20)	19 (56)
Men	38 (60.3)	24 (80)	14 (42)
Professional status, n (%)			
Farm owner	50 (79.4)	20 (66.7)	30 (90.9)
Agricultural employee	13 (20.6)	10 (33.3)	3 (9.1)
Age (mean; SD)	45.4 (7.2)	46.0 (6.2)	44.8 (8.0)
Smoking status, n (%)			
Nonsmoker	40 (63.5)	21 (70.0)	19 (57.6)
Ex-smoker	8 (12.7)	2 (6.7)	6 (18.2)
Current smoker	15 (23.8)	7 (23.3)	8 (24.2)
Childhood, n (%)			
On a farm	48 (74.6)	23 (76.6)	25 (72.7)
In a rural environment (not on a farm)	4 (13.3)	7 (21.0)	11 (17.5)
In an urban environment	3 (10.0)	2 (6.1)	5 (7.9)
Years worked on a farm (mean; SD)	21.76 (9.35)	24.83 (9.53)	19.06 (8.44) [1]
Years worked on the current farm (mean; SD)	15.65 (8.63)	17.53 (8.74)	13.94 (8.28)

In terms of health characteristics, 36.5% of the workers suffered from at least one chronic respiratory symptom – 33.3% in cage systems and 39.4% in floor systems (Tab. 2).

Table 2. Health characteristics of the poultry workers, n (%)

Variables	Total	Cage-housed	Floor-housed
Respiratory symptoms			
Morning cough	6 (9.5)	5 (16.7)	1 (3.0) [4]
Day and/or night cough	8 (12.7)	4 (13.3)	4 (12.1)
Chronic cough[1]	5 (7.9)	2 (6.7)	3 (9.1)
Morning phlegm	3 (4.8)	2 (6.7)	1 (3.0)
Day and/or night phlegm	9 (14.5)	2 (6.7)	7 (21.2) [5]
Chronic phlegm [1]	6 (9.5)	1 (3.3)	5 (15.2)[5]
Wheezing	8 (12.7)	5 (16.7)	3 (9.1)
Shortness of breath with wheezing	4 (6.3)	2 (6.7)	2 (6.0)
Wheezing apart from colds	3 (4.8)	1 (3.3)	2 (6.0)
Shortness of breath at rest	2 (3.2)	1 (3.3)	1 (3.0)
Shortness of breath during physical exercise	14 (22.2)	6 (20.0)	8 (22.9)
Allergic diseases			
Ever had asthma	5 (8)	2 (7)	3 (9)
Medically diagnosed asthma	4 (6)	2 (7)	2 (6)
Hay fever	12 (19)	5 (17)	7 (21)
Eczema and other atopic dermatitis	15 (24)	6 (20)	9 (27)
Insect allergy	13 (21)	7 (23)	6 (18)
Atopy[2]	16 (25)	9 (30)	7 (21)
Work related symptoms			
At least one symptom	38 (60)	17 (57)	21 (64)
Sneezing	29 (46)	15 (50)	14 (42)
Cough	27 (43)	12 (40)	15 (45)
Fever	2 (3)	2 (7)	0
Shortness of breath	13 (21)	8 (28)	5 (16)
Others symptoms[3]	7 (11)	3 (10)	4 (12)

[1] Throughout the day every day for three consecutive months each year; [2] At least one positive skin test to: mite, cat, dog, grass, *aspergillus, alternaria,* or *cladosporium;* 3: headache, bronchitis, conjunctivitis, skin irritations.

Shortness of breath during physical exercise was the symptom most frequently cited – 22.2% of the workers. Those working in floor systems had more phlegm and less morning cough than those working in cage systems, but the differences were not significant. Only one worker (cage system) had clinically-diagnosed chronic bronchitis, but 3 other workers (all in floor systems) had both chronic cough and phlegm. 25% were atopic (positive for at least one prick test) and 21% were sensitized to mite antigens. Five workers (8%) suffered from asthma, which had been clinically-diagnosed for 4 of them. Only 2 of these workers were atopic and 4 of them had developed asthma after the age of 40. Subjects who spent their childhood on a farm were less likely to have asthma than those who did not ($p<0.05$). Other allergic diseases, the most frequent of which was eczema, were declared by 19–24% of the workers. 60% of the workers suffered from work-related symptoms, especially sneezing (46%) and coughing (43%), when handling vegetable products, animal faeces or chemical products. The lung function indices for workers from the 2 housing systems did not differ from each other (data not shown).

