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Development of Job Exposure Matrices to Estimate Occupational Exposure to Solar and Artificial Ultraviolet Radiation

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Abstract

Introduction—Job exposure matrices (JEMs) are important tools for estimating occupational exposures in study populations where only information on industry and occupation (I&O) are available. JEMs were developed for solar and artificial ultraviolet radiation (UVR) using a U.S standardized coding scheme.

Methods—Using U.S. Census Bureau industry and occupation codes, separate lists of I&O pairs were developed for solar and artificial UVR by a panel of Certified Industrial Hygienists who assigned exposure ratings to I&O pairs with potential exposure. Parameters for exposure included prevalence (P) and frequency (F) for solar UVR and P, F and intensity (I) for artificial UVR. Prevalence, or percent of all workers employed in an I&O pair who were exposed, was categorically rated: 0-<1, 1-<20; 20-<80 and ≥80. Frequency of exposure, defined by the number of hours per week workers were exposed, was categorically rated: 0-<5, 5-<20, 20-<35 and ≥35 hours per week. For artificial UVR only, intensity of exposure was assigned three ratings: low, low with rare excursions, and >low under normal conditions. Discrepant ratings were resolved via consensus.

Results—After excluding I&O pairs assigned P and F ratings of 0 (solar UVR) and P, F and I ratings of 0 (artificial UVR) from the JEM, 9,206 I&O pairs were rated for solar UVR and

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2,010 I&O pairs for artificial UVR. For solar UVR, 723 (7.9% of all rated pairs) had ratings in the highest category for P and F; this group included 45 occupations in varied industries. Construction and extraction occupations represented most of the occupations (n=20; 44%), followed by farming, fishing and forestry occupations (n=6; 13%). For artificial UVR, 87 I&O pairs (4.3% of all rated pairs) had maximum ratings for P, F, and I; these comprised a single occupation (welding, soldering and brazing workers) in diverse industries.

Conclusion—JEMs for solar and artificial UVR were developed for a broad range of I&O pairs in the U.S. population and are available for use by researchers conducting occupational epidemiological studies.

Keywords

job exposure matrix; solar ultraviolet radiation; artificial ultraviolet radiation; industry and occupation codes; prevalence, frequency, intensity ratings; industrial hygienist, exposure estimates

Introduction

Job exposure matrices (JEMs) are an important approach for estimating occupational exposures retrospectively. Researchers often rely on expert raters to assess exposure histories retrospectively when exposures cannot be directly measured, and historical exposure records and matrices do not exist. Expert opinion is considered more accurate than self-report for broad job groupings (Kromhout et al., 1987; Teschke et al., 2002). JEMs can be linked to job histories to facilitate assessment of relations between these exposures and risk of cancer and other adverse health outcomes in study populations (Fischer et al., 2017; Peters et al., 2016; Goldberg and Imbernon, 2002). A NIOSH project designed to link state cancer registry data to potential occupational exposures included the development of JEMs for solar and artificial ultraviolet radiation (UVR). The JEMs were developed by a panel of Certified Industrial Hygienists (CIHs) who assigned exposure ratings to standardized industry and occupation (I&O) codes.

Solar and artificial UVR were of interest because of uncertainties about the health effects of exposure. Adverse outcomes that have been reported for UVR exposure are malignancies, including non-melanoma (basal cell carcinoma, squamous cell carcinoma), with estimates of four million incident cases in the 2012 U.S. population (Rogers et al., 2015), and both cutaneous and ocular melanoma, with incidence of the former projected at just over 100,000 new cases in 2020 (SEER, 2020) and the latter accounting for nearly 4% of incident melanoma cases (Jovanovic et al. 2013).These estimates reflect disease resulting from both occupational and non-occupational exposures. Positive effects of UVR exposure include enhanced production of vitamin D, which is necessary for calcium homeostasis (Lukas and Wolf, 2019) and protection against seasonal affective disorder (WHO, 2006). Studies of the effects of UVR on the immune system are less uniform, with evidence of protection against multiple sclerosis, mixed results for different lymphomas, deleterious effects related to skin cancer, and suggestions that the immunologic effects may be dose-dependent (Lu et al., 2017; Liu-Smith et al., 2017; Hart et al. 2011; van der Mei et al., 2003; Cartwright et al., 1994).

