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ODOR INTERACTION BETWEEN FORMALDEHYDE AND THE INDOOR AIR OF A "SICK BUILDING"

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Abstract

A field study was performed at a detached preschool in order to study interaction effects between formaldehyde and other odors indoors. The indoor air from the exhaust vent of the preschool, formaldehyde, and pyridine were used as stimuli. Twenty-two subjects participated in the experiment. Fourty-two mixtures of formaldehyde and indoor air were produced such that 3 concentrations of formaldehyde were combined with 7 concentrations of indoor air and 3 concentrations of indoor air were combined with 7 formaldehyde concentrations. The odor strength was determined by magnitude estimation according to a master scale principle, using pyridine as master substance. The results show that the psychophysical functions for formaldehyde in mixture with indoor air are marginally different from formaldehyde alone at high concentrations, however, the deviation is substantial at low concentrations. This deviation reflects an interaction effect. There is almost a fourfold increase in the perceived odor strength for formaldehyde at 82 ppb when mixed with 100% indoor air from the "sick building" as compared to formaldehyde mixed with 10% indoor air. At higher concentrations of formaldehyde, its own odor dominates and hides any odor of the sick building air.

Introduction

The expression "sick buildings" refers generally to modern buildings in which occupants display reactions and symptoms similar to those caused by formaldehyde exposure although the concentrations of formaldehyde are below the reaction thresholds (1, 2, 15, 16). Sensory reactions are typical for the "sick building" syndrome (8) and they involve the cutaneous as well as the chemical senses. Since the major purpose of the sense of smell is to register and warn against certain airborne chemicals, it obviously plays a prominent role in air quality control. Odors per se are also frequently associated with symptoms in the "sick building" syndrome (17). Traditionally, odors have been used as the major criterion for regulating building ventilation (e.g., 10, 12, 19).

This paper reports a field study performed at a detached preschool and focuses on the sensory consequences produced by the presence of low concentrations of formaldehyde in the indoor air of a "sick building", i.e. the study of possible interaction effects between formaldehyde odor and other odors, present in the indoor air.

Method

The study object. A field experiment was performed in a mobile laboratory (5) connected on line to an energy-economized detached preschool, built according to the Swedish Building Code of 1975, and situated in a residential area on the outskirts of the city of Stockholm. The building had been closed for two years prior to the experiment by the local occupational health authority, due to reports of adverse sensory symptoms among the staff and the children.

Stimuli. The indoor air from the exhaust vent of the preschool (100% recirculation of return air), formaldehyde and pyridine were used as stimuli. Formaldehyde (p.a. Merck) was generated by diluting the headspace of paraformaldehyde with filtered air at a constant temperature. Pyridine (p.a. Merck) was kept in a glass tube and the headspace was diluted with filtered air.

Samples of indoor air taken from the main ventilation exhaust of the preschool building were continuously sucked through polyethene tubings by fans and fed into the olfactometer of the mobile laboratory (13). The preschool indoor air was used undiluted (100%) and with 10, 25, 40, 55, 70, and 85, parts per 100 part with filtered air, i.e. percent.

Charcoal filtered air alone or dilutions of the indoor air samples flowed (100 l/min) through the exposure hoods of the olfactometer, and varying amounts of an odorous substance were added to the air flow by injecting cannulae of varying bores into the air stream. The capillary diluting system allowed rapid changes of the concentrations and the exposure hoods allowed quite natural respiration. Pyridine was used as a a reference odor and was always presented in its own exposure hood.

The concentrations of formaldehyde used covered the range of limit values established or proposed for different purposes in a number of European countries (50-1000 ppb). The range used for pyridine was from the odor threshold to the maximum limit value established for occupational health purposes. The mean concentrations of formaldehyde were 50, 82, 138, 229, 384, 640, and 960 ppb; and of pyridine 24, 56, 176, 288, 640, and 1,536 ppb. A selection of mixtures of formaldehyde and indoor air were produced such that 3 concentrations of formaldehyde (50, 229, 960 ppb) were combined with each of the 7 concentrations of indoor air, and 3 concentrations of indoor air (10, 55, 100 %) were combined with each of the 7 formaldehyde concentrations.