The mean daily working time in the poultry building was significantly greater in the cage system than in floor system (5.5 hr vs. 3.5 hr, respectively; $p=0.01$). In both the cage and floor systems, the most time was spent packing eggs (respectively, 2.74 hr/day and 1.70 hr/day). The 2 other longest periods of time were spent rearing controls in breeding room and in the egg packing room (0.58 hr/day and 0.40 hr/day, respectively). In the floor system, manual collection of eggs and egg packing in the breeding room accounted for a combined 0.59 hr/ day. For the 14 days of follow-up, averages of 60.4% and 78.9% of daily time were spent performing all these main tasks in cage systems and floor systems, respectively.

The respective average personal dust measurement times were 5:35 hr (±3:10 hr) and 4:02 hr (±1:50 hr) for cage system and floor system. Seventy-five personal dust measurements (22 workers with 2, and 31 with only 1) were retained for analysis. Thirty-three of a total of 124 measurements were below the level of detection, 14 corresponded to days with incomplete diaries, and 2 measurements were in the outer range. There was no difference between the dust concentrations measured in cold and warm seasons, and the results obtained throughout the year were therefore pooled. Distributions of measured dust concentration are presented in Table 3. The mean dust level was significantly higher in the floor system than in cage system. The concentrations of dust experienced by the workers in each system varied over a wide range.

Table 3. Personal exposure levels of respirable dust (mg/m^3)

	Number of days	Mean (ET)	Min	P25	P50	P75	P95	Max
Measured exposure concentrations								
Total	75[1]	0.270 (0.198)	0.018	0.125	0.250	0.356	0.599	1.125
Cage-housed	32	0.234 (0.225)	0.018	0.083	0.179	0.280	0.59	1.125
Floor-housed	43	0.297 (0.173)[1]	0.028	0.171	0.286	0.367	0.564	0.857
Predicted during sampling								
Total	75[1]	0.234 (0.130)	0.043	0.132	0.212	0.304	0.482	0.631
Cage-housed	32	0.190 (0.126)	0.043	0.087	0.160	0.246	0.482	0.530
Floor-housed	43	0.267 (0.124)	0.106	0.173	0.253	0.336	0.468	0.631
Long-term average exposure to respirable dust								
Total	842[2]	0.242 (0.149)	0.001	0.120	0.227	0.335	0.514	0.784
Cage-housed	394	0.181 (0.151)	0.001	0.068	0.125	0.252	0.494	0.586
Floor-housed	448	0.296 (0.124)[2]	0.082	0.212	0.284	0.350	0.550	0.784

[1] Chi-squared test equal 0.03 for difference between log transformed concentrations in cage and floor housed system;
[2] Chi-squared test <0.0001 for difference between log transformed concentrations in cage and floor housed system

In the final model for predicting the 2-day dust concentration, 8 terms were retained (Tab. 4). The first 6 were: housing system type, temperature, surveillance time, egg packing time, time spent opening trapdoors and time spent closing trapdoors. Two interaction terms were also included: time spent between the rearing system and checking, and time spent between the rearing system and egg packing. R2 reached 47%, so all these terms explained around half of the variation in the daily exposure to dust. This model was then used to estimate the dust concentrations experienced by a worker carrying out a known activity pattern for 14 days (Tab. 3). The Pearson correlation coefficient between the estimated concentrations and the 75 days of measured concentrations was 0.69 (p-value $<10^{-4}$). This result indicates that the estimates obtained from the model were in good agreement with the measured values. Reasonably good agreement was also obtained using a Bland-Altman plot (data not shown).

