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The Relation Between Subjective Dust Exposure Estimates and Quantitative Dust Exposure Measurements in California Agriculture

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Measuring exposure levels for epidemiologic research is time consuming and expensive and therefore subjective exposure estimates are sometimes used instead. In this study we related the subjective dust exposure estimates of workers in California agriculture to personal dust exposure measurements. One hundred and twenty-four observations were available for comparison of subjective dust estimates and inhalable dust measurements and 129 observations for comparison of subjective dust estimates and respirable dust measurements. Individual subjective dust estimates showed weak to moderate correlations with measured dust concentrations for both the inhalable (R_s = 0.67) and respirable dust fraction (R_s = 0.36). The within-worker reliability coefficients were low (0.2 and 0.1, respectively). Grouped subjective dust estimates performed better and showed a consistent increase with average measured dust levels, in particular for the inhalable dust fraction (R^2 = 0.81). Age, the number of years working in agriculture, education level, the presence of any respiratory symptoms, and the language of the questionnaire did not have a significant independent effect on the relationship between measured dust levels and subjective dust estimates. California agricultural workers appear to be reasonably good at estimating inhalable dust levels, in particular if an average of many different workers is taken, but they are unable to provide good estimates of respirable dust levels. Measuring dust levels remains the preferred option.
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INTRODUCTION

Measuring occupational exposure levels for epidemiologic research is time-consuming and expensive; therefore, subjective estimates are sometimes used instead. Various epidemiological studies have used workers' subjective estimation of their exposure as a measure of exposure, but few studies have validated these estimates with actual measurements [Halpin et al., 1994; doPico et al., 1983; Fonn et al., 1993, Bachmann and Myers, 1991]. Expert estimation of exposure appears to be better than workers' estimation [Kromhout et al., 1987; Teschke et al., 1989]. Expert estimation of exposure improved when some measurement data were provided [Hawkins and Evans, 1989; Post et al., 1991] and appeared to be dependent on the type of exposure [Post et al., 1991]. Most commonly used are 3- or 4-point scales or categories [Halpin et al., 1994; doPico et al., 1983; Fonn et al., 1993; Bachmann and Myers, 1991; Kromhout et al., 1987; Hawkins and Evans, 1989; Post et al., 1991] and occasionally 11-point scales [Musk et al., 1989] to rate exposure levels subjectively. The presence of symptoms was a predictor for the exposure rating in a grain mill study

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[Fonn et al., 1993]. The subjective exposure estimation might in addition be dependent on the nature, level and variability of exposure, the knowledge of the process, the rating scale, and the education level of the respondents. Although subjective exposure assessment could be useful for epidemiological research, little has been done to explore and validate it.

This study was carried out in California, a state that has a very large agricultural industry, with approximately 76,000 farms selling an estimated $19.9 billion of farm products in 1993 [California Department of Agriculture, 1993]. As many as an estimated 1.5 million people were directly employed on these farms [Nieuwenhuijsen et al., 1996]. In agriculture, airborne exposures have been associated with respiratory disease [May and Schenker, 1996]. Exposure assessment in agriculture is difficult because of the varied and cyclic nature of the farmers' work and the diverse locations of the farms. Exposures may vary with local farming practices, commodities grown or raised, climate, and other factors. The use of subjective exposure estimates by agricultural workers would be useful for epidemiologic studies of respiratory disease in this population, but little research or validation has been done in this area.

The aim of this study was to relate workers' subjective estimation of dust exposure levels to personal dust exposure measurements in an agricultural setting.

MATERIAL AND METHODS

From our farm operator cohort, which is described elsewhere [Nieuwenhuijsen et al., 1996], 17 farms in Solano and Yolo counties, California, were randomly selected, stratified for commodities; 10 farms agreed to participate (Table I). The farms were visited 8 times at periodic intervals over the period April 1995–June 1996, except for farms 1, 6, 8, and 10, which were visited 5, 7, 3, and 9 times, respectively. Farm 8 went out of business during the study. Workers on the farms were asked to wear either an Institute of Occupational Medicine (IOM) inhalable dust sampler (SKC West, Fullerton, CA) or a respirable dust cyclone (BGI Inc., Waltham, MA) during various operations on the farms. The IOM inhalable dust sampler contained a 25-mm-diameter polyvinylchloride (PVC) filter (pore size 5 µm) and was connected to a personal sampling pump run at 2 liters/minute. The respirable dust cyclone contained a 37-mm diameter PVC filter (pore size 5 µm) and was connected to a small pump run at 2.2 L/min (50% cut point diameter = 4 µm). The membranes and filters were weighed before and after sampling on a six figure ATI Cahn C-35 microbalance (ATI Orion Cahn, Boston, MA) and a dust concentration was calculated using the difference in filter weight, after adjustment for blanks, and the air-sampling volume.

