Exposure assessment in epidemiology – does gender matter?

Susan M. Kennedy, PhD

Mieke Koehoorn, PhD

School of Occupational and Environmental Hygiene

University of British Columbia

2206 East Mall, Vancouver BC, Canada, V6T 1Z3

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Correspondence to Dr. Kennedy at:

UBC School of Occupational and Environmental Hygiene

2206 East Mall, Vancouver BC, Canada, V6T 1Z3

Phone: 604 822-9577

Fax: 604 822-9588

email: kennedy@interchange.ubc.ca

running head: Gender differences in exposure assessment

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Abstract

Background: The pathway from potential hazards in the work environment to the measurement or estimation of personal exposure for epidemiologic studies comprises many steps, each of which can be influenced by factors that may or may not differ by gender. This paper explores this pathway to address the question, “Should the potential for gender differences be taken into account in the activity of exposure assessment for epidemiologic studies?”

Methods: Evidence from previously published studies and data from the investigators’ own research were examined to explore whether or not several theoretical sources of gender ‘bias’ in exposure assessment have been found in actual studies. Sources of bias examined included: differences in job tasks despite same job titles; differences in delivered exposure due to differences in protective equipment, body size, or other relationships to exposure sources; and differences in estimated exposure arising from study methods or design.

Results and Conclusions: Evidence was found for gender differences (and thus *potential* bias) from all these sources, at least in some studies. We conclude that the answer to the question posed, “Does gender matter, in exposure assessment for epidemiology?” is a qualified ‘yes’, but that the magnitude and direction of the potential bias cannot be predicted, *a priori*.

keywords: exposure assessment; gender; epidemiology; occupational hygiene

Several investigators have drawn attention to gender issues in occupational health research, in particular focussing on whether or not women are represented appropriately in research programs or studies, and on gender differences in the risk of disease due to differential exposures or differential exposure-response relationships. (London, 1998; Messing, 1998) However, little attention has been focused on the question of the potential for gender related differences that may arise as a result of exposure assessment on the part of investigators.

In occupational health research, the objective of exposure assessment is to provide the best possible estimate of true personal exposure to one or more hazard in the work environment. At first glance, it is not evident that the activity of exposure assessment, when focusing on women workers, should (or would) differ in any way from the same activity, when focusing on workers who are men. The discipline of occupational hygiene teaches that exposure is determined by sources, by tasks, by processes, and by work practices or behaviours, and not by characteristics such as gender, race, or class. Furthermore, in (assumedly) rare situations where there may be gender related differences in exposure, occupational health scientists (including the authors) are often wary of focussing on non-modifiable factors such as gender or race. Thus, many investigators report exposure-response analyses that adjust for effects of gender and race, rather than exploring stratified analyses.

The purpose of this paper is to examine whether or not this traditional non-gendered approach to exposure assessment is justified, and in particular to explore whether or not there is **evidence** that exposure assessment as a research activity should consider a gender-sensitive approach. Thus, this paper focuses specifically on exposure assessment for epidemiology, and asks the question: “Does gender matter?”

Exposure, whether to chemical, biological, physical, or psychosocial agents, is a function of sources or agents and the interaction of the person with the source. However, in epidemiologic studies, we can only

estimate the biologically relevant exposure through various exposure measures. In this paper, we examine the pathway from sources to exposure measures, for ways in which gender *might* influence the assessment of exposure in epidemiologic studies. The objective was to evaluate the evidence, from published studies and our own data that might provide some insight about whether or not there are gender differences in exposure assessment that should be taken into account, at least in some studies.

Figure 1 depicts this pathway, showing sources, agents, machines, tasks, and schedules all contributing to the exposure environment in which a person finds her or himself. This exposure environment can be modified by different individual work practices, tools, and protective measures or equipment to alter the actual exposure experienced by any given worker. This would be ‘true personal exposure’. However, as it is not possible to measure ‘true personal exposure’, investigators use different research methods, protocols, and metrics to assess exposure and develop an estimate or measure of personal exposure.

