Published in final edited form as:

J Occup Environ Hyg. 2010 December ; 7(12): 726–734. doi:10.1080/15459624.2010.530906.

Occupational Mouse Allergen Exposure Among Non-Mouse Handlers

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Abstract

This study assessed mouse allergen exposure across a range of jobs, including non-mouse handling jobs, at a mouse facility. Baseline data from 220 new employees enrolled in the Jackson Laboratory (JAXCohort) were analyzed. The baseline assessment included a questionnaire, allergy skin testing, and spirometry. Exposure assessments consisted of collection of two full-shift breathing zone air samples during a 1-week period. Air samples were analyzed for mouse allergen content, and the mean concentration of the two shifts represented mouse allergen exposure for that employee. The mean age of the 220 participants was 33 years. Ten percent reported current asthma and 56% were atopic. Thirty-eight percent were animal caretakers, 20% scientists, 20% administrative/support personnel, 10% materials/supplies handlers, and 9% laboratory technicians. Sixty percent of the population handled mice. Eighty-two percent of study participants had detectable breathing zone mouse allergen, and breathing zone mouse allergen concentrations were 1.02 ng/m³ (0.13–6.91) (median [interquartile range (IQR)]). Although mouse handlers had significantly higher concentrations of breathing zone mouse allergen than non-handlers (median [IQR]: 4.13 ng/m³ [0.69–12.12] and 0.21 ng/m³ [below detection (BD)–0.63], respectively; $p < 0.001$), 66% of non-handlers had detectable breathing zone mouse allergen. Mouse allergen concentrations among administrative/support personnel and materials/supplies handlers, jobs that generally do not entail handling mice, were median [IQR]: 0.23 ng/m³ [BD–0.59] and 0.63 ng/m³ [BD–18.91], respectively. Seventy-one percent of administrative/support personnel, and 68% of materials/supplies handlers had detectable breathing zone mouse allergen. As many as half of non-mouse handlers may have levels of exposure that are similar to levels observed among mouse handlers.

Keywords

allergen-specific antibody responses; laboratory animal allergy; mouse allergen

INTRODUCTION

Laboratory animal allergy (LAA) is a common and debilitating occupational disease. As many as 125,000 people in the United States come into contact with laboratory animals and are at risk of developing LAA.⁽¹⁾ Approximately 20% of laboratory animal workers have evidence of animal-specific IgE,^(2–4) and half of those report allergic symptoms to

laboratory animals, including rhinoconjunctivitis and dermatologic symptoms.⁽²⁾ Furthermore, 20 to 30% of those with IgE-mediated sensitization have occupational asthma, placing them at risk for irreversible lung disease.^(3,5)

Mouse allergen exposure and its impact on allergic disease are also increasingly recognized as important issues in community settings, particularly urban, socio-economically depressed communities.^(6–9) Several community-based studies have demonstrated the immunologic and clinical relevance of mouse allergen exposure in populations that have little to no direct contact with mice,^(10,11) suggesting that immunologically and clinically relevant non-contact exposure may also occur in occupational settings. However, most occupational studies to date have focused on workers with direct mouse exposure (i.e., handling mice or working in close proximity to mice) so that there are few data about exposure in non-mouse handlers working in non-mouse-containing areas of mouse facilities.

The JAXCohort Study, a prospective cohort study of new employees at a mouse research and production facility, The Jackson Laboratory (JAX), was established to address some of these major questions pertaining to mouse allergen exposure and its immunologic and clinical effects. For this analysis, baseline data from this cohort were examined to determine breathing zone mouse allergen levels across a spectrum of job types and to identify risk factors for higher exposure.

METHODS

Study Population

As a part of routine procedures at the Jackson Laboratory Health Office, new employees undergo skin prick testing, spirometry, and venipuncture for collection of serum at their post-job offer health screening. After completing the health screening, employees were approached by study staff to determine interest and eligibility for the JAXCohort Study. New employees undergoing post-job offer health screening between July 2004 and December 2007 were invited to participate. All new, non-temporary, full-time employees at least 18 years of age were eligible to participate. Interested participants were scheduled for a baseline study visit during which written informed consent was obtained. Consent included permission to use the skin testing results, lung function data, and serum that were collected at the post-job offer health screening visit. The JAXCohort Study was approved by Institutional Review Boards at the Johns Hopkins Medical Institutions and The Jackson Laboratory.

