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Analysis of real-time variables affecting children's exposure to diesel-related pollutants during school bus commutes in Los Angeles

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Abstract

Variables affecting children's exposure during school bus commutes were investigated using real-time measurements of black carbon (BC), particle-bound polycyclic aromatic hydrocarbons (PB-PAH) and nitrogen dioxide (NO_2) inside 3 conventional diesel school buses, a particle trap-outfitted (TO) diesel school bus and a compressed natural gas (CNG) school bus, while traveling along an urban Los Angeles Unified School District bus route. A video camera was mounted at the front of each bus to record roadway conditions ahead of the bus during each commute. The videotapes from 12 commutes, in conjunction with pollutant concentration time series, were used to determine the influence of variables such as vehicles being followed, bus type and roadway type on pollutant concentrations inside the bus. For all buses tested, the highest concentrations of BC, PB-PAH and NO_2 were observed when following a diesel school bus, especially if that bus was emitting visible exhaust. This result was important because other diesel school buses were responsible for the majority of the diesel vehicle encounters, primarily due to caravanning with each other when leaving a school at the same time. Compared with following a gasoline vehicle or no target, following a smoky diesel school bus yielded BC and PB-PAH concentrations inside the cabin 8 and 11 times higher, respectively, with windows open, and ~1.8 times higher for both pollutants with windows closed. When other diesel vehicles were not present, pollutant concentrations were highest inside the conventional diesel buses and lowest inside the CNG bus, while the TO diesel bus exhibited intermediate concentrations. Differences in pollutant concentrations between buses were most pronounced with the bus windows closed, and were attributed to a combination of higher concentrations in the exhaust and higher exhaust gas intrusion rates for the conventional diesel buses. Conventional diesel school buses can have a double

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exposure impact on commuting children: first, exposures to the exhaust from other nearby diesel school buses and, second, exposure to the bus's own exhaust through "self-pollution".

Keywords: Black carbon; PAH; Nitrogen dioxide; Videotape

1. Introduction

Although ambient air pollution contributes to adverse health effects, the highest exposures to a range of air contaminants may occur in other microenvironments, especially in vehicles. In-vehicle concentrations of CO and fuel-related VOCs have been found to be significantly higher than those in ambient air (Shikiya et al., 1989; Lawryk and Weisel, 1995; Rodes et al., 1998; Jo and Park, 1999; Weisel et al., 1992; Alm et al., 1999). Other research indicates commuters are exposed to elevated concentrations of respirable particles during transit bus commutes (Gee and Raper, 1999; Praml and Schierl, 2000). Rodes et al. (1998) conducted a study of commuter exposures inside passenger vehicles and concluded that vehicle occupants are primarily exposed to the exhaust of neighboring vehicles, particularly those directly ahead of the occupant's vehicle. Fruin et al. (2004) re-analyzed and extended these data and concluded that the in-vehicle microenvironment was the dominant factor in daily exposure to diesel exhaust particulate. Other variables shown by previous researchers to be important influences on in-vehicle concentrations include traffic density, driving lane, inter-vehicle spacing, traffic speed, the number of stops, wind speed, time of day, vehicle ventilation settings and engine type (Alm et al., 1999; Adams et al., 2001; Chan and Chung, 2003).

Because children are more susceptible to adverse health effects from air pollution due to their high inhalation rates relative to body mass, narrower lung airways, immature immune systems and rapid growth (Lipsett, 1989; Wiley et al., 1991; US Environmental Protection Agency (US EPA), 1996), potentially high pollutant exposures during school bus commutes are of concern (Solomon et al., 2002; Wargo et al., 2002), yet the specific variables contributing to these increased exposures were not identified prior to the present study.

We conducted an extensive exposure assessment field study of children's exposure to vehicle-related pollutants during school bus commutes in Los Angeles, including measurements on a variety of bus types and bus routes (Sabin et al., 2005), as well as measurements at bus stops and in school loading/unloading zones (Behrentz et al., 2005). In the present paper, video recordings of the events ahead of the bus during selected commutes were analyzed along with real-time pollutant concentrations of black carbon (BC), particle-bound polycyclic aromatic hydrocarbons (PB-PAH) and nitrogen dioxide (NO_2) to identify important dynamic variables governing children's exposures during school bus commutes. The goal of our videotape analysis was to gain a better understanding of the transient factors that affected pollutant concentrations inside several different types of school buses during commutes, such as the impact of vehicles ahead of the bus and roadway/traffic conditions, in combination with the contribution of the bus's own exhaust.

2. Methodology

A complete description of our school bus exposure assessment study is given elsewhere (Fitz et al., 2003; Behrentz et al., 2004; Sabin et al., 2005). Pollutant concentrations were measured in the rear of school bus cabins while traveling along urban bus routes in Los Angeles and along a rural route in nearby Riverside County during May and June 2002. Videotaped records of the bus commutes were made in conjunction with activity logs recorded during each commute. The video records from 12 of these commutes on a single urban route, including 6 morning and 6 afternoon runs, were investigated. Ambient concentrations were measured at the roadside near the start and finish of the selected bus routes, just before the commute in the morning, and at the end of the commute in the afternoon, at least once for each week of the study.