The average sampling time for the IOM inhalable dust sampler was 157 min and for the respirable dust cyclones 165 min. This reflects the duration of the operations. For the IOM inhalable dust sampler the detection limit was 0.030 mg per filter and for the cyclone 0.067 mg per filter. In total 142 inhalable dust measurements and 144 respirable dust measurements were taken. Seven-tenths of 1% of the inhalable dust samples and 46% of the respirable dust samples were below the detection limit. Measurements with values below the detection limit were assigned one-half the value of the detection limit for statistical analyses. The measurements were assumed to be independent as required for the statistical analyses. Both the IOM inhalable dust and respirable cyclone measurements could be best described with a log normal distribution.

TABLE I. Characteristics of Farms Included in a Survey of Quantitative and Qualitative Dust Exposure Estimates: California, 1995/1996

		No. of	
Farm	Commodities	Livestock	Acres
1	Hand harvested fruit, vegetables		30, 20
2	Hand harvested fruit, nuts		27, 5
3	Poultry, mechanically harvested nuts	40,000	30
4	Poultry, mechanically harvested nuts		1,200
5	Field crops, vegetables		2,100, 1,670
6	Field crops		200
7	Vegetables, field crops		3,390, 360
8	Vegetables, field crops		287, 485
9	Dairy cows, field crops	900,	120
10	Dairy cows, field crops	450,	110

After each sampling period, workers were asked to fill out a short questionnaire asking them to rate the dust exposure (dust score) on a scale from 0, ''being no dust exposure at all,'' to 10, ''being dust exposure that severely restricted your view,'' the entire sampling period. They were also asked to state their age, the number of years working in agriculture, education level and the presence of any respiratory symptoms. Both English and Spanish versions were available. The workers rated only their own exposure. Since we measured during a particular operation, we assumed that the dust concentration was fairly constant over the sampling period. One hundred and twenty-four questionnaires were filled out after the sampling periods when inhalable dust was measured. One hundred and twenty-nine questionnaires were filled out after the sampling periods when respirable dust was measured. Characteristics of the workers are given in Table II. For 20 workers, there were two dust scores and two inhalable dust measurements; for 28 workers, there were two dust scores and two respirable dust measurements.

The software package SAS (SAS Institute, Cary, NC) was used for statistical analyses. Spearman rank correlation coefficients were calculated between individual measured dust concentrations and individual subjective dust estimates.

TABLE II. Characteristics of Agricultural Workers Included in a Survey of Quantitative and Qualitative Dust Exposure Estimates: California, 1995/1996

	Inhalable dust (n = 124)	Respirable dust (n = 129)
Median age (yr)	33	34
Years in agriculture	10	10
Highest education		
Primary school	62%	62%
Secondary school	10%	9%
High school	8%	7%
Undergraduate	8%	7%
College	12%	15%
Respiratory symptoms	10%	10%
Spanish language questionnaire	84%	82%

The coefficients could be interpreted as intermethod reliability coefficients. Workers with two dust scores and dust measurements were used to calculate a within-worker reliability coefficient (scale 0–1), using an analysis of variance (ANOVA) model (Proc GLM) with dust scores as dependent variable and the measured dust exposure and the workers as independent variable. This reliability coefficient was calculated by dividing the between-worker variance by the between-worker variance and within-worker variance. (It shows how reproducible the workers' estimates are.) Analyses of variance and regression analyses were used to explore and describe the relation between dust scores and dust measurements. The adjusted R^2 could be interpreted as a validity coefficient and is a measure of the strength of the relationship between the subjective dust estimates and the measured dust exposure (scale 0-1).

RESULTS

Inhalable Dust

The individual inhalable dust concentrations increased with an increase in dust scores, although there appears to be considerable variation within each dust score category, implying that individual dust scores might not be a good estimate for the actual dust exposure level (Fig. 1). The Spearman rank correlation coefficient between the individual inhalable dust measurements and the individual dust scores was 0.67 ($P < 0.0001$) (and 0.65, $P < 0.0001$) if only one measurement per worker was used), implying that dust scores and measured dust levels correlate fairly well if many different workers are used. The within-worker reliability coefficient was low (0.2), implying that the reliability of the estimates within workers is very low. Using the repeated measurements and analyses of variance with the measured dust concentrations or the dust scores as dependent variable and the workers as independent variable, we found that the between-worker variance explained approximately 85% of the total variability in measured dust levels ($S^2 = 2.49$), as well as in the dust scores ($S^2 = 0.41$), implying that the differences in measured dust concentrations and dust scores are much larger between workers than within workers. Table III and Figure 2 show that the average dust levels increased with an increase in the dust scores, implying that grouped dust scores might be a reasonable estimate for dust exposure levels and that there appeared to be a log-linear relationship. When the geometric means were used as dependent variables and dust scores as independent variables in a regression analyses, the relationship between dust scores and average inhalable dust levels could be described as ln (dust) $= -0.92 + 0.35$*dust score (standard error regression coefficient $= 0.06$, $P = 0.0002$, $R^2 = 0.81$). When the arithmetic means were used as dependent variables, the relationship could be described as ln (dust) $=$ -0.51 $+ 0.36$*Dust score (standard error regression coefficient $= 0.06$, $P = 0.0002$, $R^2 = 0.81$). Age, the number of years working in agriculture, education level, the presence of any respiratory symptoms, and the language of the questionnaire did not have a significant independent effect on the relationship between dust concentration and dust scores (data not shown). The regression equations were very similar if only one measurement per worker was used, and if only the measurements above the limit of detection were used.

