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# Odor and irrition detection of formaldehyde by human observers*

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**Abstract** To investigate the odor of formaldehyde and its potential irritation of the upper airways of humans, 31 healthly subjects were exposed to 18 different concentration of formaldehyde ranging between 6.36 and 1000 ppb.The individual absolute thresholds for odor range from 20-539 ppb with a median of 116.47 ppb. The results are in good agreement with those from an earlier study by Berglund and Hogman (1988) in which the individual absolute thresholds for odor ranged from 21-871 ppb with a median of 115.5 ppb. The absoulute irritation threshold for the group was 573.42 ppb (P50). Concentration was a significant factor for both odor and irritation detection probability. Generally, all subjects had considerably lower thresholds for odor than for irritation. The results of the present study differ from the results obtained in other studies indicating that sensation of upper airways irritation begins around 1200ppb.

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The present results reveal that sensation of upper airways irritation begins at about 700 ppb. There are large individual differences among subjects who may have different sensitivity levels. Prominent characteristics of the sensations include growth of irritation for the higer concentrations and a slight, stable growth of irritation for the lower concentrations. The assumption of linear relationship between reported irritation detection and formaldehyde concentration does hold at concentrations above 2 log ppb but not below. A significant difference in odor and irritation detction was found between women and men.

Key words: Odors, irritants, sensory effect, formaldehyde, detection threshold.

## Introduction

Our present knowledge of sensory irritation in humans is limited. Although most chemical substances are able to cause both odor and irritation perceptions (Kobal & Hummmel, 1991), the latter usually at higher concentrations. Some substances are able to excite the trigeminal nerve below the threshold concentration for the olfactory nerve (Tucker,1971). It is also uncertain whether or not human observers are able to report the difference between "pure" olfactory sensations and the sensations complex resulting from olfactory and extra-olfactory stimulation mediated in the olfactory and trigeminal systems, respectively (cain, 1974).

The absolute detection threshold for irritation is not commonly determined due to the great difficulties of defining the task for the subject in such experiments. Although odor and irritation perceptions may be difficult to discern from each other, three important differences between the two have been shown (Cain & Murphy, 1980): (a) The reaction time to odor is shorter than that of irritation and the irritation may persist longer than the odor associated with stimulation of the olfactory nerve. (b) For prolonged exposure, odor adaptation and in particular habituation will occur, while irriation grows stronger with prolonged time of exposure. (c) While odor perception is keen and trigger exploratory behavior, learning, and odor memory, irritation has a general effect on behavior, involving respiration, cutaneous effects, and potential pathological consequences (Engen, 1986). Perceived irritation will increase more rapidly in strength than odor with each succesive breath of inhalation of a stimulus such as ammonia(Cometto-Muniz & Cain,1991).

A severe complication is that the interindividual differences are large in odor detection thresholds (Punter, 1983; Stevens, Cain,& Burke, 1988) and even larger for irritation detection thresholds (Berglund & Shams Esfandabad, 1992a). Part of the variation has been traced to an unusually large intraindividual varitation in odor thresholds (Stevens, Cain,& Burke, 1988) and a number of factors are well known to influnce odor sensitivity for example, age, gender, smoking habits, partial anosmia, as well as other diseases (e.g., Nordin, 1992). Still, the reasons for the large interindividual varitation in a particular odor experiment is non-referable to these but is suspected to depend mainly on the limited possibilities to generalize from small groups of subjects. This is particulary important to keep in mind considering that the intraindividual variation is large. In addition, the irritation thresholds show an insignificant correlation with the odor thresholds for the same group of subjects. This suggests that the requirements on irritation detection data is even larger than for odor data. As for odor thresholds, irritation thresholds have a high test-retest reliability at group level, but the relibility of interindividual variation is not well known ( Berglund & Shams Esfandabad, 1992a).

**Formaldehyde**

Formaldehyde gas is a potent odorous irritant. It represents the simplest in the aldehyde group and is a flammable colorless and readily polymerized gas. At ambient temperatures, it has a pungent odor detectable at low concentrations. Briefly, the principal sources of formaldehyde, which are of importance for health, are tobacco smoke, particle boards and plywood, furniture and fabrics, gases given off by heating systems, and cooking gas. The automobile and aircraft exhausts also contain formaldehyde gas. It is present in drinking water, soil, food, natural gas, fossil fuels, waste incineration, and oil refineries. Formaldehyde has a varity of uses in many industries, it has medical applications as a sterilant and is used as a preservative in consumer products, such as food, cosmetics, building materials, and household cleaning agents.

Formaldehyde has long been known to be an upper airways irritant. Descriptions of its respiratory effects are primarily associated with irritation effects on the mucous membrane of the upper airways. Among the symptoms caused by formaldehyde at concentrations below the tissue reaction threshold are: irritation of the eyes, nose, and throat, a sensation of dryness in the mucous memberanes and the skin, erythema of the skin, mental fatigue, and weak but persistent odors. These symptoms are similar to those known to appear in problem buildings (cf.

WHO, 1983; Stolwijk, 1984; Akimenko, Andersen, Lebowitz, & Lindvall, 1986).

**Formaldehyde odor and irritation thresholds**

Eye irritation has been reported from 0.05 ppm (Schuck, Stephans, & Middlton, 1966) and irritation from the repiratory tract from 0.1 ppm (Niemela & Vainio, 1981). Reports on the odor detection threshold vary from 0.03 to 1 ppm (Gemert & Nattenbreijer, 1977; Fassett, 1982; Ahlström, Berglund, Berglund, & lindvall, 1986). The duration of exposure has very important effects on the perceived irritation. Andersen (1979) found that three and a half hours of exposure to 0.25 ppm formaldehyde generated as much perceived irritation as an hour of exposure to 0.67 ppm.

These variations in results from different studies may be explained by at least four different type of factors: (a) Measurment methods. There are a number of methods for measuring odor and irritation thresholds (Engen, 1971; Baird & Noma, 1978). (b) Environmental factors. Several factors influence detection performance, for example, tempreature, huumidity, the presence of other agents, and fluctuation in concentration. (c) Experimental factors. The duration of exposure, stimulus range, presentation odor, and background contamination level. (d) Biological factors. The most important are age, sex, and smoking habits. Furthermore, other factors known and unknown, can cause similarities or difference from one formaldehyde study to another.

There are large individual differences among people in detection thresholds. For formaldehyde, odor and irritation detection show great variation between studies (0.03-1.0 ppm; Gemert & Nattenbreijer, 1977) and among subjects (o.01-1.0 ppm; Ahlstrom et al., 1986). According to

Amoore (1967) the variability in individual sensitivity can be caused by differences in the receptor mechanism (e.g., specific ansomia).

The differece betwwen odor and irritation concentration may be noticeable, but there is no evidence that there is a threshold at which odor is superseded by irritation. In addition, for most inhaled odorous compounds, the trigeminal nerve has a higher threshold than the olfactory nerve (Moncrieeff, 1955). When the formaldehyde concentration is increased and affects both the eyes and the nostrils, sonsory irritation is first experienced in the eyes, then the odor is percieved, and finally nasal irritation occures (Moncrieeff, 1955).

**Problem**

It is obvious that people are primarily exposed to mixtures of airborne concentrations rather than to a single chemical. One way to overcome this problem for generalization of research results is to provide an appropriate method for determining the absolute odor and irritation detection thresholds for at least a dozen already known indoor air pollutants before testing known mixtures, and to test for interactions.

Bcause of the lack of psychophysical data on sensory irritation, a series of experiments has been conducted in which odor and irritation detection is determined for some known odorous irritants. In this research, the main problem is to find an appropriate methode by which irritation detections may be assessed separately from the odor detections. So far, the experimental results are promising. A new version of the method of constant stimuli is tried for jointly assessing odor and irritation detections. It involves four forced-choice response alternatives and the procedure controls the false alarm rates associated with the four kinds of detection (see further Berglund & Shams Esfandabad, 1992a).The main aim of the present experiment was to apply this joint odor-irritation detection method to formaldehyde exposures for a larger group of subjects. In order to evalute the potentials of the new detection method, enough data were collected from each subject in order to determine the individual odor as well as irritation thresholds.

## Method

### Subjects

Thirty-one subjects, 17 women and 14 men participated in the experiment. University students were in great majority and the mean age of the participants was 24.5 years (range: 18-35 years). It was required that subjects must not be a smoker or use (oral or nasal) snuff. They had to be healthy and have no health problems with their upper airways system. Furthermore, before and during the experiment,the subjects were asked not to were perfume, scented cosmetics or skin creams or lotions .At the time of participating in the experiment, all subjects reported that they were in good general health, lacking allergies, colds, or any respiratory-tract disease. since hormonal change is suspected to influence odor sensivity (e.g., Köster,1986), the women were asked to schedule their experimental time during a non-menstruating period. the subjects were paid for their participations.

### Equipment

The experiment was carried out in a carefully tested odor laboratory (Berglund, Berglund, Johansson, & Lindvall, 1986). The stimuli were presented in an exposure hood (340 250 200 mm) installed in a stationary chamber. It was supplemented with a waiting room which also contained conditioned and charcoal-filtered air. In the present experiment,the charcoal-filtered air that flowed through the exposure hood (100 L/min) and the air of the chamber were kept at a temprature of 22 (SD=1) C and a relative humidity of 40 (SD=3) % (N=1736).