2.1. Description of school buses and the urban bus route

Commutes were run on five different buses provided by two local school districts from their in-use fleet of approximately 150 buses. These included: 1993 (RE1) and 1998 (RE2) Thomas Saf-T-Liner conventional diesel buses, selected to be of similar age as California's in-use school bus fleet; a 1985 Crown Supercoach conventional diesel bus (HE), selected to be representative of high exhaust emissions; a 1998 Thomas Saf-T-Liner (TO) diesel bus equipped with a Johnson Matthey continuously regenerating technology (CRT®) particulate filter; and a 2002 Thomas Saf-T-Liner operating on compressed natural gas (CNG). Low-sulfur, Arco emission control diesel fuel (ECD-1) was used in all diesel buses. For all bus commutes, the windows on the buses were closed during morning runs, while during the afternoon runs windows were opened (every other window open 10–15 cm), to simulate conditions observed on in-use school buses in the Los Angeles area.

The route and commute times of an in-use Los Angeles Unified School District (LAUSD) urban school bus route was followed. This route was approximately 30 km long with five bus stops (Fig. 1). This route traveled on two of the most heavily congested freeways in the US 40% of the time, and on surface streets ranging from single-lane residential streets, to heavily congested, multi-lane surface streets with high traffic densities 60% of the time. This route took approximately 1 h to complete, traveled through inner-city neighborhoods of South Los Angeles and was run during normal school commute times, starting at about 6:30 in the morning and at about 15:00 in the afternoon. At bus stops along the route, the bus pulled up to the curb, opened the doors and waited for 1 min before driving away, to simulate the conditions of children loading or unloading from the bus.

2.2. Instrumentation

Real-time BC concentrations were measured using Magee Scientific Aethalometers, Model AE-1. Sample air was drawn through a 0.5 cm^2 spot on a quartz fiber filter tape. The decrease of infrared light at 880 nm transmitted through the quartz tape was proportional to the amount of elemental carbon collected. The instrument's response to the change in light transmittance was reported as BC. EcoChem Model PAS 2000 analyzers were used to measure real-time concentrations of total PB-PAH by UV-photoionization. Real-time NO_2 concentrations were measured by reaction with luminol following GC separation of NO_2 and peroxyacyl nitrates (Fitz et al., 2002).

Bus location was determined with a Garmin MAP76 global positioning system (GPS) with Wide Area Augmentation System corrections. The GPS system also provided elevation and velocity data. The GPS unit was used as a time reference during this study and the clocks for all instruments were synchronized against the GPS at the beginning of each run. Temperature and relative humidity were measured inside the buses using a Rotronics Model MP101A sensor. Wind speeds were obtained by averaging the hourly data for the time period of each commute from two South Coast Air Quality Management District (SCAQMD) air monitoring stations, located near the start and end of the bus route.

A Sony DCR-TRV330 with a 0.5 × wide conversion lens video camera was mounted at the front of the buses to record traffic conditions in front of the bus during each commute. The camera was set to a wide angle to view as much of the scene as possible, including the lane the bus was traveling in and the lanes on either side of the bus. The video camera clock was synchronized with the GPS master clock prior to each run.

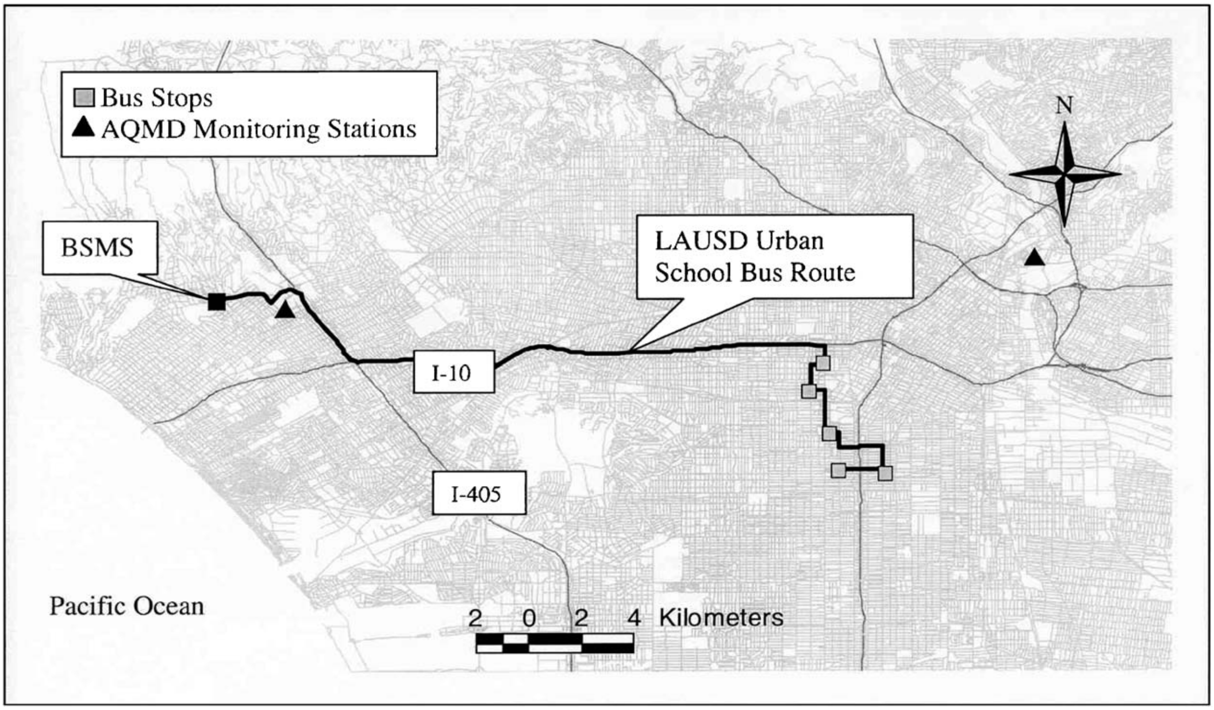

Fig. 1. LAUSD urban school bus route.