Respirable Dust

Figure 3 shows that there was little relationship between the individual dust scores and the individual respirable dust measurements. There is large variation in dust concentration within each dust score category, implying that individual dust scores might not be a good estimate for the actual respirable dust exposure level. The Spearman rank correlation coefficient between the individual respirable dust measurements and the individual dust scores was 0.36 ($P <$ 0.0001) (and 0.29, $P < 0.04$ when only one measurement per worker was used), implying that there is little correlation between the measured dust levels and dust scores (even when many different workers are used). The within-worker reliability coefficient was very low (0.1), implying that the reliability of the estimates within workers is very low. Using the repeated measurements and analyses of variance with the measured dust concentrations or the dust scores as dependent variable and the workers as independent variable, we found that the within-worker variance explained 67% of the total variability in measured dust levels ($S^2 = 1.57$) and 57% in the dust scores ($S^2 = 0.19$), implying that the differences in measured dust concentrations and dust scores

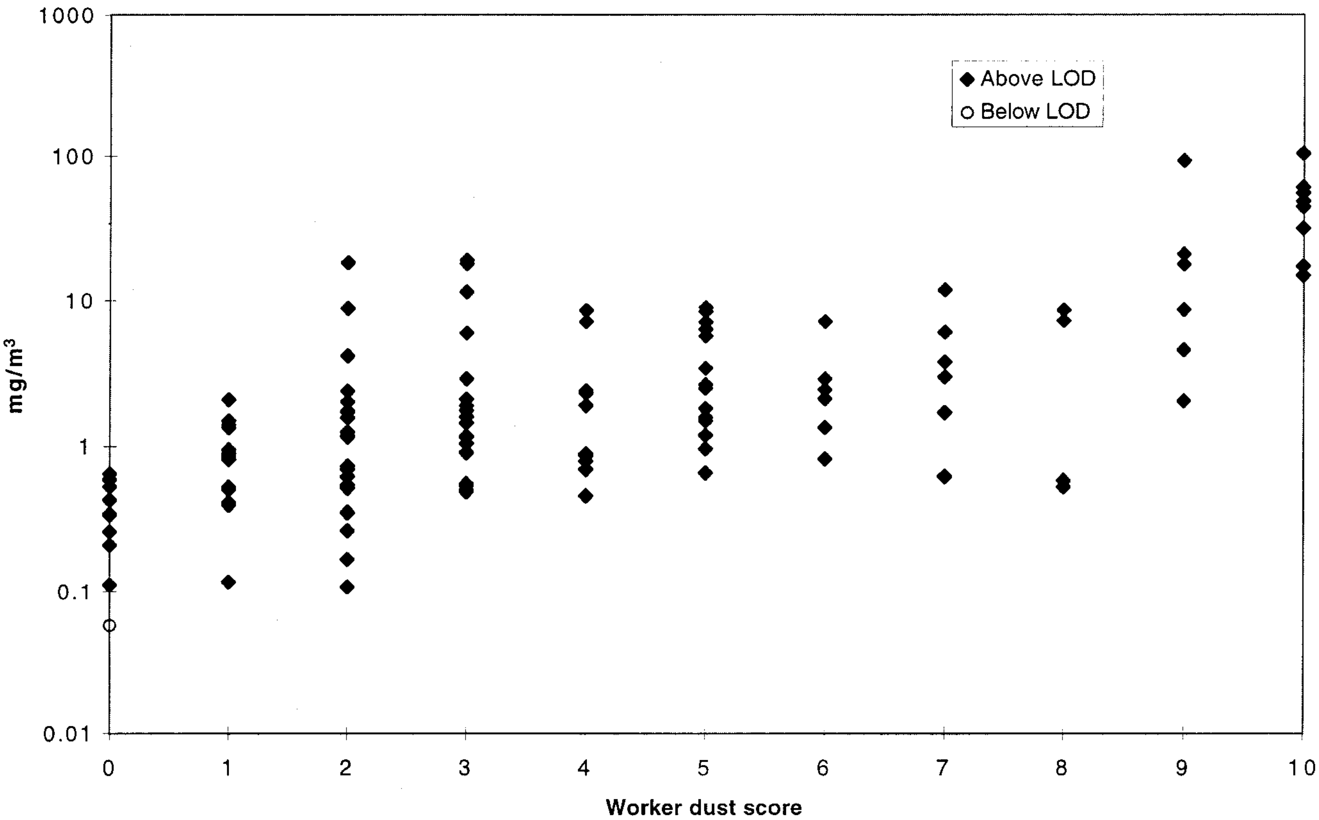

FIGURE 1. Individual inhalable dust measurements plotted against individual worker dust scores. California 1995/1996 study.

