

# Evaluation of Combined Effect of Organic Solvents and Noise by the Upper Limit of Hearing

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**Abstract:** To clarify the combined effects of organic solvents and noise on hearing, the upper limit of hearing was measured in 48 male workers exposed to organic solvents and/or noise in a factory producing plastic buttons. Measuring the organic solvent concentrations in working environments and breathing zone air, and the noise level in workplaces were also done. The readings suggested that most exposures to organic solvents and/or noise were within the occupational exposure limits. The prevalence rate of the upper limit of hearing below 75 th percentile curve was higher in workers exposed to organic solvents and noise than expected (25 percent) and the other groups, whereas it was about 25 percent in the noise and control groups. The results suggest that the probable combined effects of organic solvents and noise on hearing should be considered even when the exposures are within the occupational exposure limits.

**Key words:** Combined effect, Organic solvents, Noise, Upper limit of hearing, Hearing loss

## Introduction

Hearing impairment of workers is often caused by several factors, including age, heredity and exposure to ototoxic substances in working environments. The exposure to noise is the most common cause of hearing impairment and causes hearing loss in workers exposed to intensive noise. In working environments where organic solvents are used, noise is also common. Thus, ototoxicity of an organic solvent has a probable interaction with noise under such environments. Some animal studies have shown the interaction between organic solvents and noise<sup>1–3</sup>. Some epidemiological studies on combined effects of organic solvents and noise have also shown that the prevalence of hearing impairment found in the combined exposure group is larger than in other groups (noise group, solvents group and control group)<sup>4–6</sup>. In these studies, even though the noise level is relatively low, organic solvent concentrations are relatively high. Limited information is available on the

combined effects of organic solvents and noise at a relatively low level. This is partially because conventional audiometry might not be a sensitive indicator of hearing impairment due to combined exposure to organic solvents and noise.

Recent research in our laboratory, in which we have measured the upper limit of hearing with fixed intensity and changing frequency, has led us to conclude that the upper limit of hearing is the best indicator for evaluating age-related changes in hearing<sup>7</sup>. Moreover, we have clarified the clinical usefulness of the upper limit of hearing in detecting noise-induced hearing loss and styrene-induced hearing loss before they are identified by conventional audiometry<sup>8,9</sup>. The present study was designed to clarify the combined effect of organic solvents and noise on the upper limit of hearing in workers occupationally exposed to both organic solvents and noise at relatively low level.

## Subjects and Methods

### Subjects

Fifty-four male workers aged 20 to 68 years in a factory

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were studied. Table 1 gives the distribution of age and working careers of the subjects. The mean age and standard deviation were  $35.8 \pm 12.0$  years of age. The subjects had kept the same job. The average working career was  $6.5 \pm 5.0$  years.

The subjects were divided into three groups: combined group (n=23), noise group (n=19) and control group (n=12). The subjects in the combined group were engaged in the polymerization of unpolymerized resin for producing plastic buttons. They were exposed to noise in the working environment and vapors of styrene (monomer) contained in about 30 percent of polystyrene resin, methanol and methyl acetate used for washing instruments. They wore protective gloves (but no mask) during their work, so that the risk of skin penetration of organic solvents was slight. The subjects in the noise group were engaged in the production of plastic buttons from polymerized resin and were exposed to noise in the working environment. The subjects in the control group were in the office exposed to neither organic solvents nor noise.

Six subjects (4 in the combined group, 1 in the noise group, and 1 in the control group) were excluded from the analysis because they showed hearing impairment due to ototoxic drugs or otological diseases.

#### *Organic solvent concentrations in working environments and breathing zone air*

Diffusive samplers of 3 different types were employed for measuring organic solvent concentrations in the working environment and breathing zone air. Styrene concentration was measured with a box-type sampler equipped with carbon cloth (Toyobo, KF-1500); one-half of the exposed carbon cloth was extracted with carbon disulfide for measuring styrene<sup>10</sup>. The remaining half was extracted with water to examine the performance of carbon cloth in absorbing methanol and acetone<sup>11</sup>. Methanol concentration was measured by means of a syringe-type sampler with water as the absorbent<sup>12</sup>. Methyl acetate was measured with a tube-type sampler containing silica gel<sup>13</sup>.

To evaluate the level of exposure to mixed organic solvents, the assessment criterion for multiple organic solvents (hereafter referred to as  $E_m$ ) is given by the following equation:

$$E_m = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_i}{T_i} + \dots + \frac{C_n}{T_n}$$

where  $C_i$  represents concentrations of the respective substances and  $T_i$  represents the threshold limit value of the respective substances. According to ACGIH,  $E_m$  should not exceed 1.

