Mixed Exposures to Volatile Organic Compounds in Cleaning and Disinfecting Products among Healthcare Workers: Modeling the Effects of Tasks and Product Use

**Feng-Chiao Su**, Melissa Friesen, Aleksandr Stefaniak, Paul Henneberger, Ryan Lebouf, Marcia Stanton, Xiaoming Liang, Michael Humann, M. Abbas Virji

Expanding Research Partnerships: State of the Science, Aurora, CO

June 22, 2017
Background

- **Healthcare Industry**
  - Employs 12.3 million – 9% of US employment
  - Fastest growing occupations – 19% from 2014 to 2024
  - Typically experience a range of illnesses and injuries
Background

- **Work-related Asthma (WRA)**
  - Occupation accounts for >16% of asthma onset among adults
  - Work-exacerbated asthma occurs in >21% of adults with asthma
  - Healthcare industry and occupations have the highest prevalence of current asthma (>10% – BRFSS data)

Dodd and Mazurek, 2016; Henneberger et al., 2011; Pechter et al., 2005; Torén and Blanc, 2009
Background

- **Cleaning and Disinfecting (C&D) Activities**
  - **Tasks:** Floor, surface, equipment or instrument, patient, etc.
  - **Chemicals in products used**
    - Sensitizers: Acrylates, aldehydes, amines, enzymes, quats, etc.
    - Irritants: Amines, ammonia, chlorine, hydrochloric acid, quats, etc.
Background

- **Research Gap**
  - The lack of comprehensive exposure assessment among healthcare workers
    - A variety of C&D tasks performed by various occupations
    - A wide range of chemical mixtures in C&D products
  
  - Previous epidemiologic studies relied on self-reported exposures
    - Potential exposure misclassification and bias
  
  - High correlations between tasks and product use
    - Challenges in the statistical modeling

Delclos et al. 2009; Donnay et al. 2011
Objectives

- To reduce data dimensionality in a large number of tasks and products used

- To identify the determinants of mixed exposures to volatile organic compounds (VOCs) in healthcare settings
Data Collection

- **Study Population**
  - 143 healthcare workers at 5 hospitals (1 to 3 shifts / person)
  - 14 selected occupations (e.g., nurse, housekeeper, technician, etc.)

- **VOC Measurements**
  - 143 pairs of full-shift personal and mobile area samples
  - 14 selected VOCs analyzed by GC-MS

- **Tasks and Products Used**
  - Systematic time-activity logs
  - Every 5-minute intervals on >30 tasks and >40 products
  - Personal and area (bystander exposure) observations

LeBouf, et al., 2014; Saito et al., 2015
Data Analyses

- **Hierarchical Clustering**
  - Systematic and reproducible data reduction approach
  - Partition observations into groups with similar patterns of input variables
    - Time (min) spent on personal tasks and products
  - Mutually exclusive observations in identified clusters
    - Can be directly used as predictors in statistical models

---

Friesen et al., 2015; Hennig and Liao, 2013; Milligan, 1980; Ward, 1963
Data Analyses

- **Linear Mixed-effect Models**
  - Identify occupational determinants of VOC exposures
    - Random effects: Hospital and participant nested within hospital
    - Responses: Personal and area log-transformed VOC exposures
    - Predictors: Cleaning tasks
      - Model-based clusters (identified by hierarchical clustering)
      - Expert-based groups (identified by industrial hygienist)
Results
Figure 1. Average time spent on personal cleaning tasks (minute) by occupations (n = 143).
Figure 2. Median VOC concentrations (ppb) by occupations (n = 143).
Figure 3. Cluster Dendrogram for Personal Tasks

Clusters for Personal Tasks (predictors in statistical models)

A  B  C  D  E  F  G

Non-cleaning tasks  Patient care, blood draw  Pour/mix product, dental lab work, general cleaning, patient care  Patient care, disinfect machine, wash hands, bathe patient  Patient care, prepare/wash equipment, sterilize/disinfect, prepare procedure room  Clean bathroom/window, clean spill, mop/buff floor  Mix product, mop/buff/strip floor
Table 1. Results of multiple linear mixed-effect model for selected VOCs (log-transformed) and model-based clusters for personal tasks (N = 143).