The formaldehyde concentrations were determined by the method of sodium bisulfite (11, 18) and checked by a method including chemosorption and high pressure liquid chromatography (3). Pyridine was continously measured by a photo-ionization detector (AID Portable Organic Vapor Meter, Mod 580). The concentrations of the indoor air were controlled by a pressure drop over calibrated orifices and checked by tracer gas measurements of carbon dioxide. In addition, the naturally occuring concentration of formaldehyde in the preschool indoor air (from building materials; 100% recirculation of return air) was measured and found to be less than 30 ppb.

Subjects. Twenty-two subjects, 8 men and 14 women, participated in the experiment. The median age was 27.5 years. Almost all subjects were university students.

Scaling method and design. The odor strength of the stimuli were determined by the method of magnitude estimation (see e.g., 14) according to a master scale principle (see 6, 8). Each subject judged each of the 56 unique stimuli 6 times each. The stimuli were presented in a unique random order for each subject, with 18 blank stimuli (=filtered air), interspersed regularly over each session. Two subjects participated at a time both taking part in 6 20-min sessions.

Results and Discussion

Data treatment. The arithmetic means of the six magnitude estimates of perceived odor strength were formed for each subject and stimulus. The inter-subject agreement was satisfactory in terms of Pearson correlation coefficients (for pyridine .88, for formaldehyde .85, for indoor air .88, for mixtures of formaldehyde and indoor air .76, and for charcoal-cleaned air (blanks) .93). These correlations mainly reflect the variance in odor estimates for pyridine, formaldehyde and filtered air. For indoor air the variance also includes effects due to the natural variation in stimulus concentrations caused by changes in temperature, ventilation efficiency, etc.

Group scales of perceived odor strength were obtained as arithmetic means of the 22 individual scales for each stimulus. These scales were transformed according to the master scale principle with the aid of the power function for pyridine. The empirical function expressed in logarithmic coordinates was $y=.54+.32x$ and it was transformed into the master function reported by Berglund and Lindvall (9), $y=.045+.70x$. The perceived odor strength scale values of the other stimuli were transformed according to the same principle and consequently the resulting scales presented below are all expressed in terms of the master scale of pyridine. This makes the interpretation of the odor strength scale meaningful in comparison with other odor studies where the odor strength is expressed in pyridine units.

Psychophysical functions. The psychophysical functions for formaldehyde and indoor air from the "sick building" are presented along logarithmic coordinates in Fig. 1. The diagrams show the functions both before (open symbols) and after the master scale transformation (filled symbols). Power functions were fitted to the 5 strongest concentrations of formaldehyde ($a=.-1.11$; $b=.76$) and to the 4 most concentrated indoor air samples ($a=-.88$; $b=.77$). At lower concentrations both functions are less distinguishable from the general background of the dosing system of the olfactometer as reflected in the estimates of the "blanks" (=charcoal filtered air). The mean perceived odor strength of blanks was .35 in terms of master scale log units.

Perceptual interaction. When formaldehyde and indoor air from the "sick building" were mixed, the resultant psychophysical functions for formaldehyde are only slightly changed from the function obtained when formaldehyde is presented alone. However, the deviation is substantial at low concentrations. Fig. 2 shows the data for mixtures of formaldehyde with "sick building" air at 100%, 55% and 10%. The data are plotted as percent changes in perceived odor strength from the odor strength when formaldehyde is presented alone. An interaction effect is evident: this appering as a relative increase in the perceived odor strength of the stimulus at low concentrations of formaldehyde and conversely a relatively lower perceived odor strength at high concentrations.

The results are congruent with our present knowledge on odor interaction of mixtures (4, 7). Addition of odor occurs when low concentrations of formaldehyde are added to contaminated indoor air, and hypoaddition occurs when high concentrations are added.

In testing the odor (or the irritative effect) of the indoor air of a "sick building" candidate, it might be worthwhile to use an approach which is more sensitive to a possible sensory irritant than just the straight forward stimulus-response measurement. It is usual that the physical characteristics of the indoor air of a "sick" building is very close or indistinguishable from that of healthy buildings. By adding controlled small amounts of an odor or irritant to the indoor air when studing it two advantages may be achieved: (a) the sum of sensory effective stimuli can raise above the background "noise", which makes it possible to determine psychophysical relationships, (b) on the basis of what is known about perceptual interaction, specific features of the "sick" building may be revealed in terms of divergences from expected addition at low concentrations of the mixture and of hypoaddition at high concentrations.