All real-time instruments had analog or digital inputs connected to a PC that collected data during the runs using a data acquisition system designed with LabVIEW® software. With the exception of the NO_2 instrument, which recorded 1-min data, all other real-time instruments recorded 1-s data. The 10-s medians of these data were used for all subsequent analyses as a more robust measure of the central tendency. This 10-s time resolution was necessary because vehicle traffic and school bus behavior were dynamic, and we observed rapid changes (e.g., on the order of seconds) in pollutant concentrations inside the buses.

2.3. Video record analysis

The video record of each bus commute was used to identify all events that occurred ahead of, or adjacent to, the bus during each 10-s period of the commute (the same time resolution as the pollutant concentrations). Specific events and conditions believed to influence concentrations inside the bus were identified, including the presence of any diesel-powered vehicle (within approximately three car lengths, or 20 m of the bus); the presence of visible emissions or smell of exhaust from the vehicle being followed or from the bus itself; periods of idling (e.g., at bus stops or in traffic); and roadway type (e.g., freeway or surface streets).

The video records were viewed and all events and conditions that occurred for at least 5 s during each 10-s interval were assigned to that interval. If more than one event/condition occurred during a given interval, multiple assignments to that interval were made. The type of vehicle in front of the bus was identified for every 10-s interval according to the following vehicle classifications: medium/heavy-duty diesel truck (2–5 axles), diesel school bus, diesel transit bus or passenger car/no target. If a vehicle in front of, or adjacent to, the bus (or the bus itself, as noted by field technicians on the bus) emitted visible exhaust, this event was assigned to the first 10-s interval during which it was observed, as well as to the following 1-min, to account for residual cabin impacts of the plume. Assignments of idling were based on the bus's speed (also measured in real time during every run).

In addition to the video camera documentation, field personnel recorded observations about traffic conditions and nearby vehicles (e.g., exhaust odors or visible exhaust) to supplement the video record.

Finally, to assure unbiased assignment of events/conditions based solely on the criteria described above, initial video record analyses and all event/condition assignments were made *prior* to inspection of pollutant concentration time-series data. Once all the event/condition assignments were made based on the video

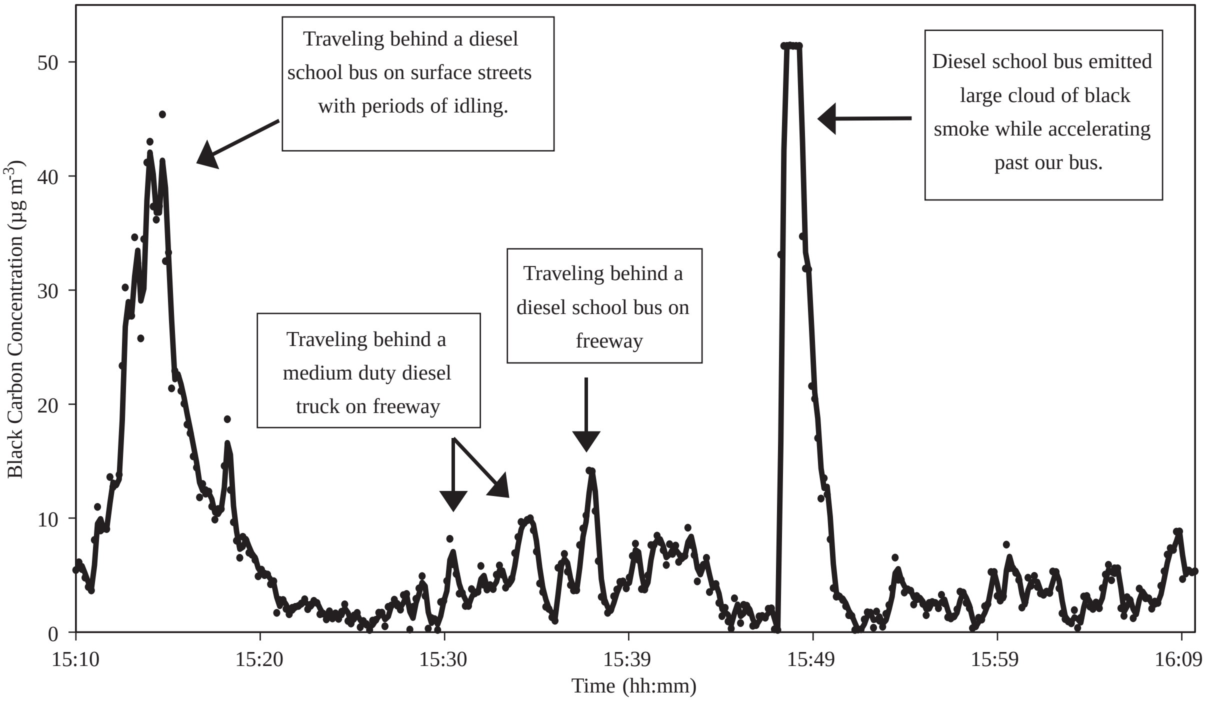

Fig. 2. Black carbon concentration time series during the 22 May 2002 afternoon run on bus RE2. Not all event assignments made for this run based on the videotape records are shown.

records, pollutant concentrations were grouped by these events or conditions. Comparisons were then made between concentrations during periods associated with each type of event or condition in order to determine the most important variables associated with high pollutant concentrations inside the buses. Fig. 2 shows a time-series for BC concentrations during the commute on 22 May 2002 on bus RE2 (windows open), and illustrates the relationships observed between event assignments based on the videotapes and peak concentrations.

