Assessment of personal exposure to ozone in asthmatic children residing in Mexico City

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Abstract

Objective. A study was conducted to evaluate personal ozone exposure (O_{3p}) among asthmatic children residing in Mexico City. **Material and Methods**. A total of 158 children were recruited from December 1998 to April 2000. On average, three O_{3p} measurements were obtained per child using passive badges. Time-activity patterns were recorded in a diary. Daily ambient ozone measurements (O_{3a}) were obtained from the fixed station, according to children's residence. Levels of O_{3a} and ozone, weighted by time spent in different micro-environments (O_{3w}), were used as independent variables in order to model O_{3p} concentrations using a mixed-effects model. **Results.** Mean O_{3p} was 7.8 ppb. The main variables in the model were: time spent indoors, distance between residence and fixed station, follow-up group, and two interaction terms (overall R^2=0.50, p<0.05). **Conclusions.** The O_{3w} concentrations can be used as a proxy for O_{3p}, taking into account time-activity patterns and the place of residence of asthmatic Mexican children.

Key words: personal measurements; ozone; asthmatics; Mexico City; activity patterns

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Resumen

Objetivo. Realizamos este estudio para evaluar la exposición personal a ozono (O_{3p}) en niños asmáticos de la Ciudad de México. **Material y métodos.** Se incluyeron 158 niños entre diciembre de 1998 y abril de 2000. En promedio se obtuvieron tres mediciones por niño, utilizando filtros pasivos para medir O_{3p}. Se caracterizaron los patrones de actividad y las concentraciones ambientales diarias de ozono (O_{3a}) se obtuvieron de estaciones fijas cercanas a la residencia del niño. Los niveles promedio de O_{3a} y las concentraciones ponderadas por el tiempo en diferentes microambientes (O_{3w}) fueron usados como variables independientes para modelar las concentraciones de O_{3p}, utilizando modelos de efectos mixtos. **Resultados.** La media de O_{3p} fue 7.8 ppb. Las principales variables en el modelo fueron: tiempo en exteriores, distancia, periodo de seguimiento y dos términos de interacción (R^2=0.50, p<0.05). **Conclusiones.** Las concentraciones de O_{3w} pueden usarse como "proxi" de O_{3p}, tomando en cuenta patrones de actividad y lugar de residencia.

Palabras clave: medición personal; ozono; asmáticos; Ciudad de México; patrones de actividad

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The effect of ozone exposure on respiratory health has been widely reviewed. The cumulative structural alteration of lung airways has been consistently observed in rats and monkeys repeatedly exposed to ozone.[1] In humans, short-term exposure to ozone is associated with a decrement in lung function, increased coughing, increased airway reactivity, increased airway permeability, increased airway inflammation, hypertrophy response of Clara cells, alteration of macrophage function and accelerated tracheobronchial particle clearance.[1-3]

Ozone can directly damage the respiratory tract, and the cytotoxicity of this pollutant is thought to be due primarily to the free radicals formed when ozone attacks biomolecules.[4] These free radicals can injure resident lung cells, such as macrophages and epithelial cells, initiating a cascade of reactions that result in lung damage, inflammation, and changes in host defense capability.[5] Other health effects which have been associated with exposure to ozone and other pollutants include increased health care utilization, increased respiratory illness, exacerbation of asthma, decreased lung function, emergency room visits, increased respiratory symptoms and increased mortality.[5-9]

Evaluation of the relationship between health effects and exposure to ozone has often been conducted using atmospheric concentrations, measured by fixed-site monitors, as a proxy for personal exposure.[10-13] However, atmospheric measurements do not generally reflect personal exposure to ozone, which should be evaluated whilst taking into account other factors, such as activity patterns, exercise habits and the characteristics of buildings occupied.[14-15]

