Särtryck 810217-6

Reprint from
Berglund, B., Berglund, U., Johansson, I., and Lindvall, T. Formaldehyde - Absolute odor threshold and perceived odor intensity. In B. Berglund, T. Lindvall, & J. Sundell (Eds.), INDOOR AIR. Vol. 3: Sensory and Hyperreactivity Reactions to Sick Buildings. Stockholm: Swedish Council for Building Research, D18:1984, pp. 89-96.

FORMALDEHYDE - ABSOLUTE ODOR THRESHOLD AND PERCEIVED ODOR INTENSITY

Birgitta Berglund
Department of Psychology, University of Stockholm, Sweden

Ulf Berglund
Department of Architecture, Royal Institute of Technology, Stockholm
National Institute of Environmental Medicine, Stockholm

Ingegerd Johansson
National Institute of Environmental Medicine, Stockholm

Thomas Lindvall
National Institute of Environmental Medicine, Stockholm
Karolinska Institute, Stockholm

Abstract

Apparently the most typical effects of formaldehyde on humans in a nonindustrial indoor environment are the sensory reactions. Measurements of formaldehyde odor were performed in mobile laboratories equipped for psychophysical measurements. Formaldehyde was generated by diluting the headspace of paraformaldehyde with charcoal filtered air. The highly-concentrated gas was fed into a dynamic dilution system that gives low and stable concentrations inside exposure hoods. Pyridine was used as an odor standard for reference purposes. 64 subjects participated in a threshold study and 22 subjects in a perceived odor intensity study. The absolute odor threshold of formaldehyde was determined by a modified method of limits with forced choice responses. The perceived odor intensity of formaldehyde was determined by a magnitude estimation method and using a master scale of pyridine. The individual odor thresholds for formaldehyde were shown to range over two powers of ten and the distribution to be extremely positively skewed. The median value of the individual odor thresholds (ED 50s) was 0.05 ppm (0.06 mg/m^3). The psychohphysical relationship for formaldehyde odor intensity is a power function (exponent = .76). The laboratory results agree well with practical experience in the field that formaldehyde at fairly high levels of concentration is not perceived at all by some people while others show pronounced sensory reactions to concentrations less than 0.3 ppm.

Introduction

Formaldehyde has a number of biological effects. It has been shown to be mutagenic as well as carcinogenic, although the available epidemiological data are inconclusive as to the effects on humans (17). Sensory reactions are apparently the most typical effects that formal-

Psychophysical methods. The absolute odor threshold of formaldehyde was determined by a modified method of limits with forced choice responses (13). The concentration at which the observer detected the formaldehyde odor 50 % of the trials was defined as the individual threshold level (ED 50). At each formaldehyde concentration level the test subject was presented two samples in a random order, one sample containing formaldehyde and the other just cleaned air. Each presentation lasted 6 sec and the interval between the pair was likewise 6 sec. The interval between pairs of samples was 15 sec. The task of the subject was to identify the stimulus interval containing a perceptable stimulus. Corrections for the threshold values were made on the assumption that the frequency of false hits was the same both in the presence and absence of the target stimulus. The formaldehyde concentrations were presented in an ascending geometric series (mean ratio 1.8). The series always started well below the presumed odor threshold of the subject and the presentations did not stop until three consecutive hits were registered. The series of presentations were repeated 6 times for each test subject.

The perceived odor intensity of formaldehyde was determined by using a magnitude estimation method with a master scale of pyridine (5, 6). The test subjects were exposed to 7 concentrations of formaldehyde (range: 0.05-1.00 ppm, 0.06-1.25 mg/m^3) presented 6 times to the subjects in random order. The subjects were instructed to judge the perceived odor intensity of the formaldehyde and the pyridine concentrations using the method of magnitude estimation. The master scale was constructed from the perceived odor intensities of the 5 concentrations of pyridine that were measured interspersed with the formaldehyde concentrations during the experiment. The whole set of odor data for formaldehyde was transformed using the master scale factors gained from the individual psychophysical functions for pyridine (a=.05, b=.70; from (6)).