3. Results and discussion

A description of the bus commutes analyzed, along with the average bus speed, ambient wind speed and temperature for each run is given in Table 1. Low wind speeds were observed in the mornings, ranging from 0.2 to 1.1 $\mathrm{m\,s^{-1}}$, with higher wind speeds in the afternoon, ranging from 2.4 to 4.7 $\mathrm{m\,s^{-1}}$. Temperatures varied little between morning and afternoon runs, and slow average bus speeds on each run indicated similar, heavy traffic congestion levels.

3.1. *Effects of following diesel vehicles with and without visible exhaust*

On average, during more than one-quarter of the time, another diesel vehicle was directly in front of the test bus, either in the lane ahead or in an adjacent lane (both considered "followed"). Analysis of the videotape records showed that when bus windows were open, the high transient concentrations observed were due to the influence of these other diesel vehicles, as shown in Fig. 3. This effect was markedly reduced if windows were closed, although mean closed-window concentrations over an entire commute were higher than for windows open. Due to these differences, commutes with open and closed windows were analyzed separately.

Bus commutes with windows open. When windows were open (afternoon commutes), mean BC and PB-PAH concentrations inside the test buses were highest when following a diesel school bus, especially if it was emitting visible exhaust, and lowest when following a gasoline vehicle or no vehicle at all (Fig. 4). Similarly, following diesel vehicles other than diesel school buses also resulted in higher concentrations than following gasoline vehicles or no vehicle for BC and PB-PAH. As shown in Table 2, when following a smoky diesel school

Table 1
Description of bus commutes, meteorological data and bus speeds

Bus[a]	Bus description	Run date	Time of day	Window position	Temperature (°C)	RH (%)	Mean wind speed[b] ($\mathrm{m\,s^{-1}}$)	Mean commute speed ($\mathrm{km\,h^{-1}}$)
HE	1985 Crown Supercoach	01-May-02	AM	Closed	20	46	0.6	20
	Conventional diesel		PM	Open	25	29	4.2	19
RE1	1998 Thomas Saf-T-Liner	16-May-02	AM	Closed	23	50	1.1	22
	Conventional diesel		PM	Open	24	44	2.4	20
RE2	1993 Thomas Saf-T-Liner	22-May-02	AM	Closed	23	42	0.4	25
	Conventional diesel		PM	Open	25	30	4.7	24
TO	1998 Thomas Saf-T-Liner	05-Jun-02	AM	Closed	25	51	0.2	25
	Diesel equipped with a Johnson Matthey CRT® particulate filter		PM	Open	28	46	3.9	24
		06-Jun-02	AM	Closed	26	53	0.2	26
			PM	Open	27	50	2.8	22
CNG	2002 Thomas Saf-T-Liner	12-Jun-02	AM	Closed	24	49	0.3	24
	CNG		PM	Open	27	40	4.2	18

[a] HE—high emitter diesel bus; RE—representative diesel bus; TO—particle trap-outfitted diesel bus; CNG—compressed natural gas bus.

[b] From nearby SCAQMD monitoring stations.

bus, the mean concentrations measured inside the bus cabin were 8 and 11 times greater for BC and PB-PAH, respectively, compared with following a gasoline vehicle or no target. The maximum concentrations of BC and PB-PAH observed while following another diesel vehicle were roughly an order of magnitude higher than overall commute averages. For each pollutant, comparable maximum concentrations were observed throughout the commutes when following diesel vehicles.

These results indicate that for open window conditions, following a diesel vehicle, particularly another school bus, was an important predictor of elevated pollutant concentrations inside the bus cabins, consistent with passenger "chase car" studies (Rodes et al., 1998; Fruin et al., 2004). Moreover, a third or more of the school buses we observed at the school we studied exhibited visible smoke when accelerating. This finding was particularly important because the type of diesel vehicle encountered most frequently during these commutes was another diesel school bus (responsible for 60% of diesel vehicle encounters), and we observed that school buses tended to caravan with each other, especially when leaving a school at the same time. The low, rear-end location of exhaust pipes in school buses also likely contributed to the high impacts of following diesel school buses, as this configuration allows for less dilution before impacting following vehicles than a high/front location such as is typical of tractor–trailer rigs (Fruin et al., 2004).

Bus commutes with windows closed. During commutes with closed windows, which occurred in the mornings, school buses represented only 20% of the diesel vehicles followed, as caravanning generally only occurred for afternoon school bus departures. As shown in Table 2 and Fig. 4, BC and PB-PAH concentrations inside the test buses were also highest when following a diesel school bus emitting visible exhaust.