The 18 formaldehyde concentrations formed a geometric series of concentrations from 6.36 to 1000 ppb (vol./vol.). The formaldehyde atmosphere in the hood was generated by blowing charcoal-filtered air through a solution of paraformaldehyde (Merck p.a., pretreated in 105-110 C for 3 h) in 0.01 N sodium hydroxide. The atmosphere was then diluted with charocal-filtered air in two steps: (a) to 100 ppm continuously monitored with infrared analysis (Miran 80) and (b) to 6.36-1000 ppb with the aid of steel capillaries injected into the main air flow to the exposure hood. Hood concentrations as well as the background air in the hood and stationary chamber were meassured during the study period 12 times with a continuous flow analysis instrument based on the acetyl acetone method and UV detection, with lowest range setting of 0-50 ppb formaldehyde (Skalar SA 9000).

**Stimuli**

The 18 concentrations of formaldehyde were made in a geometric series ranging from 6.36 to 1000 ppb. The actually measured average hood exposures during the experiment were: 6,4, 10.0, 14.4, 18.1, 23.1, 31.7, 42.4, 57.4, 73.4, 101.4, 134.1, 177.1, 236.1, 316.1, 420.1, 567.0, 755.0, and 1000.0 ppb. The highest concentration was equally low as the threshold limit value of formaldehyde permitted in 8-hours occupational exposures (=1 ppm). Each of the 18 concentrations was peresented 12 times and they were presented in an irregular order together with 72 blanks (charcoal-filtered air). Blanks were included in order to separate the true correct positive responses from the incorrect positive responses (for more information see Green & Swets, 1966).

**Experimental procedure**

Every subject evaluated the 288 hood exposures (216 formaldehyde concentrations and 72 blanks). The presentation order was divided into 8 sessions of 36 presentations each. Every session took about 12 min. Between each session there was a 10 min pause. There was a pause of 30 min between the middle sessions. The pauses were always spent in the waiting room. Each exposure was available in the hood for 5 s and sampled by the subject as one sniff (=1 s); the inter-exposure interval was set at 13 s. A subject completed the experiment within a snigle day (ca. 4 hours including pauses).

Before the experiment, the subjects were asked to sit in the waiting room for at least 30 min in order to become adapted to the clean laboratory background air. Every subject was instructed to say yes when (s)he smelled somthing or perecived something in the upper airways.They were instructed to say no when (s)he did not smell anything or the upper airways were not affected by the exposure. The subjects were told that "You may find that you will need to use yes or no quite frequently. If that happens do not worry about it. Just judge each odor or irritation the way you perceive it." Each subject was parcticed in the psychophysical procedure for at least 10 trials (formaldehyde and blanks). All subjects were paid for their participation in the experiment.

An adjusted version of the method of constant stimuli with four forced-choice response alternatives and presentations was used for jointly determining the detection performance for odor and irritation. For each exposure, the observers were instructed to take one sniff and first consider if they perceived an odor and then consider if they perceived an irritation in their upper airways. Thus, the subjects could choose between four "odor-irritation" response alternatives: (a) Yes-Yes, the first yes means that the subject experienced an odor (=odor detection) and the second yes means that (s)he experienced irritation in the upper airways (=irritation detection). (b) No-No, means that the subject experienced neither odor nor irritation. (c) Yes-No, means that the subject detected an odor but no irritation in the upper airways. (d) No-Yes, means that the subject did not detected an odor but experienced irritation in the upper airways.

Table 1. Classification scheme for the four odor-irritation response altematives used in the experiment.



Table I. Classification scheme for the four odor-irritation response alternatives used in the experiment.

| Sensory Class | Pyridine Concentrations Hits | Misses | Blanks False Alarms | Correct Rejections |
|---|---|---|---|---|
| Overall | yes-yes<br>yes-no<br>no-yes | no-no | yes-yes<br>yes-no<br>no-yes | no-no |
| Odor | yes-yes<br>yes-no | no-no<br>no-yes | yes-yes<br>yes-no | no-no<br>no-yes |
| Irritation | yes-yes<br>no-yes | no-no<br>yes-no | yes-yes<br>no-yes | no-no<br>yes-no |

A schematic presentation is given in Table 1 of how the four odor-irritation response alternatives may be referred to hits, misses, false alarms, and correct rejections when the detection is assumed to rely on overall, odor, or irritation perception, The inquiries about the subjects task, before the experiment started, after each session, and in the end of the experiment, showed that they did not become confused about the judgmental task.

The instruction to the subjects was carefully given in both oral and written form. The rationale for this is that it is important with personal contact and interaction with the subject so that the experimenter can assess that the subject has really understood the instruction. In the training session the strongest formaldehyde concentration was always present. None of the subjects found that they were unable to tolerate any of the 10 training exposures. The subjects were also instructed always to sample their sniff in a constant way.

## Results and discussion

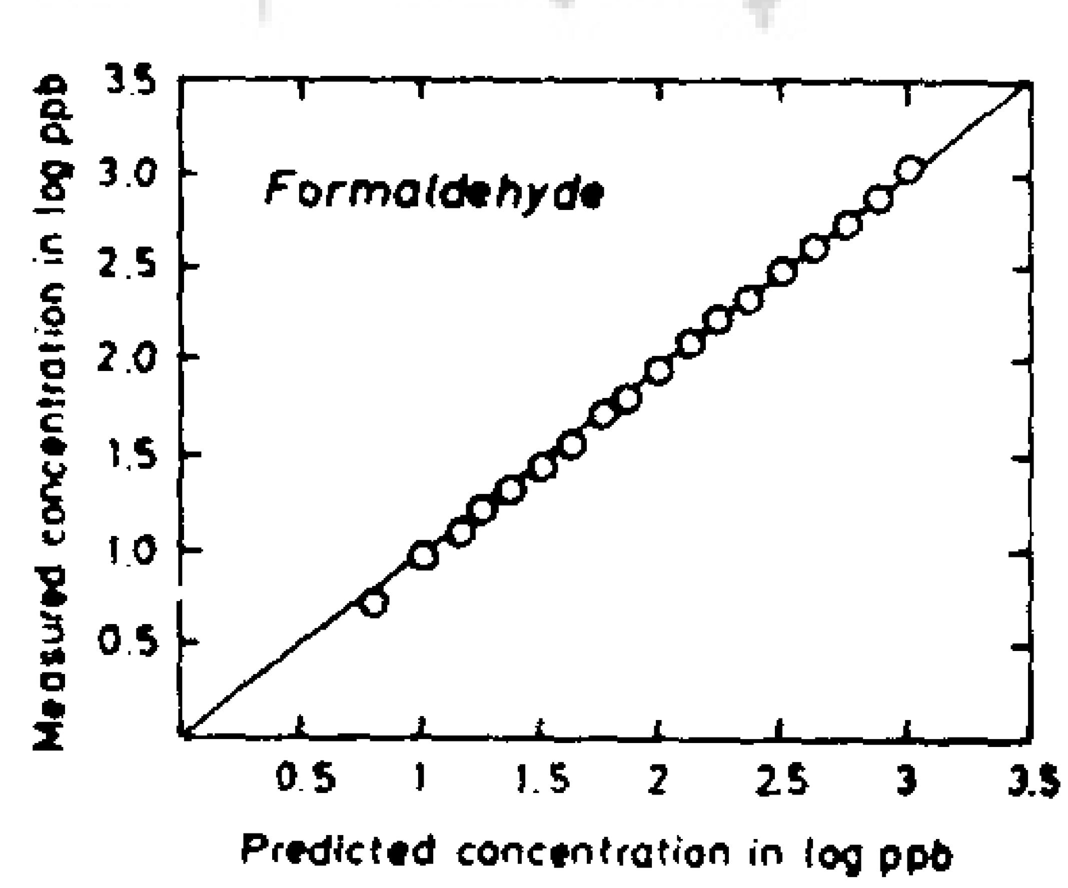


Fig.1. Measured formaldehyde concentration in the hood as a function of predicted concentrations in log ppb.

**Stimulus control**

The concentrations of formaldehyde were measured in the exposure hood [at the same position as the tip of the nose of the subject when (s)he takes a sniff] by means of the continuous formaldehyde monitor (see above). In Fig.1 concentration of formaldehyde measered in the hood is plotted against the predicted concentrations. Each point is the arithmatic mean of 12 values. The diagonal represents identity. Since the plot shows very small differences (y=1.03x-0.07;R-squared:0.99), the arithmatiic mean of the formaldehyde concentrations measured in the hood were used for all further data analysis.

**Assessment of false alarms from blanks**

A false alarm (FA) means that the subject states that an odor or irritation is present at presentation of blank (charcoal-filtered air). The false alarms were calculated for the four forced-choice response altematives as well as the sensory classes,odor,irritation,and overall.

**False alarms for response altematives.** The different possible assignment of the response altematives are given in the right-hand columns of Table 1. According to this classification scheme, the false alarm rate is generally defined in relation to the assumed simultaneous recognition and detection ability. The four forced-choise odor-irritation response alternatives were used for the blanks as follows. Only one of the 31 subjects (3.2%) wholly gave no-no response (100% correct rejections, CR) for the 72 blanks, which means that his/her false alarm rates were zero (for the group the correct rejections are:CRam=76.9%; range 20.9-100%;N=31). The corresponding false alarm rates for the group is compatible with the false alarm rates obtained for the overall response (odor and/or irritation,i,e., any detection altenatives: yes-yes, yes-no & no yes) for the blankes:FAam=23.1% (range 0-29.1%; N=31).

