原著論文

Effect of Different Activity Patterns on Weekday and Weekend Nitrogen Dioxide Exposure for University Students

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Abstract

Indoor and outdoor NO_2 concentrations were measured and compared simultaneously with personal NO_2 exposures for 25 university students for 2 days each on weekdays and weekends. House characteristics and activity patterns were used to determine the impacts of these factors on personal exposure. During the 48-hour monitoring period, mean indoor and outdoor NO_2 concentrations were 26.1 ppb and 32.9 ppb on weekdays, respectively, and personal exposure was 29.7 ppb. While mean indoor and outdoor NO_2 concentrations on weekends were 38.1 ppb and 39.6 ppb respectively personal exposure was 44.3 ppb. Since university students spent most of their time indoors, their NO_2 exposures were associated with indoor NO_2 levels rather than outdoor NO_2 levels both weekdays and weekends in spite of different time activity patterns. Using a time-weighted average model, personal NO_2 exposures of the university students were estimated by NO_2 measurements indoors at home, indoors at school, and outdoors at home. Estimated personal NO_2 exposures were significantly correlated with measured personal NO_2 exposures (Spearman r = 0.72). However, estimated personal NO_2 exposures by the time-weighted average model were significantly underestimated, compared with the measured personal NO_2 exposures. This suggests that the personal NO_2 exposure of university students is affected by other factors such as transportation.

Key words: personal exposure, nitrogen dioxide, time-weighted average, transportation

1. INTRODUCTION

Nitrogen dioxide (NO_2) is a by-product of high temperature fossil fuel combustion. Anthropogenic NO_2 emissions from indoor and outdoor combustion sources are some of the most ubiquitous pollutants in the urban environment[1]. Despite of the wide distribution of sources, the indoor NO_2 concentration is the dominant risk factor for personal exposure. Individuals were found to spend about 90% of their days indoors and about two-thirds of the day inside their home[2].

Nitrogen dioxide is a corrosive and highly oxidizing gas with a characteristic pungent odor, which has been described as stinging, suffocating, and irritating. A variety of human experimental studies under controlled conditions suggest that NO_2 may increase airway response[3]. Some chamber studies with volunteers have shown a small effect on airway response in asthmatics exposed to NO_2 concentrations similar to those near home combustion appliances[4].

The usage of a gas range has been identified as one of the major factors contributing to indoor and personal NO_2 exposures. The use of a gas range provided a mean indoor/outdoor (I/O) NO_2 concentration ratio of 1.19, compared with 0.69 for those homes without gas ranges[5]. To date, personal exposure to NO_2 has not been characterized in Korea, though the use of a gas range is common.

Since certain human activities stand out as higher exposure risks, studies of human activity patterns have recently taken on an increased emphasis[6]. In this study, indoor and outdoor NO_2 concentrations were measured and compared simultaneously with personal exposures for 25 university students on weekdays and weekends. The purpose of this study was to estimate the personal NO_2 exposure by a time-weighted average and to assess the personal NO_2 exposure from different time activity patterns on weekdays and weekends, considering university students have varying activity patterns.

2. METHODS

Time activities of 25 university students with simultaneous NO_2 measurements were investigated during a 2-day period in May 2000 in Onyang, Korea. Participants, who all belonged to the same department of Soonchunhyang University, filled out an activity diary (Table 1) about their homes and their surroundings during the course of the study and a questionnaire regarding house characteristics. The activity diary consisted of half-hour time bands during the daytime and one-hour time bands from midnight to 6 a.m. During a 2-day study period, participants were asked to report in this diary whether they were indoors at home, school or elsewhere; outdoors at home, school or elsewhere; or in transit in any kind of motor vehicle or public transportation.

Microenvironments where NO_2 concentrations were measured were indoors and outdoors of their residence, and indoors and outdoors of their school. During the same period, personal NO_2 exposures were measured for the 25 university students. Each student wore a personal sampler on their chest during

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Table 1. Table of time activity diary

	Indoor			Outdoor			Transportatio
	Home	School	Other	Near home	Near school	Other	
6:00-6:29 AM							
6:30-6:59							
11:30-11:59							
12:00-1:00 PM							

waking hours, placing it on a table or dresser during the night or while taking a shower. Indoor samplers were placed inside each participant's house, at least 3 m from any combustion sources and 2 m from any open window. Outdoor samplers were placed outside each participant's home, at least 1 m above the ground, where they could not be impacted by rain. Periods of NO_2 measurements of lecture rooms and hallways in school were from 9 a.m. to 5 p.m. Passive filter badges (Toyo Roshi, Ltd.) were utilized for all NO_2 measurements. The filter badges are small ($5\times 4\times 1\,cm^3$) and lightweight (15 g), and they do not involve pumps and other equipment[7]. The filter badges absorb NO_2 into a triethanolamine solution on a cellulose fiber filter. The use of a mass transfer coefficient of 0.10 cm/sec results in a measurement error of less than 20 %[8]. The exposed NO_2 badges were analyzed with a spectrophotometer (Shimadzu UV- 1201).

