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High-Frequency Hearing Risk of Operators of Industrial Ultrasonic Devices

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Summary. Sound and ultrasound emitted by industrial ultrasonic (Uls) devices exceed the known proposed hygienic limits, especially for frequencies 10–20 kHz. The consequence of this may be a negative influence of this energy on the auditory function in the high-frequency hearing range. To determine the hearing risk to Uls operators, an adequate method for testing the hearing threshold from 10–20 kHz has been developed. In order to get reference values, 189 non-exposed persons were tested. On this basis, the hearing thresholds of 55 operators for frequencies 500–20,000 Hz were evaluated. In addition to threshold elevations in the range 10–20 kHz, a decreasing number of subjects responding to stimuli at the highest audible frequencies was observed. The threshold shift at 10–20 kHz of subjects exposed to sound and ultrasound emitted by Uls-devices depends upon the physical parameters of the sound spectrum, time on the job and daily exposure time. No abnormalities were found in the hearing range 500–8000 Hz.

Key words: High-frequency hearing – High-frequency audiometry – Hearing loss – High-frequency noise

Introduction

One-third-octave-band sound levels measured in the vicinity of 123 industrial ultrasonic (Uls) cleaners, welders and drills [8] show above 10 kHz higher values than accepted by known proposed exposure criteria [1, 2, 7, 11]. Consequently this energy may impair the hearing of workers operating such devices, especially in the range 10–20 kHz.

Despite many years of work undertaken to develop instruments and methods, no standardized equipment is available. Also problems, such as calibration procedure, audiometric standards and presbycusis values for this hearing range have not been solved [3, 5, 6, 10, 13]. To determine the hearing risk to Uls operators, an adequate method for testing the hearing threshold from 10–20 kHz has been developed, and in order to get reference values, a non-exposed control group was tested.

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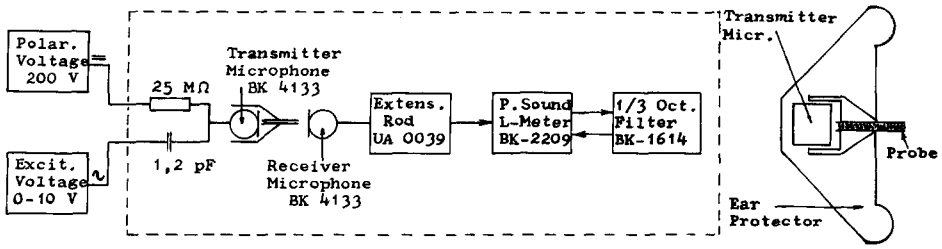

Fig. 1. High frequency test system in calibration condition

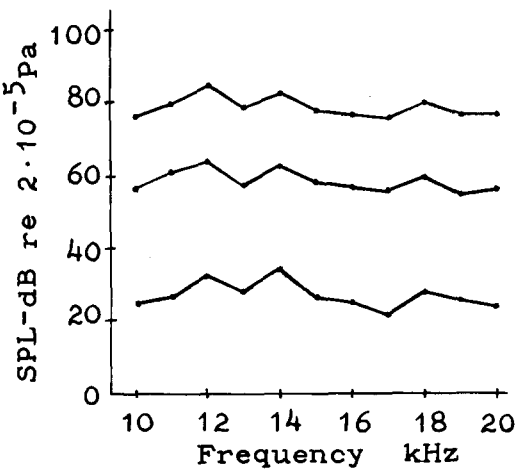

Fig. 2. Test-probe frequency characteristics at three different power levels

Material and Methods

The high-frequency pure tone system used consists of the Brüel and Kjaer (BK) beat frequency oscillator type 1022 (source of the sinusoidal signal), BK microphone amplifier type 2603 (source of the polarisation voltage) and an ear-protector TD-1A with a built-in special electro-acoustic transducer.

