ORIGINAL ARTICLE

Task based exposure assessment in ergonomic epidemiology: a study of upper arm elevation in the jobs of machinists, car mechanics, and house painters

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Aims: To explore the precision of task based estimates of upper arm elevation in three occupational groups, compared to direct measurements of job exposure.

Methods: Male machinists (n = 26), car mechanics (n = 23), and house painters (n = 23) were studied. Whole day recordings of upper arm elevation were obtained for four consecutive working days, and associated task information was collected in diaries. For each individual, task based estimates of job exposure were calculated by weighting task exposures from a collective database by task proportions according to the diaries. These estimates were validated against directly measured job exposures using linear regression. The performance of the task based approach was expressed through the gain in precision of occupational group mean exposures that could be obtained by adding subjects with task based estimates to a group of subjects with measured job exposures in a ''validation'' design.

Results: In all three occupations, tasks differed in mean exposure, and task proportions varied between individuals. Task based estimation proved inefficient, with squared correlation coefficients only occasionally exceeding 0.2 for the relation between task based and measured job exposures. Consequently, it was not possible to substantially improve the precision of an estimated group mean by including subjects whose job exposures were based on task information.

Conclusions: Task based estimates of mechanical job exposure can be very imprecise, and only marginally better than estimates based on occupation. It is recommended that investigators in ergonomic epidemiology consider the prospects of task based exposure assessment carefully before placing resources at obtaining task information. Strategies disregarding tasks may be preferable in many cases.

Accurate and precise exposure data are essential in occupational epidemiology. In the present context, ''accuracy'' and ''precision'' refer to the absence of systematic and random errors, respectively. Imprecise exposure assessment impedes determination of quantitative exposure-response relations and may result in false negative conclusions about the aetiological significance of occupational exposures.[1 2] Two basic approaches exist to estimate current exposure in a study population: an ''individual'' approach where the exposure of each subject is assessed separately, and a ''group'' approach where all individuals belonging to a group are assigned the group mean exposure.[3 4] Exposure groups may be defined by occupation or other common features of work environment.[5–7] In exposure-outcome studies based on linear regression of continuous variables, the group approach minimises attenuation but implies larger imprecision than the individual.[4] However, in logistic regression of dichotomous outcomes on continuous exposures, even a group approach results in bias that increases with increasing exposure variability between subjects and with decreasing precision of the group mean.[8] In large epidemiological studies, feasibility considerations often favour a group based approach where average exposures from a sub-sample of individuals from a particular occupational group are assigned to subjects who have not provided any exposure information except for their group membership. The precision of the job exposure estimate can be improved by adding more individuals and/or measurement days to the measured sub-sample.

Measurements are often expensive in terms of equipment and the time needed for data processing. This has lead to a search for methods of estimating exposure on the basis of cheap descriptors. The composition of tasks in the job has been proposed to be indicative of the overall job exposure. If so, an efficient way of obtaining precise group mean estimates could be to assess the job exposure of individuals in the group by combining personal task proportions in the job—obtained by diaries, for example—with directly measured task exposures from a database obtained on fewer subjects.[1]

Several ergonomic studies have used a task based approach to estimate job exposure. Some studies have used personal task exposures for modelling exposure across days within individuals.[9–11] Other studies have modelled exposure across subjects, relying on collective task exposure matrices (TEMs) obtained from the literature[12 13] or constructed as part of the study.[14–16] Task information has also been used to structure the sampling of exposure data within a measurement day.[17]

The potential usefulness of task based modelling has been discussed based on the relative exposure variability within and between tasks[18 19] and the variance of task based estimates compared to the variance of observed job exposures.[14] The ability of task based estimates to assess job exposures has been evaluated as well,[9 13 20] but without exploring whether job based exposure assessment disregarding tasks would have been equally efficient. Such investigations are needed to extend existing guidelines for mechanical exposure assessment to encompass task based strategies.[1 21–23]

The aim of the present study was to explore the performance of task based estimation of job exposures using a collective TEM, expressing performance as the gain in

Abbreviations: TEM, task exposure matrix; CNC, computer operated numerically controlled

Main messages

- Task based estimation of job exposure was unsuccessful.
- The precision of an occupational group mean exposure obtained by direct measurements on a number of subjects could hardly be improved by adding subjects for whom only task based job exposure estimates were available.