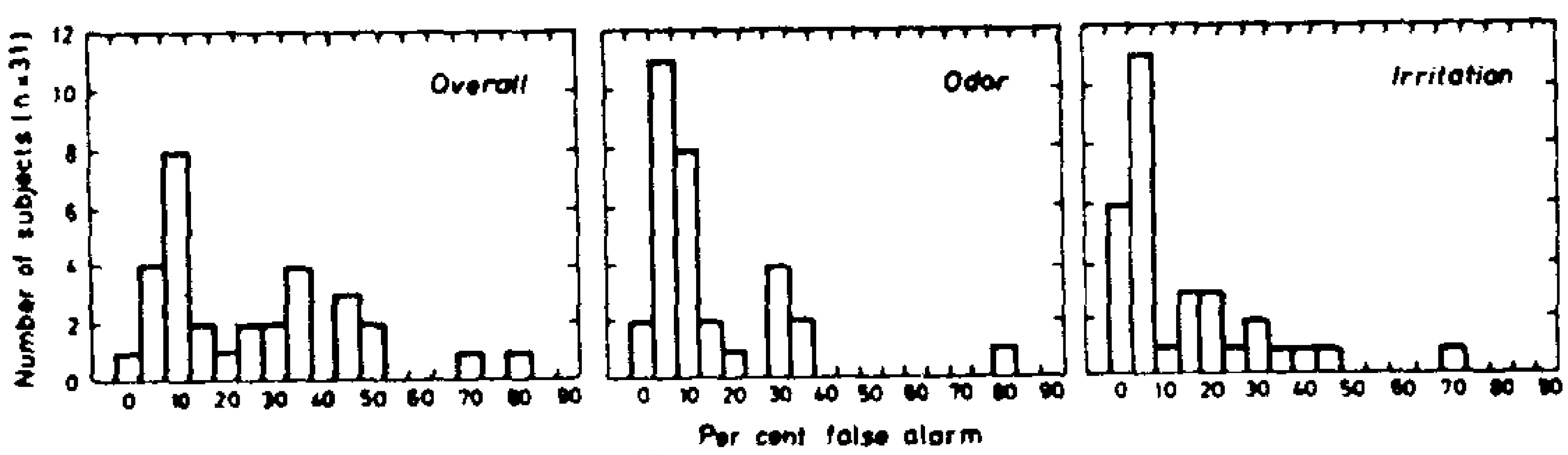


Fig.2. False alarms for the group of 31 subjects shown as distributions regarding overall sensory response (yes-yes, yse-no & no-yes), odor response (yes-yes & yes-no) and irritation response ((yes-yes & yes-no 0 and irritation response (yes-yes & no-yes).

The three odor-irritation response altrernatives representing false alarms were used as follows (the usage once corresponds to 1.4-23.6; N=16). 87.1% of the subjects used yes-no (FAam= 11.1%l; range: 1.4-77.7; N=27), and 24.6% of the subjects used no-yes (FAam= 13.1%;range: 1.4-68.0; N=23). For all three kinds of false alarms, the usage distributions for the subjects are positively skewed (Fig.3). The results for the false alarms over response alternatives show that "pure" odor (yes-no) readily is used by a majority of the subjects while the "pure" irritation (no-yes) was found appropriate on blank presentations by a minority of subjects. Half of the group (15 out of 31) gave higher false "odor" responses than false "irritation" responses for the blanks, and the reverse order was given by 13 subjects. Three gave equal rates and one of them had no false alarms at all. Although the individual differences in the false alarm rates are large, the distribution of the false alarms over the three response alternatives seems reasonable in that the yes-no and no-yes rates are approximately equal and the yes-yes rates approximately half thereof.

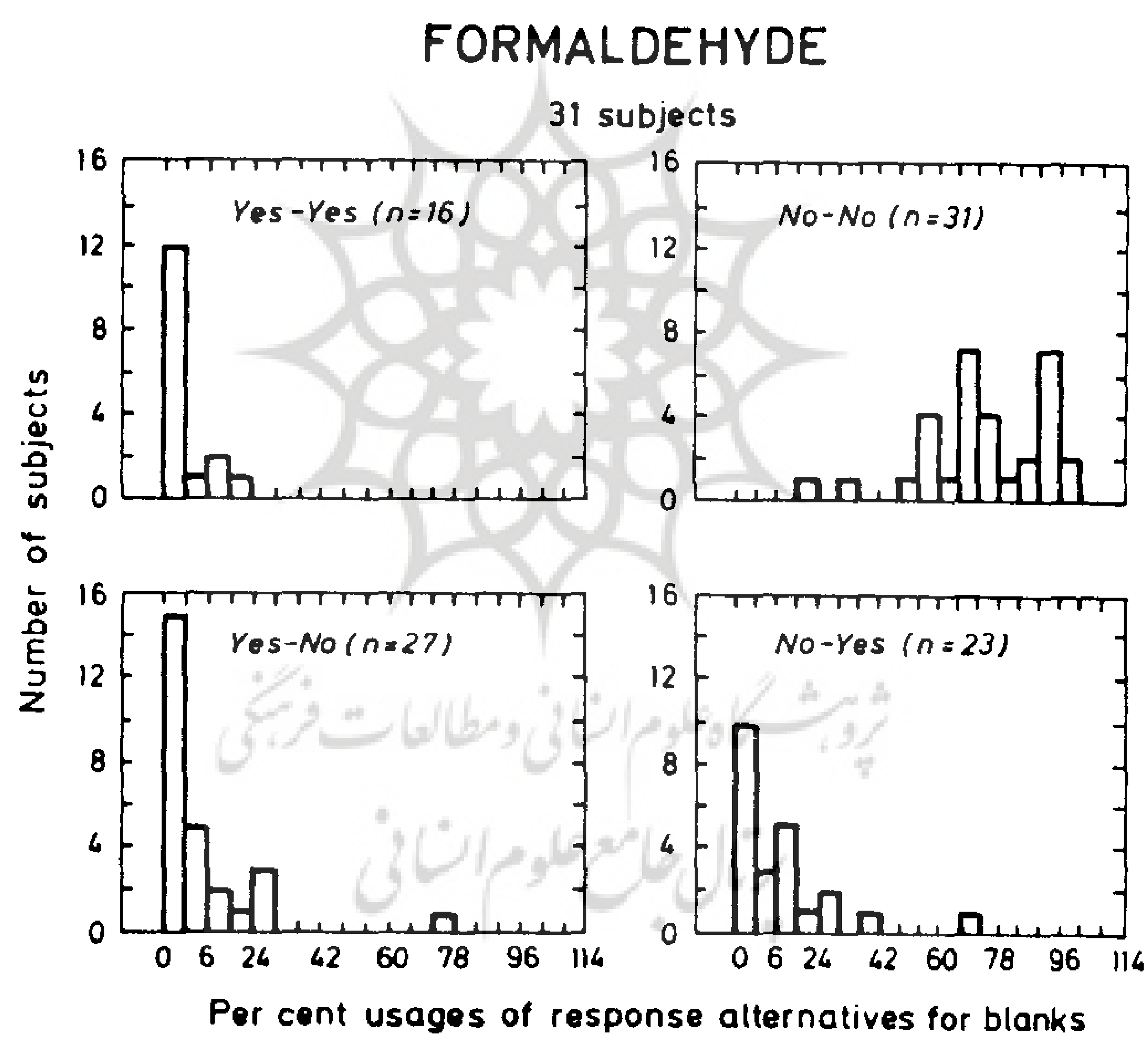


Fig.3. Distributions of correct rejections (right-hand top diagram) and false alarms (other three diagrams) for the 31 subjects. Each diagram conveys data from one of the four forced-choice response alternatives as responses to the 72 blanks.

**Assignment of false alarms over sensory classes**. The assignment of the correct rejections (zero false alarm rate) among the 31 subjects seems logical. They performed best for irritation (19.4% of subjects), followed by odor (6.5%), and worst for the overall response (3.2%). The correct rejections and the false alarms for the three classes of sensory response are displayed in the form of histograms in Fig.2. The three distributions are positively skewed for the subjects with false alarm rates (AM) for overall, odor, and irritation responses of 23.9% (N=30; range: 1.4-79.1), 13.8% (N=29; range:1.4-79.1), and 16.2% (N=25; range: 1.4-69.4), respectively. The subjects who produced 100% correct rejections are excluded from these statistics. The average false alarm rates for the whole group of 31 subjects are given in the right-hand columuns of Table 2.

Table 2. Hits, misses, correct rejections and false alarms given as average percentages for the group of 31 subjects.