There were 555 new hires at JAX during the period of recruitment (July 2004 to December 2007). Four hundred and thirty-four of these new hires had post-job offer health screening exams, including skin prick testing and pre- and post-bronchodilator spirometry. Of these, 60 were ineligible for the study because of age or temporary or part-time job status. Three hundred and seventy-four new hires were deemed eligible for the study, 114 of whom declined to participate, leaving 260 (70%) who were enrolled. Two hundred and twenty participants were followed for at least 6 months and were included in the final dataset.

Clinical Assessments

Skin testing was performed at the post-job offer health screening for all employees, including employees who later enrolled in the study. Skin prick testing for 14 allergens was performed at the baseline visit using the MultiTest II device (Lincoln Diagnostics, Decatur, Ill.), with a positive histamine control and a negative glycerol control. The allergens tested were mouse, rat, cat, dog, *D. pteronyssinus*, *D. farinae*, pine, birch, oak, orchard grass, *Alternaria*, *Aspergillus*, *Penicillium*, and ragweed. A positive skin test was defined as a net orthogonal wheal size of 3 mm or greater. Atopy was defined as ≥ 1 positive skin test.

Spirometry was performed according to American Thoracic Society (ATS) guidelines.⁽¹²⁾ Venipuncture was performed at the post-job offer health screening. Total IgE and mouse-specific IgE were measured by quantitative ImmunoCAP (Phadia, Uppsala, Sweden) in the Matsui lab. A value ≥ 0.10 kU_A/L for mouse-specific IgE was considered positive. Levels of mouse-specific IgG were measured in serum samples in Dr. R.C. Aalberse's⁽¹³⁾ laboratory using a solid phase antigen-binding assay as previously described elsewhere.

The baseline questionnaire was administered by study staff and covered demographic information, pulmonary and allergic history, smoking history, and occupational and family history. It is based on a questionnaire used in our previous study, which was a composite of the previously validated ATS respiratory symptom questionnaires⁽¹⁴⁾ and the Collaborative Study on the Genetics of Asthma questionnaire.⁽¹⁵⁾ The occupational history includes questions regarding job title, job description, and frequency and duration of mouse contact. Data regarding history of previous occupational and home exposure to mice are also collected. Baseline allergy symptom data including report of mouse-associated allergy symptoms were captured.

Exposure Assessments

Airborne monitoring was conducted starting at the 6-month study visit. This starting point was chosen because new employees are completing training activities during the first few weeks of employment and not yet settled into their regular jobs. Exposure assessment consisted of airborne sample collection of two full shifts during a 1-week period. Particles were collected on Teflon filters with a 1 μ m pore size that were loaded onto cassettes. Samples were collected during two full 8-hr shifts using Buck VSS-12 personal sampling pumps with flow rates of 2 L/min (AP Buck, Inc. Orlando, Fla.). Airborne allergen data—generated from samples collected when flow rates varied by more than 5%, pumps malfunctioned, or filters were compromised (such as a torn filter)—were discarded. The filters were loaded into closed-faced 35-mm cassettes and clipped to the worker's lapel so that the air sampled was collected directly from the worker's breathing zone. For room samples, the same methods and equipment were employed, and the monitoring equipment was deployed in the center of the room, 1.5 meters off the floor. Thirty unique rooms were sampled; 21 rooms were sampled once and 9 were sampled multiple times. All flow rates were calibrated using the BIOSDryCal DC-1 Flow Calibrator (Bios International, Butler, N.J.) and according to manufacturer instructions before and after sampling. Before sampling flow rates were set to 2 L/min and after sampling the flow rates were measured and recorded.