Following this pathway, the sources of potential gender influence on these measures of personal exposure can be grouped, according to this diagram, into three general types:

- a. apparent gender differences in exposure potential due to different job tasks and schedules
- b. true gender differences in delivered personal exposure (if they exist)
- c. gender differences in exposure measures that arise because of study methods, protocols, or design - these can be of two types:
 - gender differences in the validity or accuracy of our exposure assessment tools
 - gender differences in the impact of the healthy worker effect

One can also consider gender or sex differences in outcomes (either real differences in the biologic effect of agents or in how health outcomes are measured) – but this paper will not focus on the outcome side of the equation.

Gender differences in job tasks

The first area (i.e. gender differences in tasks) is perhaps the least controversial – sex-segregation in the labour force is typical, and men and women's work is often different – even when the job title is the same. This may be especially true in non-unionized workplaces and in the informal sector. For example, exposure to airborne flour allergen levels among bakers was shown to differ according to gender, because more male than female bakers worked in highly industrialized bakeries or were involved in dough making. (Houba R, 1996) These differences among male and female bakers would be appropriately captured in studies in which job task and industry level are taken into consideration (as was the case in the cited study), but would not be captured in studies relying only on job title. In a case-control study of asthma, we found that 43% of women bakers and 73% of men bakers reported significant exposure to flour dust. We can speculate that this may be due to task differences, but no task data were available in our study to evaluate this possibility. (Kennedy et al., 2000) Messing and colleagues interviewed 21 male and 22 female gardeners, 44% of whom reported gendered differences in job tasks (with women more likely to carry out tasks such as weeding, planting, and pruning and men more likely to do heavier tasks and use equipment.). (Messing et al., 1994)

Perhaps the most well recognized example of the impact of task differences masquerading as gender differences is in the area of risk factors for carpal tunnel syndrome. There are many studies in the literature suggesting that carpal tunnel syndrome is more common among women than among men. For example, in an 8 year prospective, population based study in Italy, (Mondelli et al., 2002) Mondelli and colleagues found an annual incidence rate for carpal tunnel syndrome about four times higher among women than men (506 v. 139 cases per 100,000 person years). Many other studies of carpal tunnel syndrome that have included both men and women in the same 'jobs' have also found that the risk is higher in women. This has often been attributed in part to biological factors. (Giersiepen et al., 2000) The question remains whether or not at least some of the 'gender' effect seen in studies of carpal tunnel syndrome (i.e. increased risk of disease in women) is truly a biological effect or whether it is partly the result of exposure assessment that is not sufficiently precise with respect to the different tasks generally

carried out by women and men. If this were true, failure to take gender differences in job tasks into account (even where the job title is similar) could lead to an erroneous conclusion of gender difference in effect, when the truth may be simply that women are more likely than men to work at tasks that put them at risk for carpal tunnel syndrome.

This possibility was raised by a study published in 2000 by McDiarmid and colleagues. (McDiarmid et al., 2000) These investigators analysed US Bureau of Labor injury data for six occupations at high-risk for CTS: assemblers, non-construction labourers, packaging and filling machine operators, janitors and cleaners, butchers and meat cutters, and data entry keyers. Exposure assessment was based only on job title. They found that for assemblers, non-construction labourers, packaging machine operators, janitors and cleaners, and butchers and meat cutters, the male to female relative risks for carpal tunnel syndrome were in the 0.3 to 0.5 range, whereas for data entry keyers, there was no difference between genders for carpal tunnel syndrome risk (relative risk 1.06). The authors suggested the possibility that the gender differential between men and women in the first 5 jobs categories may be associated with gender related differences in tasks, since these 5 jobs frequently have highly variable tasks, but that for data entry keyers, job tasks are much less likely to be variable. They speculated that even when the job title is the same, job task differences might account for some of the gender differences in risk seen in the first 5 categories.

True gender differences in personal exposure

What about the more difficult issue of real differences in personal exposure, not mediated by differences in job tasks (that could be evaluated by task analysis)? Table I shows lists four possible ways that true gender differences in personal exposure could arise among workers with similar job tasks.

