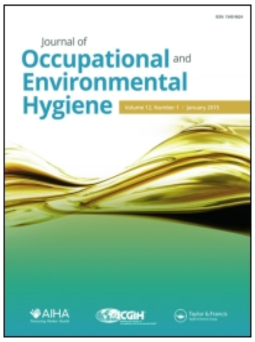

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Variability in Risk Factors for Knee Injury in Construction

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This study investigated sources of variance in exposure to risk factors for knee pain in a variety of highway construction trades, operations, and tasks. Over 15,000 discrete observations of leg postures and weights handled were made on 120 construction workers in five construction trades, in nine operations over 79 days. The contributions of trade, operation, task, and worker to the variability in work time spent kneeling, squatting, and carrying loads were evaluated with multilevel random effects models. Construction operation and task explained about 20% to 30% of total variation in kneeling, squatting, and carrying loads. There was a large unexplained component of variance thought to represent day-to-day variability of exposure within task. Reliable assessments of knee exposures require multiple days to accommodate the high variability of exposures among operations and tasks and over time. These sources of variability should be carefully considered in efforts to estimate exposures to knee loading for epidemiologic or intervention studies. Homogenous exposure groups are not easily defined from the readily available organizational features of construction work.

Keywords kneeling, manual material handling, random effect models, squatting, variance ratio

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INTRODUCTION

Knee pain is a common musculoskeletal symptom among working-age people. The prevalence of knee pain varies from 10% to 60%, depending on age, occupation, and the definition of knee pain.[1,2] Due to the strenuous construction work that involves a variety of awkward postures and manual material handling, construction workers are likely to be at high risk of developing knee disorders.[3−5]

Although there is some evidence attributing increased risk of knee disorders to specific physical demands that are hard on the knee joints,[5−8] such as kneeling, squatting, climbing stairs, and manual material handling,[9−11] most epidemiologic studies on work-related knee injuries use job titles or general work requirements to represent exposures,[2,3,12] and only a few studies have quantified a limited set of specific exposures.[13−15]

Use of job titles or exposure self-reports often leads to only a crude classification of exposure.[16] As a result, the exposure-response relationships remain uncertain for knee disorders and specific types, intensities, and durations of exposure to biomechanical loading on the knee. Whereas it is accepted that torque on the knee increases with squatting and kneeling leg postures and with manual materials handling,[17,18] the link from this biomechanical knowledge to epidemiologic risk is needed to establish exposure limits.

Obtaining quantitative exposure measurements is time consuming, labor intensive, and costly, so measurements are usually restricted to small samples of workers performing a job over a short period of time that are assumed to be representative of the long-term exposure profile. In cases where the exposures vary over time across jobs, workers, or job tasks, the sampling strategy will play an important role in securing the reliability of the measurement.

To reduce measurement error associated with sampling, the important sources of exposure variability should first be identified and then addressed in the sampling approach[19−21] by assigning the appropriate sample sizes relative to the variability, for example, decreasing the sample size for groups with the lower exposure variability and increasing the sample size for groups with the highest exposure variability.

Grouping workers based on exposure variability has not been given much attention in ergonomics assessments, even where the work is highly variable. Only a few studies have examined sources of variance in exposure to ergonomic risk factors in construction work.[22,23] In contrast, sources of variance in chemical exposures have been more often investigated.[24−27] The precision of musculoskeletal and other epidemiologic studies in construction would benefit greatly from investigations of sources of variation in ergonomic exposures as well as recognition of the characteristics of transient, seasonal, and intermittent exposures in this sector.

The specific aims of this study were to examine the homogeneity of exposures to kneeling, squatting, and carrying loads when using various grouping strategies such as construction trade, operation, task, and worker, and to estimate the contributions of these grouping variables to the overall variability in knee loading exposures.

METHODS

Study Population and Data Collection

Data were compiled from nine field studies that took place on construction sites of the Boston Central Artery/Third Harbor Tunnel highway construction project over the course of several years.[19,23,28–31] PATH (posture, activities, tools, and handling)[29] observations were made every 45 sec or 60 sec, cycling in random sequence through multiple crew members of a specified trade at a specific location. Each observation contained information about the observed worker's postures (trunk, lower limbs, and upper limbs); load handled; tool in use (if any); and task and activity being performed.

A group of workers was usually observed for about 4 to 6 hr on each day of exposure surveillance. For this study, only observations in which a worker was observed on at least 2 days performing the same task were used in the analysis. No female workers were observed in this study. Demographic information on individual workers was not collected at the time of observation. Before the field observation, the worker's trade was recorded.