Protein was extracted from the filters using standard procedures.^(16,17) After sample collection, cassettes were removed from the personal sampling equipment and refrigerated according to standard procedures for handling allergen samples. Filters were extracted with 1.5 mL of extract buffer overnight at 4°C in petri dishes on a plate rocker. Mus m 1, the major mouse allergen, was quantified immunochemically by sandwich enzyme-linked immunosorbent assay (ELISA) utilizing a protocol that is used routinely in the Matsui laboratory.^(8,18) ELISAs were performed in duplicate, and an internal standard was included on every plate.

Results were considered valid if the coefficient of variation between duplicates was <10% and the optical density reading for the blank wells was below the reading for the lowest point on the standard curve. The limit of detection for the Mus m 1 ELISA was 0.056 ng/mL. Using the total mass of Mus m 1 collected and volume of air sampled, an airborne concentration, in ng/m³, of Mus m 1 collected from the worker's breathing zone was calculated. This value represents a time-weighted average value of exposure during the time

of sampling. Since the volume of air sampled varied, the limit of detection for the breathing zone mouse m 1 concentration ranged from 0.05–0.18 ng/m³.

Each study participant had two measures of breathing zone mouse allergen exposure (Days 1 and 2), and the mean of these two measurements was used to represent average exposure for the worker. In five cases, only 1 day of monitoring occurred, and that day's value was used to represent the average exposure. In analyses examining predictors of peak exposure, the highest of the Day 1 and Day 2 measures was used as the peak exposure.

To determine the relationship between room and breathing zone airborne concentrations of mouse allergen, we conducted a nested pilot study of breathing zone and room mouse allergen concentrations. We utilized both types of sampling methods for the first exposure assessment of participants enrolled during the first 12 months of the study, yielding 91 pairs of room and breathing zone mouse allergen measurements.

Statistical Analyses

All analyses were performed with Stata 11.0 (StataCorp, College Station, Texas). Since data were not normally distributed, non-parametric statistical tests were employed. When the distribution of exposure was compared between groups, the Kruskal Wallis test was used, and Spearman correlations were used to examine relationships between different days and different methods (breathing zone vs. room) of exposure measurements. A two-tailed p value <0.05 was considered statistically significant.

RESULTS

Study Population

Of the 260 workers who completed a baseline visit, 220 of these workers remained employed at JAX by 6 months and therefore had one exposure assessment study visit. These 220 workers made up the JAXCohort study population and differed somewhat from those who either declined to participate or did not complete at least one follow-up visit in terms of age (33 vs. 28 years, respectively, $p = .02$), and gender (55 vs. 72% females, respectively, $p = .04$). There were no differences in racial/ethnic composition in the final study population as compared with those who were not included in the final study population (9% vs. 5% non-whites, respectively, $p = .44$).

The mean age of study participants was 33 years; 55% were female, 91% were white, and 55% had at least a college degree (Table I). Nineteen percent reported ever having asthma, and 10% reported current asthma, within the range of U.S. population estimates⁽¹⁹⁾ (Table II). More than half the participants were atopic (56%), defined as at least one positive skin test at baseline, similar to estimates from the National Health and Nutrition Examination Survey (NHANES)⁽²⁰⁾ (Table II). More subjects were skin test positive to dust mite than to any other allergen (39%). At baseline, 6% of the participants had a positive skin test to mouse and 4% to rat (Table II). Lung function indices were generally within normal ranges, reflecting a generally healthy adult population (Table III).

IgE and IgG Concentrations

Thirteen percent of participants had a total IgE >100 kU/L. At baseline, eight workers (4%) had a detectable mouse-specific IgE level (≥ 0.10 kU/L). Five of these workers (63%) had previously worked with mice. Five percent of workers had a detectable mouse-specific IgG level, and 73% of these workers had previously worked with mice.

Occupational and Exposure History

Approximately two-thirds of the participants reported having pets (64%), most commonly cats (71%) or dogs (59%). Fifty-five percent of participants reported ever seeing mice in their homes. The majority of participants who had seen mice reported that these observations had occurred more than 12 months prior to their baseline study visit. Twenty-five percent reported having worked with mice previously, and 16% had worked with other laboratory animals, including rats and rabbits most commonly (Table I).

