Atmospheric Environment 79 (2013) 751–759

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Aldehydes in passenger vehicles: An analysis of data from the RIOPA Study 1999–2001

Ashley E.M. Mapou [a,b], Derek G. Shendell [a,b,c,*], Jennifer H. Therkorn [c,d], Youyou Xiong [d], Qingyu Meng [a,c,d], Junfeng Zhang [e], Other Students of ENOH0644, Indoor Air and Environmental Quality, Fall 2011

[a] Department of Environmental and Occupational Health, School of Public Health (SPH), Rutgers Biomedical and Health Sciences (RBHS), Piscataway, New Brunswick, NJ, USA
[b] Center for School and Community-Based Research and Education, SPH, RBHS, New Brunswick, NJ, USA
[c] Environmental and Occupational Health Sciences Institute, Robert Wood Johnson Medical School, Rutgers University, Piscataway, NJ, USA
[d] Department of Environmental Sciences, Rutgers, The State University of New Jersey, New Brunswick, NJ, USA
[e] Nicholas School of the Environment, Duke Global Health Institute, Duke University, Durham, NC, USA

HIGHLIGHTS

- A significant difference in in-vehicle formaldehyde was observed across sites.
- Most participants (77%) spent over an hour in the vehicle during the study period.
- In-vehicle formaldehyde concentrations were significantly associated with asthma diagnosis.
- Wind speed was significantly associated with decreased in-vehicle formaldehyde concentrations.

ARTICLE INFO

Article history:
Received 7 January 2013
Received in revised form
13 June 2013
Accepted 8 July 2013

Keywords:
In-vehicle air quality
RIOPA Study
Aldehydes
Formaldehyde
Acetaldehyde
Propionaldehyde

ABSTRACT

In-vehicle air quality (IVAQ) can be a major health concern due to factors such as urban sprawl and increased commuting time spent by individuals in vehicles. Few studies, particularly in the U.S., have considered in-vehicle toxic air contaminants, and none to date collected/analyzed field data in multiple communities across multiple climate zones. This study presents analyses of field data collected during the RIOPA Study from participating non-smoking adults for communities in Los Angeles County, CA, Elizabeth, NJ and Houston, TX. A significant difference ($p < 0.001$) in in-vehicle formaldehyde concentrations was observed, with the median concentration of in-vehicle formaldehyde in the CA communities about twice as high as in the NJ and TX communities. The highest median concentration of in-vehicle acetaldehyde was observed among the TX participants, over 40% higher than the overall study median. Given small sample sizes, the community (state) differences may be driven independently by differences in individual vehicle conditions and driving habits. Positive correlations were found between average community outdoor relative humidity in CA and NJ and in-vehicle formaldehyde and acetaldehyde concentrations. The amount of time car windows were reported as closed was inversely correlated with in-vehicle formaldehyde across study locations, and for in-vehicle acetaldehyde in CA and TX. Average wind speed and varying sky conditions also had suggested associations to in-vehicle formaldehyde and acetaldehyde. In CA and TX, 88% (7/8) of participants with a diagnosis of bronchitis reported at study baseline had in-vehicle formaldehyde concentrations greater than the overall study median. Every participant with diagnoses of both asthma and bronchitis ($n = 3$) reported at study baseline had in-vehicle formaldehyde and acetaldehyde concentrations above the overall study median; one participant in TX with two seasonal in-vehicle samplings had in-vehicle concentrations > 75th percentile. IVAQ during commuting may vary based on human behavior and meteorological factors. Additional studies are needed to further characterize ways to help reduce in-vehicle aldehyde exposures, especially for people with existing chronic respiratory illnesses who could experience symptom exacerbations upon such exposures.

* Corresponding author. Department of Environmental and Occupational Health, School of Public Health (SPH), Rutgers Biomedical and Health Sciences (RBHS), Piscataway, New Brunswick, NJ, USA.
E-mail addresses: shendedg@sph.rutgers.edu, derek.g.shendell.96@alum.dartmouth.org (D.G. Shendell).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.07.018

1. Introduction

Air pollutants present in the in-vehicle microenvironment can occur from emission sources such as interior materials, fuel leakage, and pollutants from the surrounding roadway air, including those emitted by the vehicle itself. In-vehicle air quality (IVAQ) has become an increasing concern due to urban sprawl and increased time in transportation vehicles to commute to work, play, worship, etc. (Zhang et al., 2008). While past field studies have been conducted to quantify IVAQ and determine sources of in-vehicle pollutants, few have taken place in the United States and those that did were predominantly in California (CA) (Fujita et al., 2011; Park et al., 2011; CARB, 2010; Fruin et al., 2008; Kozawa et al., 2008; Xu and Zhu, 2009; Zhu et al., 2007; CARB, 2005; Fruin et al., 2004). To our knowledge none of these studies have considered various dominant outdoor air pollution sources of toxic air contaminants across multiple communities in different climate zones. Most studies to date have focused on the impact of smoking and/or particulate matter (PM), including black or elemental carbon, and persistent (including semi-volatile) or volatile organic compounds (VOCs) in air and surface dust (Fujita et al., 2011; Park et al., 2011; CARB, 2010; Zuurbier et al., 2010; Sendzik et al., 2009; Diapouli et al., 2008; Fruin et al., 2008; Kozawa et al., 2008; Zhu et al., 2007; CARB, 2005; Fruin et al., 2004; Fedoruk and Kerger, 2003).