Many studies have evaluated both active and passive ozone samplers to assess personal exposure in different populations. Liu *et al*. conducted a study of children living in State College, Pennsylvania, and found that personal ozone exposure was better estimated when both time spent indoors as well as indoor and outdoor micro-environment concentrations were included in their model (R^2= 0.76). Based on the Canadian Research on Exposure Assessment Modeling study conducted in the Toronto metropolitan area, Liu *et al*.[16] reported that mean personal concentrations for school children were 3.3 ppb during the winter season and 9.4 ppb during the summer. When they ran a model to evaluate which variables explained a substantial percentage of the variability in the measured personal exposure, they found that indoor and outdoor concentrations were the best predictors (R^2= 0.50, p<0.001). Geyh *et al*.[17] reported a field evaluation, with 40 subjects, of the Harvard active ozone sampler, developed to improve the accuracy and precision of passive sampler devices. The precision of the active device was higher than that of the passive sampler, and the active sampler measured 94% of ambient ozone reported by the UV photometric ozone monitors, on average. In a study conducted of 10 shoe shiners in downtown Mexico City, O'Neill *et al*.[18] found an overall mean correlation of 0.72 between the nearby fixed monitor and the active sampler worn by the shoe shiners.

Previous studies in Mexico City have been conducted to evaluate a passive ozone sampler.[19,20] These studies evaluated air quality inside classrooms and the reproducibility of the sample, but did not assess personal exposure to ozone. We therefore conducted a study to evaluate personal ozone exposure and to determine which personal behaviors and household characteristics contributed to personal exposure, in order to further develop a personal exposure model for asthmatic children residing in Mexico City.

Material and Methods

Study design

Children selected for this study were participants in an antioxidant supplementation study among asthmatic children in Mexico City.[21] A total of 160 children aged 6 to 14 years were recruited through the Allergy Department at the Hospital Infantil de Mexico (HIM). Children included in the study had mild or moderate asthma and lived in the Mexico City metropolitan area close to one of the fixed monitoring stations in the Red Automatica de Monitoreo Ambiental (RAMA) operated by the Mexican government. Procedures to be followed during the study were explained to the parents, who were asked to sign an informed consent form if they agreed to their children's participation. The protocol was approved by the ethical committees of both institutions (HIM and INSP).

Four groups of 40 children were followed for 12 weeks; the first group started in October 1998 and ended in January 1999; the second started in May 1999 and ended in August 1999; the third started in September 1999 and ended in December 1999; and the fourth group started in January 2000 and ended in April 2000. Two of the 160 participating children dropped out of the study before their follow up ended.

During the sampling period, participants were asked to wear a passive badge close to their breathing zone (48 to 72 hours) during the day and to place the badge on the night table when they were sleeping and taking a shower, to avoid handling problems during the sampling period. Six out of 158 participants were not able to wear the passive badge; by the end of the study 91% (n=144) of the children participated in at least one of the measurements.

The sampling period started in October 1998 and had ended by April 2000. We had planned to perform personal measurements for each child three times during the study period, during three consecutive days prior to performing the spirometry. On average, three measurements per child were obtained, but three of the participants wore a personal sampler only once and 87 wore the sampler only four times during the follow-up.

Sampling method

The Ogawa sampler badges[14] were used to measure personal concentrations. The principle of the sampler is the oxidation of nitrite (NO_2) by O_3 to form nitrate (NO_3), which is quantified by ion chromatography. Badges were assembled in Mexico City by a trained technician. Each badge cylinder was washed over three cycles using Mili-Q water and dried at room temperature. Filters were received and kept at 4 °C, with the exception of the assembly procedure, when they were warmed to ambient room temperature. After the assembly procedure, badges were labeled and kept in an amber canister at 4°C until the sampling period. After the sampling period, the badges were refrigerated again in the amber canister and later shipped to the Harvard School of Public Health for chemical analysis.

Over the entire sampling period, 10% of the samplers were used as field blanks which were assigned to some of the children, and their mothers were instructed to place the blank at room temperature inside the plastic bag and amber canister for the sampling period. Approximately 10% of these samplers were assigned to some of the participants to be used as duplicates, referring to the same time and conditions as the personal sampler.

Fixed-site monitoring measurements

Daily measurements of O_3 were obtained from the appropriate RAMA station. Mean ozone concentrations were calculated based on 24-hour measurements reported by the RAMA. The hourly air pollutant levels for the entire sampling period were averaged. The residence of each participating child was located on a map and the air quality of the closest monitoring station was assigned to that child.