**Table 1. Distribution of age and working careers of the subjects**

Working Careers (years)	Age (years)			
	20 ~ 29	30 ~ 39	40 ~ 49	50 ~
~ 5	8	5	5	1
5 ~ 10	9	5	3	1
10 ~ 15	2	3	1	1
15 ~ 20				1
20 ~ 25			1	2
Total	19	13	10	6

#### *Sound pressure level in workplaces*

The sound pressure level in the factories was recorded at 183 measurement points in the workplaces with a data recorder (TEAC R-61) on the day when the subjects were examined. A-weighted sound pressure level (dB(A), LAeq, 10 min) at each measurement point was then calculated with 1/3 octave band real-time analyzer (RION SV-73). The contour figure of the sound level in each workplace was drawn for the purpose of estimating the sound level to which the subjects were exposed in each workplace.

#### *Measuring the upper limit of hearing and hearing level*

New equipment (Matsushita Inter-Techno ME3116) was used for measuring the upper limit of hearing<sup>14</sup>. The test tonal stimuli were generated continuously with a function generator set to produce stimuli from 0.5 to 50 kHz. The stimulus output was monitored by means of a frequency counter. The stimuli were passed through an attenuator to an amplifier, the output of which was fed into a headphone. The headphone was constructed of an ear-cap, an adapter and a 0.5 inch condenser microphone (Bruel and Kjaer 4134), fitted tightly in the center of the cavity. It was coupled to the subject's head in the conventional manner. Its output sound pressure level was constant at  $75 \pm 10$  dB within the frequency range 0.5 to 25 kHz.

The headphone was fitted on the test ear so that the subject could hear comfortably, and an earmuff of the same shape was put on the opposite ear. Output frequency was gradually and continuously changed from high frequency, which the subjects were unable to perceive as a tone, to low frequency. The upper limit of hearing was the frequency that the subjects first perceived as a tone, and it was shown on the frequency counter of the equipment. After three to five trials, if the results showed little variation, the upper limit of hearing was the median value of the five measurements.

Conventional audiometry was carried out with audiometers

**Table 2. Distribution of the organic solvent concentrations in breathing zone air in the combined group**

	Logarithmic mean concentration (min.-max.) (ppm)	Occupational exposure limit (ppm)	Number of workers exceeding occupational exposure limit
Styrene	22.4 (3.7–46.3)	50	0
Methanol	23.7 (2.9–135)	200	0
Methyl acetate	24.6 (2.5–93.8)	200	0
Em	0.76 (0.13–1.52)	1	8

(RION, AA-68N) to test the air conduction threshold. Regular electronic calibrations were conducted on each audiometer to JIS-T1201 standards<sup>15)</sup>. Standards for the minimum threshold of hearing in JIS-T1201 correspond to the W.E.705A values enumerated in ISO 389-1975. The ascending threshold technique was used to determine hearing levels at the audiometric frequencies of 0.5, 1, 2, 4 and 8 kHz<sup>16)</sup>.

Measurements were taken in a quiet room in the morning as soon as the subjects came to the factory, when they had not as yet been exposed to either organic solvents or noise on the day.

## Results

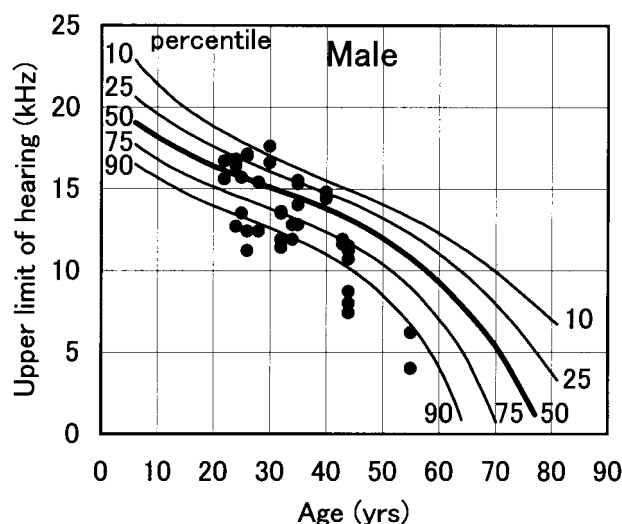
### Organic solvent concentrations

Organic solvent concentrations in the working environments were 2.9–28.9 ppm in styrene, 4.7–34.3 ppm in methanol and 9.1–69.7 ppm in methyl acetate. They were all below their working environment evaluation standards by Japanese Ministry of Labour.