<table>
<thead>
<tr>
<th>Cleaning tasks</th>
<th>Non-cleaning tasks Reference Bystander</th>
</tr>
</thead>
<tbody>
<tr>
<td>B: Patient care, blood draw</td>
<td>0.94</td>
</tr>
<tr>
<td>C: Pour/mix products, dental lab work, general cleaning, patient care</td>
<td>1.54</td>
</tr>
<tr>
<td>D: Patient care, disinfect machine, wash hands, bathe patient</td>
<td>1.99</td>
</tr>
<tr>
<td>E: Patient care, prepare/wash equipment, sterilize/disinfect, prepare procedure room</td>
<td>1.40</td>
</tr>
<tr>
<td>F: Clean bathroom/window, clean spill, mop/buff floor</td>
<td>0.65</td>
</tr>
<tr>
<td>G: Mix product, mop/buff/strip floor</td>
<td>3.38</td>
</tr>
</tbody>
</table>

P_, personal; A_, area; # 0.05 < p-value < 0.1; * 0.01 < p-value < 0.05; ** p-value < 0.01.

Fixed effects: model-based personal task cluster (1 categorical variable) and area task (1 indicator)
Random effects: hospital and participant nested within hospital
Table 2. Results of multiple linear mixed-effect model for selected VOCs (log-transformed) and expert-based groups for personal tasks (N = 143).

P_, personal; A_, area; # 0.05 < p-value < 0.1; * 0.01 < p-value < 0.05; ** p-value < 0.01.
Fixed effects: expert-based personal task groups (6 indicators) and area task (1 indicator)
Random effects: hospital and participant nested within hospital
Summary

*Elevated VOC exposures were associated with C&D tasks*

- **Model-based Clusters**
  - **Cluster D**: Disinfect machine, wash hands, bathe patient – 2-propanol, chloroform, and toluene
  - **Cluster F**: Clean bathroom/window, clean spill, mop/buff floor – chloroform and limonene
  - **Cluster G**: Mix product, mop/buff/strip floor – 2-propanol, toluene, terpenes

- **Expert-based Groups**
  - Floor cleaning – ethanol, toluene, chloroform, limonene, and α-pinene
  - Surface cleaning – chloroform
  - Instrument cleaning – toluene
  - Patient or hand cleaning – ethanol and toluene
What Else ???

❖ Current Study
  ▪ Develop a task-exposure matrix to estimate exposure surrogates of VOCs based on the results of expert-based groups

❖ Future Research
  ▪ Apply hierarchical clustering to an epidemiological study
    • Task and product use clusters
    • Respiratory outcome clusters
Acknowledgement

❖ **NIOSH**
  - Paul K. Henneberger
  - Ryan F. Lebouf
  - Xiaoming Liang
  - Marcia L. Stanton
  - Aleksandr B. Stefaniak
  - M. Abbas Virji

❖ **National Cancer Institute**
  - Melissa C. Friesen
For more information please contact Centers for Disease Control and Prevention

1600 Clifton Road NE, Atlanta, GA 30333
Telephone: 1-800-CDC-INFO (232-4636)/TTY: 1-888-232-6348
Visit: www.cdc.gov | Contact CDC at: 1-800-CDC-INFO or www.cdc.gov/info

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.
Outline

- Background
- Objectives
- Data Collection
- Data Analyses
- Results
- Summary
- Further Research
Data Analyses

Hierarchical Clustering

Systematic and reproducible data reduction approach

Dr. Eamonn Keogh’s slides @ UC Riverside
Data Analyses

- Hierarchical Clustering
  - Systematic and reproducible data reduction approach
  - Partition observations into groups with similar patterns
    - Linkage criterion: Ward’s minimum variance method
    - Determination of number of clusters: scree plots
  - Sensitive to data scale and outliers
    - VOC measurements: low, medium, and high
    - Personal tasks and products: standardized time
  - Mutually exclusive observations in identified clusters
    - Can be directly used as predictors in statistical models

Friesen et al., 2015; Hennig and Liao, 2013; Milligan, 1980; Ward, 1963
Figure 1. Boxplot of full-shift VOC measurements (ppb) in personal and mobile area samples (N = 143).

MChl, methylene chloride; MM, methyl methacrylate
Figure 3. Cluster Dendrogram for Categorical Personal VOCs

Input variables: 14 categorical VOCs (low, medium, and high)

