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Nasal Mucosal Swelling in Relation to Low Air Exchange Rate in Schools

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Abstract Acoustic rhinometry and hygienic measurements of indoor air pollutants were applied in a field study on nasal congestion among 27 subjects working in two primary schools. One school had natural ventilation only and a low air exchange rate (0.6 ac/h); the other had balanced mechanical ventilation and a high air exchange rate (5.2 ac/h). The minimal cross-sectional area and volume of the nasal cavity were estimated with acoustic rhinometry. The degree of swelling of the nasal mucosa was measured as the increase of the cross-sectional area after standardized application of nasal spray containing a decongestive adrenergic substance. Reports on weekly symptoms of nasal congestion were similar (33%) in both schools. A significantly increased decongestive effect was noticed for the minimal cross-sectional area (MCA2) among personnel in the school with a low air exchange rate. The difference between the schools in decongestive effect on MCA2 was 23%, corresponding to a 3% increase of MCA2 for a difference in personal outdoor airflow of one litre. Indoor concentration of volatile organic compounds (VOC), respirable dust, bacteria, moulds and VOCs of possible microbial origin (MVOC) were 2–8 times higher in the naturally ventilated school. In conclusion, inadequate outdoor air supply in schools may lead to raised levels of indoor air pollutants, causing a subclinical swelling of the nasal mucosa. Our results indicate that acoustic rhinometry could be applied in field studies, and that objective measurement of nasal decongestion might be a more sensitive measure of biological effects of indoor air pollution than symptom reporting.

Key words Acoustic rhinometry; Carbon dioxide; Indoor air quality; Nasal obstruction; School environment; Ventilation; Volatile organic compounds (VOC).

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Introduction

During recent years, there has been growing concern about possible health effects due to indoor air pollution in schools. The outdoor air exchange rates in many Scandinavian schools are below the current ventilation standards, and classroom temperatures often exceed the recommended maximum value of 22°C (Norbäck et al. 1990b; Ruotsalainen et al., 1995; Smedje et al., 1997; Thorstensen et al., 1990). In addition, poor cleaning has resulted in widespread contamination of schools by dust-borne contaminants, e.g. microorganisms (Gravesen et al., 1986) and allergens from furry animals (Munir et al., 1993).

The term sick building syndrome (SBS) has been used to describe nonspecific symptoms of eyes, facial skin, and upper airways, as well as headache and fatigue (Mendell, 1994; Apter et al., 1994; Hodgson, 1995). Nasal congestion is a common airway symptom, included in SBS. In one questionnaire study in a population sample of adults (20–65 years) in mid-Sweden, the three months' prevalence of nasal congestion was 19% (Norbäck and Edling, 1991). In eleven buildings with indoor air problems ("sick buildings"), the mean three months' prevalence of nasal congestion was 33% (Norbäck et al., 1990a). Some studies have demonstrated relationships between nasal congestion and the indoor concentration of volatile organic compounds (TVOC) (Norbäck et al., 1990a), and air concentration of viable moulds (Harrison et al., 1992). Nasal symptoms have also been reported to be more prevalent in newer office buildings with mechanical ventilation, as compared to older buildings with natural ventilation (Finnegan et al., 1984).

There is little epidemiological information available on relationships between indoor air pollution and clinical signs from the upper airways. In one Danish exposure chamber study, acoustic rhinometry was applied to measure nasal cavity dimensions. They found an effect of room temperature, with an increase of the nasal cavity at higher air temperatures. Moreover, they found a significant decrease of minimal cross-sectional area by 8% at exposure to a 10 mg/m^3 mixture of 22 different VOCs at high room temperature (26°C) (Möl-

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have et al., 1993). A relation between nasal inflammation and experimental exposure to 25 mg/m^3 of the same mixture of 22 VOCs has also been demonstrated (Koren et al., 1992).

Several mechanisms are involved in the swelling of the nasal mucosa: vasodilation, increased vascular permeability, cell migration, cytokines, and glandular secretion. By the deposition of a nasal decongestive adrenergic substance to the nasal mucosa, this swelling can be partly reversed. The principal aim of the study was to test the hypothesis that exposure to increased levels of indoor air pollutants in schools may result in swelling of the nasal mucosa. The assumption was made that the degree of mucosal swelling could be estimated indirectly via the decongestive effect of xylometazolin, measured with acoustic rhinometry.

