VOC personal exposures in EXPOLIS populations in Athens, Helsinki, Oxford and Prague

Rufus D. Edwards[1], Christian Schweizer [2,3], Hak Kan Lai [4], Matti Jantunen [4], Lucy Bayer-Oglesby [2,3], Mark Nieuwenhuijsen [5], Klea Katsouyanni [5], Radim Sram [5], Nino Kunzli [2,3] and EXPOLIS-Index Group

(1) Environmental Health, Science and Policy University of California at Irvine. (2) University of Southern California Los Angeles; (3) Institute of Social and Preventive Medicine, University of Basel, Switzerland; (4) KTL Finland (5) and EXPOLIS Index Group

Introduction

The EXPOLIS study was a European representative population based study of adult air pollution exposures, where personal exposure and workplace, indoor residential and outdoor residential environments were measured for participating adults. Objectives of the VOC component of the study were to determine background exposures to 30 VOCs selected for their relevance to health or as markers of pollution sources. Due to the highly skewed nature of these distributions, in the current paper we wish to expand on this approach to identify activities and sub-populations with more elevated exposures and examine differences in personal exposures of EXPOLIS populations in Athens, Helsinki, Oxford and Prague in relation to questionnaire information and 48-hour time activity diaries.

Sampling design

- Participants carried an aluminum briefcase, containing VOC sampling apparatus and other sampling equipment, at all times during the 48-hour sampling period
- VOCs were actively sampled using a modified Buck IH Pump (A.P.Buck Inc. Orlando, Florida) and absorbed onto Perkin Elmer Tenax TA absorbent tubes
- Analysis was performed by VTT (Espoo, Finland) using a Hewlett-Packard 5890 Series II gas chromatograph with flame ionization (FID) and mass selective detection (Hewlett-Packard MSD 5972). VOCs were identified from MSD total ion chromatogram by a Wiley 275 software library. Peaks on FID chromatograms were identified on the basis of retention times of standard reference materials (high purity).
- Further details of the VOC sampling and analysis including comparisons of PEM and MEM measurements, duplicates and performance evaluations may be found in Jurvelin et al (2000) (1).

Smoking

Many of the compounds that are associated with automobile emissions and other combustion processes are also present in tobacco smoke, which is such a dominant localized source that variation due to more distant sources would be overwhelmed. Thus to avoid such confounding of the source identification, the analysis is restricted on participants not exposed to environmental tobacco smoke (ETS).

Step 1: Factor Analysis

- Principal component analysis with VARIMAX rotation on Natural Log transformed VOC personal exposure concentrations
- Factor analysis is used to identify underlying patterns that explain common variations among a set of variables. Principal component analysis (PCA) relies on a slightly different mathematical model where unique factor loading and scores are left out of the analysis, and uses linear combinations of element concentrations to characterize or account for the variation of each dimension in a multivariate space.
- Linear recombination of eigenvectors of the correlation matrix of element concentrations by applying a VARIMAX rotation produces the source vectors (3). Thus, the rotated factors represent major sources or meteorological effects to explain common variations in VOC concentrations in personal exposure samples.

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
LN 1-Butanol	.456			.491	-.445
LN 2- Ethylhexanol				.805	
LN 2-Methyl-1-propanol			.456		
LN 3-Carene			.875		
LN a-Pinene			.847		
LN Benzene	.633				.457
LN Decane		.883			
LN d-Limonene					.789
LN Ethylbenzene	.882				
LN Hexanal			.608	.477	
LN m,p-Xylene	.864				
LN Nonane		.802			
LN Octanal				.678	
LN o-Xylene	.857				
LN Propylbenzene	.531	.690			
LN Toluene	.825				
LN Trimethylbenzene	.553	.659			
LN Undecane		.817			

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 14 iterations.

Identification Of Similar Source Factors in Helsinki (Edwards et al., 2001) (4)

Factor 1	Traffic/combustion emissions long range transport
Factor 2	localized traffic emissions
Factor 3	Cleaning and household products
Factor 4	product emissions from indoor environments and mould
Factor 5	d-limonene indoor sources

STEP 2: Stepwise Linear regression

Factor scores for each participant were saved for all factors. The sizes of the factor score coefficients for each case correspond to the loading for that factor. In other words the scores represent the strength of the source factor for each individual. The next approach was to use a stepwise linear regression with the factor scores for each factor or source category with the following variables as independent variables.