Policy implications

- Investigators in ergonomic epidemiology are recommended to consider the prospects of task based exposure assessment carefully before placing resources at obtaining task information.
- Strategies disregarding tasks may be preferable in many cases.

precision of occupational group mean exposures that could be obtained by adding subjects with task based estimates to a group of subjects with measured exposures in a ''validation'' design.[24] The study was based on empirical data on upper arm elevation collected as part of an epidemiological study of shoulder disorders.[25 26]

METHODS

Subjects and workplaces

The study included machinists, car mechanics, and house painters. Within a defined geographical area, all relevant companies were identified in the Danish Central Business Register. Companies with less than five journeymen were excluded, and machine shops were only included if they had computer operated numerically controlled tools (CNC tools). The final company base comprised 29 machine shops, 110 garages for domestic cars, and 119 painter's workshops with altogether 942 machinists, 692 car mechanics, and 1579 house painters. From each occupational group 13 pairs of colleagues were sampled at random. Paired sampling was motivated by logistic concerns. For each subject, one working week was selected for data collection. Inclusion criteria were at least one year of employment as a journeyman, male sex, age 30–65 years, and at least four scheduled working days in the specified week. Subjects were excluded if they had shoulder complaints that interfered with their performance at work. When a subject was excluded ($n = 1$) or did not want to participate ($n = 6$), he was replaced by another randomly sampled subject, preferably from the same company. The project was approved by the scientific ethical committee system.

Data collection

The survey was conducted from August 1999 to February 2000. All three occupational groups were represented throughout the data collection in order to cover seasonal variability. Whole day measurements were performed for all working days in the selected week, typically starting on a Monday. If recordings were lost, the subject was asked to participate an extra day. Upper arm elevation was measured with respect to gravity in six 15° intervals from 0° to 90°, and one interval covering angles larger than 90°. The measurements were performed at a frequency of 1 Hz using an inclinometer (abduflex) which allowed continuous registration for eight hours.[27–29] The present study focused on the right arm rather than the dominant arm because the working conditions of machinists and car mechanics forced right and left handed subjects to adopt similar working methods.

For each occupational group, a diary was constructed with 10–12 preprinted tasks which were identified in collaboration with occupational ergonomists and experienced tradespeople. The tasks were intended to cover all processes in the jobs and to represent meaningful and common job elements. Initially, a pragmatic task definition was chosen based on a comprehensive list of tasks prepared by the tradespeople who helped construct the diaries. In order to ensure exposure contrast between tasks, the tasks were then grouped according to what was judged to be the typical extent of upper arm elevation (0° to 30°, 30° to 90°, or more than 90°). Finally, it was controlled that the diaries unambiguously covered all tasks mentioned in a description of the Danish training of machinist's apprentices, a number of invoices from a large garage for domestic cars, and a list of tasks prepared by the Employees' Health Service for Danish Painters to help the enterprises carry through their workplace assessments according to Danish legislation. During the measurements, subjects filled in the diary each time they started a new task. The reports of clock time in the diaries were synchronised with the abduflex recordings.

Processing of the dataset

A source dataset was defined for each occupational group (fig 1). The abduflex data were processed to give the percentage of time with the right upper arm elevated (a) more than 90°, and (b) more than 90° for successive periods of 5 seconds or more. The two exposure variables were chosen according to prevailing hypotheses about the pathogenesis of shoulder disorders,[30–32] and in order to reflect the basic dimensions of exposure—that is, duration, level, and frequency.[1] The variable (b) was determined after exposure variation analysis[33] and represented the period length—among several tested alternatives—which gave the best contrast between occupations. The exposure variables were calculated for the whole working day and for each task occurring during the day. If a subject performed a given task more than once during the day, the recordings from the task were pooled.

Summary statistics were derived by calculating the arithmetic mean across days for each subject, and subsequently averaging these individual specific mean exposures to obtain occupational group mean values. The set of task exposure means formed the TEM used for estimation (below). Exposure variances between subjects and between days within subjects were estimated for each task and for the entire job using restricted maximum likelihood algorithms in a one way random effects model (SAS 6.12 Proc Varcomp).

Task based exposure assessment and regression calibration

For each participant, a specific TEM was constructed using exposure data from all other subjects in the occupational group, in order to simulate the situation that the subject had not himself contributed to the TEM. If a task had been performed by only one subject, the measured mean job exposure for the group was used instead of the missing task exposure, again omitting the subject considered. For each diary day, the job exposure was modelled by weighted averaging of task exposures in the TEM, using the task proportions from the diary as weights.[1] Each participant received four task based job exposure estimates—that is, the modelled job exposure of day 1, the average of days 1 and 2, the average of days 1 to 3, and the average across all four days of data collection.