While JEMs have been developed for solar and artificial UVR (Freedman et al., 1997; Guenel et al., 2001; Lutz JM, 2005; Peters et al., 2016; Peters et al., 2015; CANJEM, 2019; Vested et al., 2019), most focus on occupation (and do not account for industry), are limited to broad I&O categories, or were developed for case-control studies (Freedman et al., 1997; Guenel et al., 2001; Lutz et al., 2005) and therefore do not cover a wide range of jobs. No published JEM was found that included exposure ratings for solar or artificial UVR across a wide range of I&O combinations or pairs. Pilot testing by the panel determined that prevalence ratings could be assigned for both solar and artificial UVR; therefore, JEMs were constructed for both exposures.

Methods

Industry and Occupation Information

The U.S. Census 2007 industry and 2010 occupation codes were used for this project (U.S. Census Bureau, 2019a). Use of more detailed I&O codes (e.g., North American Industry Classification System (NAICS), Standard Occupation Classification (SOC) code) was considered but not used because free text I&O information in the state cancer registries was not consistently detailed enough to support their use (U.S. Census Bureau, 2019b; U.S. Bureau of Labor Statistics, 2020).

Selection of I&O Pairs for Solar and Artificial UVR

Because of the large number of I&O pairs (nearly 145,000 combinations from 269 unique Census industry codes and 539 unique Census occupation codes), a two-step process was used to limit the number of I&O pairs rated to those: 1) potentially exposed; and 2) likely to correspond to jobs in the U.S. population. The potential or likelihood of exposure was determined by assigning one of four prevalence ratings (Table 1) to each industry and each occupation separately. Industries and occupations with exposure potential were then crossed to create a list of all possible I&O pairs. I&O pairs with either industry or occupation rated as a 1 or higher (>1% prevalence) were retained for subsequent rating of two exposure parameters for solar UVR (prevalence and frequency) and three for artificial UVR (prevalence, frequency and intensity). The steps are listed below:

1. Each of the 269 U.S. Census industries and the 539 U.S. Census occupations was evaluated separately by CIHs to assess whether >1% of workers in that industry or occupation are exposed to solar UVR on the job.
2. If the CIH ratings agree, the I or O was determined to be unexposed (and excluded) or exposed (and included).
3. Discrepant ratings were resolved through consensus discussion, an approach previously shown (Rocheleau et al., 2011) to improve inter-rater agreement on future ratings of the same exposures and categorized as in step 2.
4. Each “exposed” industry was crossed with each “exposed” occupation to form potential pairs for rating.
5. To identify jobs occurring in the U.S. during the time period of interest, potential I&O pairs were compared to a dataset of I&O pairs occurring in one of

two national surveys (American Community Survey 2003–2015 and Current Population Survey 2003–2015), or one of three state cancer registries (included due to aims of the larger cancer registry study): California (partial entries 1998–2010; all entries 2011–2012), Iowa (2007–1013), and Texas (2012). I&O pairs occurring at least 5 times in the combined dataset were retained for full rating.

6. Each pair was rated by CIHs for frequency and prevalence.

7. For each I&O pair, for each metric, ratings that matched were retained as concordant.

8. I&O pairs with discrepant ratings for a metric were rated by a third CIH. If the third CIH's rating matched one of the original ratings and differed by no more than one category from the other original rating, the matching rating was assigned to the pair.

9. Ratings for I&O pairs that differed by more than one category were resolved by further research and consensus discussion.

10. I&O pairs with final ratings for all metrics assigned as 0 were excluded from the final JEM. All other I&O pairs were included.

The process was similar for artificial UVR. This process yielded a total of 9,206 I&O pairs for rating of solar UVR and 2,010 I&O pairs for artificial UVR.