The study population reflects a range of job categories, with 60% handling mice and 40% not handling mice (Table IV). Thirty-eight percent of participants were animal caretakers, 20% were administrative or support personnel, 20% were scientists, and 9% were laboratory technicians or research assistants. Among the mouse handlers, 30% reported their primary task as husbandry (animal care activities involving breeding), 42% as animal care (animal care activities not involving breeding), and 23% as conducting laboratory experiments. Most mouse handlers handled mice every day (69%), and almost a third (31%) had more intermittent mouse contact. Ninety-seven percent of mouse handlers handled live mice.

Mouse Allergen Concentrations

Two full-shift breathing zone samples were collected during 2 days within the same week for analysis of mouse allergen concentrations. One hundred and seventy of the 220 participants (77%) had valid exposure data. Air sample volumes for these samples ranged from 258–1206 L, with a mean of 737 L. Day 1 and Day 2 breathing zone mouse allergen concentrations were strongly correlated ($r_s = 0.72$, $p < .0001$; Figure 1), so that Day 1 accounted for 52% of the variability in the Day 2 concentration. Room mouse allergen concentrations were also measured to determine the relationship between room and breathing zone airborne concentrations of mouse allergen. As with breathing zone mouse allergen concentrations, room allergen concentrations were collected on 2 days during 1 week. Air sample volumes for these samples ranged from 318–1104 L, with a mean of 849 L. Room allergen concentrations for Days 1 and 2 were moderately to strongly correlated ($r_s = 0.69$, $p < .0001$).

The mean of Days 1 and 2 measurements for breathing zone exposure was used to represent average exposure for the worker. The median value for the average breathing zone mouse allergen concentration was 1.02 ng/m³ (IQR: 0.13–6.91) and for the average room mouse allergen, the median value was 0.23 ng/m³ (IQR: BD–0.56). Room and breathing zone airborne mouse allergen concentrations were moderately to strongly correlated ($r_s = 0.69$, $p < .0001$; Figure 1). Room mouse allergen concentrations accounted for 42% of the variability in breathing zone mouse allergen concentrations. Room measurements were less sensitive than breathing zone measurements: 46% of room measurements were below detection, but only 29% of breathing zone measurements were below detection.

Predictors of Exposure

We also examined predictors of breathing zone mouse allergen concentrations (Table V). Not surprisingly, mouse handlers had significantly higher concentrations of breathing zone mouse allergen than employees who did not handle mice (medians: 4.14 vs. 0.21 ng/m³, respectively; $p < 0.001$; Figure 2a). Among mouse handlers, certain tasks were associated with higher concentrations of exposure. For example, mouse handlers whose primary task was animal care had significantly higher mouse allergen concentrations than those involved in other types of tasks (animal care [median: 8.73 ng/m³]; husbandry [5.83 ng/m³], and laboratory experiments [0.36 ng/m³], $p = .0001$). Frequency of mouse handling was also associated with breathing zone mouse allergen concentrations, with greater frequency associated with higher concentrations. Similar relationships were observed between tasks

and peak breathing zone mouse allergen concentration, defined as the highest of Day 1 and Day 2 mouse allergen concentrations (Table V). Neither room airborne mouse allergen concentrations nor personal airborne mouse allergen concentrations varied by season (data not shown).

Breathing Zone Mouse Allergen Concentrations Among Non-Mouse Handlers

Eighty-two percent of study participants had detectable breathing zone mouse allergen. Although mouse handlers had significantly higher concentrations of breathing zone mouse allergen than non-handlers, 66% of non-handlers had detectable breathing zone mouse allergen (Figure 2a.). Most employees in jobs that do not entail direct mouse contact had detectable breathing zone mouse allergen: 71% of administrative/support personnel and 68% of materials/supplies handlers had detectable breathing zone mouse allergen. Breathing zone mouse allergen concentrations among 25–50% of administrative/support personnel and materials/supplies handlers were similar to concentrations measured for animal caretakers (median [range]: 0.23 ng/m³ [BD–30.94], 0.63 ng/m³ [BD–423.87], 9.6 ng/m³ [0.58–220.9], respectively; Figure 2b).

