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

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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

U.S. Bureau of Labor Statistics, 2015, 2017

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.

Quinn et al., 2015; Quirce and Barranco, 2010; Saito et al. 2015

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

"Hank just loves concocting new mixtures of cleaning products. I like to think of him as a combinajanitorial chemist."

- 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

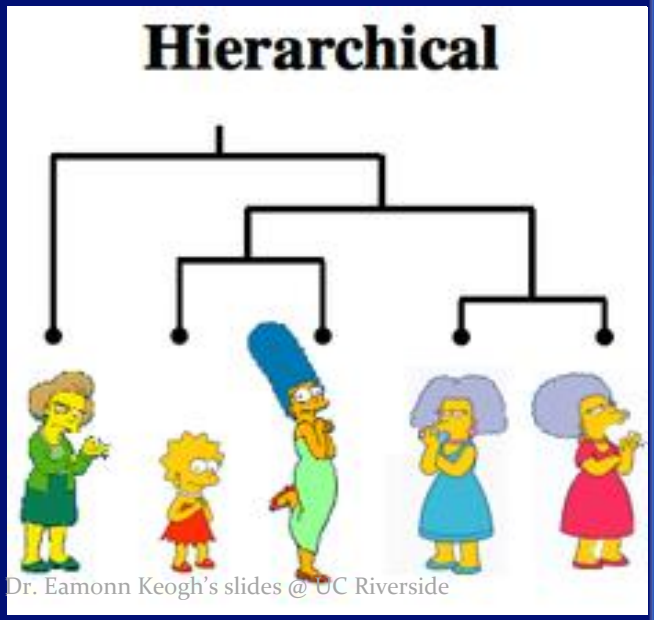
Data Collection

- **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



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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

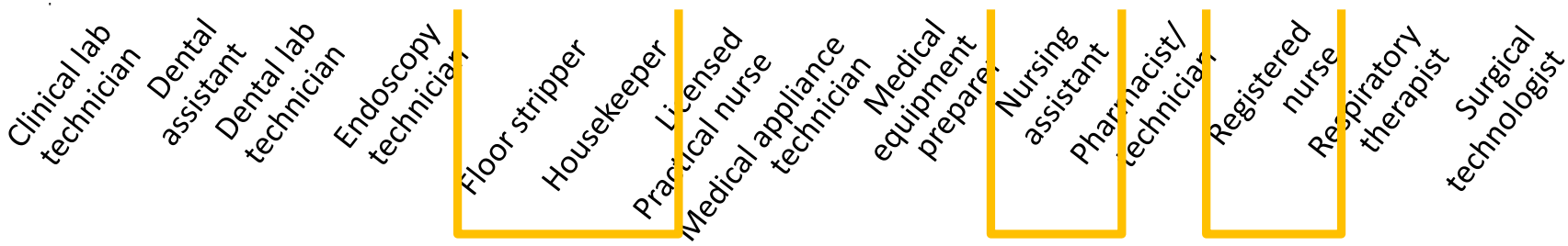

Figure 1. Average time spent on personal cleaning tasks (minute) by occupations (n = 143).

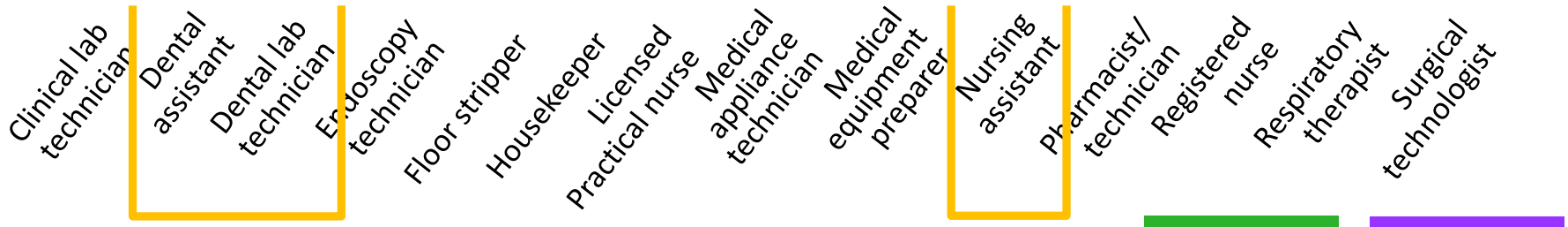

Figure 2. Median VOC concentrations (ppb) by occupations (n = 143).

