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The relationship between indoor nitrogen dioxide concentration levels and personal exposure: a pilot study

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Summary. A small, personal monitoring study was performed in a subpopulation (14 families) of a case-control study on the relationship between indoor nitrogen-dioxide exposure and respiratory diseases of schoolchildren. Mothers, schoolchildren and pre-schoolchildren were asked to carry duplicate Palmes diffusion tubes during one week. Simultaneously nitrogen-dioxide concentrations were measured in the kitchen, living room, bedroom, outdoors and—for a few participants—at school and at work. Information on time activity patterns was gathered by means of a self administered diary. Several models for estimating exposure were constructed and tested against measured exposure. The personal exposure of the participants could well be explained by models containing indoor concentrations. Models with time-weighted average concentrations did not explain personal exposure better than models containing indoor concentrations. A calculated time-weighted average exposure was found to underestimate measured personal exposure by an average 20%, probably because the average concentration in a location does not necessarily reflect the actual exposure in that location. Personal exposure of mothers and children was very similar and highly correlated, indicating that the personal exposure of the mother might be a reasonable estimate for the exposure of the child.

Key words: Personal NO_2 monitoring – Indoor pollution – Nitrogen dioxide

Introduction

One of the main difficulties in health effect studies of air pollution is characterization of human exposure. Historically, exposure was estimated by meas-

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uring air pollutants at a fixed outdoor monitoring site. Since 1970 a number of studies have been performed to evaluate the relationship between the ambient concentration of a number of air pollutants and personal exposure, showing a poor correlation between them (Ott 1980). Factors accounting for this poor correlation are, among others, the relatively short time people spend outdoors, difficulties in defining concentrations in ambient air by a single fixed station and the presence of sources of air pollution inside houses and at the workplace. Recent studies showed that nitrogen dioxide personal exposure was better correlated with indoor concentrations than with ambient concentrations (Dockery et al. 1980; Quackenboss and Kanarek 1982; Nitta and Maeda 1982). Levels of nitrogen dioxide were found to be much higher inside houses than outdoors due to the presence of unvented gas appliances (Melia et al. 1978; Goldstein et al. 1979; Lebret et al. 1983). Typical for the Dutch situation is the use of a geyser, an instantaneous natural gas-fired water heater with high NO_2 production.

In some health effects studies of indoor nitrogen dioxide pollution, home characteristics such as presence or absence of gas appliances, instead of indoor NO_2 measurements, were used to classify personal exposure. For the Dutch situation this approach is questionable, since more than 95% of the Dutch houses have gas appliances.

A pilot study in a group of 13 families was conducted with the purpose of investigating:

(1) the relation between indoor NO_2 concentration and personal exposure;
(2) the feasibility of personal exposure measurements of young children;
(3) the feasibility of using the personal exposure of the mother as a measure for NO_2 exposure of her children.

Materials and methods

Participants were selected from a larger population of an epidemiological case-control study on the relationship between indoor nitrogen-dioxide exposure and respiratory diseases of school children. Results of this study are being published in an accompanying paper (Hoek et al. 1984). Within a family, the mother, a schoolchild and a pre-schoolchild (whose presence served as selection criterium) took part in the study. Participants carried duplicate Palmes diffusion tubes during one week. Simultaneously indoor NO_2-levels were measured in the kitchen, living room and bedroom in houses and for a few participants the NO_2 levels at school and at work were established. Information on ambient levels was collected from a central monitoring station. Time spent at various locations (kitchen, living room, bedroom, school/work, outdoors, other) was recorded by the mother in a diary. The diary covered one week and had a time resolution of 15 min. The study was performed in December 1982 in the city of Rotterdam. By means of multiple regression techniques, various models for calculating personal exposure were constructed and tested against the measured personal exposure. Also a comparison was made between measured personal exposure of the mother and that of the children.

Results

Cooperation was obtained from 14 families. In ten houses a geyser was present, three of which were directly vented to the outside. Twelve families used gas for

Table 1. Mean and range of nitrogen-dioxide concentrations ($\mu g/m^3$) in different locations. Rotterdam, 1982

Location	Personal monitoring study ($n = 14$)	
	Mean	Range
Kitchen	139	28–367
Living room	85	26–248
Bedroom	60	24–164
Ambient	46	

Table 2. Weekly average personal exposure to nitrogen dioxide of mothers, schoolchildren and pre-schoolchildren. Rotterdam, 1982

Group	n	Average personal exposure ($\mu g/m^3$)	Range
Mother	13	88	32–160
Schoolchild	12	75	26–133
Pre-schoolchild	9	70	32–135

Table 3. Time (hours/week) spent at various locations by mothers, schoolchildren and pre-schoolchildren. Rotterdam, 1982

Location	Mother ($n = 12$)	Schoolchildren ($n = 11$)	Pre-schoolchildren ($n = 10$)
Kitchen	12.2	3.0	1.1
Living room	60.9	41.2	51.3
Bedroom	63.2	84.7	87.1
Work/school	1.7	14.5	7.6
Outdoors	11.8	10.4	7.6
Other locations	18.2	14.2	13.3

cooking and eleven houses had a gas heating system. Complete information was obtained from 11 mothers, 11 schoolchildren (mean age: 7.8 years) and 8 pre-schoolchildren (mean age: 3.4 years). Missing data are due to refusal of pre-schoolchildren to participate (5), participants stopping personal monitoring (2), inaccurate exposure data (4), inaccurate diary data.