Input variables to models

Continuous	Binary	Categorised
minutes walking	HELSINKI	home location
minutes riding motorcycle	ATHENS	home building type
minutes in car	PRAGUE	location height of home
minutes in bus	OXFORD	kitchen fan or vent
minutes home indoors	attached garage	year home was built
minutes home outdoors	linoleum floor	traffic volume on nearby street
minutes at work indoors	pvc floor	heavy traffic volume on nearby street
minutes at work outdoors	wood floor	use of vacuum cleaner
minutes at other indoors	wood panelling	
minutes at other outdoors	plaster board walls/ceiling	
minutes cooking	chip board walls	
hours using gas stove	wallpaper	
hours using coal stove	wall painting/paper renovation in last year	
hours using fireplace	floor renovation in last year	
hours using fan	District heating	
hours	central heating	
hours using humidifier	electric heating	
hours using air conditioning	gas heating	
hours using electric dryer	fireplace home heating	
hours windows were open	air conditioning in home	
hours painting	use of air fresheners	
hours using glue	use of parfume	
hours in workshop	home location downtown	
hours used to wash car	Home location: Suburban high rise	
hours in gas station	Home location: Suburban small buildings	
hours used to grill		
hours used in garage		
hours exercising outdoors		
number of cats		
number of dogs		

REFERENCES

1. Jurvelin, J., Edwards, R.D., Saarela, K., De Bortoli, M., Laine-Ylijoki, J., Oglesby, L., Schläpfer, K., Georgoulis, L., Tischerova, E., Lovato, L., Jantunen, M.J., 2001. Evaluation Of VOC Measurements In The EXPOLIS Study. Journal of Environmental Monitoring 3(1), 159-165
2. Edwards, R.D., Jurvelin, J., Saarela, K., Jantunen, M.J., 2001. VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki. Atmospheric Environment, 35 (27), 4531-4737
3. Henry CR, Lewis CW, Hopke PK, Williamson HJ. Review of receptor model fundamentals. Atmos Environ 1984; 18:1507-15.
4. Edwards, R.D., Jurvelin, J., Koistinen, K.J., Saarela, K., Jantunen, M.J., 2001. VOC Source Identification From Personal And Residential Indoor, Outdoor and Workplace Microenvironment Samples In Expolis, Helsinki. Atmospheric Environment, 35 (28), 4739-4888

EXPOLIS-INDEX is supported by CEFIC-LRI Contract # CEFIC-LRI NMALRI-A3.3UBAS-0207 BIS, based on EXPOLIS (EU Contract # ENV4-CT96-0202, EU Contract # ERBIC20CT96-0061, Academy of Finland Contract N36586 and BBW Switzerland Nr. 95.0894).

Dependent variable	*Source Factor Identification*	*n*	*Adjusted r^2*	*Predictor variables*	*Standardized coefficients* Beta	*Colinearity diagnostic* Condition Index
Factor score 1	Traffic and combustion long range transport	123	0.46	(Constant)		1
				PRAGUE	0.6	1.448
				ATHENS	0.294	1.548
				Time in other indoors	-0.162	1.631
				Time washing car	0.179	1.872
				Attached garage	0.168	1.963
				Home location: Suburban high rise	0.149	3.164
Factor score 2	localized traffic emissions	129	0.32	(Constant)		1
				Time exercising outdoors	0.373	1.563
				HELSINKI	-0.278	1.601
				Time in workshop	0.261	1.696
				Time cooking	-0.229	1.896
				Air conditioner in home	0.179	2.103
				Air fresheners in home	0.176	3.683
Factor score 3	Cleaning and household products	123	0.22	(Constant)		1
				electric heating	0.154	1.902
				District heating	-0.505	2.016
				HELSINKI	0.498	2.172
				chip board walls	-0.247	2.384
				paint/wallpaper renovation	0.179	4.111
				Time in car	-0.159	5.733
Factor score 4	indoor product emissions and mould	132	0.25	(Constant)		1
				OXFORD	-0.332	1.251
				minutes at work outdoors	0.262	1.499
				gas heating	0.389	1.832
				Time using gas stove	-0.293	2.137
				floor renovation	-0.208	2.596
Factor score 5	d-limonene indoor sources	123	0.27	(Constant)		1
				HELSINKI	-0.361	1.727
				Time windows were open	-0.258	1.952
				Time at work indoors	-0.224	2.506
				Time exercising outdoors	-0.171	4.422
				PRAGUE	-0.199	5.483