The use of balanced mechanical ventilation to dilute indoor air pollutants by outside air is a common and recommended method to create an acceptable indoor air environment (Sundell, 1994). A review of epidemiological and experimental studies among office workers suggests that the prevalence of SBS is reduced if the personal outdoor airflow rate is above 10 L/s (Mendell, 1994). In Scandinavian schools, displacement ventilation systems are now introduced, to be able to cope with the demands of current ventilation standards. To our knowledge, however, there is little information in the literature on the relation between air exchange rate and the indoor concentration of specific air pollutants. The second aim of the study was therefore to characterize indoor concentrations of various microbial and chemical indoor air pollutants in the two schools with low and high air exchange rate.

Material and Methods

Selection of Schools

This study is a part of a Swedish school environment project (SSEP) (Smedje et al., 1997). It involves a series of studies on different health effects and discomfort reactions among school teachers and pupils in the county of Uppsala in mid-Sweden. This county has about 130 primary and secondary schools for children aged 7–16 years; about half of the schools are situated in the city of Uppsala, the largest city. In 1992, 40 schools were randomly selected and invited to participate in the SSEP-project, and 39 schools participated. During March-May 1993, exposure measurements were performed in the schools. On the basis of the results of the ventilation measurements, two out of 14 primary schools (child age 7–13 years) in the city of Uppsala were selected for this study. One was the primary school in Uppsala in the sample with the lowest average air exchange rate; the other was the primary school with the highest average air exchange rate. The rhinometric study was performed in February 1994. Repeated exposure and ventilation measurements were performed in the schools in January-March 1995. No changes of the indoor environment, such as ventilation changes or redecoration, occurred in the two schools during the period 1993–95. Detailed information on exposure measurements during 1993–95 in all schools has been given elsewhere (Smedje et al., 1997).

Subjects

All school personnel working more than 20 hours per week in the two schools were included in the study (28 persons). Subjects on sick leave, or off duty for other reasons at the time of the investigation, were not included. Persons having a current infection or fever the last seven days were requested to come to a follow-up investigation two to four weeks later. Since some effects of the mucous membranes may be transient, all examinations were performed at the working place. All subjects had been at their workplace at least one hour prior to examination. Tests were performed in February 1994, off-pollen season.

Assessment of Personal Factors and Symptoms of Nasal Obstruction

All participants were questioned by a physician about previous diseases, allergy and atopy, smoking habits, social status, medication and occupational data. Atopy was defined as having a current history of allergic manifestations related to exposure to common IgE mediated allergens in Sweden (tree pollen, grass pollen, or furry animals), reported in the medical interview. Information on nasal congestion symptoms the week prior to the medical investigation was gathered by means of a self-administered questionnaire answered at the medical investigation.

Acoustic Rhinometry

Acoustic rhinometry (Rhin 2000; wideband noise; continuously transmitted) was performed for each individual, in a standard position (sitting), on three occasions in each nostril. The first measurement was after 5 minutes' rest (sitting); the second after nasal lavage by isotonic saline solution, as a part of a larger study on inflammatory markers (Wålinder et al., 1995). Nasal lavage was made with room tempered (20–22°C) saline solution, of which 5 ml was flushed into each nasal cavity with a plastic syringe. The third measurement was performed 10 minutes after decongestion (two douches of 140 µg xylometazolin-hydrochloride each,

5 minutes apart). Using acoustic reflection, the minimal cross-sectional areas between 10 and 32 mm (MCA1) and between 32 and 64 mm (MCA2), measured from the nasal opening, were taken as measurements of nasal patency. Also the volumes of the nose were measured between 10 and 32 mm (VOL1) and 32 and 64 mm (VOL2). Each measurement included three readings for each side of the nasal cavity, and the degree of nasal patency was assessed by adding the values from the right and the left side.

Exposure Measurements

In each of the two schools, indoor measurements were performed in two classrooms in March 1993 and two classrooms in January 1995. The measurements included room temperature, relative air humidity, concentration in the air of respirable dust, carbon dioxide (CO_2), formaldehyde, volatile organic compounds (VOC), including specific VOCs of possible microbial origin (MVOC), and airborne moulds and bacteria. In 1993 nitrogen dioxide (NO_2) and carbon monoxide (CO) were also measured, as well as cat, dog and mite allergens in settled dust collected by standardized vacuum cleaning of the floor, chairs and desks.