The results presented in Fig. 2 (left hand groups of bars) indicate that such an approach can work provided the amount of the "treatment" chemical is added of comparable sensory strength to that of the study target. There is almost a fourfold increase in the relative change of perceived odor strength for formaldehyde at 82 ppb when it is mixed with 100% indoor air from the "sick building" as compared to when formaldehyde is mixed with 10% indoor air. At higher concentrations of the formaldehyde its own odor dominates and hides any odor of the "sick" building air.

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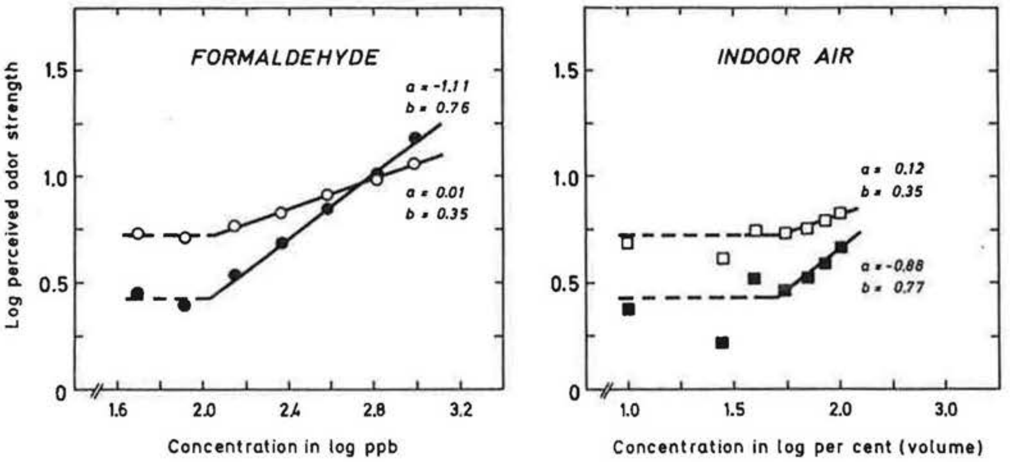

Fig. 1. Psychophysical functions for the odor of formaldehyde (left hand diagram) and the odor of indoor air (right hand diagram) presented in logarithmic coordinates. The odor strength (log) scales are given both before (open symbols) and after the master scale transformation (filled symbols). A straight line was fitted to the data and the intercepts and slopes of these lines are given in the diagrams (data around dotted line excluded).

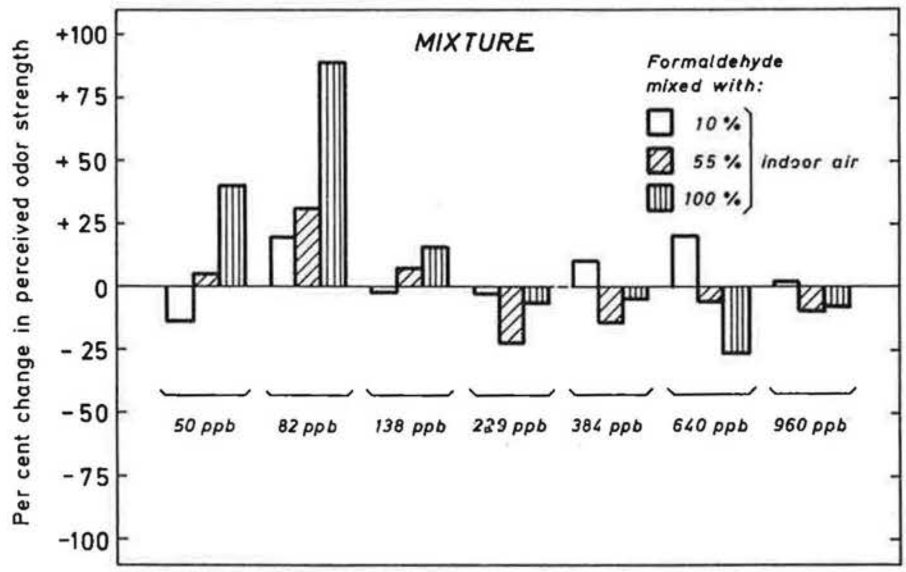

Fig. 2. The per cent change in perceived odor strength of mixtures of formaldehyde (50-960 ppb) and indoor air (10, 55 or 100%) relative to the odor strength obtained when formaldehyde was presented alone. (Zero change means that when indoor air is added to a particular concentration of formaldehyde, the perceived odor strength is equal to when it is presented alone.)