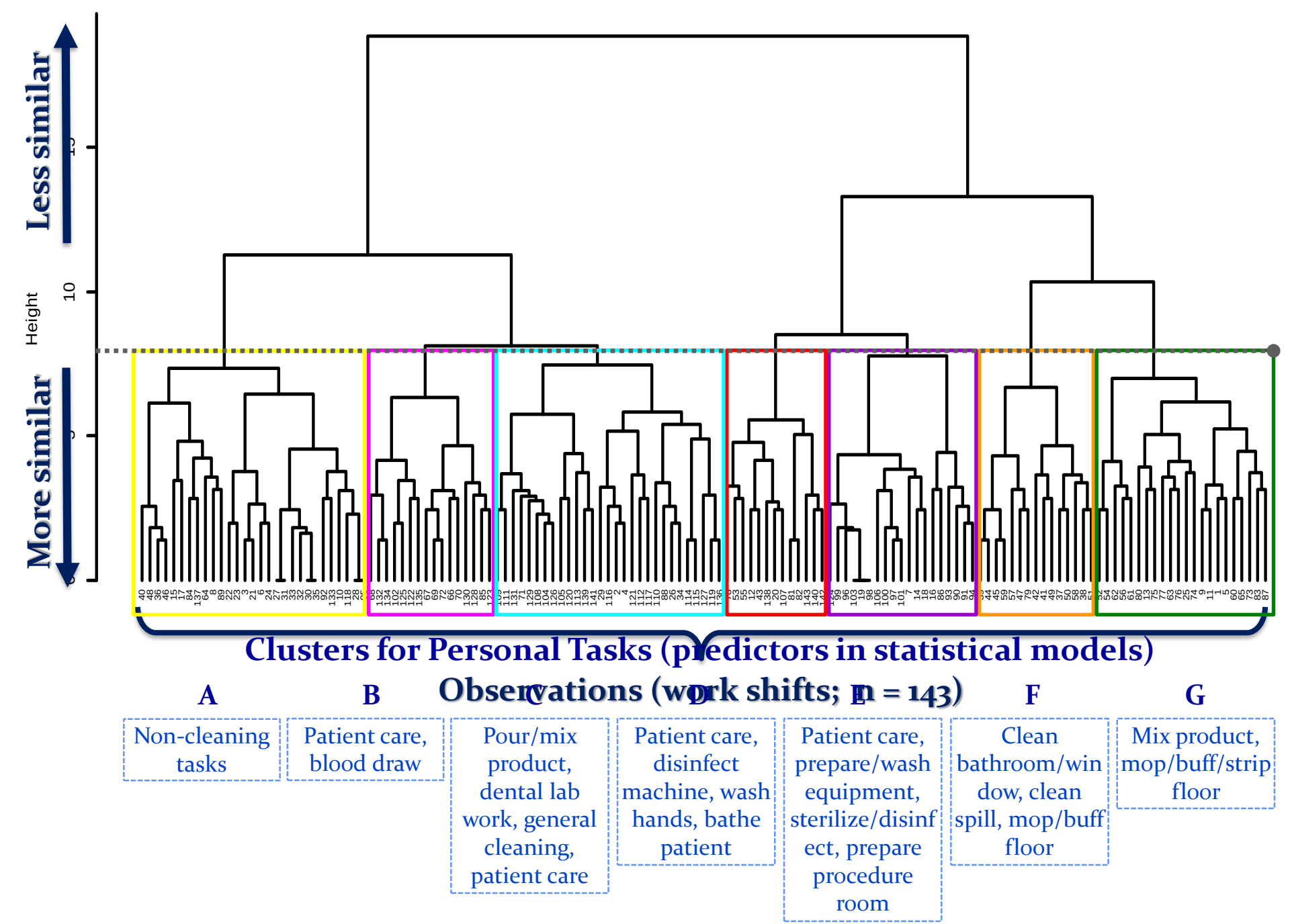

Figure 3. Cluster Dendrogram for Personal Tasks

Table 1. Results of multiple linear mixed-effect model for selected VOCs (log-transformed) and model-based clusters for personal tasks (N = 143).