3.2. *Effect of bus and fuel type*

Following a diesel vehicle on average resulted in an increase in bus cabin concentrations during all commutes. Therefore, to analyze the effect of bus and fuel type on in-cabin concentrations, only periods when no other diesel vehicles were present were used, based on the videotape records. These analyses go beyond our earlier published analyses (Behrentz et al., 2005; Sabin et al., 2005).

3.2.1. *During commutes (excluding bus stops)*

With no other diesel vehicles present, pollutant concentrations inside the cabins while driving and idling

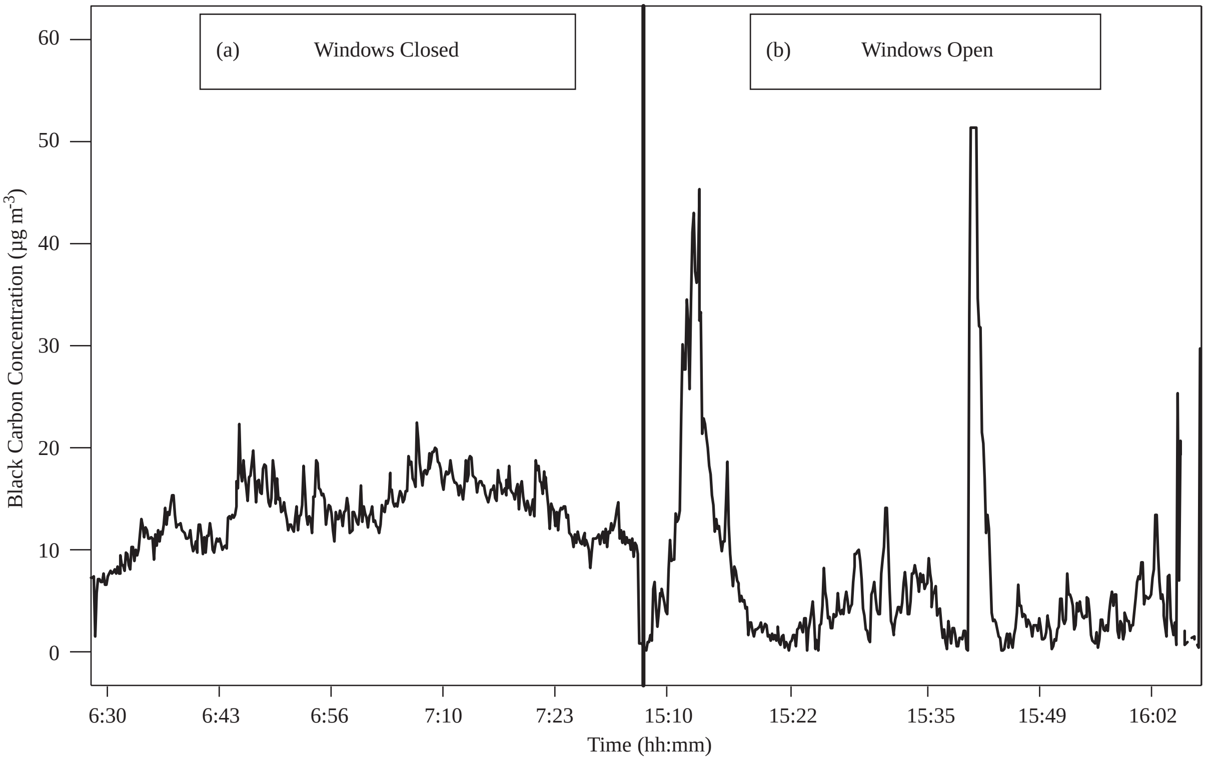

Fig. 3. Typical pollutant time series for black carbon measured on 22 May 2002 on conventional diesel bus RE2 during (a) a morning commute with windows closed and (b) an afternoon commute with windows open.

during the commutes (as opposed to idling at bus stops) showed differences between the buses tested based on bus and fuel type (CNG, TO diesel or conventional diesel), particularly when windows were closed. Pollutant concentrations were typically lowest inside the CNG bus and highest inside the conventional diesel