High exposure to most VOCs
<table>
<thead>
<tr>
<th>Cluster (no. obs)</th>
<th>I (20)</th>
<th>II (11)</th>
<th>III (36)</th>
<th>IV (29)</th>
<th>V (13)</th>
<th>VI (6)</th>
<th>VII (13)</th>
<th>VIII (15)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage (%) of High Exposure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>35.0</td>
<td>81.8</td>
<td>19.4</td>
<td>13.8</td>
<td>92.3</td>
<td>66.7</td>
<td>7.69</td>
<td>20.0</td>
</tr>
<tr>
<td>Acetone</td>
<td>25.0</td>
<td>0.00</td>
<td>25.0</td>
<td>34.5</td>
<td>69.2</td>
<td>33.3</td>
<td>46.2</td>
<td>40.0</td>
</tr>
<tr>
<td>2-Propanol</td>
<td>35.0</td>
<td>72.7</td>
<td>44.4</td>
<td>0.00</td>
<td>53.8</td>
<td>100</td>
<td>7.69</td>
<td>13.3</td>
</tr>
<tr>
<td>Methylene chloride</td>
<td>5.00</td>
<td>0.00</td>
<td>19.4</td>
<td>44.8</td>
<td>92.3</td>
<td>0.00</td>
<td>38.5</td>
<td>60.0</td>
</tr>
<tr>
<td>Hexane</td>
<td>30.0</td>
<td>0.00</td>
<td>13.9</td>
<td>55.2</td>
<td>84.6</td>
<td>50.0</td>
<td>30.8</td>
<td>13.3</td>
</tr>
<tr>
<td>Chloroform</td>
<td>25.0</td>
<td>36.4</td>
<td>30.6</td>
<td>3.45</td>
<td>84.6</td>
<td>66.7</td>
<td>84.6</td>
<td>0.00</td>
</tr>
<tr>
<td>Benzene</td>
<td>40.0</td>
<td>18.2</td>
<td>19.4</td>
<td>24.1</td>
<td>100</td>
<td>0.00</td>
<td>69.2</td>
<td>6.67</td>
</tr>
<tr>
<td>Methyl methacrylate</td>
<td>25.0</td>
<td>9.09</td>
<td>30.6</td>
<td>6.90</td>
<td>92.3</td>
<td>16.7</td>
<td>92.3</td>
<td>20.0</td>
</tr>
<tr>
<td>Toluene</td>
<td>55.0</td>
<td>63.6</td>
<td>5.56</td>
<td>17.2</td>
<td>7.69</td>
<td>16.7</td>
<td>38.5</td>
<td>100</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>15.0</td>
<td>0.00</td>
<td>0.00</td>
<td>10.3</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>73.3</td>
</tr>
<tr>
<td>m,p-Xylene</td>
<td>15.0</td>
<td>0.00</td>
<td>0.00</td>
<td>10.3</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>80.0</td>
</tr>
<tr>
<td>o-Xylene</td>
<td>0.00</td>
<td>0.00</td>
<td>2.78</td>
<td>6.90</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>α-Pinene</td>
<td>25.0</td>
<td>0.00</td>
<td>2.78</td>
<td>0.00</td>
<td>69.2</td>
<td>66.7</td>
<td>15.4</td>
<td>6.67</td>
</tr>
<tr>
<td>Limonene</td>
<td>30.0</td>
<td>45.5</td>
<td>38.9</td>
<td>10.3</td>
<td>76.9</td>
<td>0.00</td>
<td>38.5</td>
<td>26.7</td>
</tr>
<tr>
<td><strong>Count of Occupation (no. obs)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinical laboratory technologist (8)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Nursing assistant (8)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dental assistant (4)</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dental laboratory technician (4)</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Endoscopy technician (11)</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Floor stripper (13)</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Housekeeper (31)</td>
<td>13</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Licensed practical nurse (5)</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Medical appliance technician (2)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Medical equipment preparer (7)</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Pharmacist/pharmacy technician (6)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Registered nurse (34)</td>
<td>2</td>
<td>3</td>
<td>16</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Respiratory therapist (8)</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Surgical technologist (2)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Non-cleaning tasks:
- Patient care,
- Blood draw
- Pour/mix product,
- Dental lab work,
- General cleaning,
- Patient care
- Patient care,
- Disinfect machine,
- Wash hands,
- Bathe patient
- Patient care,
- Prepare/wash equipment,
- Sterile/disinfect,
- Prepare procedure room
- Clean bathroom/spill/window,
- Mop floor,
- Buff floor,
- Strip floor

Clusters for Personal VOCs

Clusters for Personal Tasks

Count
Strengths and Limitations

- Comprehensive exposure assessment
  - Unique and robust data – VOC exposures and observations of tasks
  - Can link tasks to exposure

- Limitations of hierarchical clustering
  - Data-driven method
  - Overlapped variables among clusters – may cause limited application to exposure controls

- Mixed VOC exposure seems less important
  - Tasks related to specific exposure not total VOC burden

---

effectively, all models are wrong, but some are useful

George E. P. Box

freshspectrum.com