In addition, almost all non-mouse handlers worked in offices and not in areas where mice are allowed. Among administrative/support personnel, 91% were employed as administrative assistants, computer or technical support personnel, health and safety personnel, sales and community/client relations personnel, and leadership as well as other positions that are located in non-mouse areas. Materials/supplies handlers also work in non-mouse areas, but their work locations are often in proximity or adjacent to mouse rooms.

DISCUSSION

In this population of employees at a mouse research and production facility, most non-mouse handlers were exposed to mouse allergen and many had concentrations of exposure similar to concentrations for mouse handlers. Because most studies of laboratory animal allergy have focused primarily on animal handlers, there is less information regarding exposure among non-animal handlers and a limited understanding of the full range of exposure in this group. This study highlights the importance of considering non-contact laboratory animal allergen exposure as a potential source of allergic symptoms in employees. However, because the relevance of non-contact mouse allergen exposure is unclear, future studies are needed to examine its immunologic and health effects.

A few other studies have examined non-contact exposure to rodent allergens but have not explicitly compared the intensity and range of exposure between non-mouse handlers and mouse handlers. For example, mouse allergen has been detected in non-mouse containing areas of mouse facilities⁽¹⁸⁾ and has been found on workers' protective bonnets and in their mattresses,⁽²¹⁾ demonstrating that non-contact exposure may occur via transfer of allergens on workers. Although in one study, 50% of the study population was reported to have non-contact mouse exposure, these study participants were all exposed when co-workers used mice in their laboratories, unlike our study population that included employees who did not work in mouse-containing areas.⁽²²⁾

Non-contact exposure may be immunologically and clinically relevant, as one group has reported allergy to laboratory animals in laboratory animal workers' children, who would not otherwise be exposed to laboratory animal allergens.⁽²³⁾ Another study reported a sensitization prevalence of 33% among a non-contact exposure group that included office workers as our study does, suggesting that non-contact exposure may be an important but often overlooked risk factor for sensitization and laboratory animal allergy (LAA).⁽²⁴⁾ However, there was little information about the level of exposure among this non-contact

exposure group, and it was not clear how the distribution of exposure among indirectly exposed workers compared with directly exposed workers, except that rodent allergen levels were lower on average among indirectly exposed workers. Moreover, there were very limited exposure assessment methods described, and the reported exposure results suggest that the methodology used was not consistent with methods used in most occupational studies.

Our study's findings have implications for the design of future studies. Some studies, for example, have used indirectly exposed employees as a comparison group for directly exposed workers, and our findings would suggest that indirectly exposed employees may actually have substantial exposure, often similar to that of directly exposed employees. In one such study, 3.5% of the indirectly exposed group was sensitized to rat allergens, and 1.2% met criteria for rat allergy,⁽²⁵⁾ so it is possible that this indirectly exposed group had levels of exposure that were immunologically and clinically relevant. In addition, our findings suggest that studies designed to examine exposure-response relationships may be focusing on a narrower range of exposure when excluding workers with non-contact exposure, thereby missing an opportunity to evaluate exposure-response relationships across a broad spectrum of exposure.

Findings from this baseline study population analysis confirm previous observations that mouse handlers have higher levels of exposure than non-mouse handlers and that certain tasks, such as animal care, are associated with higher levels of exposure.⁽²⁶⁾ Comparison of area and breathing zone mouse allergen concentrations indicates that these two measurements are strongly correlated but that breathing zone measurements are much greater than room area measurements. As a result, when the same flow rates and sampling times are used, there is a large proportion of area measurements that are less than the limit of detection. Larger air sample volumes are needed to better describe the low end of the distribution of area concentrations. These findings suggest that room monitoring may be sufficient for the purposes of surveillance of mouse facilities and for assessing efficacy of facility-level interventions in reducing mouse allergen levels. However, room measurements are sub-optimal for monitoring an individual worker's exposure or for studies in which exposure is a main variable of interest.