Exposure parameters

Occupational solar UVR exposure was defined as exposure to the sun at work, not including artificial sources of UVR. Occupational exposure to artificial UVR was defined as exposure to non-solar sources of UVR at work (e.g., welding, UV lasers, UV disinfection lamps). For solar UVR, prevalence and frequency were each given categorical ratings (Table 1). Prevalence (P) was defined as the percent of all workers employed in the specified I&O workforce who were exposed. Frequency (F) was defined as the number of hours per week workers were exposed. Because intensity of solar UVR is dependent on season and geographical location, it was not rated as the ratings were designed to estimate an average exposure for U.S. workers. For artificial UVR, prevalence and frequency were given the same four categorical ratings as solar UVR. Intensity (I) of exposure was also included and given three categorical ratings (Table 1). Initial selection of categorical boundaries for prevalence, frequency and intensity were made via iterative discussions among the panel, with the aim of creating prevalence categories of 0 (almost no exposed workers); 1 (few exposed workers); 2 (a moderate number of exposed workers); and 3 (a large majority of the workforce exposed). Frequency metrics were set a 0 (less than half a day per week); 1 (half a day but less than half the work week); 2 (at least half, but not all, of the workweek); and 3 (essentially the full workweek). A small pilot sample (n=53) of I&O pairs was initially evaluated by a panel of four CIHs to assess feasibility of assigning prevalence and frequency ratings and whether categorical boundaries needed refinement, followed by iterative discussions to resolve discrepancies and align ratings.

Exposure rating process

The CIHs involved in the rating process included three from academic institutions (contractors) and one from NIOSH. As the initial scope of the project included development of JEMs for multiple substances, the CIHs were selected based on their familiarity with wide range of exposures, rather than knowledge of specific industries or hazards. Because the JEMs were designed to be linked to cancer registry data, the panel was instructed to consider potential exposures in the first decade of the 2000s to allow for latency considerations. Peer-reviewed journal articles, technical references, information from the O*NET database (O*NET, 2019), and expert judgement based on the collective experience of the CIH raters were used to guide exposure assignments. O*NET includes information about numerous aspects of occupations in the SOC taxonomy and, for solar UVR, the prevalence of outdoor work reported by workers surveyed including detailed occupations but only broad industry groupings. No exposure measurement data were used in the assignments.

Solar UVR—Exposure P and F ratings were independently assigned to each industry and each occupation by two contractor CIHs, with the NIOSH CIH independently assigning prevalence ratings to discrepant ratings (i.e., all three ratings were different or two of the ratings were the same and the third was two points higher/lower). Discrepant ratings were researched further if necessary, discussed among the CIHs, and resolved via consensus.

Artificial UVR—A similar process to that described above for solar UVR was used to assign artificial UVR exposure P, F and I ratings. Three contractor CIHs were involved in the rating process - one assigned ratings to all I&O pairs and the other two CIHs each assigned ratings to half of the I&O pairs since neither were available to do all of the ratings.

Statistical methods

Inter-rater agreement—Inter-rater agreement statistics for solar and artificial UVR were calculated using SAS PROC FREQ (SAS version 9.4 (SAS Institute Inc., Cary, NC). Fleiss-Cohen kappa weights (mean and 95% confidence interval, CI) were used to maximize weight given to ratings falling in adjacent categories compared to ratings assigned to distant categories. Cohen considered kappas ≤ 0 to indicate complete disagreement, 0.01–0.20 none to slight, 0.21–0.40 fair, 0.41– 0.60 moderate, 0.61–0.80 substantial, and 0.81–1.00 as near perfect agreement (McHugh, 2012).

Assessment of differences in ratings for occupations across industries—JEMs are sometimes created based on occupation alone. Constructing the solar and artificial UVR JEMs based on I&O combinations provided an opportunity to assess the extent of variation in ratings for occupations across industries. Percentages of occupations in the JEM falling into more than one category for each exposure parameter for 1) solar UVR and 2) artificial UVR were calculated after completion of the rating process.

Results

Summary distributions for solar UVR across P and F categories and for artificial UVR across P, F, and I are shown in Table 2.