Organic solvent concentrations in the breathing zone air in the combined group are summarized in Table 2 as the time-weighted average (TWA) concentration. No subject was exposed to levels in excess of the occupational exposure limit for organic solvents, shown as TLV-TWA by the Japan Society for Occupational Health<sup>17)</sup>. The Em exceeded the criterion of 8 in 19 subjects. The level of exposure to organic solvents was, however, assessed as relatively low.

### Sound pressure level in workplaces

The sound pressure levels (LAeq, 10 min) ranged from 58 to 92 dB(A). Fifty-five of 183 measurement points (30%) showed a sound level in excess of 85 dB(A). The combined group was continuously exposed to sound at 69 to 76 dB(A). The noise group was continuously exposed to sound at 82 to 86 dB(A). The control group was exposed to sound at 58 to 62 dB(A). The level of exposure to sound was also assessed as relatively low.



**Fig. 1. Age variation in the upper limit of hearing of the subjects in the combined group and standard upper limit age curves in males.** Closed symbols indicate measured data for the subjects.

### Upper limit of hearing

The upper limit of hearing of the ears of subjects in the combined group was compared with the standard upper limit age curves for males (Fig. 1). Some results were distributed below the 90th percentile curve, but only a few results were distributed over the 10th percentile curve. They were distributed to a significant ( $p < 0.05$ ) degree below the 75th percentile curve.

Figure 2 shows the prevalence rate of cases where the upper limit of hearing falls below the 75th percentile curve in each group. The prevalence rate in the combined group was significantly ( $p < 0.05$ ) higher than 25 percent and than the other two groups. The prevalence rates in the noise and control groups were about 25 percent.

The relationships between the upper limit of hearing and levels of exposure were analyzed in the combined group. No significant correlation was found between individual percentiles of the upper limit of hearing and working careers

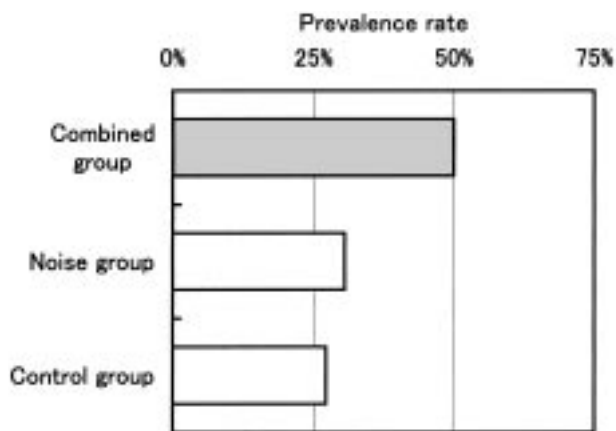


Fig. 2. Prevalence rates of cases where the upper limit of hearing falls below the 75th percentile curve in the three groups.

The shaded column shows significantly ( $p < 0.05$ ) more than 25 percent.

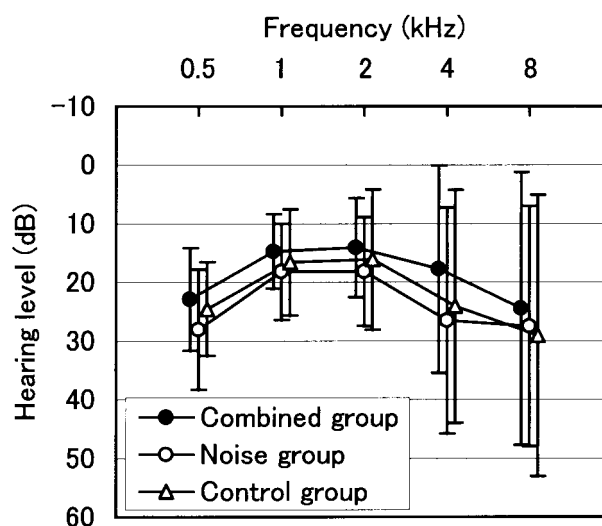


Fig. 3. Mean hearing levels at each frequency in the three groups. Error bars indicate  $\pm 1$  standard deviation about each mean.