Several chronic respiratory symptoms (cough and phlegm) were significantly associated with the long-term average exposure to respirable dust after adjusting for age, gender, smoking, and number of years at work on a farm (Tab. 5). The

Table 4. Predictive mixed model of the log-transformed personal dust concentrations

Variables[1]	ß	p
Intercept	-1.35	<0.0001
Cage-housed vs. floor-housed system	0.44	0.22
Maximum temperature	0.01	0.33
Time spent in:		
checking / floor-housed	0.45	0.12
checking / cage-housed	-0.47	0.05
egg packing / floor-housed	-0.20	0.02
egg packing / cage-housed	-0.41	<0.01
Removing hens from nests or perches	3.72	0.13
Moving hens inside from outside	-4.56	0.03

[1] R^2 = 47%.
The model included two interactions: type of system*time spent in checking and type of system*time spent in egg packaging. In the table for these interaction terms, the ß of the predictive variables are given for each system.

highest risk measured was for symptoms of chronic bronchitis, which was more than 4-fold higher when exposure levels were greater than 0.1 mg of respirable dust. No interactions between dust concentration and gender, smoking or atopy were detected. Furthermore, no association between pulmonary function indices and long-term average dust exposure was found in the entire group of workers, even after stratifying the group with respect to smoking (data not shown).

Table 5. Risks for respiratory symptoms associated with respirable dust concentrations[1]

Variables	OR[2]	95% CI[3]	p-value
Day and/or night cough	2.65	1.16–6.08	**0.02**
Chronic cough	2.80	1.12–7.02	**0.03**
Day and/or night phlegm	1.49	0.85–2.62	0.17
Chronic phlegm[1]	2.07	1.01–4.27	**0.05**
Symptoms of chronic bronchitis[2]	4.21	1.21–14.7	**0.02**
Shortness of breath with wheezing	2.13	0.87–5.24	0.10

[1] Logistic regression, results adjusted for age, sex, smoking and number of years at work in a farm;
[2] Odds ratio (OR). The OR values are expressed for levels of respirable dust >0.1 mg/m^3;
[3] 95% confidence interval (CI).

DISCUSSION

The results of the presented study confirm that there are numerous differences between cage- and floor-housed poultry systems in terms of the number of laying hens (higher in the cage system), work shift duration (longer in the cage system), staffing (more employees and a higher percentage of men in the cage system), and mean level of dust concentration (significantly higher in the floor-housed system). Nevertheless, but as expected due to the small sample size, no significant differences in the prevalence of respiratory symptoms or in lung function were detected between the 2 systems. Compared to a cross-sectional study of the French general population, the prevalence of some chronic symptoms in poultry workers appeared to be higher for chronic cough (7.9% vs. 4.8%), chronic phlegm (9.5% vs. 2.8%) and symptoms of chronic bronchitis (6.3% vs. 4.1%) [12]. However, the prevalence of chronic symptoms was lower than that reported in others studies on poultry workers. Radon et al. measure a chronic bronchitis prevalence of 14% in a population of 36 Swiss poultry workers. This group had the same mean age as those in the presented study, but the times spent at various activities and the type of production were not mentioned [13]. In addition, 58% of the workers in the Swiss study suffered from work-related respiratory symptoms. This result is similar to those in the presented research. Simpson et al. found a chronic bronchitis prevalence of 15.5% in a population of 84 poultry catchers in the United Kingdom. Again, the mean age of this group was identical to that of the presented research, but the type of tasks performed by the UK group are known to expose workers to very high levels of airborne contaminants [14, 15]. In Canada, Kirychuck et al. measured prevalences of 12.7% for chronic cough (10.1% in floor-housing system workers and 19.4% in cage-housing system); 19.3% for chronic phlegm (11.4% in floor system workers and 40.0% in cage system workers), and 15.7% for wheezing (15.6% in floor system workers and 16.1% in cage system workers) [16, 17]. Their population included 31 cage system workers and 80 floor system workers. Compared to the population in the presented study, their population had fewer current smokers, a similar mean age, but the time spent in farming was not mentioned and the floor system they studied included broiler chickens and turkeys, but not egg production. In this work, Kirychuck et al. found that some chronic respiratory symptoms were significantly higher for workers in cage-based systems, which in contrast to the presented results. In the Kirychuck et al. study, the personal levels of dust were significantly higher in the floor system than in the cage system. However, the levels of endotoxin tended to be higher in their cage systems and endotoxin concentrations are significantly linked to chronic respiratory symptoms. In the presented study, endotoxin levels in the air were significantly higher in the floor system than in the cage system [18]. Also, the prevalence of ever having asthma (8%) was similar to that found by Radon et al. (2001). As in other reports from agricultural settings, the presented study shows that asthma developed after 40 years of age for 4 out of 5 of the workers, and showed a significant relationship between the low prevalence of asthma and childhood spent on a farm [19, 20, 21].