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

Nurse

- Cluster D: Disinfect machine, wash hands, bathe patient – 2-propanol, chloroform, and toluene

House-keeping

- 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

House-keeping

- Floor cleaning – ethanol, toluene, chloroform, limonene, and α-pinene
- Surface cleaning – chloroform
- Instrument cleaning – toluene

Nurse

- 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

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  - Melissa C. Friesen

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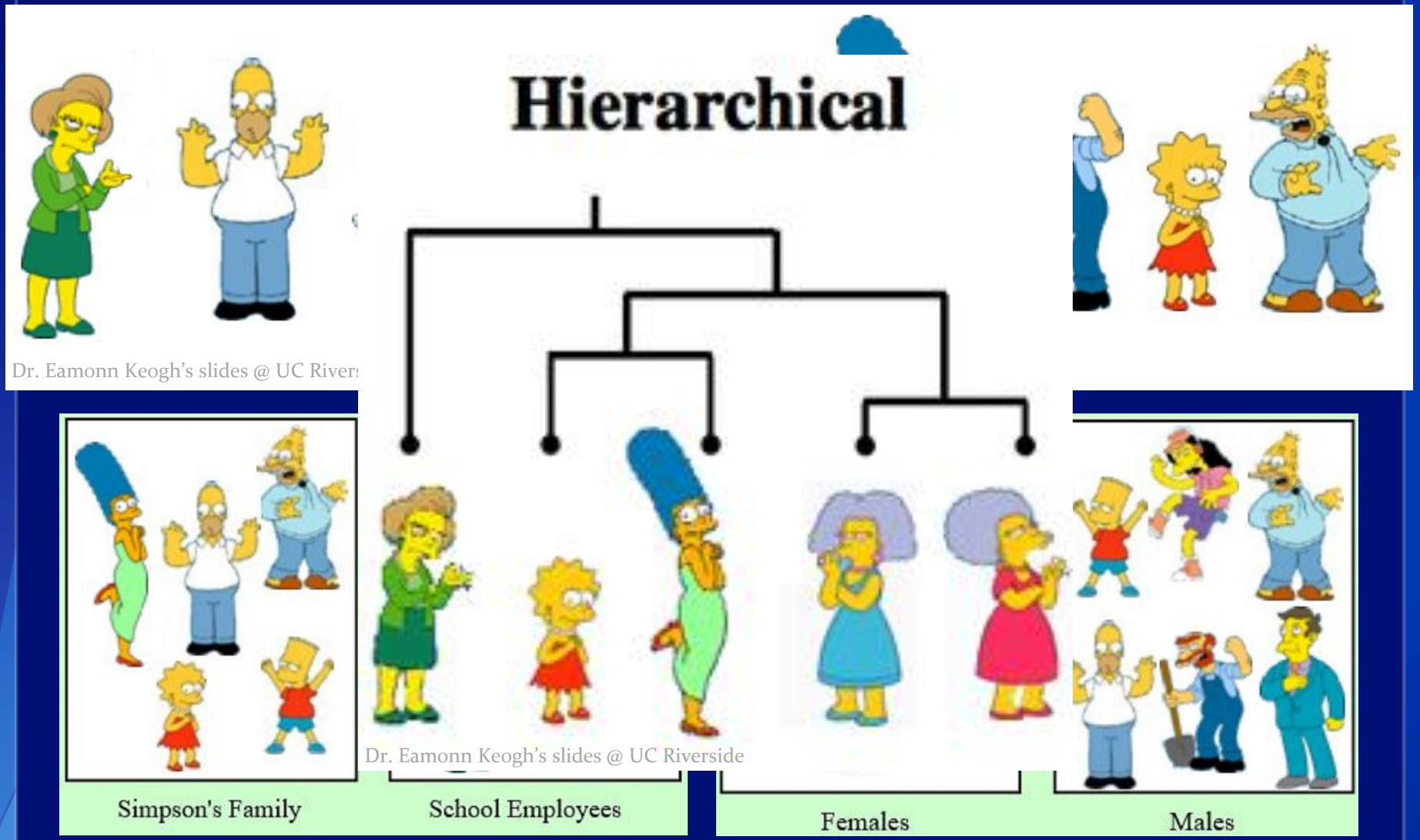
Outline