The PATH method has been embedded within a hierarchical taxonomy of construction stages, operations, and tasks. Stages are the highest levels of the construction process. Each stage consists of a variety of operations that are performed by at least one crew of workers. Occasionally, more than one trade may be involved in an operation. Task is a group of activities that have a common goal and usually are carried out by a worker. By dividing the operation into tasks, an exposure assessment can be made to characterize the ergonomic exposures within operations, trades, tasks, and workers. This resulted in a total of 15,011 observations made on 120 workers performing 45 tasks from five trades (carpenters, laborers, ironworkers, plasterers, and tilers) in nine operations. Each worker was observed performing one or more tasks within a single operation; in other words, workers and tasks are cross-classified within operation and trades. The Institutional Review Board of the University of Massachusetts Lowell reviewed the protocol of this study and approved the study.

Measures

The primary exposure variables observed were kneeling (yes/no), squatting (yes/no), kneeling or squatting (yes/no), and carrying loads (yes/no). Although there is likely to be a load differential on the knees for kneeling and squatting postures, these differences have yet to be documented in biomechanical studies. In addition, differences in loading for the knees are not affected only by leg postures but by the postures of the upper body.[4] Laboratory studies have identified differences in perceived discomfort between squatting and kneeling postures,[4,32] but the differences in loading for these postures still remain unclear. For these reasons, exposures to kneeling and squatting were evaluated individually and in combined form (kneeling or squatting).

For each exposure variable, the percentage of the observations in the exposure conditions during an observed shift was calculated. Exposures were summarized with respect to workers, tasks, operations, and trades and expressed as the percentages of total daily work time spent in each exposure conditions (e.g., percentage of time kneeling for Worker A in the tiling operation, or percentage of time squatting by laborers in Task B).

The summary exposure measures for tasks and workers were weighted for the proportions to the whole day's measurement because the proportions of tasks were different from one day to another. For example, when observations were grouped into tasks, the percentage of time in each knee posture was weighted by the total number of observations for the day. (If the number of observations for Day 1 is 100 and 200 for Day 2, the weight for the percent time for kneeling in Day 1 is 1 and the weight is 2 for Day 2.) By the four different grouping variables, i.e., trade, operation, task, and worker, different exposure estimates for each grouping were obtained.

Loads carried in construction vary tremendously in terms of object and tool type, size, and weight. In addition to percentage of time "carrying" (walking with a load in the hands), a quantitative index of carrying was generated by multiplying the load weight times the frequency of load carrying. This index used each individual's average load handled during the total work time spent carrying loads. For example, if a worker spent 20% of work time carrying and the average load was 15 pounds, the estimated carrying index would be 20% of work time × 15 pounds = 3.0 pounds time-weighted average for the time observed.

Because these percentage time exposure measures mostly averaged less than 20%, resulting in skewed distributions, all exposure measures were transformed logarithmically to reduce skewness. When the percentage of total daily work time spent exposed to a risk factor was zero for an individual worker or for a worker-task combination, a constant (0.1%) was added before transformation.

Homogeneity of Exposure

Daily estimates of exposure for workers by trade, operation, and task were used to evaluate within- and between-group variability in exposure within each level of the construction taxonomy. For example, the analysis of variability due to "operation" required the exposure frequencies to leg postures and load carrying to be calculated for each worker in each operation on each day of observation.

A one-way random effects model was used to estimate the within-group variance component (Var_W) and the between-group variance component (Var_B), for each grouping variable. The variance components were used to calculate the ratios of the 97.5th and the 2.5th percentiles of the distribution of exposures for each grouping variable.[33] Between-group variance within a level of the taxonomy was expressed by the ratio of the 97.5th percentile to the 2.5th percentile of the distribution of the group's mean exposure and represented by the range ratio: ${}_{B}R_{0.95} = \exp[3.92^{*}Var_B]$. Within-group variance (or between-worker or task variance) was also represented by the range ratio of the distribution in the same manner as the between-group variance: ${}_{W}R_{0.95} = \exp[3.92^{*}Var_W]$.

The variance ratio (λ: the ratio of the within-group variance to between-group variance), which represents the contrast of within group variance to between group variance,[26] was also examined. The variance ratio has been used to evaluate the amount of potential attenuation in the estimate of the epidemiologic exposure-response relationship[21] resulting from different grouping strategies.