TABLE III. Inhalable Dust Exposure Levels (mg/m^3) by Worker Dust Scores in a Survey of Quantitative and Qualitative Dust Exposure Estimates: California, 1995/1996

Dust score	n	n < LOD (%)	AM	GM	GSD	Min	Max
0	11	1 (9%)	0.37	0.31	2.15	0.06	0.65
1	17	0 (0%)	0.87	0.73	1.96	0.12	2.06
2	21	0 (0%)	2.31	1.01	3.45	0.11	18.28
3	20	0 (0%)	3.73	1.80	3.07	0.49	18.93
4	10	0 (0%)	2.59	1.61	2.70	0.46	8.54
5	15	0 (0%)	3.57	2.55	2.39	0.65	8.94
6	6	0 (0%)	2.77	2.19	2.08	0.82	7.13
7	6	0 (0%)	4.49	3.07	2.79	0.62	11.91
8	4	0 (0%)	4.25	2.09	4.65	0.53	8.61
9	6	0 (0%)	24.35	11.84	3.77	2.03	92.12
10	8	0 (0%)	46.97	39.57	1.92	14.86	103.46

n, number of dust measurements; AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; Min, minimum; Max, maximum; n < LOD (%) = number (percentage) of samples below the limit of detection.

are much larger within workers than between workers. Figure 4 and Table IV show that the average respirable dust levels increase slightly with an increase in dust scores and this appears to be mainly due to dust scores 9 and 10. The relationship between grouped dust scores and average respirable dust levels could be described as ln (dust) = −2.50 + 0.17*dust score (standard error regression coefficient = 0.07, P = 0.04, R^2 = 0.38) when the geometric means were used as dependent variables, and as ln (dust) = −1.66 + 0.14*dust score (standard error regression coefficient = 0.10, P = 0.18, R^2 = 0.19) when the arithmetic means were used as dependent variables. Age, the number of years working in agriculture, education level, the presence of any respiratory symptoms, or the language of the questionnaire did not have a significant independent effect on the relationship between dust concentration and dust scores (data not shown). The regression equations were similar if only one measurement per worker was used, but different if only the measurements above the limit of detection were used. [Using the GM: ln (dust) = −1.37 + 0.08*dust score, standard error regression coefficient = 0.06, R^2 = 0.14. Using AM: ln (dust) = -0.95 + 0.08*dust score (standard error regression coefficient = 0.10, R^2 = 0.10.] Excluding the measurements under the limit of detection carries the risk that many true low measurements are excluded, and not only those that are under the limit of detection because of the short sampling time and might therefore be biased.