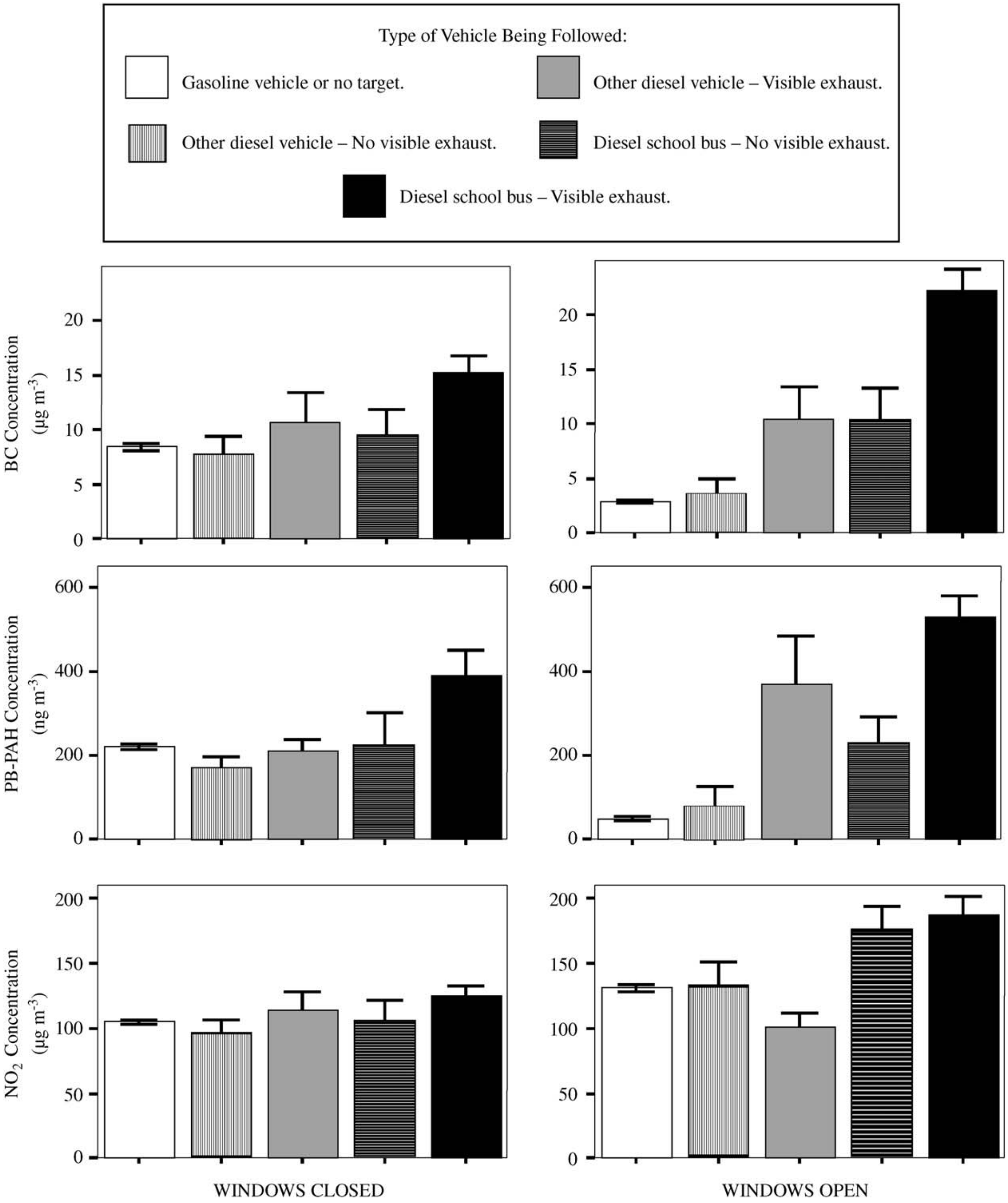

Fig. 4. Mean pollutant concentrations measured inside the test buses when following different types of vehicles. Error bars represent the 95% confidence interval for the mean.

Table 2
Pollutant concentrations measured inside the buses while traveling behind different vehicle types

Type of vehicle being followed	Bus windows open						Bus windows closed					
	BC ($\mu g\, m^{-3}$)		PB-PAH ($ng\, m^{-3}$)		NO_2 ($\mu g\, m^{-3}$)		BC ($\mu g\, m^{-3}$)		PB-PAH ($ng\, m^{-3}$)		NO_2 ($\mu g\, m^{-3}$)	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Diesel school bus with visible exhaust	22 (19–24) $n = 200$	51	550 (480–600) $n = 200$	2000	190 (170–210) $n = 159$	380	15 (14–17) $n = 67$	33	390 (330–460) $n = 61$	980	130 (120–140) $n = 64$	170
Diesel school bus without visible exhaust	12 (9.9–13) $n = 234$	51	260 (220–290) $n = 235$	1000	190 (180–190) $n = 200$	380	11 (9.0–11) $n = 90$	29	260 (200–280) $n = 89$	810	110 (110–120) $n = 76$	190
Other diesel vehicle with visible exhaust	10 (7.3–13) $n = 33$	29	370 (250–480) $n = 33$	1000	100 (92–110) $n = 29$	160	11 (8.0–13) $n = 38$	25	210 (190–240) $n = 43$	320	110 (100–130) $n = 43$	180
Other diesel vehicle without visible exhaust	4.3 (3.7–4.9) $n = 234$	27	110 (84–130) $n = 235$	1100	140 (140–150) $n = 214$	250	8.6 (7.6–9.0) $n = 317$	22	190 (160–180) $n = 319$	610	100 (97–110) $n = 288$	170
Gasoline vehicle or no target	2.7 (2.6–2.9) $n = 1640$	51	48 (44–52) $n = 1640$	1600	130 (130–130) $n = 1457$	300	8.4 (8.1–8.6) $n = 1782$	31	220 (210–230) $n = 1808$	1000	100 (100–110) $n = 1727$	230

Numbers in parentheses represent the 95% confidence interval for the mean and the *n* values represent the number of 10-s measurement intervals.

buses (Table 3). Mean BC concentrations were three and five times higher inside the conventional diesel buses with windows open and closed, respectively, compared with the CNG bus, and more than 50% higher compared with the TO diesel bus. Mean PB-PAH concentrations were five times higher inside the conventional diesel buses with the windows closed compared with the CNG bus.