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

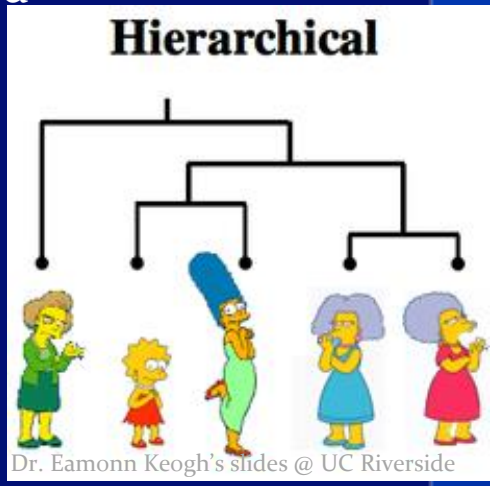
Data Analyses



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

Input variables



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  - 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

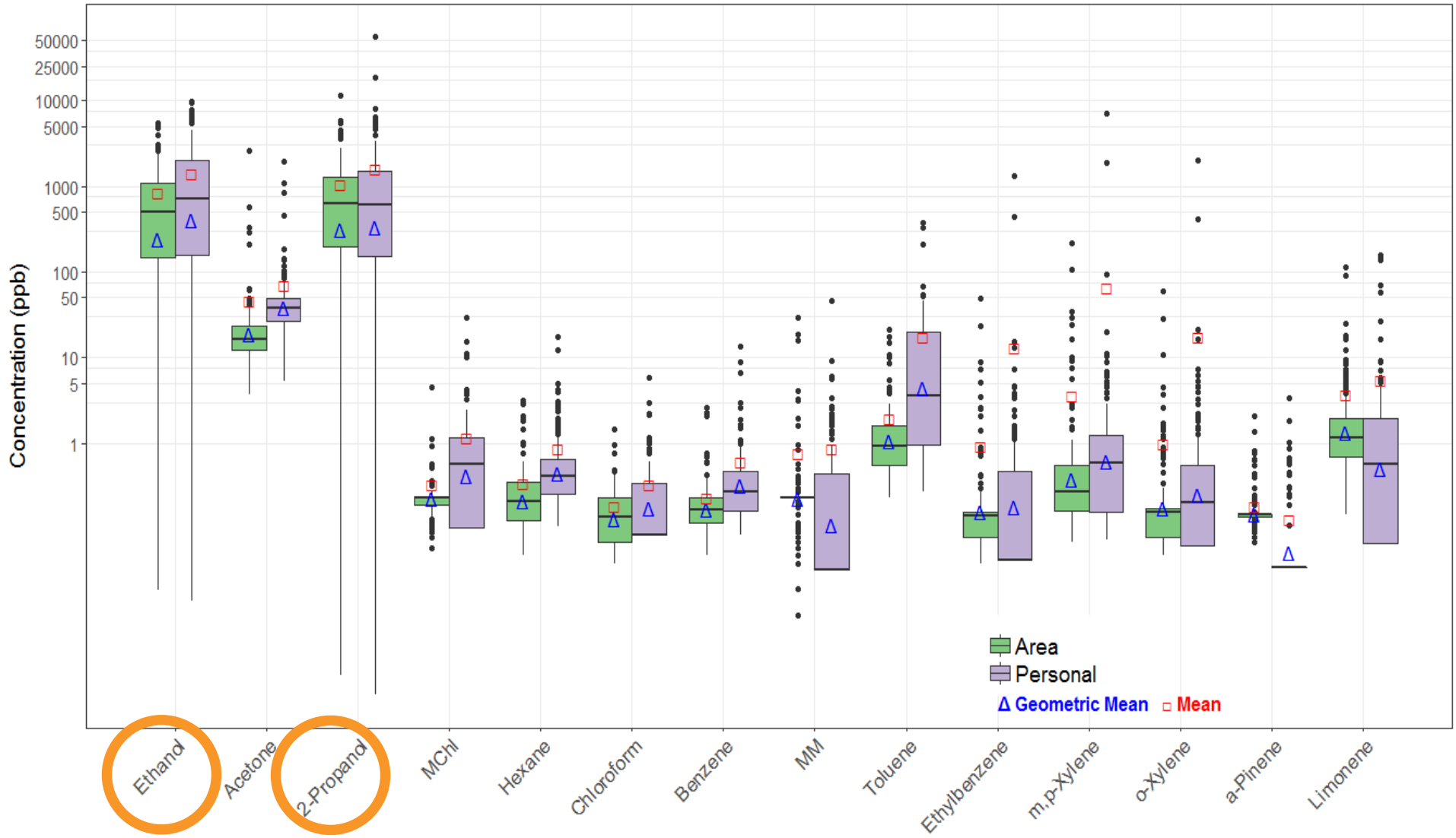


Figure 1. Boxplot of full-shift VOC measurements (ppb) in personal and mobile area samples (N = 143).