Analysis of Variance of Exposure

Sources of variance were evaluated using multilevel random effect models. Restricted maximum likelihood estimates of the variance components were obtained using the IGLS (iterative generalized least squares) estimator (MLwiN v1.0, Institute of Education, London, U.K.). All grouping factors–workers, tasks, operations, and trades–were assumed to be random samples from the total population of workers, tasks, operation, or trades. This makes it possible to generalize the results of the analyses to other construction workers. The basic structure of the two level random effect model is as follows:

$$y_{ij} = \beta_0 + \beta_1 x_{ij} + (u_{0j} + u_{1j}x_{ij} + e_{0ij}) \qquad \textbf{(1)}$$

where

$$E(u_{0j}) = 0, \quad var(u_{0j}) = \sigma^2_{u0},$$
$$var(e_{0ij}) = \sigma^2_{e0}, \quad var(y_{ij}) = \sigma^2_{u0} + \sigma^2_{e0}$$

The component u_{0j} represents deviation of the jth worker from the grand mean, β_0; e_{0ij} is the individual measurement-level random error, which was here interpreted as random day-to-day variability within worker. Equation 1 has one fixed effect (an intercept) and two random effects: worker-level variance (between workers) and individual measurement-level variance (within worker). Each level's contribution to the total variance was calculated as a percentage. It was not possible to examine the effect of trade or task within operation because to a large extent only one trade was observed in each operation and tasks were not the same across all operations.

RESULTS

In the construction trades and operations observed, workers were observed to be kneeling for an average of 5% of daily work time, squatting 3% of the time, and carrying loads 16% of the time. By operation, the ranges of exposure frequencies were 0.5% to 11% daily work time for squatting, 0.4% to 10% for kneeling, and 12% to 23% for carrying (Table I). Among the five trades, the highest frequencies of all exposure variables were observed for tilers performing grouting and tiling operations.

Squatting

The variance ratio (λ) estimates were less than 2 for operation and task, whereas they were higher for worker and trade. Thus within-worker and within-trade variability were higher than between-worker and between-trade variability for all knee exposures (Table II).

In the multilevel random effect model, task explained about 30% of total variation in time squatting when operation was included (Model 1 in Table III), whereas worker explained only 16% of total variation in an analogous model (Model 2 in Table III). Operation explained more variability when it was included with worker (Model 2) than with task (Model 1), which indicated that some of the variation between tasks was explained by operation in Model 2.

TABLE I. Distribution of Knee Risk Factors in Nine Highway Construction Operations Observed in Boston, 1994–1999

Operation/Trade	No. of Workers	No. of Days	No. of Tasks	Total No. of Observations	Knee Risk Factors: No. of Observations (%)		
					Squat	Carry	Kneel
Form building/Carpenter and Laborer	17	13	8	1677	9 (0.5)	193 (11.5)	129 (7.7)
Pipe jacking/Laborer	4	5	4	1343	13 (1.0)	148 (11.6)	5 (0.4)
Concrete pouring/Laborer	7	6	4	611	48 (7.9)	67 (11.0)	10 (1.6)
Concrete reinforcement/Ironworker	17	12	6	2093	40 (1.9)	405 (19.4)	60 (2.9)
Grouting/Tiler	18	6	5	1549	166 (10.7)	164 (10.5)	162 (10.4)
Jacking pit/Laborer	12	12	5	3089	61 (2.0)	427 (13.8)	144 (4.7)
Plastering/Plasterer	11	8	4	1607	110 (6.8)	266 (16.6)	17 (1.1)
Slurry wall/Laborer	13	3	4	933	20 (2.1)	178 (19.1)	12 (1.3)
Tiling/Tiler	21	14	5	2158	42 (1.9)	485 (22.5)	154 (7.1)
Total	120	79	45	15,011	509 (3.4)	2333 (15.5)	693 (4.6)

TABLE II. Homogeneity of Four Different Grouping Variables in Log-Transformed Percentage Working Time, Highway Construction Workers in Boston