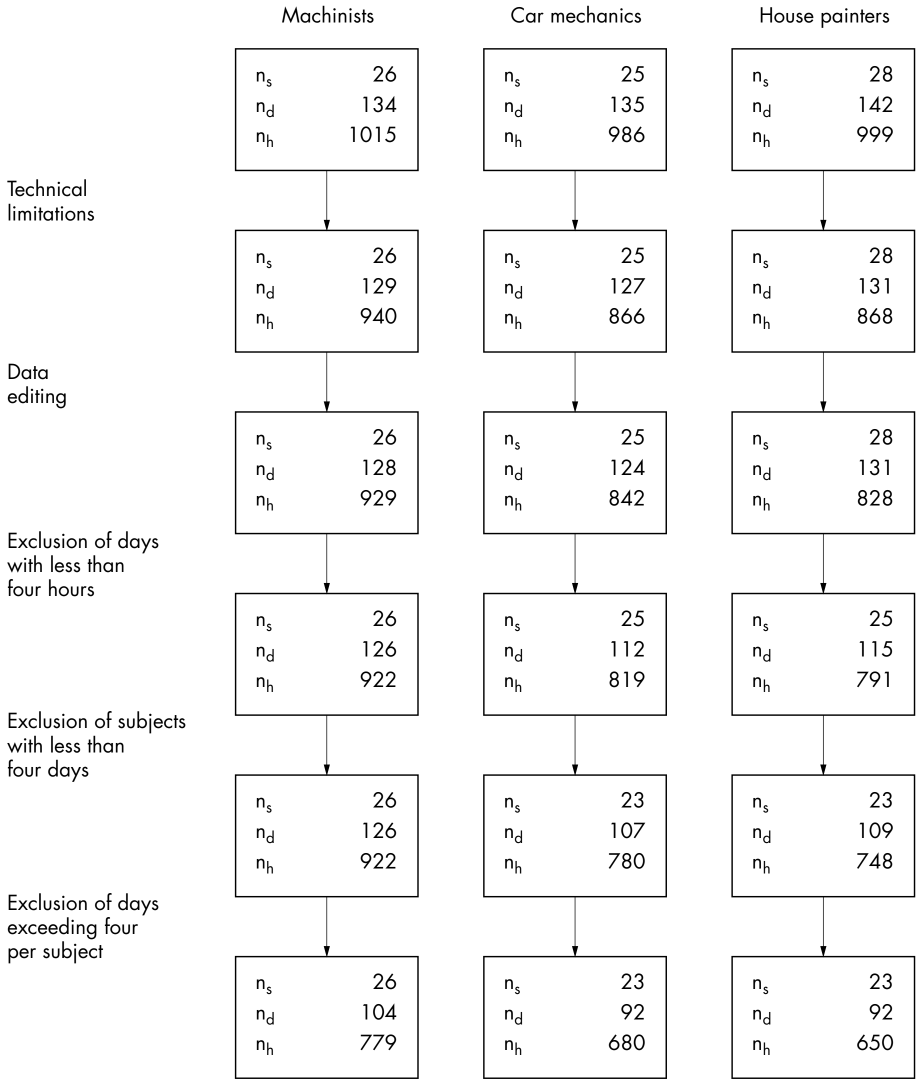

Figure 1 Source dataset (bottom boxes) for machinists, car mechanics, and house painters. n_s, n_d, n_h: number of subjects, days, and hours with arm elevation data.

Using this data set, we investigated the performance of a "double sampling",[34] "combined direct and indirect",[35] or "validation" design in which extensive exposure data are collected from a limited "validation" sample of subjects and used to estimate the exposures of additional subjects from whom only limited information is available. Validation designs have been suggested as tools for maximising the precision of estimated group means in relation to invested resources. In our case, both measured job exposures and task based estimates were available for subjects in the *validation sample*. Within this sample, linear least squares regression was used to determine the relation between task based and measured individual mean job exposures for one to four days of data collection (SAS 6.12 Proc Reg; fig 2).[34 35] Additional virtual subjects were then assumed to be included in a *diary-only sample*. For these subjects only task based job exposure estimates were available which were assumed to be calibrated using the validation sample regression.[34 35]

For the combined group of validation and diary-only subjects, the standard error, s_μ, of the group mean exposure was determined according to:[34 35]

$$s_\mu = (s_s^2 \cdot (1-\rho^2)/n_v + \rho^2 \cdot s_s^2/(n_v+n_D))^{\frac{1}{2}} \quad (1)$$