Activity patterns

For each sampling period, children recorded their activities in a diary, including their location, and briefly described their activities. Diaries were divided into 30-minute increments from 7:00 until 21:00 and into 1-hr increments from 21:00 to 6:00 of the following day. Four times during the follow-up, each child filled out one diary page for each day of the monitoring period, usually three days. By the end of the monitoring period a technician reviewed the diaries with the child and his or her parents to make sure they had been completed.

Chemical analysis

After the sampling period, badges were disassembled in Mexico City using the ozone passive sampler protocol (Ozone passive sampler protocol, 1994). Filters were kept at 4 °C until they were shipped to the Harvard School of Public Health for chemical analysis. The average ozone concentration measured by the sampler badge was calculated from the amount of NO_3-accumulated, which was determined by ion chromatography (Dionex model 2000; Dionex Corporation, Sunnyvale, CA, USA).[22]

Statistical analysis

Descriptive analysis was performed for the complete group of participants and for each cohort group. Comparisons between mean personal and ambient ozone concentrations were obtained using an ANOVA test. Original and duplicate measurements were compared using a linear regression model to check for measurement precision. Average ambient (O_{3a}) level for the entire sampling period and calculated ozone level (O_{3w}) weighted by time spent in different micro-environments (equation 1) were used as independent variables in order to model personal ozone concentrations (O_{3p}).

$$O_{3w} = O_{3a} * t_o + O_{3a} * t_t + O_{3a} * r_{i/o} \qquad \text{Equation 1}$$

where:

O_{3w} is the ozone concentration weighted by time spent in different micro-environments
O_{3a} is the corresponding ambient ozone concentration from the RAMA
t_o is the average time spent outdoors for each child (as a percentage)
t_t is the average time spent in transit for each child (as a percentage)
$r_{i/o}$ is the indoor/outdoor ratio obtained in previous studies in Mexico City[19,20]

A random effects model was used to predict O_{3p}, including in the regression models the following as predicted variables: time spent outdoors, distance of the residence from the fixed station, participation group, area of residence and certain characteristics related to living conditions. Several living conditions characteristics were included in both models, as well as activity patterns for each participant. In the final model, only those variables that contributed to the model and were statistically significant were included. All statistical analyses were performed using Stata software release 7 (Stata Corporation, College Park, Texas, USA).

Results

Characteristics of the participants

Only 144 subjects in the original group of participants wore a badge at least once. The response rate was 91%. Table I shows the general characteristics of the participants as well as their domestic conditions. More males than females participated, with 64% of the males participating during the entire follow-up period. The second study group had the highest percentage of male participants (75%). Age distribution was similar in all follow-up groups, with the 6 to 9 year-old group being the most prevalent. More children with more severe asthma were in groups 1 and 3 (67 and 60% respectively) while in groups 2 and 4 there were more children with mild asthma (69 and 60% respectively). Less than 50% of the participants in groups 1 and 3, and over 40% in groups 2 and 4, lived in a building with more than one dwelling. Cooking gas was used in almost all of the houses, and in groups 2 and 3, around 40% of the houses kept the pilot light on. Less than 10% of the children had a carpet in their bedroom. More than 70% of the participants usually kept their windows open, and more than 35% of the participants had pets at home (table I).