Grouping Variable	Var_B	$_BR_{0.95}$	Var_W	$_WR_{0.95}$	λ^A
Squatting					
Trade[B]	1.05	55.5	2.28	370.5	2.2
Operation[C]	1.11	62.0	1.63	148.9	1.5
Task[D]	0.76	30.4	1.22	75.9	1.6
Worker[E]	0.40	12.0	1.04	54.0	2.6
Kneeling					
Trade[B]	0.45	13.9	2.71	635.4	6.0
Operation[C]	0.93	43.7	1.97	245.9	2.1
Task[D]	0.68	25.6	1.71	168.9	2.5
Worker	0.46	14.1	1.39	102.2	3.1
Squatting or Kneeling					
Trade[B]	0.31	9.0	2.33	399.3	7.4
Operation[C]	0.45	13.7	1.45	113.0	3.3
Task[D]	1.02	52.3	1.99	252.2	2.0
Worker[E]	0.51	16.6	1.82	197.0	3.5
Carrying Loads (without weight)					
Trade[B]	0.08	3.0	0.83	35.2	10.8
Operation[C]	0.15	4.6	0.12	4.0	0.8
Task[D]	0.61	21.4	1.94	236.1	3.2
Worker[E]	0.41	12.1	1.48	118.5	3.7
Carrying Loads (with weight)					
Trade[B]	0.20	5.9	2.29	377.5	11.2
Operation[C]	0.53	17.2	0.72	27.7	1.4
Task[D]	1.06	56.6	4.41	3755.1	4.2
Worker[E]	0.93	43.6	3.72	1917.7	4.0

Note: Each measurement represents one daily estimate of percentage work time spent on each leg posture for the given grouping variable.
[A] λ, ratio of within-grouping variable variance to between-grouping variable variance (=Var_W/Var_B).
[B] Number of trades, 5; number of daily measures, 88.
[C] Number of operations, 7; number of daily measures, 79.
[D] Number of tasks, 45; number of daily measures, 301.
[E] Number of workers, 120; number of daily measures, 509.

There was a large proportion of residual error, interpreted as unmeasured within-and-between worker day-to-day variation within trade, operation or task in both models. This day-to-day variation was lower in Model 1 than Model 2, which means that operation and task when considered simultaneously explained more variability than operation and worker. Grouping on operation or task produced more homogeneity than grouping by trade, whereas grouping on individual worker showed the least homogeneity (Table II).

Kneeling

For kneeling postures (Table II), grouping by trades showed the least homogeneity ($\lambda = 6.0$) among the four levels. Operation level produced more within-group homogeneity ($\lambda = 2.1$) than task or worker. Task also showed reasonable homogeneity with a variance ratio of 2.5, while the variance ratio for worker was modest ($\lambda = 3.1$).

Task alone explained about 28% of total variation in exposure to kneeling; operation did not contribute to this model (Table III). In fact, all of the variability in kneeling among operations shown in Table III appeared to be due to between-task variability (Model 1). On the other hand, operation explained 12% of variation when worker was included but not task; in this model, worker explained 13% of the total variation (Model 2). A large proportion of residual (day-to-day variation) was found in both "operation + task" and "operation + worker" models, although slightly less in Model 1 than in Model 2.

Combined Knee-Straining Postures

For combined non-neutral leg postures (squatting plus kneeling), task produced the most homogeneous groups ($\lambda = 2.0$) (Table II). In the multilevel models, task was the main source of variation in logged percentage time spent non-neutral posture (Table III). Operation and worker presented modest variance ratios, 3.3 and 3.5, respectively. Within-trade variability was very high.

Task explained about 31% of total variation in non-neutral knee posture when operation was included (Model 1 in Table III), and between-worker variation was 14%. Operation explained 8% of total variation in time kneeling or squatting (Model 2 in Table III). A large proportion of variation between days still remained unexplained in both models. As before, the combination of operation and task explained more variability than operation and worker.

Carrying Loads

For time spent carrying loads, operation resulted in superior homogeneity compared with the other available grouping variables (Table II). Even though the variance between operations was small, the variance ratio was small due to the low variation within operation. In contrast, the variance ratio for task was relatively large in spite of the large between-task variance because there was a great deal of within-task variability. The variance ratio for trade was the highest ($\lambda = 10.8$). In general, when observations of carrying loads (either with or without taking into account of weight in the hands) were grouped into tasks or workers, considerable amount of day-to-day variation was found.

Task explained 21% of total variation in time carrying loads with operation included in the same model (Model 1 in Table III). Operation explained 12% of total variation when worker was included in the model (Model 2 in Table III). The day-to-day residual error was higher for this exposure than for the knee postures, and again it was slightly less in Model 1 than in Model 2.