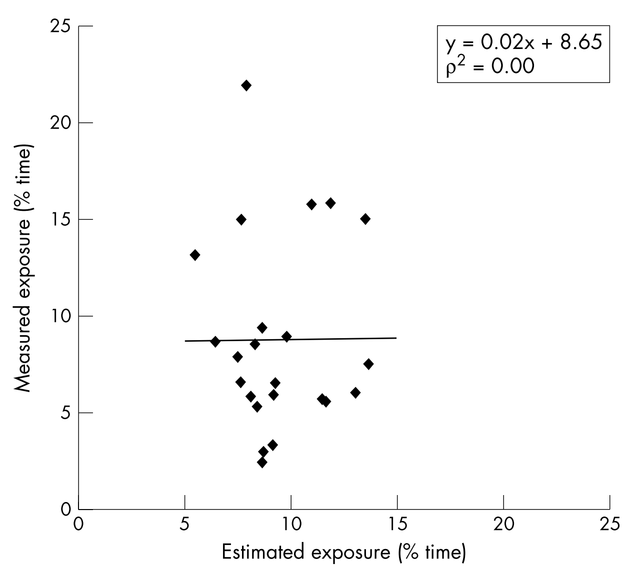

Figure 2 Example of regression analysis of measured mean job exposures on task based estimates of upper arm elevation above 90°. House painters (n = 23), four days of data collection per subject.

where s_S^2 is the variance between measured individual mean job exposures in the validation sample, ρ^2 is the squared correlation between measured and estimated individual mean job exposures obtained from linear regression in the validation sample, n_V is the number of subjects in the validation sample, and n_D is the number of subjects in the diary-only sample. Thus, if the task based estimates are perfect—that is, $\rho^2 = 1$, the first term in equation 1 disappears, and s_μ is a straightforward inverse function of the total number of subjects (n_V+n_D). If task based estimation is extremely imprecise—that is, ρ^2 approaches 0, the second term vanishes, and s_μ approaches the variance of the measured mean exposure in the validation sample, which means that adding diary-only subjects does not improve the precision of the combined group mean. We explored the precision of the combined group mean by solving equation 1 for different sizes of the validation and diary-only samples, using the source datasets to obtain squared correlation coefficients and empirical values of s_S^2 for one to four measurement days per subject.

For comparison, we estimated the precision of a group mean obtained by direct measurements, only. The standard error of the mean was calculated according to:

$$s_\mu = (s_s{}^2/n_s)^{\frac{1}{2}} \qquad (2)$$

where n_s is the number of subjects. The equation was solved for 1 to 100 subjects, and empirical values of s_S^2 for one to four measurement days per subject were used to investigate the effect of increasing the number of days.

RESULTS

Source datasets

Table 1 shows characteristics of the subjects in the three source datasets. Tables 2–4 present data material, mean exposure, and exposure variability at job and task levels for machinists, car mechanics, and house painters, respectively. For both exposure variables, the house painters showed the highest mean exposure and the machinists the lowest. At the job level, we found considerable exposure variability between subjects as well as between days within subjects, and the relative size of these two variance components differed between groups. In each occupational group, tasks differed in mean exposure. The task distribution varied substantially between individuals, as shown by the wide range in the percentage of daily measurement time spent in each task. The only task that occurred every day for all subjects in an occupation was "break" among machinists. Among house painters and car mechanics a few days were found with no breaks, but in most of these cases the diary contained periods without task specification. In general, the within-task exposure variability was considerable compared to the variability at the job level.

Task based exposure assessment

Tables 5–7 present measured group mean exposures and associated overall variances between subjects, s_S^2. As expected, s_S^2 tended to decrease when more days were included in the individual mean job exposure estimates. The tables also show the results of linear regression of measured on task based individual mean job exposures (cf fig 2). Only four squared correlation coefficients, ρ^2, exceeded 0.50, and they could all be ascribed to an outlier with high measured exposures. When he was removed from the analyses, the ρ^2 values decreased to around 0.10. His deviating results could not be ascribed to errors in his diaries and measurement data. The same was true of an outlying car mechanic.

Using arm elevation above 90° among machinists as an example, fig 3 illustrates the precision of the group mean when combining validation and diary-only samples and when including only subjects with direct measurements of job exposure. As expected, the precision of the group mean increased—that is, the standard error decreased, when more subjects with measured job exposures were included. The effect of increasing the number of measurement days per subject was far less pronounced. Thus, an s_μ of 0.5% time could be obtained by monitoring 15 subjects one day each, or 13 subjects four days each. Inclusion of subjects with task based exposure estimates improved the precision of the group mean only marginally beyond what was obtained on the basis of the directly measured subjects in the validation sample.

DISCUSSION

The present study explored the performance of task based assessment of upper arm elevation above 90° in three occupational groups. The investigated approach combined personal task proportions from diaries with exposure data from a collective TEM. Task based estimation of job exposure turned out to be unsuccessful. Consequently, only a negligible gain in precision of group mean exposures could be obtained by adding subjects with task based exposure estimates to a sample of subjects who were directly monitored, as suggested in validation designs.