Table 2. Hits, misses, correct rejections and false alarms given as average percentages for the group of 31 subjects.

| Sensory Class | formaldehyde concentrations | | Blanks | |
|---|---|---|---|---|
| | Hits | Misses | False Alams | Correct Rejection |
| Overall | 63 | 37 | 23 | 77 |
| Odor | 54 | 54 | 13 | 70 |
| Irritation | 31 | 69 | 13 | 70 |

**False alarms for the sensory class odor.** For odor, the average false alarm rate for the 31 subjects was 12.9% (AM; range:0-79.2; SD=16.26). Most of the subjects (N=21) gave a false alarm rate<10%, three of these only produced correct rejections upon blank presentations. Three subjects had a false alarm rate>10% but<20%. Six subjects had a false alarm rate>20% and <40%. Only one subject had a false alarm rate>50%.

**False alarms for the sensory class irritation.** For irritation, the average false alarm rate for the 31 subjects was 13.05% (AM; range:0-69.4; SD=16.45). Five subjects gave false alarm rates>10% and <20%. Six subjects >20% and <40%. One subject >40% (No.22), and one subject >50%. The remaining 18 subjects gave false alarm rates <10%, six of these only produced correct rejections upon blank presentations.

A paired t-test applied to the subject's false alarm rate for odor (yes-yes & yes-no) and irritation (yes-yes & no-yes) detection shows no significant difference (tdf30=0.04, p=0.97). If the shared yes-yes responses are excluded, there will still be no significant difference between "pure" odor and "pure" irritation responses. For the 31 subjects, the pearson's coefficient of correlation is -0.21 for the yes-no (odor only) and no-yes (irritation only) response alternatives, and 0.008 for the sensory classes odor (yes-yes & yes-no) and irritation (yes-yes & no-yes).

These statistical values show that the individual variation in false alarms for the same subject, for example, subject No,25 has a false alarm rate of 2.8% for odor and 69.4% for irritation; convincing in proving that the false alarms for these two sensory classes (odor and irritation) are independent.

## Asseament of odor and irritation detections from formaldehyde presentation

Kendall's coefficient of concordance was calculated as a measure of agreement among the subjects detection performance for the 18 formaldehyde concentrations regarding the four odor-irritation response alternatives (W=0.04). It is statistically insignificant implying a law agreement amomng the subjects. Therefore, the Pearson's coefficient of correlation were calculated between the correct responses over subjects. The coefficient is -0.72 for the "pure" odor (yes-no) and "pure" irritation (no-yes) response alternatives and 0.18 for the odor (yes-yes & yes-no) and irritation (yes-yes & no-yes) responsse classes. The negative correlation between the two types of "pure" response is partly explained by their negative correlation with concentration. A graphical ilustration of the concordance regarding the interindividual variation in correct positive responses for formaldehyde exposure is shown in Fig. 4.

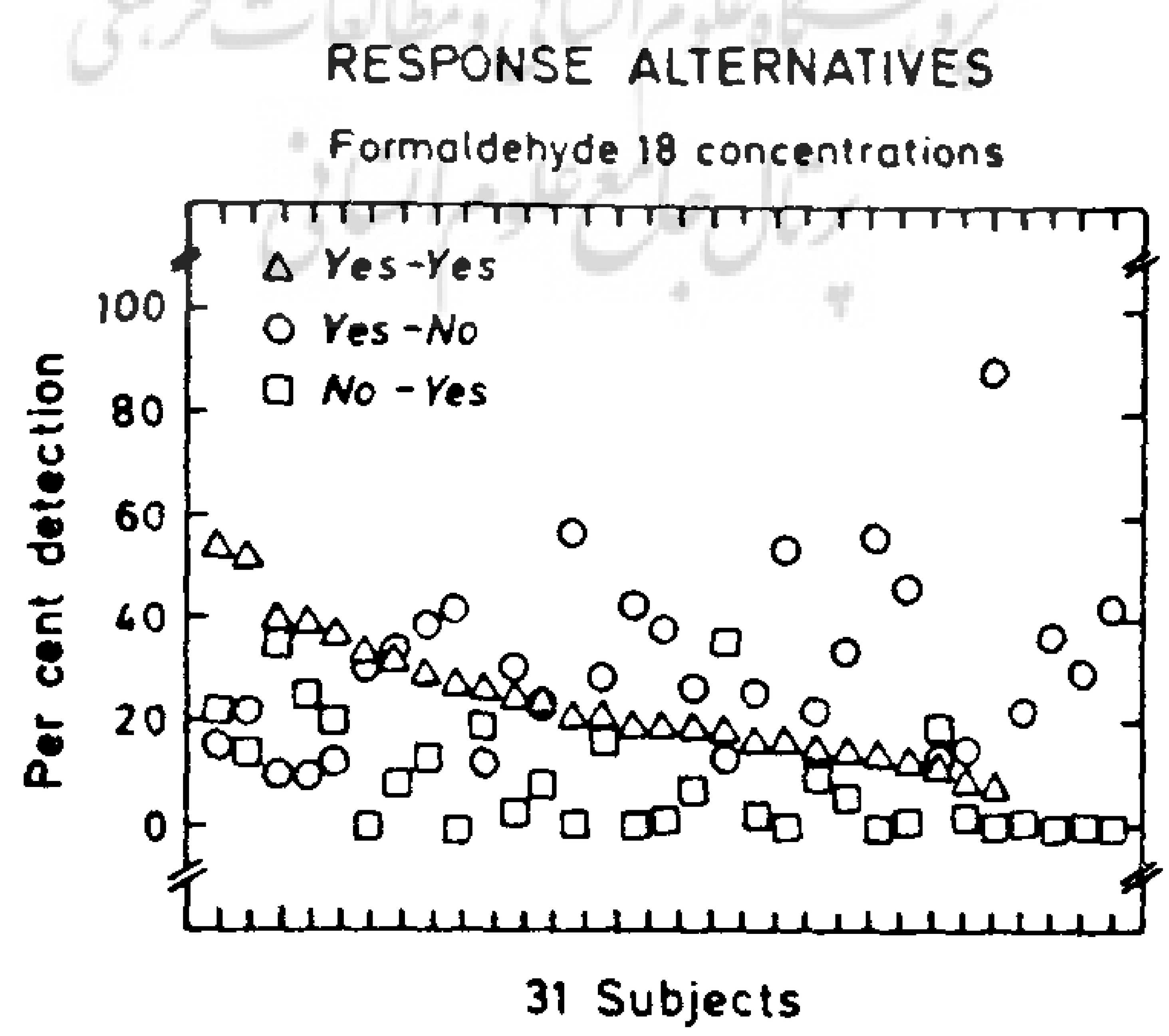

Fig.4. comparison of the usage of correct positive responses for formaldehyde exposure (AM over 18 concentrations). The 31 subjects are rank ordered according to decreasing percentage of usage of the yes-yes response alternative (triangles). The yes-no and no-yes response alternatives for the same subjects are given as circles and squares, respectively.

The 31 subjects were rank ordered according to decreasing average detection precentsge for the overall response alternative (yes-yes; tringles) and the "pure" odor (yes-no) and "pure"irritation are given accordingly for the same subjects. The rank order of subjects with regard to usage of detection precentage becomes evident: All subjects exhibit the lowest usage of no-yes response alternative (squares). Most subjects uses yes-yes somewhat frequently, while four subjects to the right uses yes-yes nearly as infrequently as the no-yes. Although the variation over subjects in detection frequencies is larger for the correct positive responses (formaldehyde) as compared to the false positive responses (blanks) the trend is the same. Since the interindividual differences in odor detection are known to be large, the low concordance between the 31 dubjects is expected. It is evident that combining odor data with information on irritation will not reduce the differences. The low inter-subject agreement in detection performance may primairly be related to the basic difference in how subjects perceive (or divide) the odor-irritation relation in the perception.

The average detection data for the group of 31 subjects were determined. In this case one detection frequency corresponde to 0.0026% (base number 327). In Fig.5, the results are shown for the four response alternatives in the left-hand diagram and for the three sensory response classes in the right-hand diagram.