For the simple percentage of time carrying, operation was the only variable that produced a variance ratio smaller than 2 (Tables II and III). When the weights in the hands were integrated into the carrying index, within-group variances were

TABLE III. Variance Components for the Effect of Three Organizational Levels on Logged Percent-time, Multilevel Random Effect Models of PATH Data, Highway Construction Workers in Boston

	Model 1[A]			Model 2[B]		
	Estimate	S.E	%	Estimate	S.E	%
Squatting						
Intercept[C]	−1.24	0.19	—	−1.49	0.15	—
Random effect						
$Var_{(OPERATION)}$	0.14	0.15	7.1	0.16	0.10	11.4
$Var_{(TASK)}$	0.58	0.19	29.8	—	—	—
$Var_{(WORKER)}$	—	—	—	0.23	0.07	15.9
Residual	1.22	0.11	63.1	1.03	0.07	72.7
Total variance	1.94		100.0	1.42		100.0
Kneeling						
Intercept[C]	−1.236	0.15	—	−1.43	0.18	—
Random effect						
$Var_{(OPERATION)}$	0	0	0.0	0.22	0.13	12.0
$Var_{(TASK)}$	0.66	0.21	27.9	—	—	—
$Var_{(WORKER)}$	—	—	—	0.25	0.08	13.4
Residual	1.71	0.15	72.1	1.39	0.10	74.7
Total variance	2.37		100.0	1.87		100.0
Squatting or Kneeling						
Intercept[C]	−0.69	0.19		−0.89	0.17	
Random effect						
$Var_{(OPERATION)}$	0.07	0.17	2.4	0.20	0.13	8.4
$Var_{(TASK)}$	0.92	0.30	30.8	—	—	—
$Var_{(WORKER)}$	—	—	—	0.32	0.11	13.8
Residual	1.99	0.18	66.9	1.80	0.13	77.8
Total variance	2.98		100.0	2.32		100.0
Carrying Loads (without weight)						
Intercept[C]	0.768	0.164		0.436	0.176	
Random effect						
$Var_{(OPERATION)}$	0.04	0.12	1.5	0.23	0.13	12.0
$Var_{(TASK)}$	0.53	0.20	21.0	—	—	—
$Var_{(WORKER)}$	—	—	—	0.13	0.07	7.0
Residual	1.95	0.17	77.5	1.52	0.11	80.9
Total variance	2.51		100.0	1.88		100.0
Carrying Index (with weight)						
Intercept[C]	−2.763	0.227		−3.23	0.26	
Random effect						
$Var_{(OPERATION)}$	0.11	0.22	1.9	0.47	0.28	10.3
$Var_{(TASK)}$	0.93	0.39	17.0	—	—	—
$Var_{(WORKER)}$	—	—	—	0.41	0.18	8.8
Residual	4.41	0.11	81.0	3.73	0.26	80.9
Total variance	5.44		100.0	4.61		100.0

Note: SE, standard error.
[A]Model 1. Var(Y) = Var(operation) + Var(task) + Residual (n = 301).
[B]Model 2. Var(Y) = Var(operation) + Var(worker) + Residual (n = 509).
[C]Fixed effect.

considerably inflated, which resulted in the increase of the ratios of between- and within-group variance.

Overall, the day-to-day variation in kneeling was slightly less in Model 1 than Model 2 (Table III), which suggests that task alone could explain more variability than operation and worker in exposure to squatting and kneeling, at least for the operations studied here. The total variance explained by operation plus task was larger than the variability explained by operation plus worker in all comparisons except for the carrying index.

DISCUSSION

This study describes loading on the knees of 120 construction workers observed for a total of about 200 to 250 hours on site. Across nine different highway construction operations, these workers spent about 15% of the time carrying loads and about 8% of the time in knee straining postures.

The specific tasks performed by these workers explained more of the variance in kneeling, squatting, and load carrying than did operation or trade; specifically, task explained about 20% to 30% of total variation in knee loading exposures. This provides support for characterizing exposures by task rather than by operation or trade. Our analysis confirmed that there is substantial day-to-day variation in exposure to these risk factors for knee disorders among construction workers.

Our results are consistent with those obtained in a previous study that used part of the same data we examined here, where task explained 25% and 30% of the total variation in kneeling posture among carpenters and ironworkers, separately.[23] Similarly consistent findings were obtained on a larger number of exposure variables from three of these trades.[19] However, we can find no previous study to have compared the homogeneity of groups defined by trade, operation, task, and worker.