Room temperature and air humidity were recorded with an Assman psychrometer. Concentrations of respirable dust were measured by a direct reading instrument based on light scattering (Sibata P-5H2, Sibata Scientific Technology Ltd, Japan), as previously described (Norbäck et al., 1990b). Indoor CO_2 concentration was measured by a direct reading infrared spectrometer (Rieken RI-411A, Rieken Keini, Japan), calibrated by standard gases containing known concentrations of CO_2. The average CO_2-concentration in each classroom was calculated by taking the average of two 15-min registrations during the last part of a lecture. General and local air exchange rates were measured by a tracer gas decay method using acetone as the tracer gas (Anundi et al., 1992). The local air exchange rate was determined at the desk of the class teacher. Based on the air exchange rate, the room volume, and the number of subjects in the classroom, the outdoor air supply per person was calculated.

Indoor concentrations of formaldehyde were measured with glass fibre filters impregnated with 2,4-dinitro-phenylhydrazine (Andersson et al., 1981), the air sampling rate being 0.2 L/min during four hours. The filters were analyzed by liquid chromatography. Volatile organic compounds, other than formaldehyde, were measured by parallel sampling on two charcoal sorbent tubes (Anasorb 747; SKC 226–81) with the same sampling time and rate as for formaldehyde. One charcoal tube was desorbed with 1 ml of carbon disulfide, and analyzed on a gas chromatograph equipped with a packed non-polar column, and flame ionization detector (FID). The total concentration of volatile organic compounds (TVOC) between the peaks of benzene (C6) and n-dodecane (C12) was calculated, assuming the same response rate as for n-decane (decane-equivalents). In addition, the total concentration of VOCs with a retention time below benzene (low boiling VOCs) was determined, expressed as decane equivalents.

The other charcoal tube was desorbed with one ml of methylene chloride, and analyzed for VOCs of possible microbial origin (MVOC). Analyses were made with a Hewlett Packard 5890 gas chromatograph equipped with a mass selective detector (HP 5970). A 50-metre cross-linked methyl silicone capillary column (HP-1, Hewlett Packard) with an inner diameter of 0.32 mm and a film thickness of 1 μm was used. The oven temperature was programmed for an initial hold for 5 min at 35°C after which the temperature increased to 200°C at a rate of 15°C min^{-1}. Carrier gas (helium) flow rate was 1 ml min^{-1}.

Compounds of possible microbial origin were determined by selective ion monitoring (SIM). For each substance, mass spectrum and retention time were determined. The SIM ion values within 0.1 atomic mass unit were determined to get the highest response. One target ion, and two qualifier ions, were selected for each compound. The molecular ion was normally selected as one of the qualifier ions. During the SIM-analysis, each mass was measured for approximately 100 milliseconds, which increases the sensitivity by the order of 100 times as compared to conventional mass spectrometry when the whole mass range is scanned. Eight common compounds of possible microbial origin were identified and quantified by external standard technique (Ström et al., 1993). The following eight compounds were measured in both 1993 and 1995; 3-methyl-furan, 3-methyl-1-butanol, 2-pentanone, 2-hexanone, 2-heptanone, 3-octanone, 3-octanol, and 1-octen-3-ol. These compounds were selected because they are described in the literature as being emitted from moulds or bacteria commonly occurring in indoor environment.

Airborne microorganisms were sampled on 25 mm nucleopore filters with a pore size of 0.4 μm and a sampling rate of 1.5 L/min for 4 hours. The total concentration of airborne moulds and bacteria, respectively, was determined by the CAMNEA method (Palmgren et al., 1986). Viable moulds and bacteria were determined by incubation on two different media. The detection limit for viable organisms was 30 colony forming units (cfu) per m^3 of air. Indoor nitrogen dioxide

was sampled during one week with a diffusion sampler (Toyo Roshi Kaisha Ltd, Japan), and analyzed by a spectrophotometric method. An overall mass transfer coefficient of 0.10 cm/s was used in the calculations as suggested by Lee et al. (1993). Indoor carbon dioxide was measured during one week by a direct reading detector tube from Draeger Ltd (50a-D).