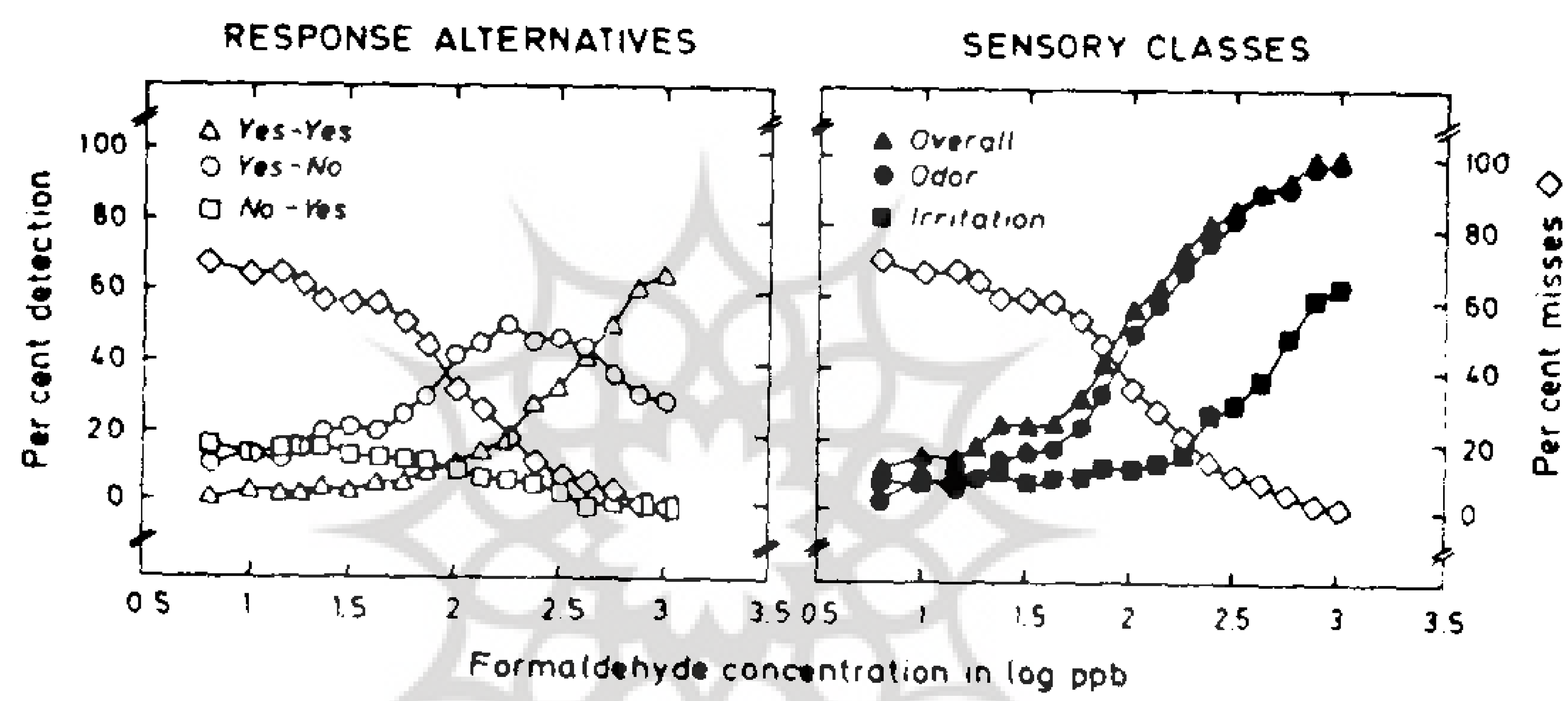




Fig.5. Percentage of correct positive responses (AM over 31 subjects) to the 18 formaldehyde concentrations as well as percentage of misses (no-no=diamond in both diagrams). The classification of detections are in the left-hand diagram according to the four forced-choice response alternatives (yes-yes =open triangle, yes-no=open circle, no-yes = open square) and in the right-hand diagram according to the three sensory response classes (overall =filled triangle, odor =filled circle, irritation = filled square).

In Fig. 5 frequencies of misses for every concentration are given in both diagrams as reference curves (diamonds). The detection curves representing the three positive response alternatives, yes-yes, and yes-no, and no-yes, are of particular interest (left-hand diagram) since ther is no redundancy among these. According to the percentages of misses, formaldehyde concentrations of approximately 750 ppb and above (=209 log units) will have a nearly 100% probability of being detected one way or another.

The probability of detection of "pure" irritation (open squares =no-yes) is nearly zero and does not covary substantially with concentration. This indicates that formaldehyde irritation perception starts at higher concentrations than odor perception, But, at a concentration of 100 ppb (=2.0 log units) the yes-yes responses start to increase indicating that the perception involves something more than "pure" odor that starts to increase with concentration at 25 ppb (=1.4 log units). Perceptually, the most interessting limit concentration is one where the odor-irritation dominance shift takes place. For formaldehyde this happens at 400 ppb (=2.6 log units).

The right-hand diagram of Fig.5 shows the detection probabilities according to sensory class: overall (filled triangle), odor (filled circle), and irritation (filled square). Although odor dominates in the overall detection of formaldehyde exposures, irritation may be equally important at the higher concentrations. The detection frequencies shown in Fig.4 are not corrected for the corresponding false alarms, but since these were low and approximately aqual for the odor and irritation response alternatives, thhe conclusions from the comparisons made above will stand.

## Individual psychometric functions

The quality of the data is best assessed and evaluated by plotting the individual psychometric functions relating percentage of detections to formaldehyde concentration in logg ppb.

It is generally belived that the higher the concentration, the higher the odor as well as the irritation detections (see Berglund & Shams Esfandabad, 1992a, 1992b; Engen, 1986). The individual psychometric function for irritation reveal that at very low concentrations of formaldehyde the detection grows linearly but very slowly. At a limit concentration, the slope representing this growth becomes steeper, but, for most subjects the 100% probability of detection is not reached within the present exposure range; if reached it happens at most for the three highest concentrations.

## Comparison of psychometric functions for odor and irritation

So far, we have shown that there is a large interindividual variation in the present data, particualry with regard to the irritation responses to formaldehyde. The concordance in correct positive responses between the 31 subjects is low and the correlation between response patterns for odor and irritation are low. This may suggest that the different subjects belong to a few different subgroups characterized by their response behavior on the odor-irritation detection task. In order to tset this, a principal components analysis was made. It was based on intercorrelations (Pearson's coefficients) between subject's responses on the four response alternatives. For every subject, four subsets of data were calculated from the mean frequencies for each of the 18 concentrations over the 12 presentations for each of the four possible response alternatives; no-no (misses), yes-yse, yes-no and no-yes. The test-retest correlation was estimatted to be 1 and the solution of the principal components analysis was subsequently submitted to a varimax rotation. Acording to Kaiser's criterion of eigenvalues greater than or equal to unity (Kaiser, 1974; Kim & Muller, 1990) three factores were extracted. The eigenvalues for the three factors were 17.15, 5.47, and 3.82. These three factors explained 85.3% of thc total variance.

Based on the results obtained from the principal components analysys, the detection data on odor and irritation follows three principle models. The psychometric functions for these, based on pooled data from the subgroups of subjects are shown in Fig.6.

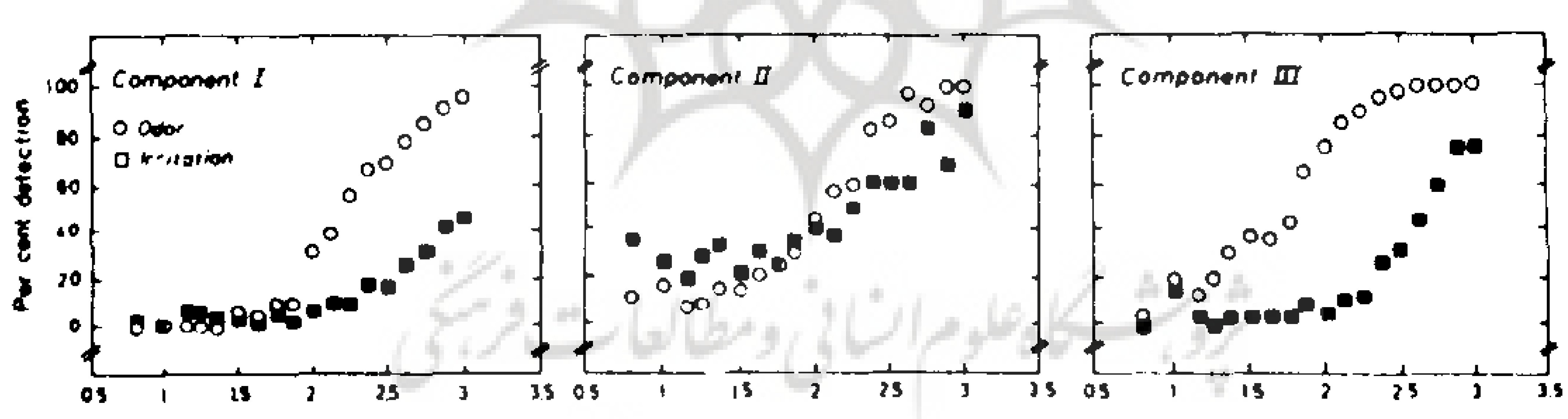


Fig.6. classification of subjects according to three principle modles of responding with regard to the sensory classes odor and irritation. The classification is based on a principal components analysis and the odor (open circlees) and irritation (fielled squres pairs of psychometeric functions refer to the subjects classified into the first componrent (left hand digram), the second component (midlle digram), and the third component (right-hand digram).

It should be pointed out that the classification accomplished with the principal components analysis does not preclude the possibility of other models. The psychometric function for the subjects (N=31) can be described according too one of the following three models (the concentration scales is given in logarithmic nuits). Model A (N=12; left-hand diagram): The pychometric functions for odor and irritation both start at approximately the same concentration but the slope of the detection growth with concentration is steeper for odor and irritation. Model B (N=7; middle diagram): The psychometric functions for odor and irritation are almost identical, that is, they both start at approximately the same concentration and have approximately the same slope of detection growth with increased concentration. [This interpretation is valid if consideration is given to the false alarms which differ]. Model C (N=12; right-hand diagram): The form of the psychometric functions is identical but irritation function is displaced and covers a shorter range of higher concentrations. For the pooled group data (Fig.7) the appearance of Model C dominates.