As transducer works a ½-inch (ca. 1.3 cm) BK condenser microphone type 4133 with a flat response up to 20 kHz that is enclosed within the BK adaptor DB 0243 and connected with a probe, which is 4 mm diameter and 50 mm in length. The microphone is converted so that it can transform electrical signals into acoustical ones [14]. The probe, filled with steel wool, couples the transducer to the ear allowing the test stimuli to enter the external ear canal. The non-tested ear is covered with a similar ear protector without a transducer.

Figure 1 shows the measuring arangement in calibration condition. The receiving BK microphone type 4133, linked to the BK ⅓-octave filter type 1614 and the BK sonometer type 2209, is kept 5 mm in front of the output of the test probe. The total arrangement is placed in a soundproof chamber and operated from outside. The readings were from 20 to 85 dB in 2.5 dB steps, for frequencies from 10 to 20 kHz, in 1 kHz steps. The highest achievable sound pressure level at the tip of the probe was 85 dB. Figure 2 illustrates examples of test-probe frequency characteristics at three different power levels.

Table 1. Median hearing threshold (dB) of normal hearing subjects (control group) in the range 500–10,000 Hz. R: right ear. L: left ear

	Frequency (kHz)																				
	0.5			1			2			4			6			8			10		
	R	L	RL	R	L	RL	R	L	RL	R	L	RL	R	L	RL	R	L	RL	R	L	RL
Age group I (17–19 years), 33 females, 30 males																					
Females	4	4	4	2	0	1	0	0	0	1	0	1	2	2	2	0	0	0	5	5	5
Males	4	4	4	1	1	1	0	−2	−1	1	1	1	0	−2	−1	−2	−1	−1	5	5	5
Age group II (20–29 years), 33 females, 30 males																					
Females	8	7	8	6	4	5	2	2	2	4	3	4	5	3	3	2	2	2	6	5	5
Males	8	8	8	5	5	6	4	5	5	5	5	5	1	4	1	4	3	3	7	8	7
Age group III (30–39 years), 30 females, 9 males																					
Females	11	9	11	9	7	8	7	6	6	9	9	9	6	6	6	7	8	7	10	9	10
Males	9	9	9	7	6	7	6	5	5	7	6	7	6	8	8	8	9	9	12	15	15
Age group IV (40–49 years), 13 females, 11 males																					
Females	16	15	15	13	12	13	12	10	11	16	17	17	14	20	19	17	11	14	22	28	24
Males	11	11	11	11	9	9	10	8	9	20	11	13	6	8	7	9	12	12	17	22	19

Table 2. Median thresholds (dB-SPL) of normal hearing subjects (control group) in the range

	Frequency (kHz)														
	10			11			12			13			14		
	R	L	RL	R	L	RL	R	L	RL	R	L	RL	R	L	RL
Age group I (17–19 years), 33 females, 30 males															
Females	23	20	21	26	25	25	26	27	26	28	27	28	33	34	33
Males	22	20	20	26	23	25	29	26	27	29	26	27	31	34	32
Age group II (20–29 years), 33 females, 30 males															
Females	21	20	21	25	22	25	26	26	26	33	27	30	39	36	37
Males	23	21	22	23	23	23	28	27	27	29	32	29	35	38	36
Age group III (30–39 years), 30 females, 9 males															
Females	25	26	25	31	31	31	32	33	32	35	35	36	47	48	48
Males	28	34	30	33	38	35	36	42	37	37	44	41	51	55	52
Age group IV (40–49 years), 13 females, 11 males															
Females	36	38	37	47	52	48	57	58	58	62	76	70	67	78	75
Males	28	29	28	29	31	31	43	36	40	58	36	50	64	58	61

x = less than 5 ears

Control Group

The control group consisted of 189 otologically normal persons with no occupational noise exposure (nurses, medical assistents, technicians) and no experience of impair hearing system (head injuries, ototoxic drugs, infections, etc.). Four age groups were formed.