Solar UVR JEM

P and F ratings for the 9,206 I&O pairs with non-zero ratings for at least one exposure parameter are presented in Table S1 (online only Appendix). Nearly a third (32%, n=2,948) of the I&O pairs were assigned a rating of 2 or higher for P and F; a rating of 3 for both exposure parameters was assigned to 7.9% of the pairs (n=723). Forty-five different occupations are included in the I&O pairs with the highest rated exposure, 30 (67%) of them represent three broad occupational groups: construction and extraction (n=20, 44%), farming, fishing and forestry (n=6, 13%), and installation, maintenance and repair (n=4, 9%). The number of different industries associated with each of the 45 occupations ranged from one (e.g., pile-driver operator in construction) to as many as 107 industries (for grounds maintenance workers).

Artificial UVR JEM

P, F and I ratings for the 2,010 I&O pairs are presented in Table S2 (online only Appendix). Nearly 15% (n=294) of the I&O pairs were assigned ratings of at least 2 for P and F and 2 for I. Eighty-seven (4.3%) I&O pairs were assigned the highest rating for each of the three exposure parameters, all from a single occupation: welding, soldering and brazing workers. I&O pairs with ratings of 2 or higher spanned multiple industries and included the following occupations: pipelayers, plumbers, pipefitters and steamfitters; structural iron and steel workers; boilermakers; reinforcing iron and rebar workers; rail-track laying and maintenance equipment operators; structural metal fabricators and fitters; and metal furnace operators, tenders, pourers and casters.

Inter-rater Agreement

Inter-rater agreement was evaluated using weighted kappa statistics for all exposure parameters for solar and artificial UVR. For solar UVR, the weighted kappa for prevalence (0.29, 95% CI=0.28–0.30) was much lower than that for frequency (0.52, 95% CI=0.50–0.53). In contrast, for artificial UVR, the weighted kappa for prevalence was 0.49 (95% CI=0.46–0.52), for frequency, 0.39 (95% CI=0.26–0.41), and for intensity, 0.28 (95% CI=0.25–0.30).

Differences in final ratings for occupations across industries

For solar UVR, 34% of occupations received final ratings (after concordance discussions) in more than one prevalence category, while 43% were rated in more than one frequency category (Table 3). The percentages were larger for two of the three artificial UVR exposure parameters, with 57% of occupations spanning multiple prevalence categories and 45% spanning multiple intensity categories; for frequency, 40% of occupations spanned multiple prevalence categories.

Discussion

JEMs that incorporate industry and occupation can be used to identify and protect workers at risk of adverse outcomes due to high UVR exposure. The exposure assignments can also be used with surveillance data and in etiologic studies to investigate relations among UVR exposed workers and health outcomes.

Strengths of this project include the incorporation of both I&O in the JEMs and the wide range of U.S. based I&O combinations incorporated. The data for both JEMs are contained in Excel files and rank ordered from highest to lowest P, F, and I exposure ratings, and then by occupation code. The data can be quickly sorted by other variables including industry code, industry title, and occupation title. We did not combine exposure ratings for P, F and I, so this can be done by individual researchers based on research needs. For example, the solar UVR JEM did not incorporate 1) regional differences, 2) seasonal variation, 3) protective clothing and exposure mitigation practices, 4) shiftwork, or 5) non-occupational solar UVR; keeping the exposure parameters separate facilitates application of modifying factors specific to the study population and research objectives. Moreover, some researchers will be interested in more or less refined categorizations for specific parameters; in the case of the former, these JEMs offer a starting point and, for the latter, categories can be collapsed.

Several caveats should be considered when using the solar and artificial UVR JEMs. It was not uncommon for the raters to initially assign discrepant exposure ratings to the I&O pairs. The raters were selected for overall industrial hygiene experience rather than for knowledge of specific industries or hazards. Solar UVR was rated before artificial UVR. While the raters clearly understood the frequency (and for artificial UVR, intensity) parameters, prevalence for solar UVR was initially problematic, as evidenced by the particularly low inter-rater agreement. Discussions of the reasons for assigning prevalence ratings identified some confusion about whether raters were to identify the prevalence of all solar UVR-exposed workers who were in a specific industry, or to identify the prevalence of all workers employed in the industry who were exposed to solar UVR; the latter was the intended rating target. Following intensive concordance discussions, this confusion abated. This clearer understanding of the scope of this parameter likely explains much of the higher concordance rating for prevalence for artificial UVR. The probability of misclassification of ratings between adjacent categories is substantially higher than for non-adjacent categories. Therefore, the exposure ratings are perhaps most suitable for contrasting industries with high vs. low prevalence, frequency, or intensity of exposure, rather than a fully populated continuum of exposures