Settled dust was collected by standardized vacuum cleaning of desks, chairs and the floor by a 400 W vacuum cleaner (ELRAM HSS 09, ELRAM, Sweden) provided with a special dust collector (ALK laboratories, Copenhagen), containing a Millipore filter with a pore size of 6 μm. After passing through a sieve with a porosity of 300 μm, the amount of fine dust was determined by weighing. Cat allergen (Fel d I) and dog allergen (Can f I) were quantified with an enzyme-linked immunosorbent assay using monoclonal antibodies (Munir et al., 1993). Major mite allergen content (Der p1 and Der f 1) in the dust were determined by monoclonal immunoassays (Chapman et al., 1987).

Statistical Methods

Differences in prevalences were determined by Chi-square analysis for 2*2 tables. Absolute values of rhinometric measurements were compared prior to and after decongestion. Student's t-test was used when comparing averages of continuous variables. Multiple regression analysis was performed with SPIDA statistical package (Gebski et al, 1992). In all statistical analyses, a 5 per cent level of significance was used. The standard error (SE) of variation between three readings was calculated from the formula:

$$SE=(((\Sigma a^2-(\Sigma a)^2/n)+ (\Sigma b^2-(\Sigma b)^2/n) +(\Sigma c^2-(\Sigma c)^2/n)) /6(n-1))^{0.5}$$

where a=difference in reading between reading 1 and reading 2
b=difference in reading between reading 2 and reading 3
c=difference in reading between reading 1 and reading 3
n=number of triplicate readings.

Results

Personal Characteristics

The participation rate was high (96%). In the first school with a low air exchange rate, 15 of 15 persons participated, of which 7% were smokers, 27% had atopy, and 100% were females (median age 48 years). In the second school with a high air exchange rate, 12 out of 13 persons participated, of which 25% were smokers, 25% had atopy, and 83% were females (median age 45 years). There was no significant difference between the two schools as to age, atopy or smoking habits.

Building Characteristics

The first school, with a low air exchange rate, consisted of two buildings with natural ventilation only, built in 1920. The largest was a four-storey stone building with basement, and the other building was a two-storey wooden building without basement. The room height was 3.50 metres in the large building and 2.50 metres in the smaller two-storey building. The second school with a high air exchange rate was a one-store, wooden building built in 1984, with an additional part constructed in 1989. It was constructed on a concrete slab, without basement, with a room height of 2.70 metres. The ventilation system was a supply/exhaust ventilation system with a complementary addition of a new type of displacement ventilation system in the part from 1989, which compromised about half of the building. Both schools had leaning roofs, none had visible signs of building dampness, and both were situated away from larger roads.

Exposure Measurements

The average room temperature was similar (21.5°C and 21.6°C) in the two schools. The general air exchange rate was 8.7 times higher in the school with good ventilation (5.2 versus 0.6 ac per hour). Even larger differences were detected for the local air exchange rate at the teachers' desks (0.3 versus 9.2 ac per hour). Increased concentrations of airborne pollutants such as microorganisms, respirable dust, carbon dioxide, volatile organic compounds (VOCs), including VOCs of microbial origin (MVOC) were measured in the naturally ventilated school, but the concentration of formaldehyde was low and similar in both schools (Tables 1–3). The largest difference of airborne pollutants was observed for total moulds. Among viable moulds, *Cladosporium sp., and Penicillum sp.*, were identified in air samples from both schools. *Streptomyces sp.* were found only in the school with a low air exchange rate, and *Pseudomonas sp.* occurred only in the school with a high air exchange rate. The concentration of airborne pollutants in both schools was generally lower in 1995 than in 1993.

In the school with good ventilation, two measurements, one in 1993 and one in 1995, were made in the newest part of the school building, which had the new type of displacement ventilation system. In this part the general air exchange rate was somewhat higher, compared to the older part of the school with an old

Table 1 Indoor climate, ventilation and number of subjects present in two primary schools where rhinometry was performed, as compared to the total material of 39 schools in the county of Uppsala. N=number of measurements in 1993–95, M=arithmetic mean