Personal exposure levels can be estimated by the time - weighted average of the microenvironment concentration[9]. Although all environments were not measured in this study, personal NO_2 exposure was estimated using indoor home exposure, indoor school exposure and outdoor home exposure according to equation (1):

$$P_i = (IH_I \cdot I_i + OH_I \cdot O_i + SI_I \cdot S_i + SO_I \cdot SO_i) / (IH_I + OH_I + SI_I + SO_I) \quad (1)$$

Where P_i = estimated time - weighted average of personal NO_2 exposure for participant i, IH_I= number of hours spent inside the home for participant i during the sampling period, OH_I = number of hours spent outside the home for participant i during the sampling period, SI_I = number of hours spent inside the school for participant i during the sampling period, SO_I = number of hours spent outside the school for participant i during the sampling period, Ii = measured average indoor NO_2 concentration for participant i, Oi = measured average outdoor NO_2 concentration for participant i, Si= measured average indoor school NO_2 concentration for participant i and SOi = measured average outdoor school NO_2 concentration for participant i.

3. RESULTS

3.1 House characteristics and time activity pattern

The mean age of participants was 19.6 ± 2.6 and the number of males and females were 11 and 14, respectively. The average number of family members was 3.8. Twenty-three houses had gas ranges; only the two students who live in a dormitory of the university did not have gas ranges. The mean gas range usage was 2.1 hours during the sampling period[10].

Twenty-five university students completed an activity diary during the sampling period in Table 3. The participants spent most of their time indoors. The percent of time spent indoors was 72.9 % and

Table 2. House characteristics in 25 houses

	Number of house with the house characteristic	Number of house without the house characteristic
House type (single detached house)	5	20
Presence of smoker	10	15
Gas range	23	2
Commuting time per day (<60 min)	12	13

Table 3. Fraction of times on each weekday and weekend (n=25)

		Indoor			Outdoor			Trans-portation
		Home	School	Other	Near home	Near school	Other	
Weekday (2 days)	%	40.4 (± 11.7)	25.1 (± 9.4)	7.4 (± 8.9)	4.4 (± 5.1)	11.8 (± 5.3)	3.1 (± 4.5)	7.9 (± 7.4)
	Total %		72.9			19.3		7.8
Weekend (2 days)	%	69.0 (± 20.3)	0.7 (± 3.3)	13.1 (± 14.0)	6.2 (± 7.3)	0.7 (± 1.8)	5.6 (± 7.7)	4.7 (± 5.8)
	Total %		82.8			12.5		4.7

82.8 % on each weekday and weekend, respectively. The mean time that participants spent in their homes was 40.4 ± 11.7 % on weekdays and 69.0 ± 20.3 % on weekends. Transportation time fractions such as commutes were 7.9 ± 7.4 % and 4.7 ± 5.8 % on each weekday and weekend, respectively.

3.2 Indoor and outdoor NO_2 levels and personal exposure

The measured NO_2 concentrations and the mean I/O NO_2 ratios are shown in Table 4. Mean personal NO_2 exposure concentrations were between the mean indoor and outdoor concentrations on weekdays, but higher than mean indoor and outdoor concentrations on weekends. Mean NO_2 I/O concentration ratios were 0.8 on weekdays and 0.9 on weekends. Mean indoor and outdoor NO_2 concentrations at the school for 2 weekdays were 19.5 ± 5.2 ppb and 21.9 ± 3.2 ppb, respectively. On weekends, indoor and outdoor NO_2 concentrations at the school were 17.6 ± 2.3 ppb and 20.3 ± 2.5 ppb, respectively.