Precision of measurements

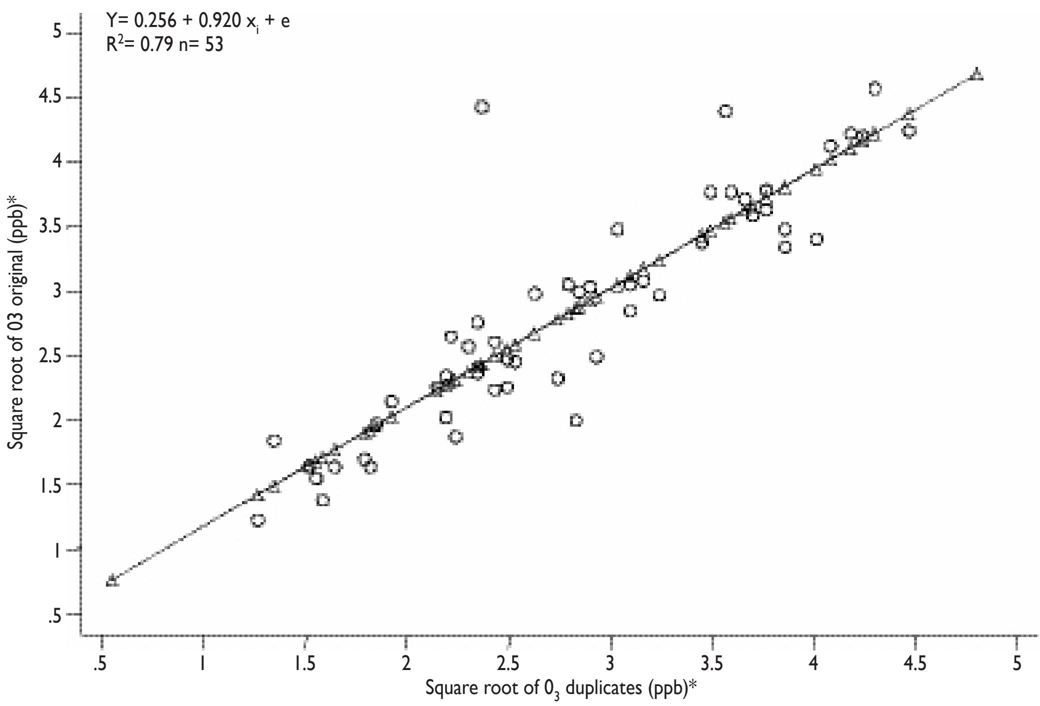
The precision of ozone measurements was determined using duplicates. Ten percent of the total samplers (n=53) were randomly assigned to some of the participants who wore a duplicate during one of the sampling periods. Figure 1 shows the regression graph comparing the

Table I

Characteristics of participants in personal ozone measurements by group. Mexico City, 1998-2000

Characteristic	*Group 1*	*Group 2*	*Group 3*	*Group 4*	*Mean*	*p-value**
Gender (%)						
Male	62.5	75.0	64.1	55.0	64.2	
Female	37.5	25.0	35.9	45.0	35.8	0.314
Participants by age (%)						
< 6 years	0.0	0.0	5.1	0.0	1.3	
6 – 9 years	50.0	75.0	46.2	62.5	58.5	
10 – 13 years	40.0	22.5	41.0	30.0	33.3	
> 13 years	10.0	2.5	7.7	7.5	6.9	0.118
Severity of asthma (%)						
Mild asthma	32.5	69.2	30.8	60.0	48.1	
Moderate and severe	67.5	30.8	69.2	40.0	51.9	0.000
Household characteristics (%)						
Single family	52.8	39.5	58.9	30.8	45.4	0.000
Cooking with gas	97.7	100.0	100.0	96.8	98.6	0.063
Carpet in bedroom	7.5	9.1	15.4	7.5	9.9	0.602
Lighted stove pilot	16.0	40.0	36.4	26.9	26.8	0.001
Opened windows	79.4	81.8	81.7	72.4	78.8	0.220
Pets at home	38.1	37.9	48.7	48.8	43.1	0.115

* *p*-value obtained by Pearson Ji^2



* Ozone measurements based on square-root-transformed

FIGURE 1. RELATIONSHIP BETWEEN ORIGINAL AND DUPLICATE OZONE MEASUREMENTS IN ASTHMATIC CHILDREN IN MEXICO CITY, 1998-2000

original concentration with the corresponding duplicate. The linear regression equation was $Y_i = 0.256 + 0.920X_i$ (where Y_i= the duplicate O_{3P} measurement, X_i= the original O_{3P} measurement), with a significant intercept and a regression coefficient (R^2= 0.79).