	School 1 low air exchange rate (N=4) M (min-max)	School 2 high air exchange rate (N=4) M (min-max)	Mean of 39 schools in 1993–95 (N=199) M (min-max)
Room temperature (°C)	21.5 (21–22)	21.6 (20–23)	22.7 (19–28)
Relative air humitity (%)	42 (37–45)	25 (12–39)	37 (16–75)
Number of subjects present[a]	19 (10–29)	23 (13–28)	21 (6–39)
General air exchange rate (ac/h)	0.6 (0.1–1.4)	5.2 (3.5–7.8)	2.8 (<0.1–9.8)
Local air exchange rate (ac/h)[b]	0.3 (<0.1–0.6)	9.2 (2.8–23)	3.3 (<0.1–26)
Outdoor airflow (L/s and person)	2.5 (0.2–4.4)	8.9 (5.8–12.1)	6.8 (0.1–26)

[a] Number of pupils and adults present during the measurement
[b] Measured at the desk of the school teacher

Table 2 Indoor concentration of pollutants in two primary schools where rhinometry was performed, and in the total material of 39 schools in the county of Uppsala. N=number of measurements in 1993–95, M=arithmetic mean

	School 1 low air exchange rate (N=4) M (min-max)	School 2 high air exchange rate (N=4) M (min-max)	Average exposure in 39 schools 1993–95 (N=199) M (min-max)
Airborne pollutants:			
Carbon dioxide (ppm)	1160 (1090–1300)	720 (590–880)	1010 (400–2800)
Respirable dust (μg/m^3)	23 (10–40)	12 (9–14)	16 (6–60)
Nitrogen dioxide (μg/m^3)	4 (4–4)	5 (4–6)	5 (1–11)*
Carbon monoxide (μg/m^3)	0.2 (0.2–0.2)	0.2 (0.2–0.2)	0.2 (0.1–1.1)*
Formaldehyde (μg/m^3)	4 (<5–6)	6 (<5–13)	8 (<5–72)
TVOC C6–C12 (μg/m^3)[a]	58 (18–149)	27 (8–50)	38 (3–392)
Low boiling VOC(μg/m^3)[b]	52 (15–110)	18 (7–43)	50 (<1–601)
Total VOC(μg/m^3)[c]	110 (33–259)	45 (15–80)	88 (10–649)
Viable bacteria (cfu/m^3)	1500 (110–3600)	870 (80–1400)	730 (70–18000)
Total bacteria (10^3/m^3)	76 (6–160)	50 (9–94)	43 (5–730)
Viable moulds (cfu/m^3)[d]	580 (60–1500)	250 (100–600)	310 (50–4500)
Total moulds (10^3/m^3)	105 (6–360)	14 (11–18)	26 (5–360)
Settled dust pollutants:			
Amount of fine dust (mg)	110	105	170 (30–370)*
Cat (Fel d I) (ng/g)	170	190	130 (<16–390)*
Dog (Can f I) (ng/g)	440	470	640 (<60–3990)*
House dust mites (ng/g)	<1	<1	<1 (<1–31)*

Figures marked with an asterix were only measured in 1993.
[a] Sum of VOCs in the range from benzene to n-dodecane (C6–C12)
[b] Sum of VOCs with a retention time below benzene (<C6)
[c] Sum of all VOC below n-dodecane (<C12)
[d] Colony forming units per m^3

mixing type of supply/exhaust system (6.4 versus 4.1 ac/h). The average carbon dioxide concentration was also somewhat lower in the building with displacement ventilation (630 ppm versus 800 ppm). For other air pollutants such as total moulds, total bacteria, respirable dust, formaldehyde or VOCs, the average concentrations were numerically similar in the two parts of the new school. For viable moulds and bacteria, however, the concentration was 2–3 times higher in the part with displacement ventilation, as compared to the part with a mixing system.

In contrast to the difference in airborne pollutants, the amount of settled dust, and the concentrations of cat and dog allergens in the dust were similar in both schools. No house dust mite allergens were detected in either of the two schools. The indoor concentrations of traffic-related pollutants, such as carbon monoxide and nitrogen dioxide, were low and similar in both schools (Table 2).