Activities and behaviors related to personal exposures to source factors

Factor 1: (Traffic / combustion long range)

- The variables included are compatible with the less volatile components of automobile emissions. In Helsinki this factor was clearly associated with long range transport, as wind vectors showed directional dependency of this factor although participants were spread over the whole metropolitan area and monitored during the whole year (4).
- Prague is the most dominant factor clearly identifying a more exposed population. The second more exposed population is Athens, both showed considerably elevated concentrations of these compounds relative to other centers. This is perhaps not surprising given that the exposure sample from Prague was selected from municipality employees, in other words downtown office workers, and in Athens indoor levels of these compounds were elevated and greater time was spent in the car. This is related to the third factor where more time spent in other indoor (not home or workplace) was related to reduced exposure to this factor.
- Secondary sub-populations with greater exposure and sources appear to be those who spend greater time in a carwash, whose homes have an attached garage and those who live in high-rise suburban neighborhoods. It is interesting to note attached garage appearing as these variables have also been identified as leading to higher exposures to the compounds in this factor in other studies.

Factor 2 (local traffic emissions)

- This factor was associated with the more volatile components of vehicle emissions and related to localized sources.
- The strongest predictor was the amount of time spent exercising outdoors
- A negative coefficient for those in Helsinki indicated that they were less exposed to this factor (but not because they exercised outdoors less).
- Subsequently the regression models identified those with a home workshop, a factor that has previously been identified with elevated exposures.
- Interestingly the next factor identified is those participants whose homes had an air conditioner, which allow penetration of outdoor air to indoors, followed by use of air fresheners. Use of air fresheners, however was associated with having an attached garage (r = 0.35, p<0.001) and those living downtown (r=0.16, p=0.06)

Factor 3: (Cleaning and household products)

- This factor appears to identify different types of homes and socioeconomic levels, associated with different product use.
- Helsinki participants were associated with increased exposure to this factor, and demonstrated the largest standardized co-efficient
- Electric heating – more prevalent in suburban single family homes – was associated with this factor. Interestingly district heating was less associated with this source, which is associated with apartment buildings, and suburban areas with high-rise buildings. This could reflect socioeconomic differences in the use of consumer products.
- Chipboard was also associated with suburban areas with single family homes but not associated with electric heating, and was negatively correlated with this source.
- Time spent in the car was negatively associated with this factor. Although time spent in the car was inversely correlated with time spent home indoor (r=-0.25, p=0.003) and time spent at work indoors (r=-0.19,p<0.03), removal of car did not allow these variables to enter the model.

Factor 4: (Product emissions and mould)

- Factor 4 was associated with product emissions from the indoor environment and mould. Interestingly Oxford, whose homes were more associated with the periphery and lower traffic, was less associated with this factor. More importantly, however, Oxford homes mostly had central heating, which may reduce damp and mould.
- Work outdoors was also positively associated with this factor, possibly due to products used or mould.
- Gas heating was also positively associated with this factor, but was mainly associated with homes in Prague (r=0.55,p<0.001). Time using a gas stove, however, was inversely associated with this factor.
- Floor renovation or repairs during the past year were also less associated with this factor, supporting association of this factor with mould.

Factor 5:(d-Limonene source)

- This appears to be a residential indoor source of d-limonene associated with product use.
- Predictors for this factor were all negative and associated with reduced exposure to this source. Exposures to this factor were negatively associated with participants in Helsinki, time windows were open at home, time spent at work indoors, time spent outdoors exercising and participants in Prague.