The present study represented most of the exposure spectrum in a wide range of occupational groups for which directly measured data on upper arm elevation above 90° have been reported, including construction workers,[36–38] industrial workers,[36] and office workers.[28] When allowing for differences in survey design, our results are in accordance with previous abduflex measurements for house painters.[36]

Numerous ergonomic studies have classified tasks in biomechanical terms such as the proportion of daily working hours with hands above shoulder level.[29 39–41] However, it has

Table 1 Characteristics of subjects in source datasets

	Machinists n = 26	Car mechanics n = 23	House painters n = 23
Age (years), mean (SD)	44.6 (10.6)	44.1 (10.2)	45.1 (9.6)
Height (cm), mean (SD)	178.7 (5.9)	180.4 (5.7)	179.7 (5.1)
Weight (kg), mean (SD)	83.6 (12.5)	80.3 (11.2)	81.8 (12.0)
Handedness			
Right handed (%)	96.1	82.6	82.6
Left handed (%)	3.9	8.7	4.4
Both handed (%)	0.0	8.7	13.0
Duration of employment in trade* (years), mean (SD)	25.8 (12.1)	26.1 (10.9)	26.8 (9.1)

All subjects were male.
*Including apprenticeship.

Table 2 Data material, mean exposure, and exposure variability at job and task levels for machinists

	Job	Regular lathe	Break	CNC*: Lathe turning Programming	Grinding Surface grinding	Other assembly	CNC*: Setting up Milling Drilling	Large lathe/ drilling machine/ machine centre	Assembly at fitter's bench	Milling cutter	Upright drilling machine	Unspecified	Bench drilling machine
Data material													
Subjects	26	8	26	6	4	10	6	2	6	2	5	5	0
Days/subject	4	3.5	4	3.8	4	2.3	3.5	2.5	2.1	2.5	1.8	1.8	0
% of daily measurement time													
Mean	100	20.4	14.5	13.9	13.4	12.8	10.1	2.0	4.9	2.0	1.8	1.8	0
Range		0–94.8	4.6–59.8	0–92.8	0–93.6	0–95.4	0–94.5	0–61.0	0–92.1	0–61.0	0–34.1	0–34.1	
Exposure variables													
% time >90°													0
Mean	1.6	1.1	1.6	0.8	0.8	1.0	1.2	5.4	0.6	5.4	5.9	5.9	
var_{BS}	2.8	0.8	2.8	0.0	0.1	0.5	0	0	0.3	0	99.2	99.2	
var_{BD}	0.9	1.2	8.2	0.3	0.2	0.6	1.3	11.6	0.0	11.6	23.8	23.8	
% time >90° at least 5 seconds													
Mean	0.9	0.6	1.3	0.5	0.4	0.6	0.8	3.7	0.4	3.7	1.2	1.2	0
var_{BS}	0.4	0.5	2.5	0.0	0.0	0.1	0	11.5	0.3	11.5	1.4	1.4	
var_{BD}	0.6	1.1	7.6	0.2	0.1	0.7	1.4	1.6	0.0	1.6	0.3	0.3	

All tasks occurring in the diaries are shown, ordered according to decreasing proportion of daily measurement time. The task category ''unspecified'' was formed a posteriori for periods with insufficient task information.
s_{BS}^2, s_{BD}^2, variance between subjects and between days (within subject), respectively.
*CNC, computer operated numerically controlled tools.

proved to be very difficult to obtain accurate and precise information about the duration of such ''tasks'' by inexpensive methods such as self-report or expert judgement.[42 43] As an alternative, tasks can be classified according to natural elements of the job.[9 10 14 18] Such tasks are more easily recognised by the subjects which suggests that reasonably correct task durations can be obtained by self-report,[44 45] at least in jobs without rapid changes of tasks. However, natural task categories may not contrast much in exposure.[17 46] We developed a procedure for constructing diaries which was intended to synthesise the best features of classifications based on biomechanical and ''natural'' criteria.

The diaries worked well in practice. Periods without task specification occurred infrequently, and the option of inserting supplementary tasks in the diaries was rarely used. In addition, the contrasts between task exposures were large when compared to other studies where jobs have been divided into their constituent tasks.[14 17 46 47] The face validity of the TEM was good in that the task exposures were ranked as expected by the tradespeople who helped construct the diaries. Task proportions also varied between individuals (cf tables 2–4) as a further indication that task based exposure estimation could be successful.