The indoor NO_2 concentration in the 14 houses are given in Table 1. In this survey it was found that NO_2-levels indoors were higher than outdoors, with mean levels in the kitchen exceeding living room and bedroom levels. The indoor levels were comparable to those found in the larger group of homes of the case-control study (Hoek et al. 1984).

Personal exposure levels of the three groups did not differ much, although the mother had a slightly higher exposure than the schoolchild as well as the pre-schoolchild (Table 2).

Table 3 shows the time spent at the various locations by the three groups. As to be expected, the mother spent more time in the kitchen and living room and less time in the bedroom than the children.

Table 4. Percentage of variance in measured personal exposure, explained by separate indoor concentrations. Rotterdam, 1982

Personal exposure	Kitchen	Living room	Bedroom
Mothers	50	65	45
($n=11$)	(<0.025)*	(<0.005)	(<0.025)
Schoolchildren	35	63	62
($n=11$)	(>0.05)	(<0.005)	(<0.005)
Pre-schoolchildren	14	88	68
($n=8$)	(>0.05)	(<0.001)	(<0.025)

* In parentheses; significance level

Table 5. Relationship between personal exposure and different models of indoor concentrations. Rotterdam, 1982

Model	Group	Concentrations in model (only significant contributions)	R^2 (%)	n	p
1[a]	Mother	Kitchen, living room	89	11	<0.001
	Schoolchild	Living room	63	11	<0.005
	Pre-schoolchild	Living room	88	8	<0.001
2[b]	Mother	Kitchen, living room	81	11	<0.005
	Schoolchild	Bedroom, living room, ambient	92	11	<0.001
	Pre-schoolchild	Living room, bedroom	93	8	<0.005

[a] Model 1 = models developed by stepwise inclusion of measured nitrogen dioxide concentrations

[b] Model 2 = models developed by stepwise inclusion of time-weighted measured nitrogen dioxide concentrations ($t_i \times c_i$)

The percentage of variance in measured personal exposure, explained by separate indoor concentrations, is shown in Table 4.

For all groups personal exposure was highly associated with the NO_2 concentration in the living room and bedroom, and, to a lesser extent, also with the kitchen NO_2 concentration.

In a next step a multiple regression of personal exposure on a set of indoor concentrations (kitchen, living room, bedroom) was performed. Regression models were developed using a stepwise inclusion method ($p = 0.05$). Also models with a set of time-weighted indoor concentrations were tested. Time-weighted indoor concentrations were calculated by multiplying the time fraction spent in a location with the measured concentration in this location. Again, a stepwise inclusion method was applied. Results of the multiple regression calculations are shown in Table 5. For all groups a large part of the variance in personal exposure was explained by these models. The living-room concentration was present in all models. The models with time-weighted indoor concentrations dit not explain personal exposure better than models with indoor concentrations.

Table 6. Relationship between estimated and measured personal exposure of the different groups. Rotterdam, 1982

Group	Model	n	%D[b]	R^2(%)	p
Mother	13.98 + 0.99 TWA[a]	11	+17	85	<0.001
Schoolchild	–9.60 + 1.50 TWA	11	+23	84	<0.025
Pre-schoolchild	18.55 + 0.83 TWA	8	+19	92	<0.001
Whole group	13.24 + 1.01 TWA	30	+20	82	<0.001

[a] Model of time weighted average of concentrations in the different locations ($\mu g/m^3$)
[b] Percentage difference between measured and estimated average personal exposure

Table 7. Relationship between measured personal exposure of mothers, schoolchildren and pre-schoolchildren. Rotterdam, 1982

Dependent variable	Explaining variable	n	R^2	p
PE[a] schoolchild	3.18 + 0.81 PE mother	12	0.91	<0.001
PE pre-schoolchild	7.22 + 0.76 PR mother	8	0.93	<0.001
PE pre-schoolchild	9.87 + 0.90 PE choolchild	8	0.95	<0.001

[a] PE = personal exposure

A time-weighted average NO_2-exposure was calculated by combining time spent at the various locations with the concentrations measured at these locations. The results of a regression of measured personal exposure on this time-weighted average calculated exposure for the three groups and the whole population are shown in Table 6. The calculated personal exposure explained the measured exposure very well, but the calculated exposure was on average 20% lower than the measured exposure.

Finally a comparison was made between the personal exposure of the mother, the schoolchild and the pre-schoolchild (Table 7). The table shows that the personal exposure of mothers and children is highly associated. The regression coefficients (lower than 1) indicate that on average the personal exposure of the mother is higher than that of the children, and that the personal exposure of the schoolchild is higher than that of the pre-schoolchild.

Discussion

This study showed that personal NO_2 exposure in winter could be well explained by indoor concentrations. This is in line with findings of Quackenboss and Kanarek (1982), Dockery et al. (1980) and Nitta and Maeda (1982). The models with time-weighted average indoor concentrations did not explain personal exposure better than the models with indoor concentrations. This may be due to the fact that explanation of variance was already very high. A calculated time-weighted average NO_2 exposure was found to underestimate the measured personal exposure by 20% on average. An explanation for this phenomenon