Aldehydes may be present at elevated concentrations in the in-vehicle microenvironment and can contribute significantly to personal exposure (Jo and Lee, 2002). Aldehydes (e.g., formaldehyde, acetaldehyde, and acrolein) are known to be toxic, mutagenic or carcinogenic (Kean et al., 2001). It is known that vehicular exhaust emissions are a major source of aldehydes in urban areas. Aldehyde concentrations in-vehicle can depend on traffic conditions, surrounding cars and indoor–outdoor temperature differentials (Hanoune, 2009). Furthermore, formaldehyde may originate inside the vehicle due to off-gassing from interior finish materials (Hanoune, 2009). Zhang et al. (2008) examined the connection between interior materials and aldehyde levels and reported that both cars with lower quality materials and newer cars had higher pollutant concentrations.

Volatile organic compounds (VOCs), which can include aldehydes, may also be emitted by vehicles due to age-related breakdowns or can migrate into or occur inside vehicles from tobacco smoke, ventilation system operation, open windows and deodorizers (Fedoruk and Kerger, 2003). VOCs may also be detected inside vehicles due to diffusion of automobile exhaust from other vehicles or fuel leakage (Brown and Cheng, 2000; Fedoruk and Kerger, 2003).

During the “Relationship of Indoor, Outdoor and Personal Air” (RIOPA) Study, data were collected inside personal passenger vehicles — cars, sport utility vehicles and/or light-duty trucks (e.g., pick-up trucks) — for fine PM and toxic air contaminants from July 1999 to February 2001. The present paper focused on targeted aldehydes measured above analytic method detection limit, including formaldehyde and acetaldehyde. We examined data overall, by season and by study site (Los Angeles County, CA; Houston, Texas (TX); Elizabeth, New Jersey (NJ)). Moreover, unlike most IVAQ studies published to date, the present study incorporated both quantitative and qualitative field data to assess the underlying factors potentially influencing measured IVAQ, e.g., concentrations of various aldehydes.

2. Material and methods

2.1. Collection methods

The data collection and participant recruitment methods employed during the RIOPA Study were previously described in detail by Weisel et al. (2005a,b) and Turpin et al. (2007). Specifically, the techniques and equipment employed for active sampling of airborne aldehydes during the RIOPA Study were previously well described in detail by Liu et al. (2006). The present paper represents new secondary analyses of the final RIOPA Study database now available online to the public through the Health Effects Institute (HEI) and AER, Inc. In the present paper’s analyses, we reviewed reported data on the following aldehydes: formaldehyde, acetaldehyde, acrolein, acetone, propionaldehyde, benzaldehyde, glyoxal, and methylglyoxal.

2.2. Data abstraction and statistical analyses

Data were abstracted from the RIOPA database available online per HEI via AER, Inc. Files were exported then combined, reviewed and matched based on the home study identification number in Microsoft Excel. A baseline survey outlined subject’s general behaviors and an activity survey summarized specific activities in the 48-h sampling period. Data were analyzed in SAS (Cary, NC) and XLSTAT (Anglesey, Wales) including Kruskal–Wallis one-way analysis of variance (ANOVA), logistic regression, and Pearson correlation matrices. Sequential covariate selection all-possible-regression procedure was used to identify the best five models for each combination of predictors for each aldehyde and models were selected for further investigation based on favorable adjusted R-squared values, Mallow’s Cp, and mean squared error. A Box–Cox transformation was used to satisfy statistical model assumptions of constant variance, normality, and linearity. These assumptions were checked using scatter plots and QQ plots with studentized residuals plotted against each variable, residuals and studentized residuals plotted against predicted value, and studentized residuals plotted against calculated leverage.

3. Results and discussion

3.1. Demographic information

There were 115 in-vehicle sampling events in the RIOPA Study in the final database among 90 households—72 samples in 51 households in CA (i.e., two seasonal samplings in 21 households), 33 samples in 29 households in TX (i.e., two seasonal samplings in four households), and 10 in NJ. In these 90 households, there were a total of 222 adult and child participants; one adult per household performed in-vehicle sampling, even if one or more participants were riding and/or driving the vehicle reported as used. A majority of participants for the in-vehicle sampling portion of the RIOPA Study responding to the baseline questionnaire were white females (Table 1a). The respondents were highly educated with a clear majority (~80%) having at least some college education. Also, the majority of the respondents had a household income in the range of $25,000–49,999 U.S. (as of year 2000). The household income levels observed in the study population are comparable to those reported on a national level by the U.S. Census Bureau (Table 1a). However, income level $16,500–24,999 made up a relatively higher percentage in the study population than nationally, and the $25,000–49,999 income range comprised of a relatively lower percentage in the study population than nationally (DeNavas-Walt et al., 2001). In addition, the vehicle age and type of vehicle driven by study participants can be found in Tables 1b and c.

3.2. Targeted aldehydes

Tables 2 and 3 present statistics for each sampled in-vehicle aldehyde. The overall median of formaldehyde concentrations in the vehicles was 20.0 μg m^{-3} (range ND (detection limit of 4.65 μg m^{-3})–1095.6 μg m^{-3}). The highest median formaldehyde concentration was observed in CA and was over double the median