Our findings have several indications for a situation where exposures to load bearing knee postures need to be historically reconstructed as opposed to measured directly throughout the study time period. Because the exposures varied over time (day-to-day), monitoring a single or small number of workers within an operation and/or task would be sufficient to characterize the exposure of a population. However, due to the high day-to-day variability, either monitoring of those workers' exposure should be done over a long period time, or shorter-term measurements distributed randomly over a certain period would be required to accurately characterize the exposure. The optimal exposure assessment strategy for this situation would be to maximize the amount of data collected for a small number of workers.

Information about operations and tasks may prove useful for ergonomics intervention or for the development of operation- or task-weighted exposure estimates in epidemiologic studies. For exposure to carrying loads, weight in the hands introduced more day-to-day variation than when the weights are not considered in exposure assessment. Therefore, it is necessary to observe a longer period when the exposure to carrying load posture contains the information on the weight in the hands. Assessments should be made over multiple days to accommodate the large inter-day variability of exposures within operations, tasks, and workers.

Study Strengths

Our study included a variety of construction trades. Ironworkers, laborers, and carpenters alone represented approximately one-half of the total work forces on the construction project. We believe that by including more trades such as tilers and plasterers, the generalizability of our findings was enhanced.

Study Limitations

There may be many more sources of variability in such exposures that have not been investigated in the construction setting. For example, some of the tools and equipment could be a source of variability in these exposures. In addition, some of the day-to-day variability found in this study may be due to different observers. We believe that the effect of different observers would be minimal because PATH observers had received 32 hr of PATH training and had used PATH in a variety of work settings intermittently for more than one year previous to these studies. However, this should be further investigated to quantify its contribution to the total variability in these exposures.

Some methodological issues in analyses of variance components should also be acknowledged. By the nature of observations that are described dichotomously, the binomial distribution is the correct distribution assumption for the squat and kneel observations. Thus, a generalized linear model that has a log-link function was considered for use in examining the covariance structures.

However, because our variance components models do not have predictor variables, the generalized linear model with log-link was not useful, as the variances in this model are totally dependent on the means of the predictors.[34,35] As for the models that predict exposure to kneeling and/or squatting, a generalized linear model with a log-link function could be used with predictors that characterize construction tasks or individual work practice and work setting.

The frequencies for kneeling and squatting postures seemed to represent the Poisson distribution because many operations showed that the mean percentages are similar in their variances. However, we could not employ Poisson regression models because the numbers of observations per day varied greatly, meaning that we could not use the count data. Poisson multilevel regression models may be appropriate for exposure variance analysis in future studies, if the data collection is done in such a way that the number of observations for each day is constant and thus the integral number of frequency can be used as a dependent variable.[36]

The estimates of daily percent working time squatting or kneeling included many zero values for individual tasks and workers. In other words, some tasks do not require kneeling or squatting during the job or some workers avoid squatting or kneeling during their work. Zero values may also have resulted from sampling error in tasks with very low exposure frequencies or for workers observed only briefly. There were a few statistical choices for this matter in terms of analysis: (1) remove all zeroes, (2) obtain likelihood estimate for the lower level, or (3) add a constant to the zero that would give a straight line on the probability plot. Because we strongly believed that the zero value represented important information, we included the zero values after adding a constant (i.e., 0.1%)

to allow for logarithmic transformation, when needed. In the supplementary analyses in which zero values were excluded, it appeared that variance components for level variables were moderately affected by the zero values compared with the full models that included all the zero values after data transformation.

The overall interpretation of the results described above was not altered by the small change of estimated variance components created by using 0.1% rather than 0%. In addition, standardized residual analyses showed no significant problems with distribution at each level when included zero values.

CONCLUSIONS

Despite the limitations discussed above, it is apparent that the task and operation levels are the most important sources of variation in the risk factors for knee disorders for at least the trade, operation, and task conditions included in this study. The results of the analyses showed that construction operation and task variables explain about 20% to 30% of total variation in kneeling, squatting, and carrying loads. This knowledge should be used in the design of strategies for assessing occupational exposure to various risk factors for knee disorders. For example, the way in which knee exposures varied across trades, operations, workers, and tasks in this study suggests that exposures should be stratified by operation and task for the development of similar exposure groups. Thus, PATH observations should be made randomly within a crew or group of workers that perform the same operation or task. Also, considering the large day-to-day variability in exposure to kneeling and squatting, study resources should be allocated so as to maximize the number of observation days, prior to beginning an observational study of a particular operation or task in construction.

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