The task based estimates turned out to be very imprecise. The predictive ability of the task based estimates might have been better if tasks with large exposure variation could have been split into sub-tasks. Another possible improvement could be to cluster tasks a posteriori according to their empirical exposure.[17] In any case, considerable within-task variability in upper arm elevation would probably be unavoidable, as suggested by data from highly constrained tasks under controlled experimental conditions.[48] The points in time when tasks started and ended were reported with a resolution of 5–15 minutes. This introduced errors in the estimated job exposures, not only because task durations were imprecise, but also because task exposures were extracted according to the diary timeline.[17] However, inspections of the abduflex recordings showed that the exposure level did not change abruptly around the time when a new task was commenced. Also, the task sequences were relatively long which further reduced the significance of this source of error. More exact information on task schedules could have been obtained by observing the subjects,[46] but then, in the present study, indirect exposure assessment would have been more expensive than direct measurements. Information about individual task occurrences could also have been pursued in production records. However, the quality of such data might not be superior to diary information, and comparable records were not available for the three occupational groups. Due to the consecutive measurement schedule, the amount of data for a particular task was proportional to its occurrence in the occupation. While proportional sampling can be an efficient strategy for determination of mean task exposures in individuals,[17] it also implies uncertain exposures for rare tasks. Additional data collection for selected rare tasks might have been appropriate. However, we believe that none of the possible improvements discussed above would substantially change the performance of the task based strategy.

The use of a collective TEM to model job exposure across subjects has been explored in a study of energy expenditure using a validation sample.[13] Estimates of individual job exposures were obtained by combining self-reported ''usual'' task durations with task exposures from a literature database. ''True'' job exposures were obtained by task stratified measurements for two working days. A squared correlation coefficient of 0.49 was found between estimated and true exposures, and this was ascribed to the use of task information. However, the study comprised 27 subjects from

Table 3 Data material, mean exposure, and exposure variability at job and task levels for car mechanics

	Job	Engine room	Break Waiting time Testrun	Brakes	Suspension	Brake pipes Dashboard Airbag	Wheels Tyres	Door lock New car Lights	Clutch Gearbox Drive shafts	Unspecified	Electronics	Seats Comfort	Tow-bar	Change of oil	Exhaust
Data material															
Subjects	23	23	23	19	15	16	18	16	9	7	12	10	8	14	3
Days/subject	4	2.9	3.9	1.9	1.6	2.1	2.3	2.1	1.6	2	2.3	1.8	1.4	2	1
% of daily measurement time															
Mean	100	20.0	17.8	9.8	8.1	7.0	6.4	5.9	5.5	5.3	4.6	3.9	2.6	2.4	0.7
Range		0–98.4	0–50.2	0–86.2	0–90.6	0–64.7	0–48.2	0–77.1	0–87.4	0–67.3	0–43.3	0–40.4	0–67.8	0–39.1	0–28.7
Exposure variables															
% time >90°															
Mean	4.7	3.9	1.3	4.6	9.0	5.7	2.8	3.7	11.9	5.0	4.1	4.0	5.7	6.5	5.4
var_{BS}	2.9	2.2	0.5	3.9	23.8	0.9	2.1	9.2	93.0	22.5	6.6	0.7	19.1	8.5	19.5
var_{BD}	4.2	19.6	1.1	6.1	13.9	33.3	10.3	8.5	5.6	1.9	14.1	32.0	3.3	24.7	–
% time >90° at least 5 seconds															
Mean	3.4	2.9	0.6	3.2	6.5	4.4	1.8	2.4	9.8	3.8	2.8	2.9	3.9	5.0	4.2
var_{BS}	1.5	1.2	0.2	2.2	15.6	0	0.9	5.0	70.8	19.5	7.7	1.1	4.5	6.4	18.4
var_{BD}	3.3	16.0	0.6	5.3	7.9	29.3	6.7	5.9	5.9	1.1	6.2	29.3	2.9	20.8	–

All tasks occurring in the diaries are shown, ordered according to decreasing proportion of daily measurement time. The task category ''unspecified'' was formed a posteriori for periods with insufficient task information.
s_{BS}^2, s_{BD}^2, variance between subjects and between days (within subject), respectively.

Table 4 Data material, mean exposure, and exposure variability at job and task levels for house painters