Although ventilation characteristics can have a significant impact on airborne allergen concentrations, because ventilation characteristics are similar across mouse rooms, these factors likely contributed little to the variability in airborne mouse allergen concentrations across mouse rooms. Specifically, because of animal care regulations, all mouse rooms have at least 10 air changes per hour and there is no recirculation of air; 100% of the air is outside air. All air that is circulated into mouse rooms is HEPA-filtered. Engineering characteristics of non-mouse space, on the other hand, are quite variable. Although there is much greater variability in these engineering characteristics among offices, air locks are in place between all mouse rooms and non-mouse rooms, including office space, so airborne mouse allergen detected in office space is very unlikely to have been a result of recirculated air or a negative pressure gradient from mouse rooms to office space. If mouse allergen had been tracked into office space on clothing, however, higher ventilation rates would reduce mouse allergen concentrations at a greater rate than lower ventilation rates.

Although our study demonstrates how commonplace non-contact exposure is in a mouse facility, the health implications of non-contact exposure in the workplace are unclear. One study of indirect cat allergen exposure, however, lends some insight into the health impact of this type of exposure. Almqvist et al.⁽²⁷⁾ found that cat-sensitized children with asthma who were in classrooms with a high proportion of classmates who had cats at home developed worsening asthma symptoms and lung function compared with cat-sensitized

children who were in classrooms with a very low proportion of cat owners. Further, the investigators established that cat allergen was transferred into classrooms on the clothes of the children with cats at home. These findings support the notion that mouse-allergic workers who experience non-contact exposure to mouse allergen are likely to develop symptoms and provide a conceptual model for occupational mouse allergen exposure since no risk thresholds have been established.

Although there are many potential approaches to reducing non-contact exposure to mouse allergen, engineering controls, including alterations in ventilation, recirculation of air, and installation of air locks, should be implemented. Engineering controls should be augmented by administrative controls, and perhaps the most effective administrative control would be to limit travel within the facility by workers with direct mouse contact unless they have changed clothes. In addition, respiratory protection (RP) should be mandatory for symptomatic workers. One study⁽²⁸⁾ examined the effects of RP on airborne rodent allergen exposure using nasal samplers and found that the equivalent of an N95 mask reduced exposure by approximately 90%, suggesting that symptoms should be reduced by RP.

Although reduction of exposure is of critical importance for workers who are already allergic to mice, it is premature to recommend specific personal protective equipment or administrative or engineering controls as a *primary prevention strategy* to prevent development of allergy, since risk thresholds are entirely unknown. For now, there are insufficient immunologic and health data to speculate about the potential health effects of low-level exposure in non-allergic individuals. Prospective studies with repeated exposure, immunologic, and clinical outcomes are needed to appropriately examine the impact of both direct and non-contact exposure, and few, if any, studies such as this have been conducted.

The JAXCohort Study, however, is well positioned to provide insights into the implications of mouse allergen exposure across a spectrum of exposure concentrations, since repeated exposure, immunologic, and clinical outcomes have been collected every 6 months since 2004 in this study population. More specifically, the JaxCohort Study may provide insight into the nature of the relationships among-allergen exposure and IgE-sensitization and LAA and the role of non-IgE antibody responses as biomarkers of exposure and predictors of risk of subsequent IgE sensitization. This issue is particularly important, given recent evidence that high-level allergen exposure may protect against the development of allergic sensitization,^(29,30) suggesting that modest exposure reduction may not result in a reduced risk of sensitization.