( $r=0.224$ ,  $p>0.1$ ). There was a highest correlation between individual percentiles of the upper limit of hearing and styrene concentrations in breathing zone air ( $r=0.231$ ), but it was not significant ( $p>0.1$ ). No significant correlation was found between individual percentiles of the upper limit of hearing and organic solvent concentrations in the working environments or the breathing zone air.

#### Hearing levels

The mean hearing levels at each frequency were computed for the three groups. The mean age was  $33.8 \pm 9.0$  years of age in the combined group,  $33.2 \pm 11.1$  years of age in the noise group, and  $43.6 \pm 15.1$  years of age in the control group. The mean age of the control group was significantly ( $p < 0.05$ ) higher than that of the other two groups, but the mean hearing level at each frequency showed little difference in the three groups (Fig. 3). In the noise group, there was a tendency of 4 kHz-dip.

#### Discussion

It was made clear that the reduction of the upper limit of hearing was largest in the combined group. This indicates a probable combined effect of organic solvents and noise even when most exposures to organic solvents and/or noise were within the occupational exposure limits.

The combined effects of organic solvents and noise have been studied in the field of occupational exposure. Increased prevalence of hearing impairment has been reported after exposure to organic solvents in the presence of a noise level below the occupational exposure limit value<sup>5,6</sup>. In a study

by Morata *et al.*<sup>18</sup>, simultaneous exposure to noise and mixed organic solvents in which benzene was the major component significantly affected conventional audiometric thresholds among refinery workers, even though measurements of the working environments suggested that most exposures to organic solvents and noise were within the occupational exposure limits recommended by international agencies. Their findings show the combined effects of organic solvents and noise at a relatively low level.

Conventional audiometry is often carried out on workers exposed to organic solvents and noise in factories. In this study, however, no significant finding was obtained. In a study to examine the relationship of hearing impairment, age, and exposures to noise (87.2 dB(A)) and styrene (geometric mean: 23.0 ppm), hearing acuity was assessed in 299 workers in the fiber-reinforced plastics manufacturing industry<sup>19</sup>. No consistent relationship was found with cumulative noise or styrene exposure and conventional audiometric thresholds. Age was, however, positively correlated with hearing loss. Age, as a probable confounding factor may be a problem in studies on occupational hearing impairment estimated by means of conventional audiometry. The treatment of the age factor in the analysis should be recommended in some cases in which exposure to organic solvents and noise is within the occupational exposure limits.

The standard aging curves of the upper limit of hearing have enabled us to examine the ototoxic factors without the treatment of age factor in the analysis. Moreover, interest in the upper limit of hearing lies in the fact that hearing thresholds at high frequencies are more vulnerable to ototoxic

factors than those at lower frequencies. In recent years, the upper limit of hearing has been used for early detection of ototoxic factors, such as noise and styrene<sup>8,9</sup>. In this study, the lowering of the upper limit of hearing was largest in the combined group.

In the noise and control groups, the prevalence of cases in which the upper limit of hearing was below the 75 th percentile curve corresponded to the expected value (25%). The noise level (82–86 dB(A)) had no effect on the upper limit of hearing. In the styrene group occupationally exposed to styrene (0.1 to 91.6 ppm) and unexposed to noise, the prevalence rate was 35%<sup>9</sup>. Even if workers were exposed to styrene alone, their upper limit of hearing was reduced. The prevalence rate was increased, but it was 35 % at most. In the combined group, the prevalence rate was highest (50%). This study has therefore suggested the probable combined effect of organic solvents and noise even at a relatively low level on the upper limit of hearing.

We have failed to find a relationship between the reduction of the upper limit of hearing and working careers or organic solvent concentrations. This might be because of the short working careers and the organic solvent concentrations involved.

In our previous study on the effect of styrene on the upper limit of hearing, the upper limit of hearing was lowered in workers exposed to more than 16 ppm styrene for 5 years or more<sup>9</sup>. In this study, because the workers in the combined group were exposed to 22.4 ppm (logarithmic mean) for 5.4 years, the conditions might not represent a “relatively low” level of exposure to styrene. Much research is needed for defining a “relatively low” level exposure to styrene.

In conclusion, the findings obtained in this study show that we must pay attention to the hearing of workers exposed to organic solvents and noise, even though most exposures are within the occupational exposure limits. The lowering of the upper limit of hearing is one of the early clinically detectable signs of health effects of combined exposure to organic solvents and noise on workers. Consequently, the upper limit of hearing is recommended as a routine procedure for workers occupationally exposed to organic solvents and noise.

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