	Job	Wall except sanding and sand-filling	Woodwork except eaves Iron	Break Driving	Eaves	Ceiling except sanding and sand-filling	Unspecified	Wall: Sand-filling	Covering Carrying materials and tools Cleanup	Wall: Sanding	Floor except sanding	Floor: Sanding	Ceiling: Sand-filling	Ceiling: Sanding
Data material														
Subjects	23	16	18	23	8	7	3	3	11	3	3	1	2	0
Days/subject	4	2.8	2.4	3.9	1.9	1.9	2	1.7	2	1	1	2	1.5	0
% of daily measurement time														
Mean	100	27.6	26.5	18.7	10.5	7.5	3.4	1.7	1.6	1.1	0.6	0.6	0.1	0
Range		0–92.8	0–86.7	0–52.8	0–91.2	0–87.4	0–100	0–89.3	0–15.8	0–55.6	0–32.1	0–31.4	0–5.6	
Exposure variables														
% time >90°														
Mean	8.8	10.6	8.3	2.0	19.8	13.9	6.6	14.8	3.2	12.6	3.6	2.6	26.5	0
var_{BS}	21.4	44.4	25.0	2.4	79.8	72.7	9.6	23.5	15.0	83.9	6.7	–	245.9	
var_{BD}	12.2	12.0	35.0	7.6	7.2	16.7	24.7	4.5	25.3	–	–	7.3	3.3	
% time >90° at least 5 seconds														
Mean	5.8	6.4	5.7	1.3	14.5	9.9	3.9	7.3	1.8	6.9	1.6	1.5	22.6	0
var_{BS}	13.7	29.7	15.8	1.5	51.7	39.2	3.3	7.9	9.8	52.6	3.4	–	166.5	
var_{BD}	7.9	5.3	24.0	5.9	6.0	16.0	13.4	10.2	15.2	–	–	3.0	12.4	

All tasks occurring in the diaries are shown, ordered according to decreasing proportion of daily measurement time. The task category ''unspecified'' was formed a posteriori for periods with insufficient task information.
s_{BS}^2, s_{BD}^2, variance between subjects and between days (within subject), respectively.

Table 5 Mean daily exposure, exposure variability in the job, and results of linear regression analyses of measured on task based individual mean job exposures according to number of days with data collection per subject for machinists

Exposure variables	Data collection days/subject	Direct measurements Mean	s_S^2	Regression results ρ^2	α	β
% time >90°*	1	1.5	3.7	0.52	−0.83	1.68
	2	1.7	3.5	0.54	−0.87	1.99
	3	1.6	3.8	0.54	−1.29	2.16
	4	1.6	3.0	0.52	−1.06	1.90
% time >90° at least 5 s	1	0.8	1.0	0.14	0.36	0.48
	2	1.0	1.0	0.08	0.63	0.46
	3	0.9	0.7	0.07	0.58	0.36
	4	0.9	0.5	0.05	0.62	0.27

s_S^2, variance between measured individual mean job exposures; ρ^2, squared correlation coefficient; α, intercept; β, slope.
*Regression results heavily influenced by one outlier. When he was excluded from the TEM and from the regression analyses, the ρ^2 values for 1, 2, 3, and 4 days were: 0.08, 0.14, 0.13, 0.09.

21 occupations which could be expected to differ considerably in exposure even without examination of tasks—for example, a librarian versus a carpenter. The results of the present study suggest that a job exposure matrix would have served equally well to estimate the exposures of the study subjects, and that the efforts invested in obtaining and using task information were probably not very efficient. This possibility was not discussed by the authors. In a study of tank terminal workers, task based modelling across subjects was performed using a collective TEM constructed as part of the study.[14] The within-day exposure variance was smaller for task based estimates than for observed exposures. Based on this, it was concluded that estimation of physical load could be improved by task based exposure assessment. However, this interpretation did not consider the fact that collective mean task exposures mask the variability between and within subjects performing a particular task.

Other ergonomic studies have evaluated the alternative approach of using personal task exposures to estimate exposure across days within subjects. In a study of cleaners and office workers, direct measurements were performed for one whole working day per subject, and estimated job exposures were obtained using averaged task proportions across 10 diary days for each participant.[9] For the 10th and 90th centiles of the cumulated distribution of arm elevation angles, one-day measurements and 10-day average estimates were highly correlated, with squared correlation coefficients of 0.95 and 0.98, respectively. The authors concluded that it was unnecessary to collect task information since it appeared that one measurement day was sufficient to assess a worker's long term average exposure level. However, the analyses did not take into account that the predictive ability of task based estimation across days is reduced by variability of task exposures between days (cf tables 2–4). In an evaluation of a task based interview technique, ''true'' job exposures were obtained by observation during one work shift, and estimated job exposures were calculated by combining task durations and personal task exposures reported in the interview.[20] It was assumed that both interview and observation represented the subject's mean job exposure. In this respect, the results concerned modelling of exposure across days, although no account was made for day-to-day variability. For four exposure variables, including ''standing with one or both hands above shoulder level'', squared correlation coefficients ranged from 0.53 to 0.86 for the relation between estimated and ''true'' exposure. However, the evaluation was based on subjects from occupational groups which differed considerably in exposure. As discussed above, this implied that the study did not assess the benefit of task based exposure assessment in excess of what would have been obtained by job based exposure assessment disregarding tasks—that is, by interviewing subjects about the overall exposure in their jobs.