In addition, with windows closed, mean BC and PB-PAH concentrations inside the TO diesel and conventional diesel buses were 3–11 times higher than ambient concentrations measured near the bus route, while concentrations inside the CNG bus were similar to ambient for BC and NO_2, and higher by about 50% for PB-PAH. Because the CNG bus and ambient concentrations measured near the bus route were similar, indicating the contribution from self-pollution for this bus was low, we used the concentrations measured inside the CNG bus as our estimate for the contribution from surrounding traffic, as this bus traveled in the same line-source with similar traffic congestion levels as the other buses. Thus, subtracting these concentrations from those measured in the TO and conventional diesel buses provided an estimate of the contribution from self-pollution inside these buses. Based on these assumptions, we estimate self-pollution contributed as much as 65% and 77% of BC, and 70% and 80% of PB-PAH concentrations inside the TO and conventional diesel buses, respectively, when windows on the buses were closed and no other diesel vehicles were followed.

3.2.2. At bus stops

Investigation of pollutant concentrations inside the bus cabins while idling at bus stops, which were all located on small residential streets away from the immediate influence of other vehicles and traffic congestion, provided further evidence of the differences between bus types (Fig. 5). With closed windows, large differences between bus types were observed while the buses were idling at the bus stops.

When idling at bus stops, both the CNG and the TO diesel buses had relatively low mean concentrations and no high peaks of BC and PB-PAH when the windows were open. In contrast, the range of BC and PB-PAH concentrations inside the conventional diesel buses at the bus stops was similar to the range observed during other portions of the commutes. Moreover, the mean concentrations of BC and PB-PAH inside the conventional diesel buses were at least twice as high when idling at bus stops with the windows open compared with other portions of the commutes. This was an interesting finding, since the time spent idling at the bus stops was least impacted by surrounding traffic, and supports the conclusion that for the conventional diesel buses, self-pollution was primarily responsible for these high concentrations.

Table 3
Pollutant concentrations inside different bus types during portions of the commutes with no other diesel vehicles present

	BC ($\mu g\,m^{-3}$)		PB-PAH ($ng\,m^{-3}$)		NO_2 ($\mu g\,m^{-3}$)	
	Mean	Max	Mean	Max	Mean	Max
Windows closed						
Ambient—morning ($n = 1200$)	2.5 (2.4–2.6)		27 (24–30)		99 (96–100)	
CNG ($n = 287$)	2.3 (2.2–2.4)	6.0	57 (53–62)	160	65 (63–67)	88
TO diesel ($n = 562$)	7.1 (6.9–7.3)	17.0	190 (180–190)	520	80 (80–82)	110
Conventional diesel ($n = 870$)	11 (11–12)	31.0	290 (280–300)	1,000	130 (130–140)	230
Windows open						
Ambient—afternoon ($n = 1700$)	1.9 (1.8–2.0)		26 (24–27)		41 (40–42)	
CNG ($n = 345$)	1.5 (1.4–1.7)	6.9	43 (38–48)	380	73 (69–74)	110
TO diesel ($n = 492$)	2.3 (2.1–2.4)	11.0	42 (37–47)	340	160 (150–160)	250
Conventional diesel ($n = 619$)	3.9 (3.5–4.3)	51.0	58 (50–66)	1,600	140 (140–150)	300

95% confidence intervals for the mean are in parentheses.

3.2.3. *Summary of effect of bus and fuel type*

Our results indicate that in addition to the effects of following another diesel vehicle, the type of test bus and fuel were also important predictors of elevated mean and peak concentrations. When no other diesel vehicles were present, the highest mean and peak pollutant concentrations were consistently observed inside the conventional diesel buses, both with open and closed windows. Pollutant concentrations inside the TO diesel bus were generally in between those observed inside the conventional diesel buses and the CNG bus, although diesel-related pollutant concentrations on board our specific TO diesel bus appeared to be higher than expected, based on emissions data reported for other trap-equipped diesel vehicles (Johnson, 2001).

As demonstrated by tracer gas tests on the buses in this study (Behrentz et al., 2004) with closed windows, all buses showed some degree of self-pollution (Table 4), with similar rates of exhaust intrusion for one conventional diesel bus (RE2) and the TO diesel and CNG buses, and higher rates (by approximately a factor of four) for the older conventional diesel bus (HE). (When the windows were open, all buses had similar exhaust intrusion rates as expected.) Thus, for the conventional diesel buses, both higher concentrations in the exhaust and higher rates of exhaust intrusion explain our observations of higher bus cabin concentrations. For the TO diesel and CNG buses, high concentrations of BC and PB-PAH occurred *only* while traveling behind a diesel vehicle.

The amount of time spent following a diesel vehicle was 25%, 30% and 31% (windows open), and 24%, 28% and 20% (windows closed) for the conventional diesel, CNG and TO diesel buses, respectively. Thus, differences found between bus types were not due to substantial differences in the frequency of encounters with diesel vehicles.

3.3. *Effect of road type*

To investigate the impact of differences in traffic volume, speed and other variables related to road type (freeway vs. surface street), the commutes were divided into three categories: freeway, moving on surface streets and idling on surface streets. Only those portions of the commutes with no other diesel vehicles present, based on the videotapes, were included. Both with open and closed windows, neither the type of roadway nor idling behavior were important predictors of pollutant concentrations inside the bus cabins.