There are several characteristics of the study population that will optimize our ability to examine relationships among exposure, immune responses, and LAA. For example, because a range of job types are represented exposure-response relationships can be examined across a wide spectrum of exposure. A variety of primary tasks and range of exposure frequency are also represented. In addition, there is a baseline mouse sensitization rate of 6%, so that data from more than 200 non-sensitized study participants will be available for examining exposure and immune predictors of incident sensitization. The study population appears to be generally representative of the U.S. adult population, as atopic characteristics are similar to those observed in nationally representative study populations.⁽²⁰⁾

One limitation of the study was the differences in age and gender between workers who enrolled and those who were not enrolled. Data collected in the course of this study will help answer questions regarding mouse allergen exposure, immune responses, and clinical allergy.

Because repeated exposure assessments are logistically challenging in community settings, occupational studies may serve as a model for community-based allergen exposure.

Although community exposure certainly differs in some aspects from occupational exposure, and the population most affected by community mouse allergen exposure is largely urban and minority, key findings from the JAXCohort Study can be tested in community-based populations. These findings highlight the potential immunologic and clinical implications of non-contact mouse allergen exposure and underscore the importance of developing a better understanding of exposure-response relationships across a broad spectrum of exposure. Since the JAXCohort Study has continued to follow this population since 2004, the study is well positioned to answer several seminal questions related to allergen exposure and its impact on immune and clinical responses. Ultimately, the findings from this study will provide a foundation for developing scientifically sound strategies for primary and secondary prevention of mouse allergy.

Acknowledgments

We thank Cristy Benson for her assistance in collecting breathing zone air samples, and the Jackson Laboratory leadership, Health and Safety Office, and community for their support, and the study participants for their participation in the study. We also thank Rob Aalberse and Steven Stapel for the conduct of the mouse-specific IgG assays. Funding was provided by the National Institute of Allergy and Infectious Diseases (R01 AI081845, K23 AI060955, R03 AI62974).

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FIGURE 1.

Scatterplots of airborne mouse allergen concentrations. (a) Day 1 vs. Day 2 breathing zone mouse allergen ($n = 164$), $r_s = 0.72$, $p < .0001$; (b) Breathing zone vs. room mouse allergen concentrations ($n = 90$), $r_s = 0.67$, $p < .0001$

FIGURE 2.

Boxplots of breathing zone mouse allergen concentrations by job type. (a) mouse handlers ($n = 97$) vs. non-mouse handlers ($n = 71$); $p < .001$; (b) job categories (administrative/support (34); animal care (57); laboratory technician (18); scientist (34); materials/supplies handler (19); $p = .0001$). The median is represented by the horizontal line within the box, the 25th percentile by the bottom border of the box, and the 75th percentile by the upper border of the box. The whiskers represent the values that are 1.5 times the interquartile range above and below the nearer quartile. Any values outside the whisker values are plotted as individual points.

TABLE I

Study Population Characteristics

Characteristics	n (%)
Age (y), mean $\pm$ SD	33 $\pm$ 10.6
Female, n (%)	120 (55)
Race, white, n (%)	201 (91)
Educational Attainment	
High school degree or equivalent or less	43 (19)
Some college	55 (25)
College degree	57 (26)
Post-graduate study	65 (30)
Smoking history	
Ever smoked	94 (43)
Current smoker	52 (24)
Family history	
Maternal asthma	22 (10)
Paternal asthma	14 (6)
Past Exposure and Occupational History	
Worked with mice, ever	54 (25)
Worked with other lab animals, ever	35 (16)
Rats	16 (46)
Guinea pigs	5 (14)
Rabbits	11 (31)
Other	32 (91)
Ever seen mice in home	120 (55)
In the past 12 months	40 (33)
More than 12 months ago	80 (67)
Pets, current	140 (64)
Cat	99 (71)
Dog	83 (59)

