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Scripted drives: A robust protocol for generating exposures to traffic-related air pollution

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HIGHLIGHTS

- Scripted drives on the NJ Turnpike and local roads on 190 days over 8 years.
- Measured $PM_{2.5}$, PNC, CO, BC, and NO_2 in the car cabin.
- Higher concentrations on NJ Turnpike (NJT) compared to local roads.
- NJT exposure increase robust to season, traffic congestion, and ventilation.

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ABSTRACT

Commuting in automobiles can contribute substantially to total traffic-related air pollution (TRAP) exposure, yet measuring commuting exposures for studies of health outcomes remains challenging. To estimate real-world TRAP exposures, we developed and evaluated the robustness of a scripted drive protocol on the NJ Turnpike and local roads between April 2007 and October 2014. Study participants were driven in a car with closed windows and open vents during morning rush hours on 190 days. Real-time measurements of $PM_{2.5}$, PNC, CO, and BC, and integrated samples of NO_2, were made in the car cabin. Exposure measures included in-vehicle concentrations on the NJ Turnpike and local roads and the differences and ratios of these concentrations. Median in-cabin concentrations were 11 $\mu g/m^3$ $PM_{2.5}$, 40 000 particles/cm^3, 0.3 ppm CO, 4 $\mu g/m^3$ BC, and 20.6 ppb NO_2. In-cabin concentrations on the NJ Turnpike were higher than in-cabin concentrations on local roads by a factor of 1.4 for $PM_{2.5}$, 3.5 for PNC, 1.0 for CO, and 4 for BC. Median concentrations of NO_2 for full rides were 2.4 times higher than ambient concentrations. Results were generally robust relative to season, traffic congestion, ventilation setting, and study year, except for PNC and $PM_{2.5}$, which had secular and seasonal trends. Ratios of concentrations were more stable than differences or absolute concentrations. Scripted drives can be used to generate reasonably consistent in-cabin increments of exposure to traffic-related air pollution.

1. Introduction

Being on or near heavily-trafficked roadways has been associated with acute adverse cardiovascular and respiratory outcomes (Laumbach et al., 2010, 2014; McCreanor et al., 2007; Peters et al., 2000, 2004, 2013; Sarnat et al., 2014). Air pollution exposure may affect health through oxidative stress pathways. Increased concentrations of biomarkers for oxidative stress pathways have been observed in study participants in studies for both general air pollutants (Huang et al., 2012; Rich et al., 2012) and pollutants related to highway traffic in a relatively unpolluted region (Laumbach et al., 2010, 2014; Patel et al., 2013; Pettit et al., 2015). Exposure to traffic-related air pollution (TRAP) is one possible cause of these adverse outcomes (Fruin et al., 2008; Lane et al., 2016; Laumbach et al., 2014).

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For many individuals in the industrialized world, a substantial fraction of exposure to traffic-related air pollutants (e.g., ultrafine particles) may be experienced while commuting (Knibbs et al., 2011). For example, it has been estimated that Los Angeles residents experience 33%–45% of their total exposure to ultrafine particles during the ~6% of their time that is spent on daily driving commutes (Fruin et al., 2008). Not only are Americans exposed to peak concentrations of traffic-related air pollution during their commutes, but many commute long distances. In 2011, 8.1% of American workers who did not work at home, and 14.6% of workers living and working in New Jersey, had one-way driving commutes of 60 min or greater (McKenzie, 2013).

To study the health effects of short-term exposures to traffic under real-world conditions, robust exposures with well-characterized variability and sufficient duration are needed. Scripted drive studies have demonstrated increased in-cabin concentrations of many traffic-related air pollutants while travelling on busy roadways (Greenwald et al., 2014; Hudda et al., 2011; Jiao and Frey, 2014; Laumbach et al., 2010, 2014; Lawryk et al., 1995; Lawryk and Weisel, 1996; Mapou et al., 2013; Pettit et al., 2015; Sarnat et al., 2014; Zhu et al., 2008). Many of those studies have used scripted commutes, in which study participants drive or ride in private cars (their own or provided) through routes selected for high traffic volume and/or diesel vehicle intensity (Greenwald et al., 2014; Jiao and Frey, 2014; Laumbach et al., 2010, 2014; Lawryk et al., 1995; Lawryk and Weisel, 1996; Sarnat et al., 2014). Factors affecting in-cabin concentrations in these studies have included vehicle age and model, season, traffic congestion, and road type (Greenwald et al., 2014; Hudda et al., 2011; Weichenthal et al., 2015; Zhu et al., 2007). In addition, closing windows or vents in the cars has been shown to reduce pollutant infiltration and decrease concentrations in the vehicle cabin (Greenwald et al., 2014; Hudda et al., 2011; Zhu et al., 2007). In-cabin concentrations typically follow the same trends as on-road concentrations, which are strongly associated with land use and the density of gasoline and diesel-powered vehicles (Weichenthal et al., 2015; Zhu et al., 2008). However, it is unclear to what extent the relationships between in-cabin concentrations on commuting highways and on local roads are affected by season, traffic congestion, ventilation setting, or secular trends. Rigorous evaluations of real world exposure protocols, including defining the appropriate metrics, will support the use of these protocols in panel studies to evaluate the acute and subacute effects of TRAP exposure during commuting.