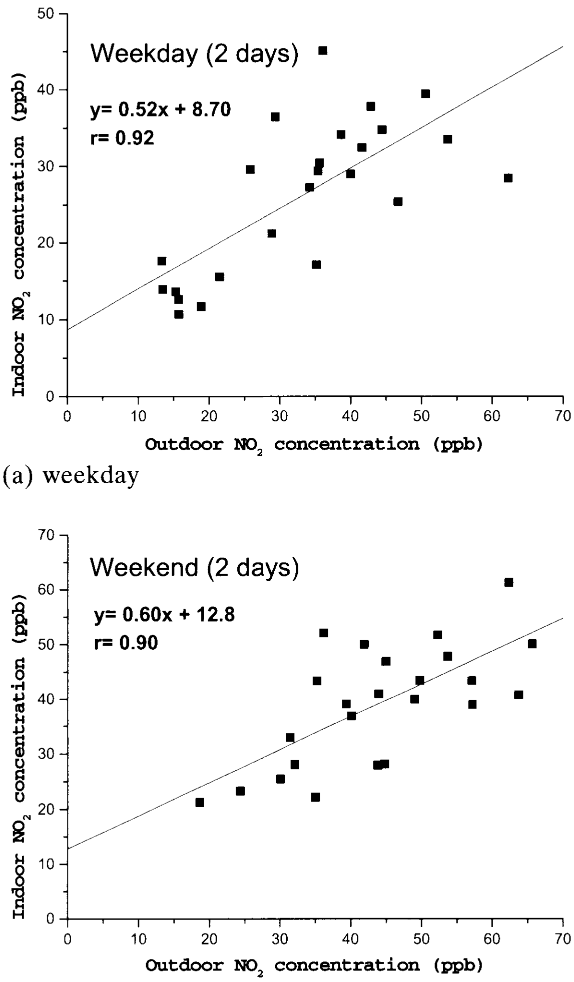
Indoor NO_2 concentrations were significantly correlated with outdoor NO_2 concentrations, as shown in Fig. 1. The Spearman correlation coefficients on weekdays and weekends were 0.92 and 0.90, respectively. Personal NO_2 exposures were correlated more strongly with indoor NO_2 concentrations both on weekdays and weekends, as shown in Fig. 2. The Spearman correlation coefficients were 0.76 and 0.64 on weekdays and weekends, respectively.

3.3 Estimation of personal NO_2 exposure

Since university students spent most of their time indoors, personal NO_2 exposures could be estimated

Table 4. Measure NO_2 concentrations and personal exposure (unit: ppb)

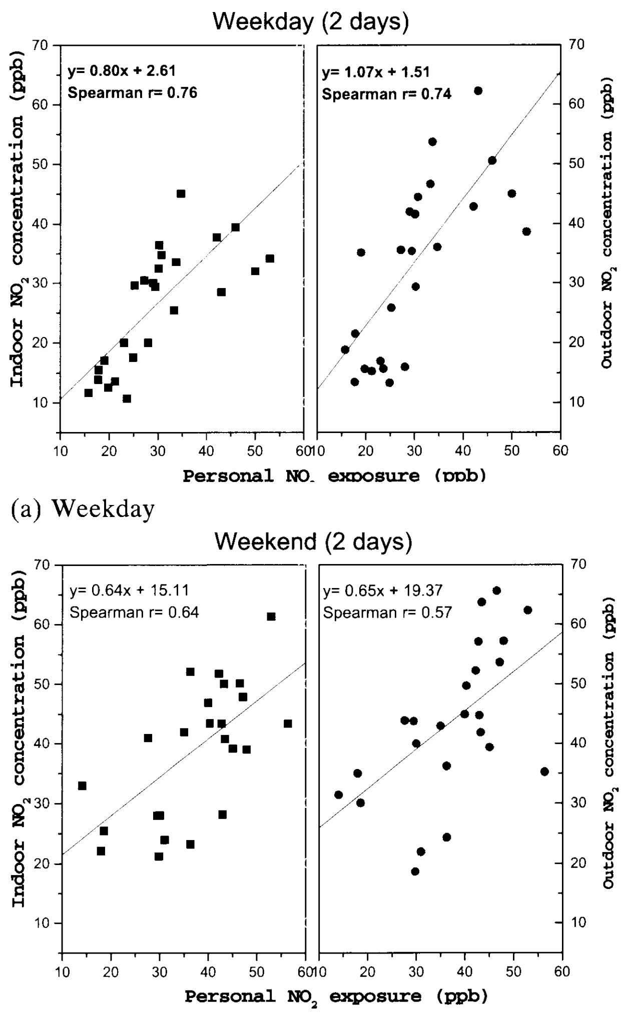
	Indoor	Outdoor	I/O	Personal
Weekday (2 days)	26.1 ± 10.6	32.9 ± 14.5	0.8 ± 0.2	29.7 ± 10.1
Weekend (2 days)	38.1 ± 11.4	39.6 ± 12.4	0.9 ± 0.2	44.3 ± 13.0



(a) weekday

(b) weekend

Fig. 1. Relationship between indoor and outdoor NO_2 measurements on weekdays and weekends.