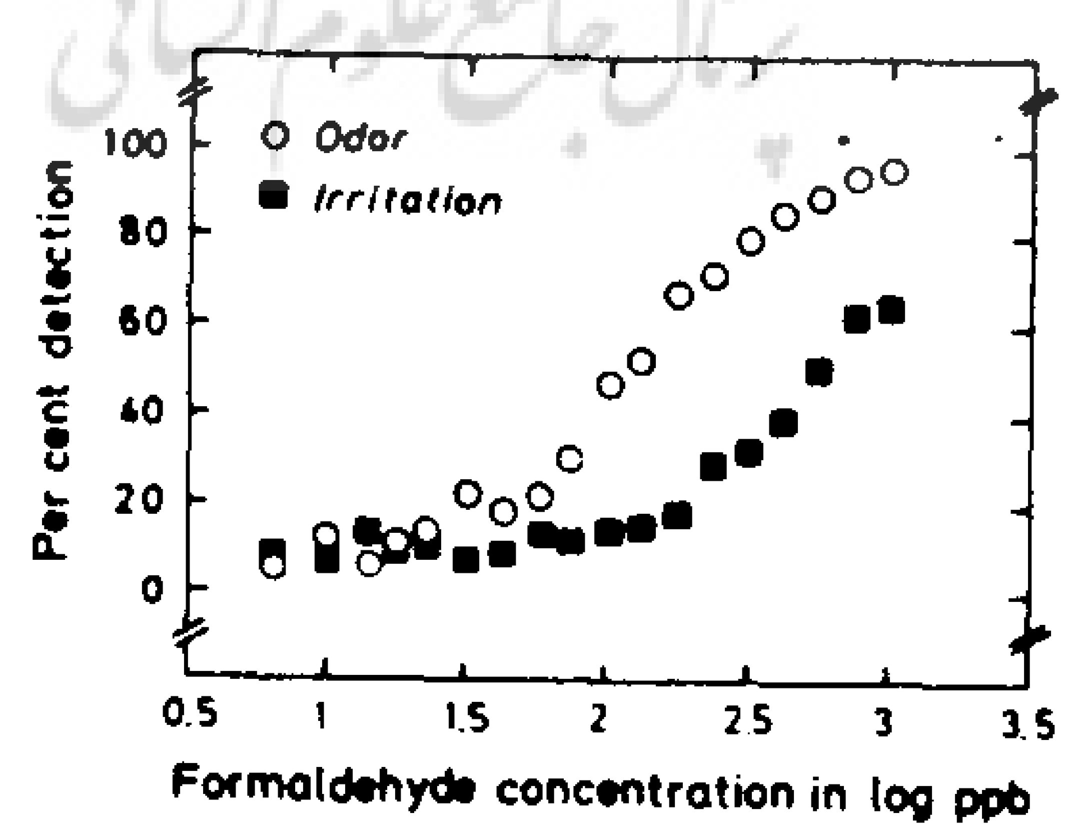


Fig. 7. Percent detections for the sensory classes odor (open circles) and irritation (filled squres) plotted against formaldehyde concentration in log ppb. The psychometeric curves constitute the result for the group of 31 subjects.

Although the classification of subjects by the principal components analysis was based on the responses of the four alternatives to formaldehyde exposures, the false alarm rate also turned out to differ for the groups. The subjects fitting Model A has an approximately identical fals alarm rate for odor and irritation, the subjects referable to Model B has a higher false alarm rate for irritation than for odor, and those of Model C has a higher false alarm rate for odor than for irritation.

**Odor and irritation detection thresholds**

The odor and irritation thresholds were calculated in two different ways. The odor thresholds were first determined for each of 31 subjects and then the group data was formed as average threshold concentrations at different detection probabilities. On the other hand, the irrtation detection data formed for each subject do not provide a good basis for individual thresholds because the majority of them did not rach the 100% probability of detection within the experimental range of concentrations. Thus, the irritation thresholds are here only calculated from the detction function for the group. In Fig. 7 the group psychometric functions for the sensory classes odor and irritation are plotted against formaldehyde concentration in log ppb. Each poinnt represents 372 judgments and for the blankss 2232 judgments. The steps of data treatment for calculating the absolute odor and irritation thresholds are given below.

**Method for calculating absolute odor thresholds.** The individual data were corrected for false alarm according to Eq.1 (Engen, 1971), where Pc stands for the probability of a positive response corrected for false alarms, phits the probability of positive response in the presence of an odoor (and/or irritation) presentation, and pfalse alarms, the probability of positive response in the presence of a blank presentation.

Table 3. Odor detection thresholds (at PO, P25, P50, P75, P100) and interqurtile ranges (P75-P25) expressed in formaldehyde concentration in ppb. The odor detection data were corrected for false alarms (Eq.1) and transformed to z-values and plotted against concentration in log ppb, then regression lines were fit to the transient part of the functions with method of least squares.

| Subject No. | False Alarms % | Odor Detection Thresholds, Pc *P0 | P25 | P50 | P75 | P100 | Interquartile Range (P75-P25) |
|---|---|---|---|---|---|---|---|
| 1 | 1.4 | 64.65 | 177.83 | 477.89 | 1288.24 | 2213.65 | 1110.41 |
| 2 | 30.6 | 2.71 | 12.64 | 90.24 | 644.02 | 1630.10 | 631.38 |
| 3 | 1.4 | 22.65 | 58.41 | 121.28 | 251.88 | 662.75 | 193.47 |
| 4 | 27.8 | 18.40 | 43.53 | 120.34 | 332.66 | 650.01 | 289.13 |
| 5 | 1.4 | 46.93 | 87.96 | 160.29 | 292.15 | 722.53 | 204.19 |
| 6 | 29.2 | 194.95 | 19.92 | 62.07 | 193.15 | 671.58 | 173.59 |
| 7 | 9.7 | 4.17 | 11.29 | 20.18 | 38.35 | 79.75 | 27.06 |
| 8 | 11.1 | 3.57 | 11.96 | 45.95 | 176.56 | 155.09 | 164.60 |
| 9 | 4.2 | 37.52 | 75.67 | 138.77 | 245.48 | 476.28 | 178.81 |
| 10 | 2.8 | 7.90 | 20.73 | 55.64 | 149.28 | 267.74 | 128.55 |
| 11 | 34.7 | - | - | - | - | - | - |
| 12 | 2.8 | 77.83 | 145.98 | 277.49 | 527.23 | 892.58 | 381.25 |
| 13 | 6.9 | 12.43 | 49.53 | 120.78 | 294.44 | 851.92 | 244.91 |
| 14 | 12.5 | 15.70 | 44.76 | 109.02 | 265.52 | 836.15 | 220.76 |
| 15 | 18.1 | 45.18 | 85.62 | 177.09 | 366.27 | 585.24 | 280.65 |
| 16 | 8.3 | 98.44 | 273.40 | 539.26 | 1063.90 | 2760.63 | 790.49 |
| 17 | 5.6 | 34.68 | 65.99 | 113.45 | 195.03 | 392.16 | 129.04 |
| 18 | 5.6 | 50.72 | 89.51 | 140.76 | 221.35 | 233.45 | 131.84 |
| 19 | 8.3 | 34.84 | 68.06 | 116.47 | 199.25 | 352.14 | 131.19 |
| 20 | 9.7 | 16.70 | 28.75 | 62.22 | 134.59 | 252.46 | 105.84 |
| 21 | 0.0 | 70.82 | 125.45 | 174.98 | 243.78 | 454.01 | 118.33 |
| 22 | 1.4 | 48.08 | 112.98 | 221.31 | 433.41 | 898.59 | 320.43 |
| 23 | 4.2 | 6.58 | 16.87 | 32.56 | 62.81 | 128.19 | 45.94 |
| 24 | 2.8 | 24.08 | 37.07 | 62.00 | 103.51 | 175.37 | 66.44 |
| 25 | 2.8 | 11.38 | 40.74 | 78.16 | 150.31 | 578.59 | 109.57 |
| 26 | 5.6 | 20.79 | 107.77 | 293.86 | 801.26 | 868.82 | 693.49 |
| 27 | 2.8 | 7.71 | 18.28 | 32.96 | 59.43 | 125.99 | 41.15 |
| 28 | 26.4 | 35.17 | 49.88 | 65.46 | 85.31 | 123.89 | 35.43 |
| 29 | 79.2 | - | - | - | - | - | - |
| 30 | 0.0 | 66.02 | 149.28 | 325.84 | 709.58 | 1761.63 | 560.30 |
| 31 | 27.8 | 6.28 | 20.18 | 63.83 | 201.84 | 557.05 | 181.66 |
| AM | 12.42 | 37.48 | 70.69 | 148.30 | 335.86 | 715.67 | 295.17 |
| GM | - | 22.96 | 50.11 | 109.80 | 240.51 | 505.07 | 178.57 |
| MD | 5.60 | 24.08 | 49.88 | 116.47 | 243.78 | 578.59 | 178.81 |
| SD | 16.21 | 39.50 | 60.16 | 126.87 | 301.62 | 635.95 | 256.90 |
| P25 | 2.80 | 10.51 | 20.59 | 62.18 | 150.05 | 263.92 | 116.14 |
| P75 | 16.70 | 48.74 | 94.08 | 175.51 | 383.06 | 862.15 | 296.96 |

*Footnote.* *P0 is identical to the symbol ETc in Berglund, Högman, and Johansson (1988) and Pc is data corrected for false alarms and transformed to z-value.*

phits - pfalsh alarm

pc= ------------------------

1 - pfalsh alarms

The probabilities of odor detections (pc) were transformed to z-values. The absoluute thresholds at P25, P75, and the (p75-p25) interquartile range were calculated on the basis of the regression lines fitted to the detection data for each of the 31 subjects. The absolute thresholds at P0, P100 and the absolute range (p100-p0) were calculated on the basis of the regression lines fitted to the corrected, but not z-transformed data. The medians, geometric and arithmetic means of the thresholds over 31 subjects were expressed in formaldehyde concentration.