First is the potential for differential use of, and effectiveness of, protective equipment that may be gender related. Anecdotal examples are easy to propose – the gloves or respirators that don't fit women's hands or faces (or the hands or faces of small men) and the training programs or engineering controls that tend

to be focused more on the jobs with more status in any given workplace – often, those held by men. There are few studies providing data with which to evaluate the *magnitude of exposure assessment bias* associated with this issue. However, a recent Korean study of respirator fit factors investigated both facial dimensions (face length and lip length) and gender differences on the effectiveness of three types of commonly used respirators. (Han, 2000) The authors found lower fit factors (indicating less protection) for women than men, even when taking differences in the facial dimensions into account. Other indirect evidence is provided by Murphy and colleagues, who studied the energy cost of physical task performance among women and men in the armed services when the subjects were wearing full body chemical protective clothing. (Murphy et al., 2001) They found that perceived exertion was higher in women than men and that the actual measured energy cost, relative to maximum ventilation was also higher in women. In the armed services, this kind of difference may not have influenced compliance with wearing the personal protective clothing, but in the general workforce, this type of gender difference could well make a difference in the use of personal protective equipment.

Second, gender differences in true exposure could also occur due to gender differences in body size, in relation to the tools, tasks, or equipment used in the job (other than personal protective equipment). Data from automobile production line workers, all with the same job title and tasks, were presented by Walker et al. The proportion of women who reported having to work in awkward postures was 58% compared to 41% among men. Similarly, 55% of women reported their physical workload to be ‘too heavy’ compared to 38% of men. (Walker, 1998) These differences could result in gender differentials in exposure to biomechanical stresses despite the same job tasks.

The potential impact of this kind of exposure assessment error can be seen our work examining musculo-skeletal injuries among hospital workers. (Koehoorn et al., 1999) In this five year retrospective cohort study of all workers (in all jobs) in a large acute care hospital, we found no gender differences in injury risk for lower body or back injuries, after adjustment for ergonomic and biomechanical factors (e.g. repetitive or static awkward postures, contact stress, vibration, pushing or pulling loads) associated with

different jobs. However, we found a two-fold gender differential in risk for upper body injuries associated with work organization stressors (e.g. low job control and work support, and high workload), after taking into account job related differences in upper body biomechanical and ergonomic factors.

This gender difference may be real – or it may be explained in part by residual bias due to the fact that the assessment of the biomechanical risk factors was done for different jobs, but was not gender specific. In preparing for this paper, we re-evaluated the person-specific exposure assessment results (which had been based on direct observation using an OSHA ergonomic checklist of biomechanical stresses) for one job held by significant numbers of both men and women: dietary aids. This re-evaluation showed that women with this job were more likely to adopt awkward postures of the shoulder than men, even given the same job tasks. However, because the original exposure estimates used in the study had been collapsed at the level of job, but were not gender specific, this type of gender differential in awkward postures (even for the same task) was not captured by the ergonomic exposure assessment. This kind of residual error could explain some of the apparent gender difference in risk seen in the original study.

Third, for some exposures, in particular psychosocial stressors, the way in which the worker responds to the source may be an important component of exposure intensity, in addition to the nature of the source itself. This could give rise to “true” gender differences in exposure for these stressors. In the same study of musculo-skeletal injuries among hospital workers described above, our main objective was to examine the relationship between work-organization factors and injuries. When we examined factors associated with exposure to various work organization stressors, gender was not a determinant of job control, but it was a determinant of social support, with women reporting higher levels of social support (where social support is defined as the effect of relationships at work on working conditions). In this case, ‘being female’ was sufficient to shift an employee from one exposure quartile to the next highest quartile based on the overall distribution of social support scores in the population. Thus, taking gender into account proved to be an essential component of the exposure assessment for at least some psychosocial stressors in this study.