TABLE II

Allergic Disease Characteristics

Characteristics	n (%)
Hay fever, ever (n = 220)	37 (17)
Age of start (y), mean $\pm$ SD	16 $\pm$ 9
Asthma ever, self-report (n = 219)	41 (19)
Doctor-diagnosed asthma	40 (18)
Age of onset (y), mean $\pm$ SD	13 $\pm$ 9
Current asthma	22 (10)
Pollen-associated allergy symptoms, ever	81 (37)
Cat/dog-associated allergy symptoms, ever	38 (17)
Mouse-associated allergy symptoms, ever	13 (6)
Eczema, ever	13 (6)
Allergen immunotherapy, ever (n = 219)	11 (5)
Total IgE >100kU/L (n = 215)	28 (13)
Atopic (any positive skin test) (n = 218)	123 (56)
Skin Test Sensitivity	
Dust mite	85 (39)
Grass pollen	59 (27)
Cat	42 (19)
Mold	24 (11)
Birch	25 (11)
Ragweed	24 (11)
Oak	17 (8)
Mouse	14 (6)
Pine	10 (5)
Rat	9 (4)
Dog	4 (2)

TABLE III

Lung Function Measures

Lung Function Indices	Absolute Value, Mean $\pm$ SD (N = 219)	Percent Predicted, Mean $\pm$ SD (N = 219)
FEV1 (L)	3.55 $\pm$ 0.78	101 $\pm$ 14
FVC (L)	4.43 $\pm$ 0.92	104 $\pm$ 14
FEV1/FVC	0.82 $\pm$ 0.06	N/A
FEF25–75 (L/sec)	3.68 $\pm$ 1.14	95 $\pm$ 27

TABLE IV

Occupational History

Occupational Characteristics	n (%)
Job Category (n = 214)	
Animal caretaker	82 (38)
Scientist	43 (20)
Administrative/support personnel	42 (20)
Supplies or materials handler	22 (10)
Laboratory technician/research assistant	20 (9)
Other	5 (2)
Mouse handler, yes	131 (60)
Primary Task (n = 128)	
Animal care	54 (42)
Husbandry	39 (30)
Laboratory experiments	30 (23)
Autopsies	2 (2)
Dumping dirty boxes	2 (2)
Preparing mice for shipment	1 (1)
Frequency of Mouse Handling (n = 130)	
<1 day/week	6 (5)
1–2 days/week	15 (12)
3–4 days/week	19 (14)
5 or more days/week	90 (69)
Type of mice (n = 128)	
Live mice	124 (97)
Dead mice	4 (3)

TABLE V
Predictors of Breathing Zone Mouse Allergen Concentrations Among Mouse Handlers

Predictors of Exposure	Yes (n = 97) No (n = 71)	Avg. Mus m 1 (ng/m ³) Median (IQR) ^A	p-value	Peak Mus m 1 (ng/m ³) Median (IQR) ^A	p-value
Mouse handler	Yes (n = 97) No (n = 71)	4.14 (0.70–12.12) 0.21 (BD ^B –0.63)	<0.001	6.70 (1.27–18.45) 0.31 (BD ^B –1.17)	<0.001
Primary task	Animal care (n = 42) Husbandry (n = 26) Laboratory exp. (n = 25) Live, conscious (n = 92) Dead mice (n = 3)	8.73 (3.56–18.68) 5.83 (3.26–14.95) 0.36 (0.07–1.77) 4.46 (0.74–13.53)	<0.001	11.44 (4.67–24.08) 7.82 (3.46–18.75) 0.61 (0.14–1.81) 6.79 (1.29–18.60)	<0.001 0.89
Frequency of mouse handling	<1 day/week (n = 4) 1–2 days/week (n = 13) 3–4 days/week (n = 16) 5+ days/week (n = 63)	4.11 (BD ^B –379.86) 0.20 (BD ^B –2.26) 0.38 (0.06–1.93) 0.84 (0.18–2.41) 7.73 (3.49–18.54)	0.99 <0.001	8.08 (BD ^B –682.50) 0.31 (BD ^B –4.34) 0.65 (0.13–3.43) 1.07 (0.27–2.80) 11.32 (4.57–23.44)	<0.001

Note: Peak concentration was defined as the highest concentration of Day 1 and Day 2 measurements.

^A Interquartile range.

^B BD, below detection. The limit of detection for the breathing zone Mus m 1 concentration ranged from 0.05–0.18 ng/m³.