(a) Weekday

b) Weekend

Fig. 2. Relationship between personal NO_2 exposure and indoor, outdoor NO_2 measurements on weekdays and weekends.

with combinations of time activity patterns and NO_2 concentrations measured in each microenvironment. Although all environments were not measured, personal NO_2 exposure was estimated by indoor home exposure, outdoor home exposure, indoor school exposure, and outdoor school exposure using a time activity diary. By combining personal NO_2 exposures both on weekdays and weekends, the measured personal NO_2 exposures were significantly associated with the estimated personal exposures with a Spearman correlation coefficient of 0.72 ($p < 0.01$) as shown in Fig. 3. Association between estimated personal NO_2 exposure and measured exposure yields a slope of 0.74. The measured personal NO_2 exposure (33.8 ± 11.5 ppb) was higher than the estimated personal exposure (31.0 ± 11.9 ppb).

4. DISCUSSION

Previous studies on the precision of passive filter badges indicated an overestimation of 22 % for NO_2 from the passive diffusion tube model simulation[11]. Therefore 10 replicate measurements for the passive filter badges in this study were carried out and produced a precision of 6.5 %. Mean NO_2 concentration for blank samples with 10 passive filter badges was 1.5 ppb, which means there was no severe impact on NO_2 concentrations between study completion and analysis.

Regression analysis indicates that indoor NO_2 concentrations were about 90 % of outdoor levels. Sexton et al.[12,13] estimated the annual indoor NO_2 level to be about 60 % of the outdoor level in homes without gas ranges. This difference was considered in that outdoor NO_2 level could strongly affect the indoor level because the mild and warm climate during the sampling period made the house's

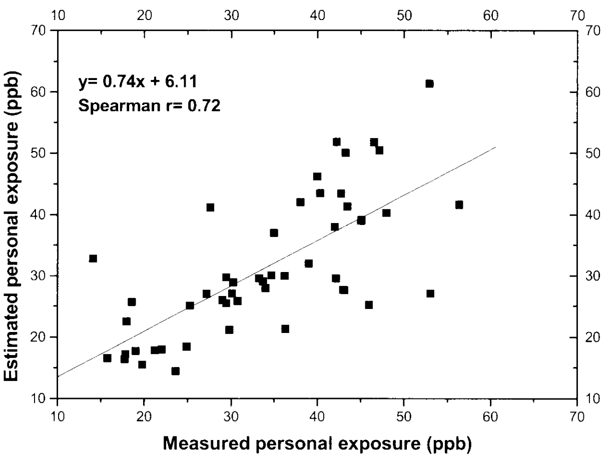


Fig. 3. Association between measured and estimated personal NO_2 exposures.

ventilation high. The presence of gas ranges provided mean I/O NO_2 concentration ratios of 0.8 and 0.9 on weekdays and weekends, respectively. Tobacco smoking as a source of NO_2 did not have a significant effect on indoor NO_2 concentration ($p>0.05$). Tobacco smoke could be considered to have negligible emissions compared to the use of a gas range[14].

The difference between the calculated values of P_i obtained from equation (1) using the data and the measured personal exposure can be explained by exposure to other microenvironments. The concentrations in different microenvironments were estimated as the regression coefficient, b, in equation (2).

$$P - P_i = b_{IO} \cdot F_{IO} + b_{(SO+OO)} \cdot F_{(SO+OO)} + b_T \cdot F_T \qquad (2)$$

Where, P = measured personal NO_2 exposure (ppb), F_{IO} = fraction of hours spent inside other than home and school, $F_{(SO+OO)}$ = fraction of hours spent outside other than near home and near school, and F_T = fraction of hours spent on transportation.

The results of the multiple regression analysis are shown in Table 5. The regression coefficient for transportation was statistically significant. These results indicate the need for future research on personal exposure during transportation such as commutes because the major contribution to air pollution in a metropolitan area is generally from traffic emission.

5. CONCLUSION

This study provides the measurement of university students' NO_2 exposures in Korea. According to time activity patterns, some population groups could be risks for higher exposure to air pollutants. Since university students are generally young and highly active, their NO_2 exposures on weekdays and weekends were measured using a passive sampler and estimated using a time-weighted average model. In addition, the personal NO_2 exposures on weekdays and weekends were compared with activity patterns. Although personal NO_2 exposures were different between weekdays and weekends, personal NO_2 exposures were significantly more closely associated with indoor NO_2 concentrations than with outdoor NO_2 concentrations. The estimated personal NO_2 exposure from the time-weighted average model was significantly lower than the measured personal exposure. This result indicates that personal NO_2 exposures are also affected significantly by other factors such as transportation.

Table 5. Estimated NO_2 concentrations and fraction of time in three environments

	Regression coefficient ± SE	Fraction of time (%)	Sig.
Indoor other than home and school	−0.07 ± 0.3	10.2 ± 11.9	0.825
Outside other than home and school	−0.43 ± 0.5	4.3 ± 6.3	0.415
Transportation	1.33 ± 1.3	6.3 ± 6.8	0.015

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