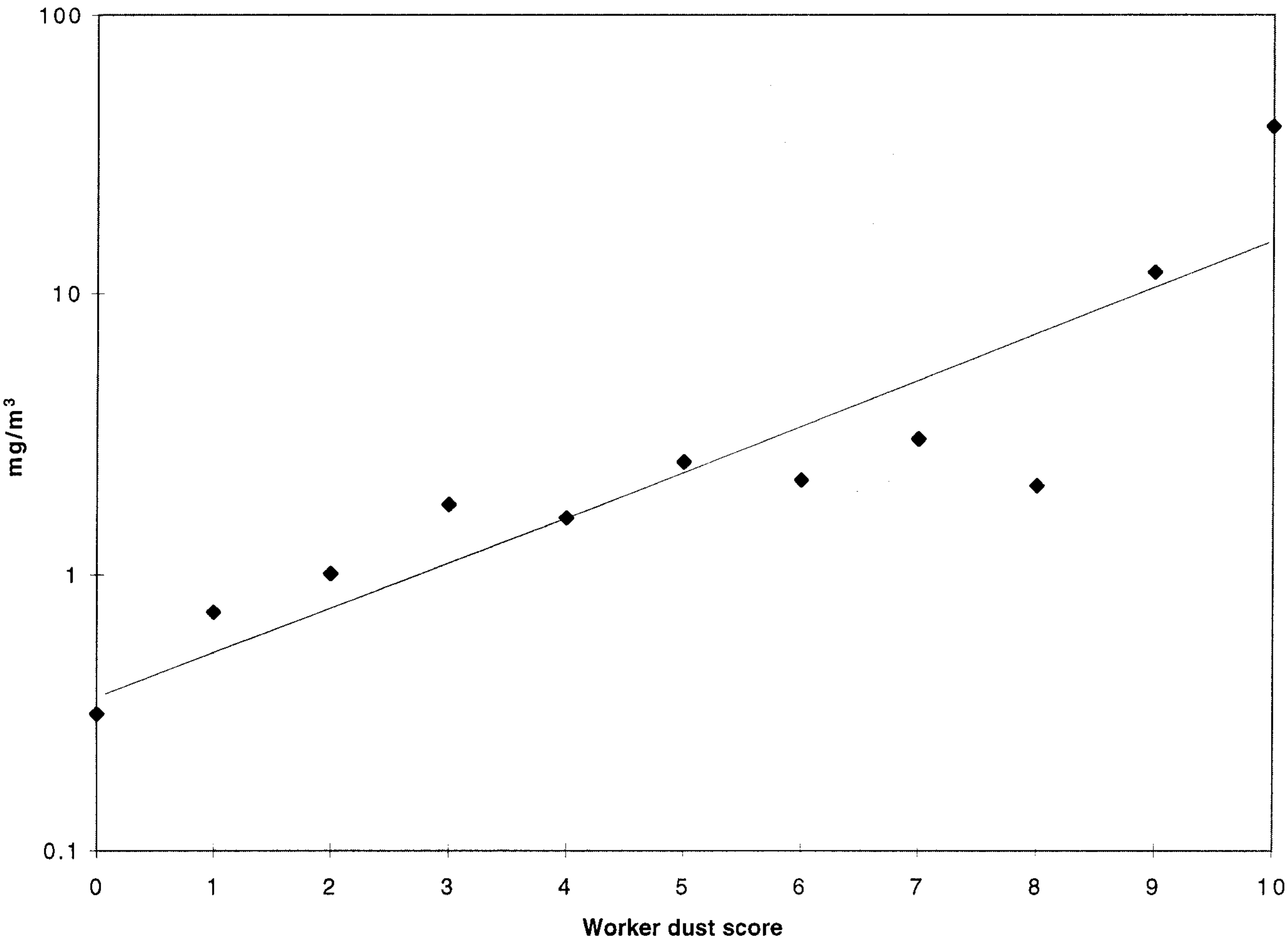

FIGURE 2. Average inhalable dust levels plotted against grouped worker dust scores. California 1995/1996 study.

DISCUSSION

This study relates subjective dust estimates to personal inhalable and respirable dust measurements in California agricultural workers. Individual subjective dust estimates showed weak to moderate correlations with measured dust concentrations for both the inhalable and respirable dust fraction. The within-worker reliability coefficients were very low. Grouped subjective dust estimates performed better and showed a consistent increase with measured dust levels, in particular for the inhalable dust fraction. Age, the number of years working in agriculture, education level, the presence of any respiratory symptoms, or the language of the questionnaire did not have a significant independent effect on the relationship between dust concentration and dust scores. California agricultural workers appear to be reasonably good at estimating inhalable dust levels, in particular if an average of many different workers is taken, but they are unable to provide good estimates of respirable dust levels. Measuring dust levels remains the preferred option.

Several studies have explored the relationship between subjective dust estimates and measured dust levels [Halpin et al., 1994; doPico et al., 1983; Fonn et al., 1993; Bachmann and Myers, 1991; Kromhout et al., 1987; Teschke et al., 1989; Hawkins and Evans, 1989; Post et al., 1991; Musk et al., 1989]. Expert opinion appeared to be better at estimating exposure levels [Hawkins and Evans, 1989; Post et al., 1991], it appeared to be dependent on the type of exposure [Post et al., 1991], and grouped exposure estimates showed a consistent increase with measured dust exposure levels [Halpin et al., 1994; Fonn et al., 1993; Bachmann and Myers, 1991; Kromhout et al., 1987; Musk et al., 1989]. In this study, only workers estimated dust exposure levels and they estimated only their own exposure. Grouped dust exposure estimates appeared to be better than individual dust exposure estimates because the latter showed a large range in measured exposure for individual estimates, resulting in lower correlation coefficients. Grouped subjective dust level estimates showed a consistent increase with measured dust levels, in particular for the inhalable dust fraction.