In addition, UVR exposures change over time, and these changes should be considered for application of the JEMs to exposure periods other than 2000–2009 (the focus of this project). Intensity of solar UVR changes with calendar time, season, and location, so the intensity parameter was not included in the solar UVR JEM. Growing public awareness of the hazards of solar UVR exposure over time could also affect exposure prevalence and frequency. In contrast, use of artificial UVR is evolving rapidly, with use likely increasing as an antimicrobial/disinfection method but perhaps decreasing in other applications due to increased hazard awareness (OR Today, 2018; Katara et al., 2008); increasingly, UVR is used in some scenarios where robots, not people, are present. Therefore, application of the artificial UVR JEM to exposure periods other than 2000–2009 requires consideration of these changes.

A number of other JEMS have been developed for solar and artificial UVR. The majority of these JEMs incorporated measurement data, an advantage over the reliance on expert-opinion only in the current project. The lack of measurement data for UVR exposures for industry-occupation combinations across large numbers of industries would have precluded consistent application of measurement data to our JEMs, and is the reason the previous JEMs that were comprehensive with respect to job types, such as CAREX, accounted for occupation alone. However, evaluation of the distribution of occupation ratings across industries suggests that for some exposures, including UVR (both solar and artificial) JEMs based solely on occupation, may provide insufficient information for JEMs intended to cover a wide range of industries. This difference in approach precludes direct comparison between these new JEMs and those developed previously. Between-country differences in both jobs and solar UVR exposure also hinder comparisons. Some of the variation in ratings is likely due to misclassification, and some might be ameliorated using a more detailed occupation coding scheme that narrows the range of industries corresponding to each occupation. However, the finding that at least one third, and in the case of artificial UVR prevalence, more than half of occupations, spanned multiple ratings categories across industries suggest the need to carefully consider the question of differences within occupational groupings when constructing JEMs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Exposure parameters and categorical boundaries for solar and artificial UVR

Categorical Rating	Prevalence[1] within Workforce (solar and artificial UVR)	Frequency (for exposed workers) (solar and artificial UVR)	Intensity (for exposed workers) (artificial UVR only)
0	0 - <1%	0 - <5 hours/week	Low
1	1 - <20%	5 - <20 hours/week	Low under normal conditions, although rare excursions possible
2	20 - <80%	20 - <35 hours/week	> Low under normal conditions
3	≥80%	≥35 hours/week	Not applicable

[1]Percent of all workers employed in the industry who were exposed at work

Table 2.

Summary of exposure ratings for solar and artificial UVR (number of I/O pairs included in final JEM per category)

Categorical Rating	Prevalence[1] within Workforce (solar and artificial UVR)	Frequency (for exposed workers) (solar and artificial UVR)	Intensity (for exposed workers) (artificial UVR only)
Solar UVR			
0	Not applicable[2]	1392	Not applicable[3]
1	4121	4679	Not applicable[3]
2	2503	2405	Not applicable[3]
3	2582	730	Not applicable[3]
Artificial UVR			
0	Not applicable[2]	1158	524
1	1412	522	1136
2	483	198	350
3	115	132	Not applicable[4]

[1] Percent of all workers employed in the industry who were exposed at work

[2] I&O pairs with exposure prevalence for either industry or occupation=0 were not further rated

[3] Solar UVR was not rated for intensity

[4] Intensity has 3 rating categories

Table 3.

Distribution of ratings for an occupation across industries for solar and artificial UVR

	Solar UVR		Artificial UVR		
% of occupations rated in:	**Prevalence**[1]	**Frequency**	**Prevalence**[1]	**Frequency**	**Intensity**
One category	65.9	57.1	43.4	60.5	55.3
Two categories	21.7	27.6	48.7	32.9	44.7
Three categories	12.4	12	7.9	6.6	0
Four categories	0	3.2	0	0	Not applicable[2]
Total occupations rated	217	217	76	76	76

[1]Percent of all workers employed in the industry who were exposed at work

[2]Intensity has 3 rating categories