In fitting the stright lines to the two types of false-alarm corrected psychometric plots, the data points included were from the lowest concentration presentation > 100% detection to the highest concentration that was smaller or equal to the false alarm rate. The five absolute thresholds (at P0, P25, P75 & P100) as well as the interquartile (P75-P25) ranges are presented in Table 3 for odor detection (yes-yes & yes-no).

Absolute odor thresholds. The individual absolute odor thresholds (at P0, P25, P50, P75 & P100) and (P75-P25) interquartile ranges are presented in Table 3 for the 31 subjects, as well as the averaged group data. The P50-absolute odor thresholdes found for formaldehyde is 148.3 ppb (AM; range: 220.2-5339.1 ppb; median: 116.5 ppb; GM: 109.9 ppb). The average (P75-P25) interquartile range is 266.7 ppb (AM; range: 27.1-1110.4 ppbl median: 178.7 ppb; GM: 178.82 ppb). The distribution over subjects of the absolute thresholds at P25, P50 and P75 are shown in the three diagrams of Fig.8. All three thresholds show approximately normal distribution.

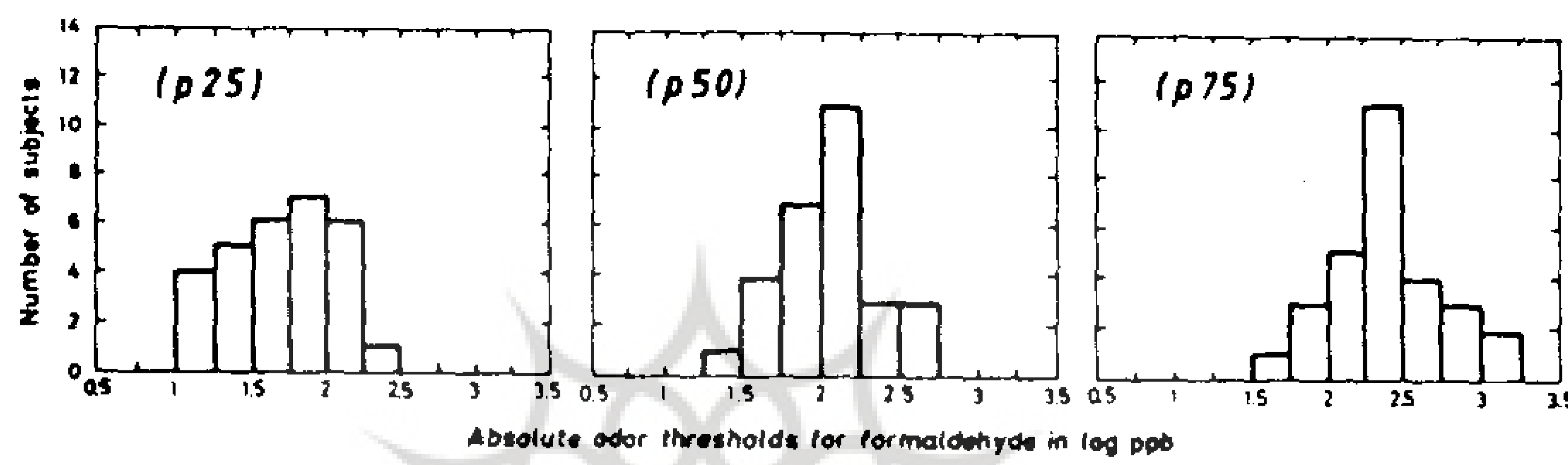


Fig. 8. Formaldehyde odor threshold distributions for 29 subjects at 25% (left-hand digram), 50% (middle digram), and 75% (right-hand digram) probability of detection.

Table 3. Odor detection thresholds (at P0, P25, P50, P75, P100) and interqurtile ranges (P75-P25) expressed in formaldehyde concentration in ppb. The odor detection data were corrected for false alarms (Eq.1) and transformed to z-values and plotted against concentration in log ppb, then regression lines were fit to the transient part of the functions with method of least squares.

**Method for calculating absolute irritation thresholds.** Inspecting the individual psychometric functions for irritation, it is seen that the majority of the subjects did not reach a 100% irritation detection. Thus, assessment of the absolute irritation thresholds for individual subjects would be of dubious value. Therefore, the results for irritation detection were analyzed at the group level. First the arithmetic means of the frequency of irritation detection for the 31 subjects were determined for the 18 formaldehyde concentrations and then these were corrected for false alarms (Eq.1). The absolute irritation threshold was expressed in formaldehyde concentration to the three probabilities of detection, at P25, P50, and P75. The absolute irritation thresholde were calculated from the regression line fitted to the transient parts of the psychometric curve (z-values) for the group data (cf.Fig.7).

The first data point to be included in fitting the straight line (cf.Fig.5, right-hand diagram) is the lowest concentrations of formaldehyde where irritation detection is slightly higher than the falsh alarm rate. A clear growth in irritation detections and formaldehyde concentrations (in log ppb) does not appear until a concentration of 100 ppb (=2 log units) is reached. At concentrations below this level (9 exposure concentrations) the probability of irritation detection is approximately invariant. As concentration increases above 100 ppb, the percentages of irritation detection increasese quite sharply. The growth elicits a rectilinear relationship for irritation detection curve above 100 ppb. Hence, visual inspection of these data reveals that the irritation detection curve conforms to a bisected form while the odor detection conforms to the conventional ogival form. As a consequence, a straight line was fitted to the upper part of the irritation detection curve after that corrections accordins to Eq.1 was made for false alarms at the group level. The absolute irritation threshold was expressed in formaldehyde concentration corresponding to P25, P50, and P75, and they were 212.5, 573.4, and 1547.1 ppb, respectively. The interquartile range (P75-P25) is

1334.6 ppb.

In summary, at high concentrations (=700 ppb) close to the highest concentration used in this experiment, odor detection probability reaches a plateaue at 100% probability of detection while irritation does not show this pattern of growth. The following three possibilities exists: (a) At a much higher concentration than the highest one used in the present study (1000 ppb), irritation detection also reaches a plateaue. (b) The bisected psychometric plot indicates that ther is a shift in the percieved quality of the irritation sensation. At higher concentrations other such shift may appeaar (e.g., shift from irritation to pain). (c) The rectilinear form of the psychometric curve imply that senssory irritation starts abruptly at a higher concentration than odor. In this case there is an odor-irritation break point which represents the point where perceptual irritation content takes precedence over odor content.

**Gender differences in sensitivity**



The 31 subjects were divide in two groups of 14 men and 17 women and the absolute odor thresholds (at P10, P25, P50, P75 & P90) were calculated for both groups. These absolute odor thresholds were in previously mentioned order for the men 31.1, 66.7, 153.8 354.8, and 759.6 ppb and for the women 12.2, 27.6, 67.5, 165.2, and 372.8 ppb. The underlying (average) psychometrice functions for odor detection are shown in the left-hand diagram of Fig.9 where the men's data are given as filled circles and the women's as open circles (the detection data are corrected for false alarms at the individual level). For every formaldehyde concentration the women give a higher probability of detection than the men, and consequeently the five absolute thresholds determined, all are 2.3 times higher for the men than women.

The detection curves for irritation corrected for false alarm rate at the group level are shown in the right-hand diagram·of Fig.9. Also for irritation detections, the women (open squares show a higher sensitivity for irritation than the men (filled squares) as soon as the critical concentration around 100 ppb has been passed. The present findings for formaldehyde show clear gender differences for odor and for irritation detection.