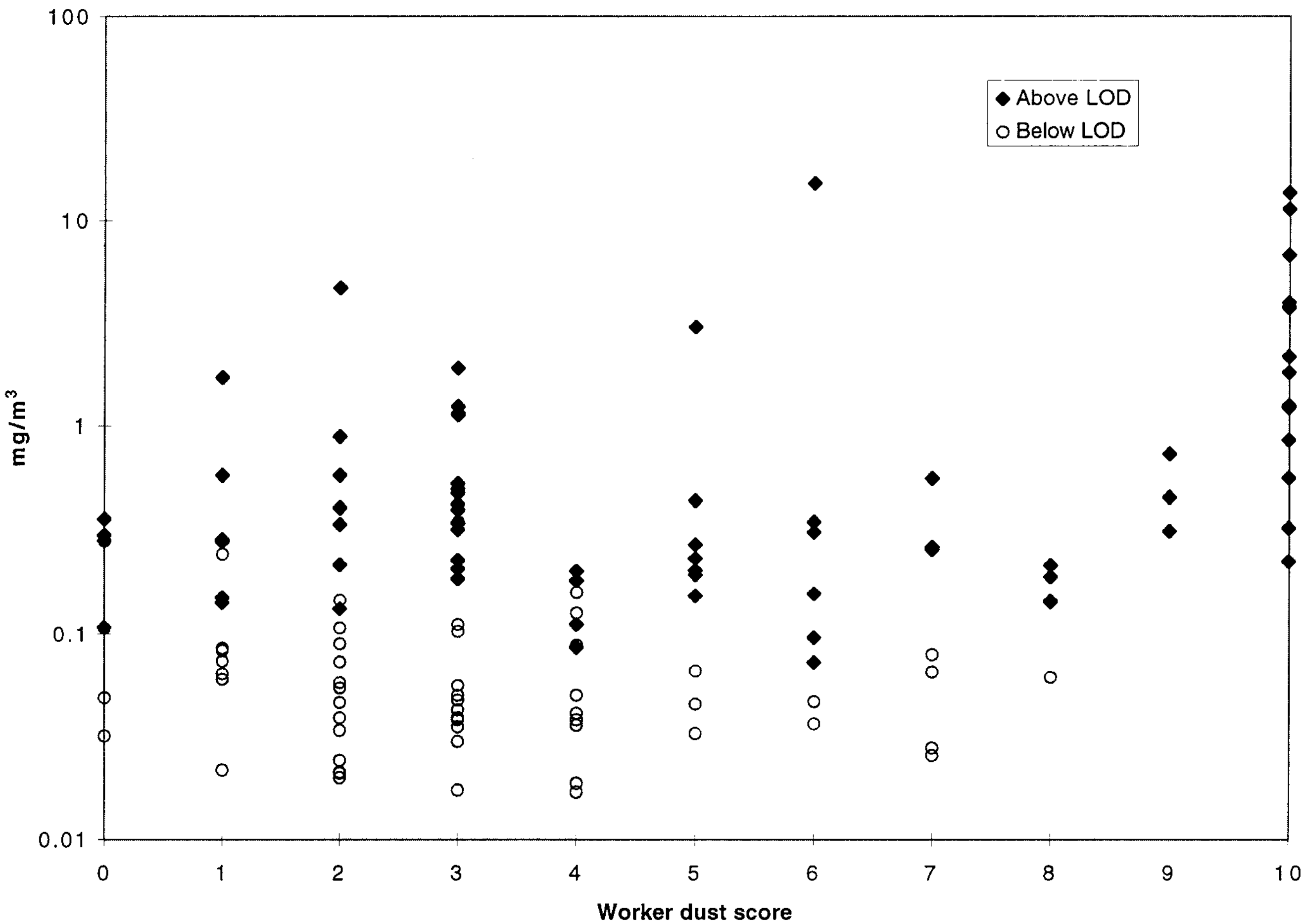

FIGURE 3. Individual respirable dust measurements plotted against individual worker dust scores. California 1995/1996 study.

Using experts has the advantage that they can be trained, while this is fairly difficult for workers, mainly because of time constraints. In this study, we gave the workers only a brief, but consistent, explanation. Workers might only be able to detect larger differences in dust levels, while experts can be trained to observe smaller differences and they can compare many different situations leading to a more consistent rating of exposure. There is most likely to be a learning curve and experts might have done many pilot ratings before they start the actual study. On the other side, various studies have shown that there are differences in the ratings of experts and that even they might not be able to come up with acceptable estimates [Hawkins and Evans, 1989; Post et al., 1991]. The advantage of using workers is that one can use many different workers to get many estimates for, for example, an operation, and then take an average and average out the unwanted variation. Some workers are better at estimating the exposure levels than others, some will overestimate and others underestimate the exposure levels. Of course, one has to realize that there can be true differences in exposure levels between workers within operations, and this should be taken care of. There are many different reasons why workers, but also experts, might not be good at estimating dust levels. There might be number preferences, sensory differences, a wide variation in individual sensitivity, or the desire to go home straight after work, among many other possibilities. Also, subtle differences at low exposure levels are not likely to be estimated well, but large differences at high exposure exposure levels are perceived reasonably accurately.