Results

Stimulus control. In the odor threshold study the high concentration dilution step was monitored by chemical analysis with the sodium bisulfite method. Calculated on double observations taken in immediate time succession, the standard error of the method was 2.1 ppm (2.7 mg/m^3; n = 15). The concentration of formaldehyde in the exposure hood was measured by the chromotropic acid method (standard error of the method = 0.13 ppm (0.17 mg/m^3; n = 10).

In the perceived odor intensity study the high concentration dilution step was monitored by two methods of chemical analysis (sodium bisulfite and Lions). Parallel measurements showed that there was good agreement between the methods (linear regression analysis, r = 0.93; n = 26). From practical reasons the large number of measurements during the study was made with the rapid Lions instrument. Calculated on doubled samples taken in immediate time succession, the standard error of the Lions method was 3.4 ppm (4.2 mg/m³; n = 29). The concentration of formaldehyde in the exposure hood was measured by a combination of chemosorption and HPLC. It was also predicted from the high concentration dilution step and the calibrated dilution devices. The standard error of the method for the chemosorption-HPLC method was 0.15 ppm (0.19 mg/m³; n = 6), the error seeming to increase as the concentration of formaldehyde increased.

Fig. 1 shows the empirical concentrations of formaldehyde within the exposure hood plotted against the values predicted from the high concentration dilution step. Logarithmic coordinates are used. The diagonal in the figure represents identity between the methods. The agreement between the methods is satisfactory, both for the threshold study (sodium bisulfite/chromotropic acid) and for the perceived odor intensity study (Lions/chemosorption-HPLC) (in linear regression analysis r = 0.98 and 0.97, n = 23 and n = 16, respectively), and there are no systematic deviations.

Absolute odor thresholds. The distribution of the individual absolute odor thresholds (ED 50s) for formaldehyde are shown in Fig. 2 using logarithmic concentration values. The odor thresholds range over two powers of ten and in linear coordinates the distribution is extremely positively skewed.

Fig. 3 shows two cumulative frequency distributions of individual odor thresholds for the odor of formaldehyde. One distribution refers to 50% detection (ED 50) and the other to 100% detection (ED 100). The median value of the individual odor thresholds (ED 50s) is 0,05 ppm (0,06 mg/m³). The median value of the individual concentrations at which the observer detects the formaldehyde odor with approximately 100% certainty (ED 100) is 0.17 ppm (0.20 mg/m³).

Psychophysical function of perceived odor intensity. Fig. 4 presents the psychophysical functions for formaldehyde and for the control substance, pyridine, in logarithmic coordinates. The data in the right hand diagram have been transformed according to the master scale principle (5, 6). The linearity in the log-log plots confirms that the psychophysical relationship for formaldehyde odor intensity is a power function (the parameters of the linear function being a = -1.11, b = .76) when odor intensity is expressed in the master scale units. As is evident from the results, formaldehyde odor cannot be distinguished from the background "clean air" at concentrations lower than about .08 ppm.

Discussion

In olfactometry, the sample-equipment interaction is of great importance since during sampling and dilution even minute changes in the chemical composition of the sample may distort the odor of the chemical under study. Furthermore, when "absolute" determinations are made of the minimum effect level, the dosage must be reliably assessed. We have performed a number of investigations to estimate how much of the original gas sample is retained in the odor hoods of our olfactometers during the presentation (4, 13). So far the sample representativity has been good for all the chemicals investigated with our dilution technique (hydrogen sulfide, dimethyl monosulfide, other volatile organic compounds such as toluene, n-butanol, C_{11}+C_{10}-alkane, C_9-alkane and α-pinene). Good sample representativity is now shown to hold for formaldehyde too.

The median value of the 64 individual absolute odor thresholds for formaldehyde is 0.05 ppm. In addition, the perceived intensity of formaldehyde above 0.08 ppm is distinguishable from the odor intensity of charcoal-filtered air. These formaldehyde threshold values are often exceeded in the indoor air of modern buildings. However, prolonged exposure is accompanied by olfactory adaptation which must be considered when the data are generalized to real-life situations. The large individual variability in odor thresholds of formaldehyde may be explained by the fact that formaldehyde causes mucosal irritation in addition to an odor sensation. It must be stressed that formaldehyde odor around 50 ppb is possible to perceive .