We also examined this issue of gender differential in psychosocial work exposures in a recent study of retail liquor store employees concerned about indoor air quality problems associated with a bottle recycling program. (Kennedy et al., 2001) In this study, women reported higher level of job demands, and lower job control than men. As shown in table II, these differences resulted in a trend towards high job strain (i.e. the ratio of demands to control) being more common among women clerks than men. These differences were present despite the fact that both men and women clerks were performing exactly the same job, with the same assigned job tasks. Interestingly, when the association between symptoms and high job strain was examined by gender, the risk of having somatic symptoms associated with high job strain was higher among men than among women. The reason for this difference of effect is not evident from these data, but this result underscores the point that the direction of potential bias associated with not considering gender-related exposure differentials cannot always be predicted in advance. (Kennedy et al., 2001)

Finally, there is the possibility of gender differences in delivered personal exposure – not due to differences in tasks that are readily observable, but presumably due to differences in other factors that may be more difficult to detect using most conventional task analysis approaches. In the same study of retail liquor store clerks, we found mean concentrations for inhalable dust exposure from personal dust measurements higher among women than men. As shown in figure 2, for each of 3 different job titles in the stores, women had consistently higher levels of dust exposure than men.

The reason for this gender difference in quantified exposure to dust is not apparent. In this study, dust exposure was likely generated from two main sources: from glass crushing machinery located in the warehouse area of the store, and from manipulation of liquor and beer cartons. One can speculate that exposure differences may be due to subtle differences in work practices or tasks, or in differences in the relationship between the body and the environment (e.g. women on general being shorter and possibly closer to the exposure sources). In this case, gender stratified exposure-response analyses showed higher

risks for chest symptoms linked to dust exposure among women than among men (data not shown), in contrast to the example discussed above in which the gender stratified analysis showed higher risks in men than women.

Overall, the evidence from this study suggests that, in some settings, there may be gender differences in “true” personal exposure, and that adjusting for gender differences as opposed to stratifying, may obscure potentially relevant gender differences in disease risk.

Gender differences in exposure estimation in epidemiologic studies

Next we move to the issue of potential for gender differences in the way we assess or measure exposure in epidemiologic studies. Here we will examine evidence regarding the potential for differential validity in self-reported exposure data, in estimates based on job exposure matrices, and in quantitative measurement data.

There is some evidence that the validity of self-reported exposure data may vary with the degree of concern about, or familiarity with, hazards. In the environmental literature it has been suggested that women are more concerned about environmental toxins than are men; (Flynn et al., 1994) however, there is also contrary evidence showing no gender differences. (Ostry et al., 1993) Evidence from the occupational literature is harder to find.

We studied the validity of self-reported exposure to five general classes of industrial chemicals against a ‘gold standard’ (in this case measured exposure) among skilled trades workers (all male), and found sensitivity values ranging from 0.44 to 0.85 and specificity values ranging from 0.66 to 0.92. (Teschke et al., 1994) In contrast, Bauer and colleagues measured validity of self-reported exposure to solvents, paints, and agricultural chemicals (similar classes of chemicals to those studied by us) among women in various jobs and found generally lower sensitivity values (from 0.14 to 0.44) but higher specificity values

(0.81 to 0.98) compared to the values found for men in our study. (Bauer et al., 1999) In a study of male and female workers from five UK printing and plastics factories, Joffe asked workers if they were “in contact with” or “worked directly with” eight compounds in their present job and compared responses to company records. In general, sensitivity values were somewhat higher for men and specificity values somewhat higher for women although the differences were not large. (Joffe, 1992) These studies raise the possibility that women may be more likely to under-report exposure (but more likely to be correct when they report no exposure), at least to the kinds of industrial chemicals studied here. Wiktorin and colleagues examined the reproducibility of several measures of physical activity (using 9 different response scales). They found that test-retest agreement statistics ranged from moderate to very good, depending on the task, with physical activity and exercise in the current job having the highest kappa scores. However, they found no significant gender differences in the reproducibility of this measure. (Wiktorin et al., 1996)

We also examined the possibility of gender differences in the validity of exposure estimates arising from studies using job exposure matrices (JEM). Using an asthma-specific JEM, we have previously demonstrated that the validity of exposure estimates based on a JEM is linked to the accuracy of job coding and to the quality and quantity of the input data used to construct the matrix. (Kennedy et al., 2000) In a multi-centre case-control study in which the asthma-specific JEM was used, we showed that correction of subtle job title coding errors resulted in an increase of the odds ratio for the risk of asthma associated with exposure from 1.0 to 1.5. Furthermore, when exposure misclassification was reduced by an expert review step, the odds ratio increased to 1.8, and then increased even further to 2.2 when jobs still likely to be misclassified were excluded from the analysis. (Kennedy et al., 2000) In preparing for this paper, we reviewed the original data from this study to examine whether or not these factors varied by gender.