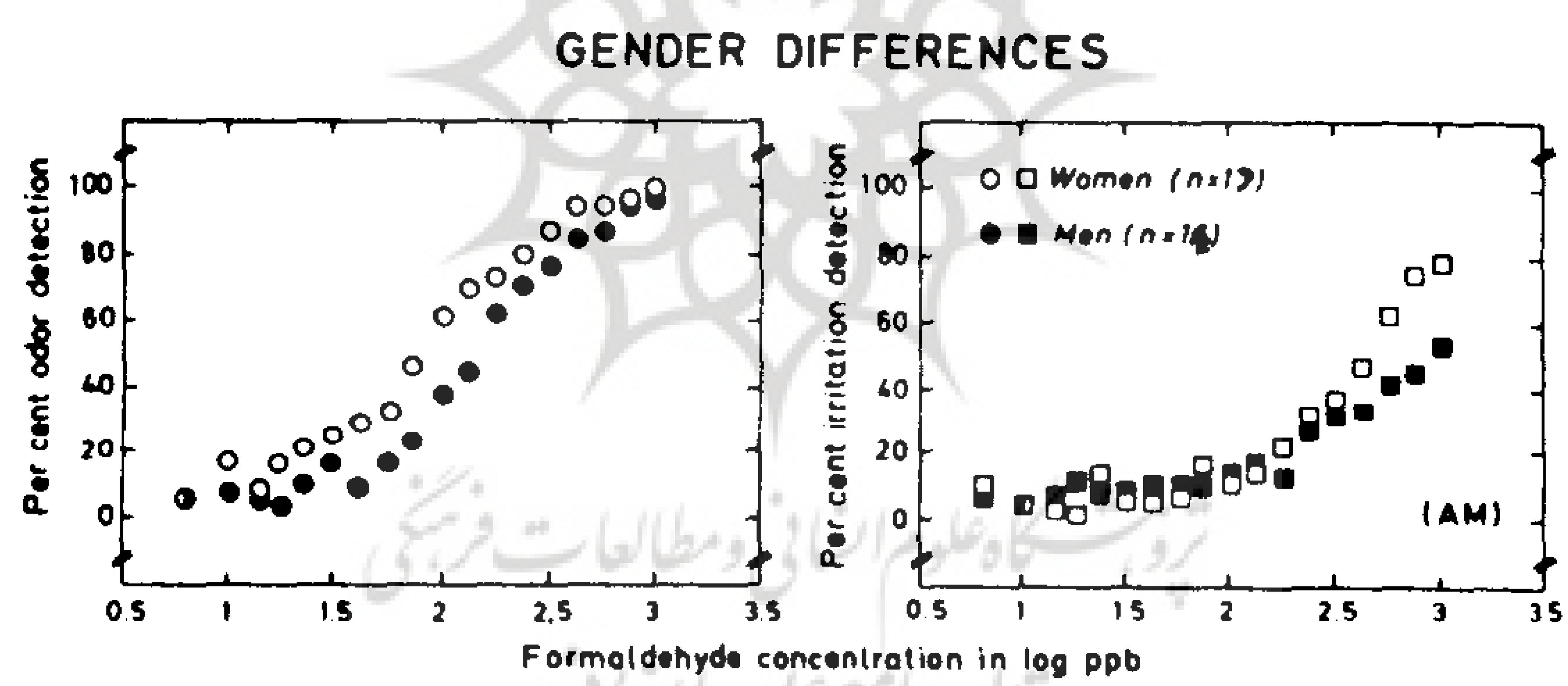


Fig. 9. Psychometeric group functions (AM) for the 17 women and 14 men participating in the experiment. The detection percentages are corrected for individual false alarm rates separately for odor (left-hand digram) and irritation (right-hand digram).

## Conclusions

The pressent findings demonstrate that formaldehyde is an upper airways irritant at concentration as low as 700 ppb. The results also confirm that for formaldehyde odor thresholds are lower than irritation thresholds. The P50-absolute odor thresholds found for formaldehyde is 148.3 ppb.

The psychometric function for formaldehyde odor detection exhibits the common ogival form while that for irritation detection shows a rectilinear form. The irritation detections are close to the corresponding false alarm rates up to a concentration around 100 ppb where an abrupt shift takes place. Above this concentration point the function grows steep, but 100% probability of detection was not reached for the present experimental range (<1000 ppb).

The interindividual variation in absolute odor thresholds is large. Since the irritation detections started for most subjects at a relatively high concentration among the exposure concentrations, individual detection thresholds for irritation could not be determined appropriately. However, dividing the group data according to gender showed that men have significantly higher odor thresholds than women and also steeper rectilinear psychometric functions for irritation compared to the men.

People are able to discern odor from irritation when they are asked to them jointly. The human senses can be used for characterizing indoor air as well as emissions with regars to sensory irritation.

**References**

Ahlstrom, A., Berglund, B., Berglund, U., & Lindvall, T. (1986). Formaldehyde odor and its interaction with the air of a sick building. Environmental International, 12, 289-295.

Akimenko, V.V., Anderssen, I., Lebwits, M.D., & Lindvall, T. (1986). The sick building syndrome. In B. Berglund, U. Berglund, T. Lindvall, & G. Sundell, (Eds.), Indoor Air: Evaluations and conclusions for health and technology (Vol 6, pp. 87-97). Stockholm: Swedish Council for Building Research (D 13: 1986).

Amoore, J.E. (1967). Specific anosmia: A clue to the olfactory code. Nature, 214, 1095-1098.

Anderson, I. (1979). Formaldehyde in the indoor environment. Health implications and the setting of standards. In P. O. Fanger & O. Valbjorn (Eds.), Indoor Climate (pp. 65-87). Copenhagen: Danish Building Research Institute.

Baird, J.C., & Noma, E. (1978). Fundamentals of scalling and psychophysics. New York: Wiley.

Berglund, B., & Lindvall, T. (1986). Sensory reactions to sick buildings. Environment International, 12, 147-159.

Berglund, B., & Nordin, S. (1992). Detectability and perceived intensity for formaldehyde in smokers and non-smokers. Chemical Senses, 17, 291-306.

Berglund, B., Hogman, L., & Johansson, I. (1988). Reliability of odor measurements near threshold. Reports from the department of Psychology, Stockholm university, No. 682.

Berglund, B., Johansson, I., & Lindvall, T. (1986). Research equipment for sensory air quality studies of nonindustrial environments. Environment

International, 12, 189-194.

Berglund, B., & Shams Esfandabad,H. (1992b). A bisensory method for detection of odorous irritants. In G. Borg & G. Neely (Eds.), Fechner Day' 92 (pp. 15-20). Stockholm: International Society for Psychophysics.

Berglund, B., & Shams Esfandabad,H. (1992a). Humans as discerners of odor and irritation. In G. Borg & G. Neely (Eds.), Fechner Day' 92 (pp. 15-20). Stockholm: International Society for Psychophysics.

Cain, W.S. (1974). Contribution of the trigeminal nerve to perceived odor magnitude, Annals of the New York Academy of Sciences, 237, 28-34.

Cain, W.S., & Murphy, C. L.(1980). Interaction between chemoreceptive modalities of odour and irritation. Nature, 284, 255-257.

Cometto-Muniz, G. E. & Cain, W.S. (1991). Influence of airborne contaminants on olfaction and the common chemical sense. In T.V.Getchell, L.M. Bartoshuk, R.L. Doty, & J.B. Snow (Eds.), Smell and taste in health and disease (pp. 287-314). New York: Raven Press.

Engen, T. (1971). Psychophysics I. Discrimination and detection. In G. W. Kling & L. A> Riggs (Eds.). Woodworth and Schlossberg;s experimental psychology (pp.11-46). New York: Holt.

Engen, T. (1986). Perception of odor and Irritation. Environment International; 12; 177-187.

Fasset,D.W.(1962). Aldehydes and acetals. In F.A. Patty (ED.), Industrial hygiene and toxicology (Vol.2,pp.1959-1989). New York: Wiley.

Gemert,L.J.,& Nattenbreijier, A.H. (1977). Compilation of odor threshold value in air and water. Zeits, The Netherlands: Central Institute for Nutrition and Food Research, TNO,

Green, D.m., &Sweats, J.A. (1966). Signal setection theory and psychopysics. New YorkL Wiley.

Kaiser, H.F. (1974). An index of factorial simplicity. Psychometrika, 39,31-36.

Kim, J., & Muller, E.W. (1990). Factor analysis. Statistical methods and practical issues. London: Sage.

Kobal, G., & Hummel, T. (19991). Olfactory evoked potentials in humans. In T.V. Getchell, L.M. Bartoshuke, R.L. Doty, & J.B. Snow, Jr. (EDs.),Smell and taste in health and disease (pp.255-275). New York: Raven Press.

Koster.E.P. (1986). Limitation imposed on olfactometrics by the human factor. In V.C. Nielson, J.H. Voorburg & P.L'Hermite (Eds.), Odour prevention and control of organic sludge and livesstock farming (pp.86-93). New York: Elsevier.

Moncrieff, R.W. (1955). A technique for olfactory, trigminal, and ocular irritations. journal of Experimental Psychology, 7, 128-132.

Niemela, R., & Vainio, H. (1981). Formaldehyde exposure in work and the general environment. Scandinavian Journal of Work, Environment & Health, 7, 95-100.

Nordin, S. (1992). On psychophysical evaluation of olfactory sensitivity in health and disease. Reports from the Department of Psychology, Stockholm University, No 746.

Punter, P.H. (1983). Measurment of huyman olfactory thresholds for several groups of strucurally related compounds. Chemical Senses, 7, 215-235.

Schuck, E.A., Stephans, E.R., & Middleton, J.T.(1966). Eye irritation response at low concentration of irritants. Archives of Environmental Health, 13, 570-575.

Stevens, J.c., Cain, W.S., & Burke, R.J. (1988). Variability of olfactory thresholds. Chemical Senses, 13, 643-653.

Stolwijik, J.A.J. (1984). The 'sick building' syndrome. In B. Berglund, T. Lindvall, & J. Sundell (Eds.), Indoor Air (vol. 1, pp. 23-29). Stockholm: Swedish Council for Builiding REsearch (D16:1983).

Tucker, D. (1971). Nonolfactory responses from the nasal cavity: Jacobson's organ and the trigminal system. In L.M. Beidler (Ed.), Handbook of sensory physiology. Chemical senses. Part 1: Olfactory (vol. 4,pp.151-181). Berlin: Springer Verlag.

World Health Organization (1983). Indoor air pollutants exposure and health effects. Copenhagen: WHO Regional Office of Europe, EURO Reports and studies No. 78.

World Health Organization. (1989). Formaldehyde. Geneva: WHO, Environmental Health criteria 89.