The main strengths of the presented study are the long-term personal dust exposure estimation method, and the analysis of the relationship between these estimated values of exposure and chronic respiratory symptoms, especially symptoms of chronic bronchitis. Many cross-sectional studies of livestock production workers that lacked personal exposure measurements found elevated risks of chronic bronchitis in exposed workers, compared to non-exposed workers. Kirychuck et al. found that personal endotoxin exposure was a significant predictor of chronic phlegm (OR=1.69, CI_{95} [1.01–2.83], p=0.05); however, dust concentration were not measured [17]. In this study, the environmental exposure was measured during a single day only and the time of sampling was very short (95.4 min in the floor system and 161 min in the cage system). These features make it difficult to link exposure to chronic symptoms. Measurement of environmental exposure is critical for studying the effects on health. However, it is quite difficult to obtain good exposure estimates anyway because the variability of exposure is high and depends on many factors, including the tasks performed [15]. Furthermore, comparison of the personal exposure levels measured here with measurements obtained in other studies is difficult because the values measured are frequently total dust concentrations rather than respirable dust concentrations. Nevertheless, Donham et al. measured a personal dust (<5 μm) level of

0.63 ± 0.98 mg/m^3 for poultry housing workers, which is in the range of the presented measurements [22].

An important goal of the presented research was to construct a model for respirable dust exposure to estimate the average long-term exposure. This type of modeling was proposed by Preller et al. in a study of pig farmers in order to replace repeated environmental measurements and take in account the large intra- and inter-individual variations in exposure, repeated measurements that are responsible for high constraints for the workers, and significant cost [10].

In this study, the variables that modified personal dust exposure levels were the type of housing system and the frequency and time spent performing 2 main tasks common to the 2 systems: egg packing and checking. In floor-based systems, the opening and closing of trapdoors also contributed to the levels of exposure. Others tasks may generate high levels of exposure, but as they are of very short duration, their contributions were low and they were not retained in the final model.

There are several limitations in to the presented study:
1) its transversal design, but this step is only the first stage of an on-going cohort study;
2) the small size of the sample, especially for comparing the 2 housing systems.

Indeed, there is some diversity within each type of system, especially in the floor housing systems (e.g. access to an open-air run or not). This factor limited the statistical power of the study and the comprehensiveness of the data. The number of valid personal measurements – 75 instead of 124 – is another limitation. For the 33 measurements that were below the level of detection, the samplers may not have been used correctly by the farmers and/or the wrong manipulations were used in the laboratory during extraction. However, the presented estimations of the long-term personal dust exposure levels for each worker made it possible to measure significant relationships between dust exposure and the presence of chronic respiratory symptoms. On the other hand, no association between exposure levels and pulmonary function was detected in the presented study. Kirychuck et al. detected decreased pulmonary function in cage system workers (laying hens) versus floor system workers (broilers and turkeys) [16]. Dust and ammonia concentrations were significantly higher in the floor system, but endotoxin concentrations were nearly the same in the 2 systems.

CONCLUSIONS

Despite some limitations, the presented study demonstrates the utility of using a modeling strategy to estimate the long-term average personal exposure to respirable dust, and revealed an association between this long-term average personal dust exposure and chronic respiratory symptoms. The follow-up of this population of workers is ongoing to determine whether the predictive model is valid, and whether relationships exist between long-term dust exposure and the incidence of respiratory symptoms.

Acknowledgements

The authors gratefully acknowledge the cooperation of the following: Didier Huonnic and Loic Balaine (ANSES); Sylvain Héder (MSA); the MSA occupational physicians Nicole Castel, Pol Galès, Bernard Georgelin, Carole Mailloux, Virginie Martin, Patrick Morisseau, Dominique Perron and Guy Savatier; together with the egg production companies and poultry farmers. The AIRPOUL project was financially supported by the Region Bretagne (Brittany Region) in France.

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