The subjective dust estimates appeared to be dependent on the size fraction of the dust. Grouped subjective dust estimates for the inhalable dust fraction were better correlated with measured dust levels than the respirable dust fraction. This might be due to the large proportion of measurements under the limit of detection for the respirable fraction, or because the inhalable dust fraction is more visible and workers estimate the inhalable, rather than the respirable, dust fraction. Another explanation might be that there was more variation in dust exposure between operations for the inhalable dust fraction compared with the respirable dust fraction, something that was also noted by Kromhout et al. [1987], even though the overall variability between all the dust measurements was the same (inhalable

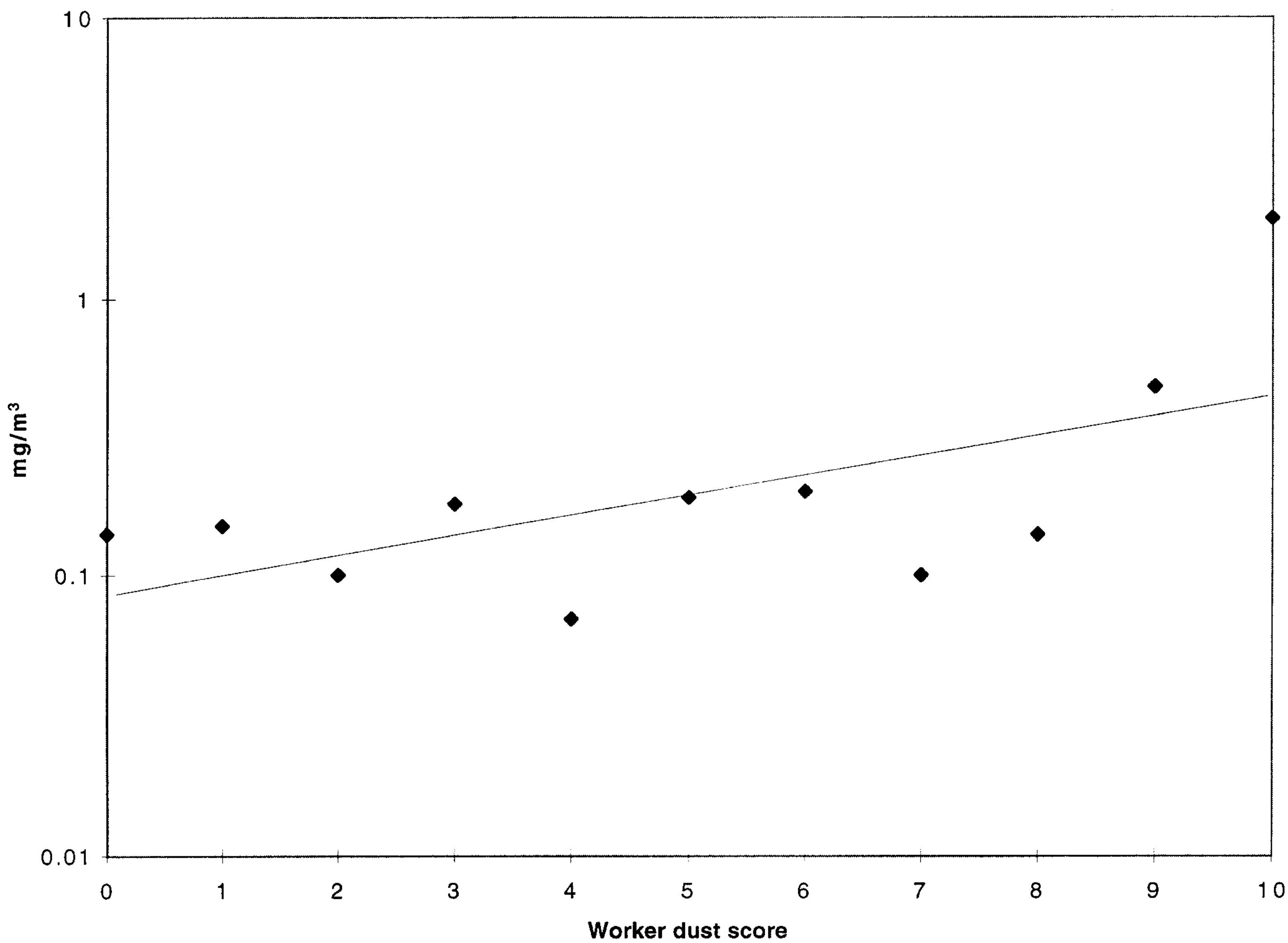

FIGURE 4. Average respirable dust levels plotted against grouped worker dust scores. California 1995/1996 study.

dust GM = 1.8 mg/m^3, GSD = 4.4, respirable dust GM = 0.17, GSD = 4.4). In this population, 60% of the variation in inhalable dust levels could be explained by the type of operation, the type of commodity and the presence of an enclosed tractor cabin, while only 40% of the respirable dust levels could be explained by these factors. In a small subgroup of this population for whom we had repeated measurements, the between-worker variance was much larger than the within-worker variance of dust exposure for the inhalable dust fraction, and the within-worker variance was much larger than the between-worker variance for the respirable dust fraction. This might partly explain why there was a fairly reasonable correlation between measured dust levels and the individual dust scores for the inhalable dust fraction, but not for the respirable dust fraction.