First, we examined the differences in coding accuracy for jobs, according to the gender of the study subject. As shown in Table III, we found that significant coding errors (i.e. those that resulted in a

difference in exposure assignment by the JEM) were seen more often for jobs held by male study subjects than for jobs held by women subjects in this study (4.6% v. 1.5% errors). The reason for this is not clear. We could speculate that, in this case, it may have arisen because the female coder was more familiar with the jobs more likely to be held by women than men, despite considerable training and experience in coding. Clearly the direction of potential bias from this kind of effect could not be predicted in advance and could differ from study to study for unknown reasons. We also examined the issue of potential exposure misclassification in JEM estimates. When we looked at the extent of potential misclassification in jobs held predominantly by men compared to in jobs held predominantly by women (shown also in Table III), jobs held by men were more likely to have job codes that were not rated as being precise enough to classify by the matrix alone and for which an expert review step was recommended (jobs held by men: 30.7% v. jobs held by women: 16.5%; $p < 0.01$). Conversely, jobs held mainly by women were more likely to be ‘poorly classified’ overall by this particular JEM (10.6% of jobs for women v. 3.4% of jobs for men; $p < 0.01$), where ‘poorly classified’ means that the JEM identified the job as having a low likelihood of accurate exposure estimation using the JEM even after expert review of job tasks. These findings emphasize again that the direction of potential gender bias due to differential exposure misclassification by gender would be difficult to predict, a priori.

Gender differences in quantitative exposure estimates of exposure duration and cumulative exposure

There are a few examples in the literature suggesting that risk categories using cumulative exposure or duration of exposure may result in an apparent gender differential in risk in some situations. This can occur in industries or sectors where women are more likely to be hired into the most exposed jobs but also more likely to have shorter duration of employment by leaving the workplace, rather than being promoted to the lower exposure jobs that may be more available to men. Since, in some studies (especially those of chemical hazards) cumulative exposure is often more heavily determined by exposure duration than by intensity (because of relatively smaller variability in exposure intensity), women may be categorized into

lower exposure categories, despite what might be considerable exposure intensity, albeit for a shorter time period than many men.

This phenomenon was seen in a study of refractory ceramic fibre workers reported by Lemasters and colleagues in 1998. The authors speculated that this might be a possible explanation for the increased symptoms and reduced pulmonary function seen among women, despite lower exposure duration.

(Lemasters et al., 1998) It was also seen in a mortality study in the Swedish porcelain industry reported here at this conference. (Plato and Soderman, 2002)

It should be pointed out that this is not really an example of exposure misclassification by gender, but rather a reminder that the use of the cumulative exposure metric, in settings where duration plays a greater role than intensity, may reflect different exposure profiles for men and women, and thus, may not always be the best single summary measure of exposure.

Gender differences in the healthy worker effect

Finally, there is potential for gender differentials in the impact of the healthy worker effect – both for the healthy worker hire effect (i.e. the tendency for the healthier individuals in society to be hired into jobs) and the healthy worker survivor effect (i.e. the tendency for the healthier members of a workforce to remain employed).

We are aware of two studies that have investigated this issue. The first is a study of vitreous fibre workers showing that among men, in the first 4 years of employment in the industry, standardized mortality ratios (SMR) for all causes of death (comparing workers to the general population) were significantly below 1 among men (SMR: 0.82, 95% CI: 0.7, 0.98), suggesting a healthy hire effect. This healthy hire effect was not as pronounced among women (SMR: 0.94, 95% CI: 0.5, 1.6). (Lea et al., 1999) In contrast, in the same study, the healthy worker survivor effect, seen by comparing mortality of

inactive workers to active workers, was considerably more pronounced among women (SMR: 3.4 in women, 1.8 in men). The same effect was seen in a study of workers from 15 different industrial cohort studies in Poland, reported at this meeting, in which the healthy worker survivor effect – in this case seen in the reduced mortality for the whole cohort - was more pronounced among women. (Sobala, 2002)