For the odor of formaldehyde the exponent of the power function is less than one, reflecting the attenuating mechanism of the olfactory system. However, the size of the exponent (b = .76) is fairly large compared to, e.g., exponents obtained for n-butanol (0.32-0.48) or hydrogen sulfide (0.25-0.38) (5). This may be due to the influence of the irritative properties of the substance. The exponent of the psychophysical power function for pain and irritation is larger than one. It is known that trigeminal stimulation influences the parameters of the suprathreshold power function for odors (7, 8).

The laboratory results agree well with practical experience from indoor environments where formaldehyde at fairly high levels of concentration (about 0.7 ppm) is not perceived at all by some people while others show pronounced sensory reactions to concentrations that are less than 0.3 ppm.

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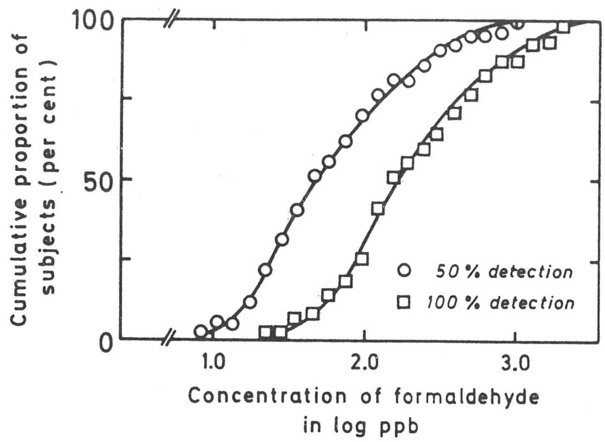

Fig. 3. Cumulative frequency distributions for the individual detection of the formaldehyde odor; 50% detection (ED 50) and 100 % detection (ED 100).

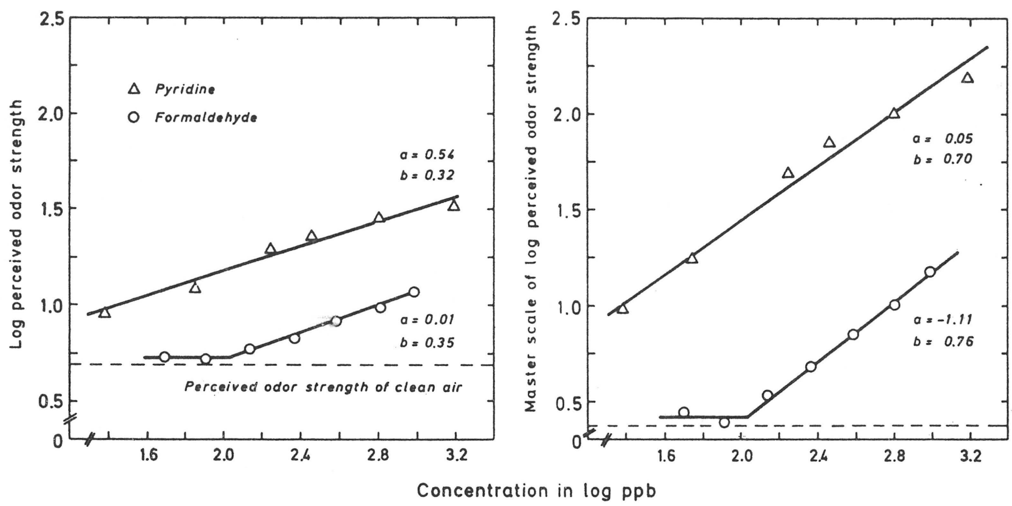

Fig. 4. Psychophysical functions for formaldehyde and pyridine shown in logarithmic coordinates. The left hand diagram shows the results as means of magnitude estimates and the right hand diagram shows the same data after a master scale transform of the pyridine function.