Activity patterns

In general, more than 80% of participants' time was spent indoors, with no differences between genders. Although the time spent outdoors was similar between genders, groups 1 and 3 spent significantly less time outdoors than groups 2 and 4, which might explain why a higher percentage of severe asthmatics were found in the latter group. Regarding the time spent in any type of transportation, the highest percentage was in males from group 2 (8.7%); the percentage in other groups was between 5 and 7% (table II).

Personal and ambient ozone concentrations

Table III summarizes personal and corresponding ambient O_3 concentrations among groups by gender. The highest median personal concentration was observed in boys from group 1 (13.0 ppb) and the lowest was found in boys from group 3 (4.1 ppb). Regarding ambient concentration, the highest concentration was also found in boys from group 1 (36.0 ppb) and the lowest was in girls from group 3 (25.4 ppb). The highest mean concentration was observed in group 1. The mean concentrations for groups 2, 3 and 4 were similar and significantly lower than that of group 1.

As for corresponding ambient concentrations, the highest mean concentration was also observed in group 1 and the lowest was observed in group 3 (table III). Figure 2 shows personal, weighted, and ambient ozone concentrations (O_{3p}, O_{3w} and O_{3a}) according to the area of residence of the participants. The highest concentrations for the three –ambient, weighted, and personal ozone concentrations– were observed in the southwestern area of the city, while the lowest concentrations were observed in the northeastern area. The correlation between each of the ozone concentrations was significant, with r=0.21 between O_{3p} and O_{3w} (p=0.000), r=0.35 between O_{3p} and O_{3a} (p=0.000), and r=0.46 between O_{3w} and O_{3a} (p=0.000).

Table II
TIME SPENT BY PARTICIPANTS IN DIFFERENT MICRO-ENVIRONMENTS BY GENDER AND GROUP OF PARTICIPATION. MEXICO CITY, 1998-2000

Micro-environment by gender	*Group 1 n = 131*	*Group2 n = 132*	*Group 3 n = 115*	*Group 4 n = 131*	*Mean n = 509*	*p-value**
Male						
Indoors	84.5	77.1	82.8	78.6	80.5	0.000
Outdoors	10.6	14.2	11.8	14.8	12.9	0.037
In transit	4.9	8.7	5.5	6.6	6.6	0.000
Female						
Indoors	83.2	80.1	83.4	78.3	81.2	0.141
Outdoors	11.1	13.8	11.2	14.6	12.7	0.073
In transit	5.7	6.1	5.4	7.1	6.1	0.564

* *p*-value obtained by Bartlett's test for equal variances

Table III
PERSONAL AND AMBIENT OZONE CONCENTRATION (PPB) BY GENDER AND GROUP OF PARTICIPATION. MEXICO CITY, 1998-2000

	Group1		*Group 2*		*Group 3*		*Group 4*	
Ozone	*Boy*	*Girl*	*Boy*	*Girl*	*Boy*	*Girl*	*Boy*	*Girl*
Personal concentration								
Number of samples	83	48	99	32	82	49	70	57
Mean	13.2	13.5	7.2	4.8	4.7	5.4	7.2	6.0
SD	6.1	6.1	4.6	2.4	3.0	3.4	3.3	3.1
Minimum	2.6	2.9	0.2	0.2	0.2	0.5	0.7	1.8
Maximum	30.9	27.6	29.9	13.2	12.0	16.6	14.9	19.9
Ambient concentration								
Number of samples	83	48	100	32	82	49	73	62
Mean	35.8	34.9	34.9	29.6	28.5	26.8	37.4	34.9
SD	7.8	7.7	8.9	9.3	7.7	6.7	9.3	7.8
Minimum	14.1	14.6	13.5	12.5	14.9	15.0	13.6	13.6
Maximum	64.6	57.7	64.4	52.2	52.2	44.2	59.7	54.6