Age group	Age range (years)	Number of subjects	
		Males	Females
I	17–19	30	33
II	20–29	30	33
III	30–39	9	30
IV	40–49	11	13

The hearing thresholds for frequencies 500 Hz to 10,000 Hz were examined with a clinical audiometer (Peters AP-6) twice on consecutive days. The threshold sound pressure levels (SPL) for frequencies 10–20 kHz were determined three times on consecutive days. The examinee was placed in an anechoic chamber.

Operators of Ultrasonic Devices

Before work, 84 operators employed in six factories were tested twice. They were placed in a sound insulated room in the factory's polyclinic. Excluding operators with otological changes and burdening anamnesis, 55 subjects were finally analyzed.

10–20 kHz. R: right ear. L: left ear

Frequency (kHz)																	
15			16			17			18			19			20		
R	L	RL	R	L	RL	R	L	RL	R	L	RL	R	L	RL	R	L	RL
40	37	39	46	47	46	60	58	59	73	73	73	78	78	78	x	82	82
36	42	40	50	50	50	68	60	63	71	70	70	75	82	80	82	x	82
48	47	47	61	57	58	72	72	72	80	81	80	83	84	83	84	84	84
45	50	46	52	63	58	66	68	68	78	76	77	79	83	81	x	x	83
62	63	63	78	76	78	82	81	82	83	84	84	x	x	84	(–)	(–)	(–)
70	76	73	79	81	81	x	x	x	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)
82	x	82	x	x	x	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)
73	76	74	84	x	84	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)

Table 3. Percentage of subjects (control group) responding at 10–20 kHz

Total number	Age group	Frequency (kHz)										
		10	11	12	13	14	15	16	17	18	19	20
63	I	100	100	100	100	100	100	100	94	67	37	14
63	II	100	100	100	100	100	100	100	80	58	30	13
39	III	100	100	100	100	97	95	83	44	22	12	–
24	IV	100	100	100	86	70	57	30	–	–	–	–

Results

Control Group Data

Results regarding the four age groups, expressed as median thresholds for right and left ears and for both ears of males and females are presented in Tables 1 and 2. Table 3 shows the percentage of subjects responding in the range 10–20 kHz at the highest available sound pressure level 85 dB. These data are similar to results published by Rosen et al. [12] for three urban populations (Table 4).

No significant threshold elevations in the hearing range examined (500–10,000 Hz) and also no significant differences between right and left ears and between males and females in the range 500–20,000 Hz were observed in the age groups I and II. In the range 10–20 kHz, a two-segmental hearing sensitivity curve

Table 4. Percentage of subjects (control group) responding at 10–20 kHz compared with data published by Rosen et al. for three urban populations

Age	Source of data	Population	Frequency (kHz)				
			12	14	16	18	20
17–19	Authors	Silesia District	100	100	100	67	14
10–19	Rosen et al.	New York	100	100	100	95	55
		Düsseldorf	99	100	97	82	33
		Kair	100	100	98	81	24
20–29	Authors	Silesia District	100	100	100	58	13
	Rosen et al.	New York	100	99	96	62	12
		Düsseldorf	100	100	84	50	9
		Kair	99	99	90	67	13
30–39	Authors	Silesia District	100	97	83	22	–
	Rosen et al.	New York	98	90	61	16	–
		Düsseldorf	95	89	61	16	2
		Kair	99	92	68	26	1
40–49	Authors	Silesia District	100	70	30	–	–
	Rosen et al.	New York	95	70	28	7	–
		Düsseldorf	82	69	16	2	–
		Kair	94	75	35	4	2

Table 5. Median thresholds (dB-SPL) at 10–20 kHz of normal hearing subjects compared with results published by Erickson et al.