Based on the discussion above, we suspect that the lack of success of task based estimation is not confined to the occupational settings investigated in the present study. On the other hand, studies from other areas of occupational epidemiology suggest that task information may be valuable for exposure assessment within an occupational group if the exposure contrast between tasks is very large and if individuals within a job have thoroughly different work roles.[49 50] It is possible that this may also apply to selected ergonomic exposure variables in certain occupations (cf Nordander and colleagues[51]).

Conclusion

The precision of a group mean obtained by direct measurements on a number of subjects could be only marginally

Table 6 Mean daily exposure, exposure variability in the job, and results of linear regression analyses of measured on task based individual mean job exposures according to number of days with data collection per subject for car mechanics

Exposure variables	Data collection days/subject	Direct measurements Mean	s_S^2	Regression results ρ^2	α	β
% time >90°*	1	4.7	6.1	0.22	2.09	0.53
	2	4.7	5.4	0.11	2.34	0.47
	3	4.7	4.7	0.06	2.54	0.44
	4	4.7	4.0	0.00	4.10	0.12
% time >90° at least 5 s	1	3.5	4.2	0.19	1.69	0.49
	2	3.4	3.4	0.08	1.96	0.38
	3	3.4	3.0	0.03	2.30	0.32
	4	3.4	2.3	0.00	3.42	0.00

s_S^2, variance between measured individual mean job exposures; ρ^2, squared correlation coefficient; α, intercept; β, slope.
*Regression results influenced by one outlier. When he was excluded from the TEM and from the regression analyses, the ρ^2 values for 1, 2, 3, and 4 days were: 0.30, 0.30, 0.21, 0.09.

Table 7 Mean daily exposure, exposure variability in the job, and results of linear regression analyses of measured on task based individual mean job exposures according to number of days with data collection per subject for house painters

Exposure variables	Data collection days/subject	Direct measurements		Regression results		
		mean	s_S^2	ρ^2	α	β
% time >90°	1	7.6	25.2	0.09	−0.46	0.96
	2	8.2	29.6	0.03	4.15	0.45
	3	8.5	25.5	0.00	7.93	0.06
	4	8.8	24.5	0.00	8.65	0.02
% time >90° at least 5 s	1	4.8	16.4	0.08	0.03	0.87
	2	5.3	19.7	0.04	2.42	0.49
	3	5.5	15.8	0.01	4.20	0.22
	4	5.8	15.7	0.01	4.46	0.21

s_S^2, variance between measured individual mean job exposures; ρ^2, squared correlation coefficient; α, intercept; β, slope.

improved by adding subjects for whom only task based job exposure estimates were available. This was a consistent finding in three occupational groups representing a wide range of work tasks and job exposure levels. The result questions the use of task based exposure assessment in ergonomic investigations aiming at precise group mean values, including group based studies of exposure-response relations. The finding of weak correlations between estimated and measured job exposures also suggests that task based job exposure estimates may not be superior to estimates based on occupation in exposure-response studies adopting an individual approach to exposure assessment. Therefore, we recommend investigators in ergonomic epidemiology to consider the prospects of task based exposure assessment carefully before placing resources at obtaining task information. Strategies disregarding tasks may be preferable in many cases.

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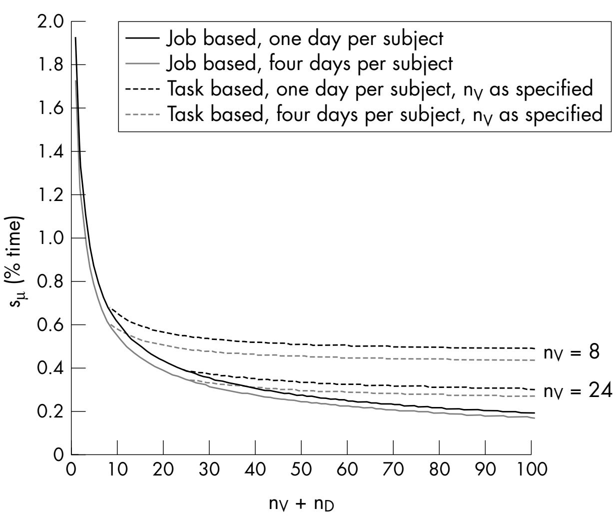

Figure 3 Performance of task based exposure assessment of arm elevation above 90° among machinists. The relation between the standard error of the group mean, s_μ, and the size of the study population is shown for job based strategies based exclusively on measurements, and for strategies combining a ''validation sample'' of subjects with measured job exposures and a ''diary-only sample'' of subjects with calibrated task based estimates. n_V, number of subjects in the validation sample; n_D, number of subjects in the diary-only sample.

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