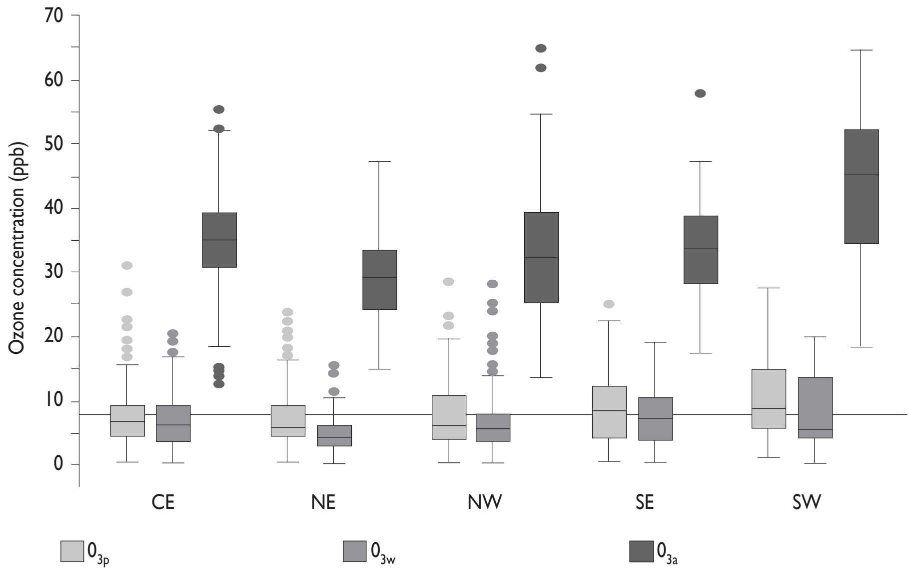
Regression model

Table IV shows the regression model for personal ozone concentration using ambient ozone concentration as the main predictor variable. The variables which contribute most to the model were: distance to the fixed station, time spent outdoors, study group, area of residence and the two interaction terms –area of residence of the group, and distance to the fixed station with time spent outdoors. The overall R^2 was 0.50, and the interclass correlation was 0.36. In the lower part of table IV the regression model is presented for personal ozone concentration using the O_{3w} (weighted personal ozone concentration) as the main predictor variable. The variables which contributed most to the model were: distance from the fixed station, time spent in any type of transportation, study group, area of residence, and one interaction term, –the area of residence with the study group. The overall R^2 was 0.49, with an interclass correlation of 0.30.

Discussion

The present study found an average O_{3p} of 7.8 ppb (range 0.2 to 30.9 ppb), average O_{3a} of 33.3 ppb (range 12.5-64.6 ppb) and an average O_{3w} of 6.6 ppb (range 0.05 to 28.0 ppb). There was no difference according to gender. These ozone concentrations might be considered low; however, similar results have been found in previous studies in Mexico and also in other cities. Romieu et al.[13] reported an indoor ozone concentration of about 5 and a 7 ppb mean concentration, although there were no personal ozone measurements. Geyh et al.[21] reported personal ozone concentrations in the range of 0.5 to 72.3 ppb in children from two communities in California. Liu et al.[16] found personal ozone concentrations in the range of 0.6 to 19.6 ppb in winter and 0 to 52.9 ppb in summer in the Toronto metropolitan area. In Fraser Valley, Brauer et al.[23] reported personal ozone concentrations in the range of 2 to 47 ppb.

In the population in this study, the majority of participants' time was spent indoors (81%). This percentage is similar to that of other studies.[22,23] The children in the



CE= Central area, NE= North East, NW= North West, SE= South East, SW= South West

Figure 2. Personal, Weighted and Ambient ozone concentration by area of residence for asthmatic children. Mexico City, 1998-2000

Table IV
Regression model for predicting personal ozone concentration in asthmatic children. Mexico City, 1998-2000

Variable	*Coefficient*	*SE*	*95% CI*	*p-value*
Ambient O_3*	0.169	0.022	0.127 – 0.212	0.000
Distance to fixed station	- 0.066	0.069	- 0.203 – 0.068	0.334
Time spent outdoors	- 0.006	0.030	- 0.065 – 0.0539	0.844
Area • Group	-0.286	0.167	-0.615 – 0.042	0.088
Distance • Time outdoors	0.013	0.004	0.005 – 0.021	0.001
Estimated O_3‡	0.353	0.050	0.254 – 0.453	0.000
Distance to fixed station	0.099	0.045	0.011 – 0.187	0.028
Time spent in transit	-0.127	0.039	-0.205 – (-0.049)	0.001
Area • Group	-0.323	0.164	-0.645 – (-0.001)	0.049