MChl, methylene chloride; MM, methyl methacrylate

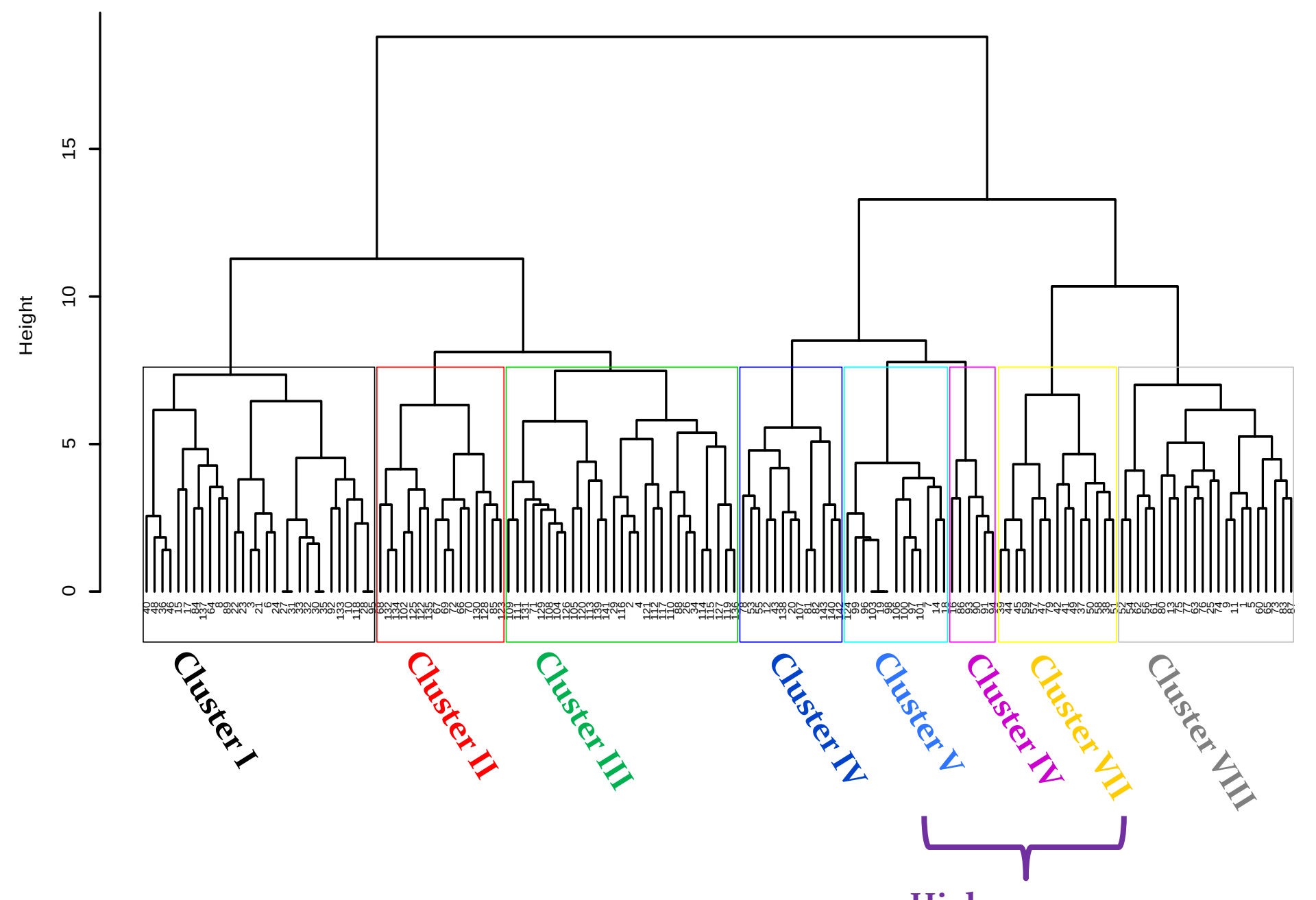
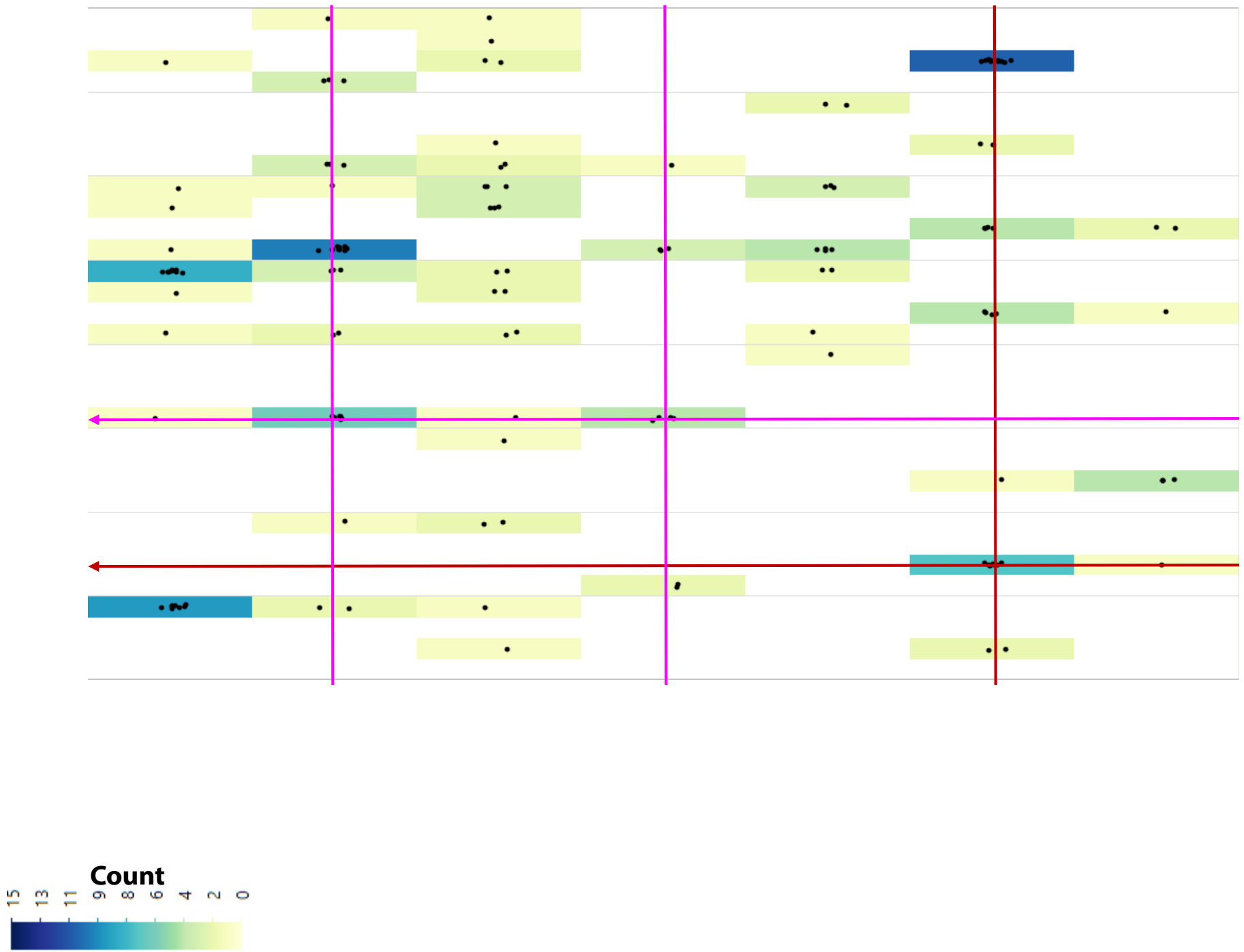