Conclusions

What can we conclude from this review of rather limited available literature? First, it must be pointed out that there are not many studies that have directly addressed the question of gender differences in exposure, with the exception perhaps of studies of physical exposures affecting joints and soft tissues. Therefore, our conclusions should be taken as speculative, not definitive. Nevertheless, this investigation of available evidence suggests the possibility that the validity of exposure estimates in epidemiology may be threatened by failure to consider possible gender differences along the pathway from sources to exposure measures, in particular with respect to

- job tasks within job titles,
- true exposure differences within otherwise similar jobs,
- differential validity of exposure estimates based on questionnaire tools or when cumulative exposure or exposure duration are used as surrogates for biologically relevant exposures (when exposure intensity is important), and
- the magnitude and direction of the healthy worker effects.

The important message is that failure to at least *consider* gender differences *may* result in biased estimates of risk. Equally important is that direction of the bias is not obvious a priori. Of course, this is not to imply that bias would always occur. Further study of possible gender differences in exposure to inhaled agents is especially warranted given the paucity of data addressing this question.

Therefore, to answer the initial question, “In exposure assessment for epidemiology, does gender matter?”, the answer is a qualified yes, probably not always, but often enough that investigators should routinely consider the possibility of gender stratified analyses in addition to gender adjusted analyses, *and* evaluate possible gender difference in exposure misclassification as possible explanations for apparent gender differences in exposure-response relationships.

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Table I – Sources for gender differences in “true” personal exposure among workers with the same job tasks

<ul style="list-style-type: none"> • differential effectiveness of personal protective equipment, availability of protection or training programs
<ul style="list-style-type: none"> • differences in body to tool/equipment/task configurations
<ul style="list-style-type: none"> • true differences ‘exposures’ not attributable to sources or agents <ul style="list-style-type: none"> ○ e.g. psychosocial exposures: job control, social support
<ul style="list-style-type: none"> • differences in micro-level tasks, scheduling of tasks: <ul style="list-style-type: none"> ○ different work practices ○ differences in exposure intensity from part-time or casual work (despite reduced exposure duration)

Table II – Gender differences in psychosocial job strain among retail clerks involved in glass bottle recycling.

	total	men	women
n	186	81	105
reported high job strain (%) ¹	27%	22%	31% ²
	relative risk	strata specific relative risk	
association between high job strain and somatic symptoms ³	2.7 (1.3, 5.9)	4.4 (1.3, 14.6)	2.0 (0.7, 5.4)

1. high job strain: high demand / low control job

2. p=0.16 comparing men and women

3. somatic symptoms: 2 or more of (fever, headache, dizziness, tiredness, nausea) at the end of the work shift

From: (Kennedy et al., 2001)

Table III – Gender differences in the accuracy of job coding and exposure estimation using a job exposure matrix, in a case-control study of asthma.

	women	men	p
total number of subjects	659	653	
% having significant coding errors in job titles	1.5%	4.6%	<0.01
subjects working in jobs held mainly (>80%) by one gender, n	254	205	
% with exposure classified by the JEM as ‘needs expert review’ ²	16.5%	30.7%	<0.01
% with exposure classified by the JEM ¹ as ‘poor estimate’ ³	10.6%	3.4%	<0.01

1. asthma-specific job exposure matrix

2. ‘needs expert review’ refers to a job title for which a valid exposure estimate is unlikely with the JEM alone (using coded job title), but for which the exposure estimate validity would be enhanced by expert review of exposure estimation using the written (text) job title and industry sector information

3. ‘poor estimate’ refers to a job title for which a valid exposure estimate is unlikely with the JEM even after expert review

From: (Kennedy et al., 2000)

Legends for figures

figure 1 – Exposure assessment pathway from sources to personal exposure estimates, showing determinants of exposure estimates

figure 2 – Measured inhalable dust exposure levels (from full shift personal samples) among retail clerks and managers with the same job titles (n=270 subjects and 270 personal dust samples). From (Kennedy et al., 2001)

figure 1

figure 2