* For the first model coefficients were obtained using a random effects model with an intercept= 6.55 (p=0.000), overall R^2= 0.50, and an interclass correlation of 0.36 (with 478 observations and 147 subjects with a minimum of one measurement, maximum of four and on average three measurements per participant). Both models were adjusted by study group and area of residence

‡ For the second model coefficients were obtained using a random effects model with an intercept= 10.62 (p=0.000), overall R^2= 0.49, and an interclass correlation of 0.30 (with 478 observations and 147 subjects with a minimum of one measurement, maximum of four and on average three measurements per participant)

SE= Standard error

present study having spent most of their time indoor (81%) might explain the low O_{3p} exposure observed. Our results can be extrapolated only to a similar population since activity patterns among asthmatics are different than those among healthy children.

In the present study, the highest ozone concentration was found in the southwest sector of the city, which is similar to previous studies in Mexico City.[13] The principal contributors to personal ozone exposure were identified and include time spent outdoors, distance of the residence from the fixed monitoring station, study group, and two interaction terms. The overall R^2 was 0.50 when ambient ozone concentrations were used, with an intercept of 6.55 (*p*=0.000), and the R^2 was 0.49 when estimated ozone concentrations were used as a predicted variable, with an intercept of 10.62 (*p*=0.000). These R^2 values were similar to those estimated in other studies where investigators evaluated personal concentrations of ozone and other gaseous pollutants compared with corresponding ambient concentrations.[14,16,18,23,24] However, other studies found R^2 values lower than the present study. Chang *et al*.[25] reported a weaker coefficient during winter and a stronger one during the summer season in Baltimore. Avol et al.[12] also reported a poor correlation between personal O_3 and ambient hourly data in southern California. Although the R^2 found in the present study was higher than in other studies, the coefficient was fairly low which might be due, among other factors, to the use of different methods to measure personal exposure; the present study used passive samplers and compared these concentrations with active samplers used at fixed stations in the network system.

Because we usually correlate ambient ozone concentrations to evaluate health effects, cross-classification between O_{3p} and O_{3a} was calculated and a higher concordance among the extreme groups was found (percentiles of classification). In the first percentile of concentrations the correlation was 53% and in the third, the correlation was 50%. When O_{3p} was compared with O_{3w}, the correlation was 47% in the first percentile and 39% in the third percentile.

These results are important for this study since a misclassification of the exposure could be considered a limitation; ambient concentrations were used to evaluate the acute effect of ozone on the respiratory health of asthmatic children[6] and an inverse association was found between lung function and ozone ambient levels. Obtaining a stronger correlation between personal and ambient O_3 supports the findings in the present study.

Several personal exposure assessments for ozone have been demonstrated to be acceptable models for predicting personal exposure using ambient ozone concentrations as a predicted variable; this was observed in the present study. Variables such as distance from residence to the fixed station, time spent in different micro-environments, and interaction terms (area of residence times participation group and time spent outdoors times distance of residence from the fixed monitoring stations) were found to significantly contribute to the model for predicting personal exposure; these types of variables have been found to be significant by other investigators. The model for the present study might be improved by having other information, such as the ventilation rate at home and indoor and outdoor micro-environmental passive measurements.

Conclusions

Several key results were found in the present study: low personal ozone concentrations among asthmatic children residing in the Mexico City metropolitan area; children in this population spent most of their time indoors (81%); time spent outdoors and distance between the residence and the fixed ambient monitoring stations were the major predictors of personal exposure; variations in personal ozone exposure were greater between individuals rather than for the same individual; estimated personal ozone exposure based on fixed ambient monitoring stations can be used as a proxy for "actual" personal ozone exposure, taking into account time-activity patterns and place of residence of asthmatic children in Mexico City. Our findings can support the use of ambient ozone concentrations as an exposure index in studies where researchers need to determine the impact of air pollution on respiratory health in asthmatic children, taking into account the time spent in different micro-environments.

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