Source of data	Number of subjects	Age (years)	Frequency (kHz)										
			10	11	12	13	14	15	16	17	18	19	20
Erickson et al.	30	18–27	18	21	19	23	25	29	31	34	42	61	83
Own	33	17–29	18	22	23	24	26	30	34	43	63	75	83

is noted. The first segment from 10–14 kHz (age group I) and 10–13 kHz (age group II) shows a weaker slope, and the second, from 14 or 13 kHz, a much stronger one.

Table 5 presents median thresholds (dB-SPL) from 10–20 kHz in comparison with data published by Erickson et al. [4]. In order to get a sample similar to Erickson's population, the 33 best ears responding in the whole range tested (10–

Table 6. Mean and median hearing threshold levels (dB) at 500–8,000 Hz. Control group (C) and operators of Uls-devices (OP) in 3 age groups. Right and left ears are combined

Age group	Number of subjects			Frequency (kHz)											
				0.5		1		2		4		6		8	
	C	OP		C	OP	C	OP	C	OP	C	OP	C	OP	C	OP
II	63	16	Mean	7	9	6	8	3	4	5	6	4	4	3	2
			Median	8	10	5	8	3	5	4	4	2	5	3	2
III	39	22	Mean	10	13	8	12	7	8	9	9	9	11	9	9
			Median	9	13	7	13	6	8	8	8	6	8	8	8
IV	24	17	Mean	14	15	12	14	11	11	15	12	14	19	13	18
			Median	12	14	11	14	10	9	15	12	12	16	12	17

20 kHz) were selected from groups I and II. The results obtained are close (0–4 dB) to those presented by Erickson et al. for frequencies 10-16 kHz. In the range 17-20 kHz, the differences are larger (up to 21 dB at 18 kHz), and may be due to the methods used.

In age group III, the difference between right and left ears is 0-3 dB (range 500-10,000 Hz) and 0-7 (range 10-20 kHz). Between males and females, the relevant values are 1-5 dB (range 500-10,000 Hz) and 3-10 dB (range 10-20 kHz).

In age group IV, the differences between right and left ears and males and females are greater. The median hearing level of males and females in the range 500-10,000 Hz is elevated up to 15 dB (age group III) and up to 28 dB (age group IV). Also in the range 10-20 kHz, a two-segmental hearing sensitivity was noted with a weaker slope from 10-13 kHz (age group III) and 10-11 kHz (age group IV), and a stronger one from 13-18 kHz (age group III) and 11-16 kHz (age group IV).

Uls Operators

Table 6 presents the age related mean hearing threshold level of Uls operators and of the control group in the range 500-8,000 Hz, whereas Table 7 shows the sound pressure level (dB-SPL) in the range 10-20 kHz.

No significant differences between the mean hearing threshold of Uls operators and the control group were observed in the range 500-8,000 Hz, but differences were found in the range 10-20 kHz.

Age Group II

The time on the job of Uls operators belonging to group II was up to 5 years. Fifteen operated Uls-cleaners and one an Uls-welder. The mean SPL of both groups (Uls-operators and controls) shows no essential differences. Only a slight decrease of the percentage of operators responding at frequencies 16-20 kHz was found (Table 7), compared with control group data.

Table 7. Mean threshold levels (dB-SPL) at 10-20 kHz, standard deviations (SD) and percentages of Right and left ears are combined

	Frequency (kHz)									
	10		11		12		13		14	
	C	OP	C	OP	C	OP	C	OP	C	OP
Age group II										
Mean	22	23	25	25	27	28	31	31	38	37
%	100	100	100	100	100	100	100	100	100	100
Age group III										
Mean	26	34	31	37	34	41	39	46	48	54
SD	7.8	17.4	7.5	19.7	9.0	17.6	12.4	19.3	14.7	20.9
%	100	100	100	100	100	95	100	93	97	91
Age group IV										
Mean	34	39	42	47	49	54	56	64	64	70
SD	11.9	15.9	14.4	16.2	17.4	12.1	19.1	15.1	16.7	13.9
%	100	100	100	100	100	94	87	91	65	65