4. Conclusions

With open windows, the presence of a diesel vehicle in front of the test bus was the dominant determinant of high bus cabin pollutant concentrations, irrespective of the type of test bus or traffic conditions. With windows closed, the type of test bus was the most important factor, due to self-pollution. The differences between bus

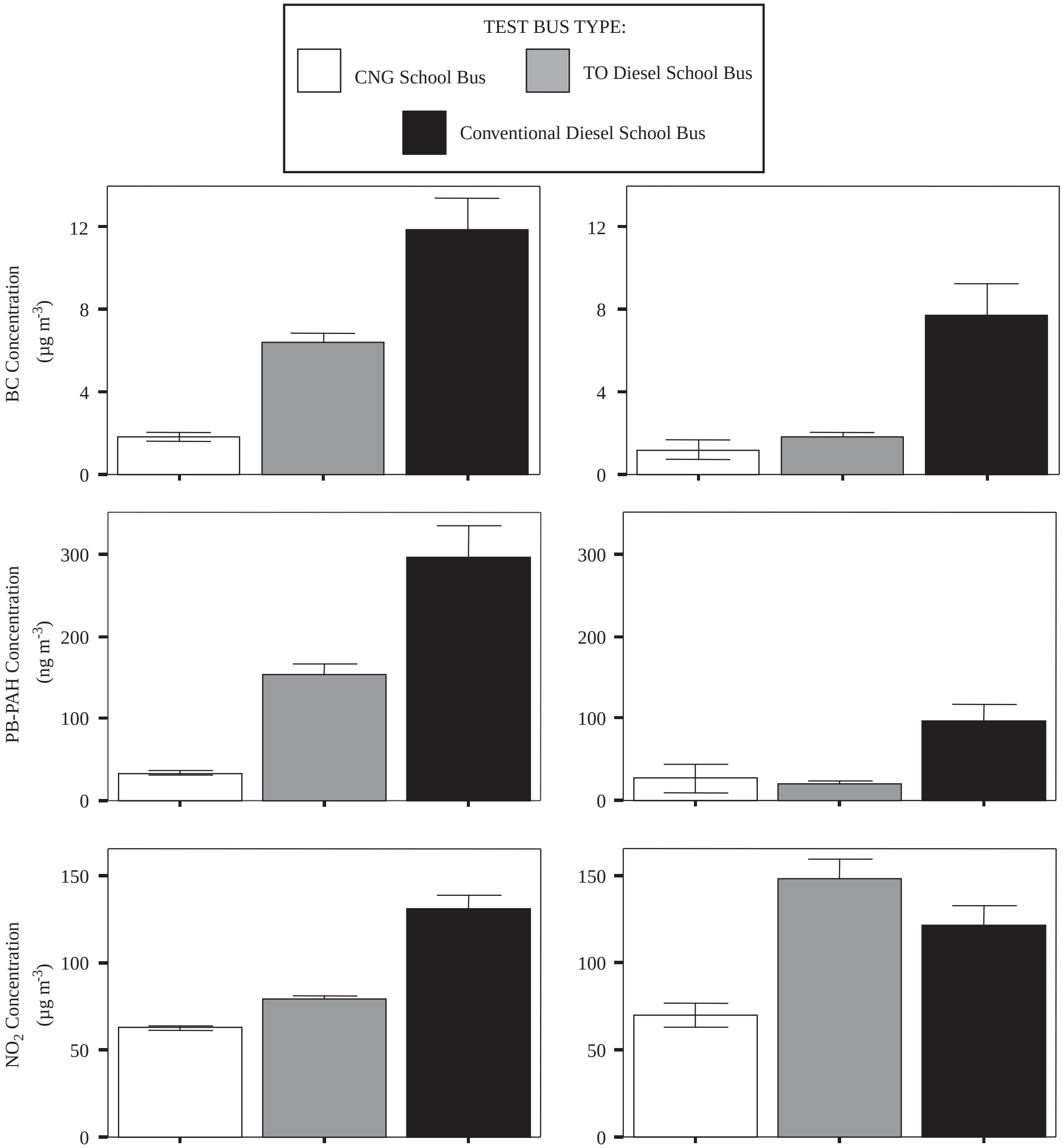

Fig. 5. Mean pollutant concentrations while idling at bus stops away from traffic and when no other diesel vehicles were present, by bus type. Error bars represent the 95% confidence interval for the mean.

types were most pronounced with closed windows when buses were idling at bus stops, away from the influence of traffic congestion or other diesel vehicles.

Our results demonstrate that conventional diesel school buses can have a double impact on children's exposures: through the influence of self pollution from the bus's own exhaust inside the cabin and through exposures to the exhaust from other nearby conventional diesel school buses. This study involved long commutes, often in congested conditions and with significant self-pollution for several buses; therefore our findings cannot be viewed as typical for all buses

Table 4
Exhaust gas intrusion into the bus cabin during commutes measured using an SF_6 tracer gas

Bus	Percent of air inside cabin from bus's own exhaust	
	Windows open	Windows closed
HE2 (1985)	0.04	0.13
RE2 (1993)	0.02	0.03
TO (1998)	0.03	0.04
CNG (2002)	0.03	0.04

under all commute scenarios. To reduce school bus commute exposures under the conditions we studied, we strongly recommend avoiding caravanning with other school buses, minimizing children's commute times, using the cleanest buses for the longest bus routes, maintaining conventional diesel buses to eliminate visible emissions, and transitioning to cleaner fuels such as CNG and advanced particulate control technologies, such as the particle-trap used on a diesel buses in this study.

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