The information presented in this paper is used to derive dust exposure indices for a cohort of California farmers, in which the relation between dust exposure and adverse respiratory health effects is explored. For this cohort, it is impossible to measure the exposure levels for all operations and obtain a sufficient number of measurements per operation. Instead, we asked the subjects in the cohort to rate the dust exposure for the operations they did during the past year on the same rating scale as in this study. We calculated an average rating for the various operations. To obtain exposure indices for the subjects in the epidemiologic study, we multiplied the number of days a worker reported for a particular operation over the past year with the average number of hours they reported doing it, and multiplied this with an exposure intensity estimate. This exposure intensity estimate was either the measured (or assigned for some operations) exposure level for that particular operation, or an estimate obtained from the regression equations in this paper. The average exposure rating of the cohort members for each operation was used in the regression equation to calculate an estimated exposure level in mg/m^3 for that operation. Subsequently, all estimates (day*hr*mg/m^3) for the various operations were summed and a dust exposure index for the past year derived for each cohort member. This was done for inhalable as well as for respirable dust. The correlation between ‘‘regression equation/subjective estimates’’ derived indices and ‘‘measured’’ derived indices was

TABLE IV. Respirable Dust Exposure Levels (mg/m^3) by Worker Dust Scores in a Survey of Quantitative and Qualitative Dust Exposure Estimates, California 1995/1996

Dust score	n	n < LOD (%)	AM	GM	GSD	Min	Max
0	8	4 (50%)	0.19	0.14	2.54	0.02	1.08
1	13	7 (54%)	0.29	0.15	3.10	0.02	1.70
2	21	14 (67%)	0.38	0.10	4.21	0.02	1.70
3	27	12 (44%)	0.38	0.18	3.79	0.02	1.89
4	13	9 (69%)	0.09	0.07	2.31	0.02	0.20
5	10	3 (30%)	0.47	0.19	3.63	0.03	3.01
6	8	2 (25%)	2.01	0.20	6.85	0.04	15.01
7	7	4 (57%)	0.18	0.10	3.32	0.03	0.56
8	5	1 (20%)	0.15	0.14	1.64	0.06	0.22
9	3	0 (00%)	0.51	0.48	1.52	0.32	0.74
10	14	0 (00%)	3.68	1.96	3.48	0.23	13.54

n, number of dust measurements; AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; Min, minimum; Max, maximum; n < LOD (%) = number (percentage) of samples below the limit of detection.

0.90 for the inhalable dust fraction and 0.79 for the respirable dust, implying that it mattered little which method was chosen to get an estimate for the dust intensity. This might be due to the large influence of the duration of exposure. Also, the number of measurements were small compared with the number that was required to obtain accurate and precise exposure level estimates. A study with a sufficient number of dust exposure measurements for all operations would have been the preferred option, and probably will be in the future, although it is also a fairly unrealistic option, given the large number of samples required and costs involved.

The regression lines in this study tended to overestimate or underestimate the dust exposure levels for some dust scores. This might be due to the limited number of samples, which might also lead to some attenuation of the regression coefficients.

There is a large range in dust exposure levels in California agriculture with high dust levels being measured in operations that disturb the soil during the dry growing season, for example during ground preparation operations [Popendorf et al., 1982; Lawson et al., 1995; Nieuwenhuijsen et al., 1997]. California agriculture is very varied and there are many different operations for which it would be difficult to measure the dust exposure levels. Subjective exposure estimates would be useful in cases when dust exposure measurements cannot be taken, although the latter remains the preferred option. As was shown in this study, this works reasonably well for inhalable dust exposure but to a much lesser extent for respirable dust exposure. However, it is very likely that there are hazardous exposures in California agriculture for which this might not work. Also, levels for dust constituents such as endotoxin or crystalline silica are most likely difficult to estimate subjectively.

In cases where subjective exposure assessment seems to work, we encourage its use, in particular in California agriculture with its large agricultural population and evidence of increased respiratory morbidity and mortality among agricultural workers. Relatively little has been published on exposures and exposure levels experienced in California agriculture, but this information is essential to set health and safety priorities. Subjective exposure estimation by those who work in California agriculture could be successful in estimating exposure levels, as was shown in this paper, and could be used to evaluate high-risk environments.

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