Figure 3. Cluster Dendrogram for Categorical Personal VOCs

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

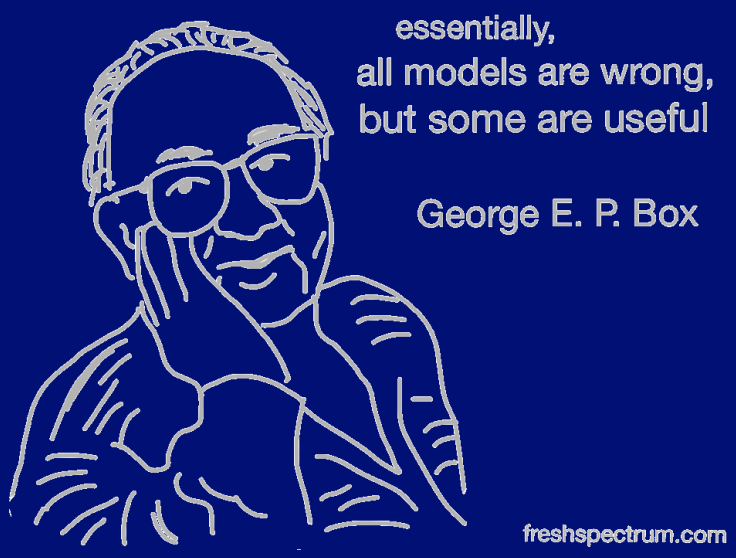
Table 1. Distribution of occupations by clusters for categorical personal VOCs (N = 143).

Cluster (no. obs)	I (20)	II (11)	III (36)	IV (29)	V (13)	VI (6)	VII (13)	VIII (15)
Percentage (%) of High Exposure								
Ethanol	35.0	**81.8**	19.4	13.8	**92.3**	**66.7**	7.69	20.0
Acetone	25.0	0.00	25.0	34.5	**69.2**	33.3	46.2	40.0
2-Propanol	35.0	**72.7**	44.4	0.00	**53.8**	**100**	7.69	13.3
Methylene chloride	5.00	0.00	19.4	44.8	**92.3**	0.00	38.5	**60.0**
Hexane	30.0	0.00	13.9	**55.2**	**84.6**	**50.0**	30.8	13.3
Chloroform	25.0	36.4	30.6	3.45	**84.6**	**66.7**	**84.6**	0.00
Benzene	40.0	18.2	19.4	24.1	**100**	0.00	**69.2**	6.67
Methyl methacrylate	25.0	9.09	30.6	6.90	**92.3**	16.7	**92.3**	20.0
Toluene	**55.0**	**63.6**	5.56	17.2	7.69	16.7	38.5	**100**
Ethylbenzene	15.0	0.00	0.00	3.45	**100**	**100**	**100**	**73.3**
m,p-Xylene	15.0	0.00	0.00	10.3	**100**	**83.3**	**76.9**	**86.7**
o-Xylene	0.00	0.00	2.78	6.90	**100**	**100**	**100**	**80.0**
α-Pinene	25.0	0.00	2.78	0.00	**69.2**	**66.7**	15.4	6.67
Limonene	30.0	45.5	38.9	10.3	**76.9**	0.00	38.5	26.7
Count of Occupation (no. obs)								
Clinical laboratory technologist (8)	0	0	0	2	0	0	0	**6**
Nursing assistant (8)	0	1	2	0	**5**	0	0	0
Dental assistant (4)	1	0	2	1	0	0	0	0
Dental laboratory technician (4)	0	0	2	2	0	0	0	0
Endoscopy technician (11)	0	2	2	6	1	0	0	0
Floor stripper (13)	1	0	2	2	0	**4**	2	2
Housekeeper (31)	**13**	3	4	3	0	1	**6**	1
Licensed practical nurse (5)	1	2	0	0	1	0	1	0
Medical appliance technician (2)	0	0	0	0	0	0	1	1
Medical equipment preparer (7)	0	0	3	2	0	1	1	0
Pharmacist/pharmacy technician (6)	0	0	1	3	0	0	0	2
Registered nurse (34)	2	3	**16**	6	**6**	0	1	0
Respiratory therapist (8)	2	0	1	1	0	0	1	3
Surgical technologist (2)	0	0	1	1	0	0	0	0


Count
15
13
11
9
8
6
4
2
0

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