We have conducted five scripted drive studies (three previously published) on the relationship between commuting exposures to traffic-related air pollution and varying biomarkers of early biological effects (Laumbach et al., 2010, 2014; Pettit et al., 2015). In this work, we explore the in-cabin measurements made during those studies to explain some key factors affecting the relationship between in-cabin exposures to air pollution on a 12-lane highway (NJ Turnpike) and exposures in other locations. Our specific aims were to (1) examine in-vehicle concentrations of $PM_{2.5}$, PNC, CO, BC, and NO_2, and correlations of these pollutants, during scripted car rides on the NJ Turnpike and local roads between April 2007 and October 2014; (2) compare in-cabin concentrations of air pollutants on the NJ Turnpike to in-cabin concentrations on local roads and ambient concentrations at regulatory monitoring stations; and (3) test whether season, traffic congestion (measured as travel time on the NJ Turnpike), ventilation setting, or study year modifies the relationship between in-cabin concentrations on the NJ Turnpike and on local roads.

2. Methods

2.1. Scripted drives

We evaluated a standard protocol for quasi-controlled in-cabin exposures from five successive studies. The studies featured scripted passenger vehicle drives on the New Jersey Turnpike (NJT) between April 2007 and October 2014 (Table 1). Individual studies (NJT 1–5) lasted from 9 to 24 months, with 21–84 drives per study (190 total). Drives were made from 08:30 to 10:45 on weekday mornings throughout the year. For uniformity of the exposure protocol, drives were only conducted when the forecast probability of precipitation during the ride was <50%; there was intermittent or light rain on ~5% of drives and no drives were conducted in steady rain. Each drive included 26 miles on local streets and 60 miles on the NJ Turnpike (Fig. 1). All rides started at the Environmental and Occupational Health Sciences Institute clinic parking lot (EOHSI) at Rutgers University, and a short break was taken at the halfway point at the Vince Lombardi service area before returning to EOHSI. For most of the New Jersey Turnpike part of the drive,

Table 1
Study overview.

Study name	NJT 1 (Laumbach et al., 2010)	NJT 2	NJT 3 (Laumbach et al., 2014)	NJT 4 (Pettit et al., 2015)	NJT 5	Overall
Health outcomes[a]	BP, P-nitrite	BP, HR, HRV, P-nitrite, EBC-nitrite	BP, HR, HRV, EBC-nitrite	BP, HR, HRV, P-nitrite	BP, HR, P-nitrite	
Participant disease status	All Diabetic	All COPD	All Healthy	Diabetic & Healthy	All Healthy	
# drives	21	15[b]	42	84	28[c]	**190**
Start date	04/23/2007	10/13/2008	1/12/2010	9/20/2010	12/13/2013	**04/23/2007**
End date	01/23/2008	10/8/2009	4/26/2011	8/29/2012	10/21/2014	**10/21/2014**
Earliest start time	8:17	8:00	8:00	8:16	8:04	**8:00**
Latest end time	13:55	13:55	11:38	11:45	11:30	**13:55**
Turnpike ADT[d]	N/A	136 000	132 000	131 000	132 000	**131 000**
Turnpike % Diesel	N/A	12	13	13	13	**13**
ULSD use[e]	92%–95%	98%	>99%			**92% – 100%**
Vent Filter	Unmodified				Removed	
Vehicle	Ford Explorer SUV & Chevy SUV	1998 or 2002 Ford Taurus			2005 Ford Taurus	

[a] The health outcomes were blood pressure (BP), heart rate (HR), heart rate variability (HRV), plasma nitrite (P-nitrite), and exhaled breath condensate nitrite (EBC-nitrite).
[b] In NJT 2, 15 drives were conducted in following the standard protocol and included in inter-comparison of studies. 15 additional drives with vents closed were used for sensitivity analysis.
[c] NJT 5 had a small number of runs because many of the drives had two participants in the same car.
[d] ADT is the average daily traffic in vehicles per day.
[e] NJT 1 took place towards the end of the phase in of ultra-low sulfur diesel fuel (ULSD) from low sulfur diesel fuel (U.S. Environmental Protection Agency, 2011).