Acoustic Rhinometry

Reports on weekly symptoms of nasal congestion were common, and similar (33%) in both schools. For rhinometry, the standard error of variation for the tri-

Table 3 Indoor concentration of selected volatile organic compounds (μg/m³) of possible microbial origin (MVOC) in two primary schools where rhinometry was performed, and in the total material of 39 schools in the county of Uppsala

	School 1 low air exchange rate (N=4) M (min-max)	School 2 high air exchange rate (N=4) M (min-max)	Average exposure in 39 schools 1993–95 (N=199) M (min-max)
3-methyl-furane	0.04 (<0.01–0.08)	0.003 (<0.01–0.01)	<0.01 (<0.01–0.24)
3-methyl-1-butanol	0.20 (<0.01–0.51)	0.13 (<0.01–0.28)	0.09 (<0.01–10.0)
2-pentanone	0.05 (0.01–0.09)	0.02 (<0.01–0.04)	0.03 (<0.01–0.45)
2-hexanone	0.05 (0.04–0.09)	0.03 (0.02–0.03)	0.03 (<0.01–0.23)
2-heptanone	0.22 (0.08–0.39)	0.15 (0.04–0.29)	0.08 (<0.01–0.91)
3-octanone	0.03 (<0.01–0.05)	0.04 (0.02–0.06)	0.02 (<0.01–0.41)
3-octanol	<0.01 (<0.01–0.01)	<0.01 (<0.01–0.01)	<0.01 (<0.01–0.04)
1-octen-3-ol	0.27 (0.02–0.96)	0.06 (0.01–0.13)	0.04 (<0.01–1.54)

plica readings was 7.2% for MCA1, 7.3% for MCA2, 5.6% for VOL1 and 8.0% for VOL2. Numerically, absolute values of minimal cross-sectional areas and volumes were lower in the school with poor ventilation prior to decongestion, but the differences were not statistically significant (0.10>P>0.05). After decongestion, the numerical differences between the two schools were reduced and close to zero (Table 4). Age was the only personal factor significantly related to minimal cross-sectional areas and volumes, with a significantly decreased decongestive effect of xylometazolin-hydrochloride on MCA2 and VOL2 in older subjects (P<0.05). The increase of MCA2 after nasal spraying with xylometazolin-hydrochloride was more pronounced in the school with poor ventilation, and was statistically significant after adjusting for age by multiple linear regression analysis (P<0.05). The buildings differed 8.7 times in general air exchange rate, and the difference in average personal outdoor airflow was 6.4 L/s. This information was used to estimate the hypothetical increase of the nasal volumes at a twofold increase of the air exchange rate, or an increase of personal outdoor airflow by one L/s, respectively. The increase of MCA2 in relation to a twofold increase of the general air exchange rate was 4%, and the increase of MCA2 related to a difference in outdoor air exchange rate of one litre per person was 3% (Table 5).

Table 4 Rhinometry data prior and after nasal decongestion in one school with a low (School 1) and one with a high ventilation rate (School 2) (M=arithmetic mean, SD=standard deviation)

	Prior to nasal decongestion		After nasal decongestion	
	School 1 M (SD) (N=15)	School 2 M (SD) (N=12)	School 1 M (SD) (N=15)	School 2 M (SD) (N=12)
MCA1(cm²)	1.15 (0.26)	1.32 (0.38)	1.32 (0.38)	1.34 (0.27)
MCA2(cm²)	1.94 (0.33)	2.23 (0.52)	2.65 (0.61)	2.59 (0.57)
VOL1(cm³)	3.59 (0.50)	4.06 (0.82)	4.08 (0.83)	4.31 (0.78)
VOL2 (cm³)	8.57 (1.23)	9.42 (1.77)	10.3 (1.95)	10.3 (1.92)

Acoustic rhinometric values (right+left side) of minimal cross-sectional areas (MCA1, MCA2) and volumes (VOL1, VOL2)

Table 5 Age-adjusted percental changes in rhinometry after nasal decongestion, in relation to general air exchange rate in the two schools

	Difference (%) between the two schools	Estimated reduction (%) of nasal congestion at an increase of personal outdoor airflow of one litre per second and person
MCA1	7.1 (−11–25)	1.2 (−1.7–3.7)
MCA2	23.0 (4–42)*	3.2 (0.5–5.9)*
VOL1	7.1 (−4–18)	1.2 (−0.3–2.7)
VOL2	11.5 (−2–25)	1.8 (−0.1–3.7)

* Significant influence by multiple linear regression analysis, controlling for age (P<0.05). Percental change of rhinometric values, with 95% confidence limits. Calculations of these changes were based on decongestion divided by the value before decongestion

Discussion

Our study indicates that acoustic rhinometry could be a useful method to measure human nasal reactions to the indoor environment. The study confirmed the hypothesis that exposure to raised levels of indoor air pollutants in schools may affect the airways, and cause a swelling of the nasal mucosa.

Many methodological problems are inherent in an epidemiological study with regard to internal validity. In this particular study, selection bias due to low response rate is less likely since the participation rate was high (96%). Response bias due to awareness of exposure may cause a general over-reporting of symptoms in exposed groups, but is less likely to affect data obtained by a clinical computerized method such as acoustic rhinometry. Potential confounders such as age, gender, atopy and smoking habits were controlled for, and only age had a significant influence on the de-

gree of decongestion. A time difference between clinical investigations and exposure measurements may also induce a possible bias. In the present study, however, exposure measurements were performed on two occasions, at the same time of the year as the clinical investigations. This would most likely give a better average estimate of the exposure, since no major repairs of the buildings or adjustments of ventilation were made. Thus, we do not believe that our conclusions are seriously biased by response or recall bias, but the cross-sectional design of the study could have underestimated the true effect of the exposure if there were a health-based selection.

We could demonstrate an increased degree of decongestion in the posterior part of the nose among subjects working in a school with low air exchange and increased levels of various indoor pollutants. The stronger effect in the posterior parts could be explained by the larger effect of adrenergic nasal spraying in this part of the nose, because of the greater bulk of soft tissues there. In the school with a high air exchange rate, the outdoor airflow rate was above the current Swedish ventilation standard of about 8 L/s (National Swedish Board of Occupational Safety and Health, 1993) in three out of four measurements. In the school with natural ventilation and a low air exchange rate, the outdoor airflow rates were below the ventilation standards in all four measurements. The school with low ventilation had a higher relative air humidity, but the average room temperature was similar in both schools (21.6°C and 21.5°C, respectively). Exposure measurements showed that the indoor concentration of various types of airborne indoor air pollutants was higher in the school with a low air exchange rate. Most marked differences were found for the total concentration of moulds. Less pronounced differences in indoor concentration of volatile organic compounds, bacteria, moulds, and air humidity were observed.

Formaldehyde is a strong irritant, known to affect the nasal mucosa (Sundell, 1994), but the indoor formaldehyde concentration was low and similar in both schools. Thus it is unlikely that the observed difference in nasal congestion between the schools could be explained by indoor exposure to formaldehyde. Volatile organic compounds have been shown to be related to nasal congestion symptoms (Norbäck et al., 1990a), and a decrease of the minimal cross-sectional area measured by acoustic rhinometry (Mölhave et al., 1993). In the latter study, a four-hour exposure to a 10 mg/m^3 mixture of 22 VOCs at 26°C resulted in an 8% decrease of the minimal cross-sectional area. They could also prove a strong interaction between room temperature and the effect of VOC. In our study, the average room temperature was well below 26°C, and the maximum measured temperature was 23°C. Moreover, the indoor concentration of total VOC (TVOC) in our study was much lower than the effect level of 10 000 μg/m^3 in the rhinometry study by Mölhave et al. (1993). We measured a maximum TVOC of 260 μg/m^3 in the school with poor ventilation and a maximum value of 80 μg/m^3 in the school with good ventilation. The exposure time is, however, much longer in the schools than in exposure chamber studies, and the types of VOC in our dwellings may differ from the VOC-mixture used in the experimental study. Thus it is possible that the VOC levels measured in our study may contribute to nasal congestion in some sensitive subjects. Another possible explanation of the effect observed in our study could be exposure to aerosols, including microorganisms. We detected differences in aerosol concentration between the two schools, and the difference was largest for the indoor concentration of total moulds. There is little information in the literature on nasal effects of indoor microorganisms. One study, however, could demonstrate a statistical relationship between indoor concentration of viable moulds and symptoms of nasal obstruction (Harrison et al, 1992).

In conclusion, our study indicates that raised levels of indoor air pollutants due to inadequate ventilation in schools may affect the upper airways and cause a swelling of the nasal mucosa. This illustrates that there is a need to improve the air exchange rate in schools, e.g. by the introduction of displacement ventilation systems. Finally, our study indicates that acoustic rhinometry could be applied in field studies, and that objective measurements of nasal decongestion at the workplace may be a more sensitive measure of biological effects of indoor air pollution than symptom reporting.

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