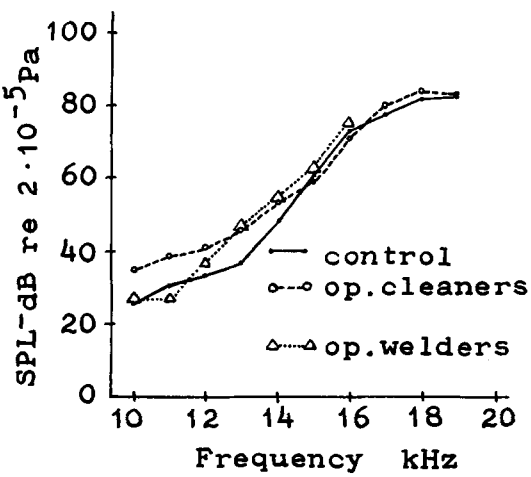

Fig. 3. Mean SPL-dB of control group and Uls-operators. Age group III (30–39 years)

Age Group III

The time on the job of operators in age group III was up to 17 years. A slight increase (7-12 dB) of the mean SPL of the exposed group compared with the control group does exist in the range 10-13 kHz. There is also a decrease of the percentage of operators responding at 12-17 kHz (Table 7).

Since age group III consisted of operators of cleaners (18 workers) and welders (4 workers), the mean SPL of these two sub-groups were compared separately. The results related to the three groups (control group, operators of cleaners and operators of welders) are illustrated in Fig. 3. A significant elevation of the mean

subjects responding at tested frequencies. Control group (C) and operators (OP) in three age groups.

Frequency (kHz)											
15		16		17		18		19		20	
C	OP	C	OP	C	OP	C	OP	C	OP	C	OP
49	47	60	56	68	63	76	75	81	76	83	84
100	100	100	97	80	78	58	53	30	19	13	13
63	62	73	73	77	80	81	83	84	83	–	–
14.7	15.1	12.3	11.4	10.5	9.6	4.1	2.2	2.1	2.2	–	–
95	70	83	53	44	33	22	23	12	12	–	–
73	76	82	82	–	–	–	–	–	–	–	–
11.9	6.1	5.8	4.4	–	–	–	–	–	–	–	–
54	32	28	15	–	–	–	–	–	–	–	–

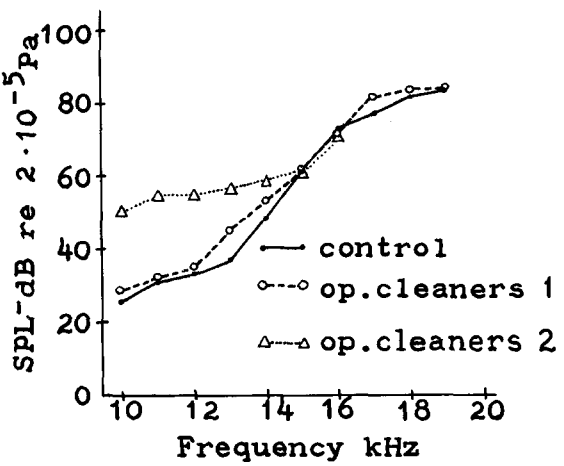

Fig. 4. Mean SPL-dB of control group and cleaner-operators with different time on job. Age group III (30–39 years)

hearing threshold (increase of the mean SPL—7–9 dB) of operators of cleaners can be seen in the range 10–13 kHz. In the sub-group of welders, only the highest frequency of the hearing range decreases to 16 kHz in comparison to 19 kHz of the control group and operators of cleaners.

The time on the job of cleaner-operators was up to 17 years. By dividing them into two sub-groups, the first with experience of up to 7 years, the second from 13-17 years (Fig. 4), it can be seen that the mean threshold SPL of the first sub-group does not differ from that of the control group. In the second sub-group it

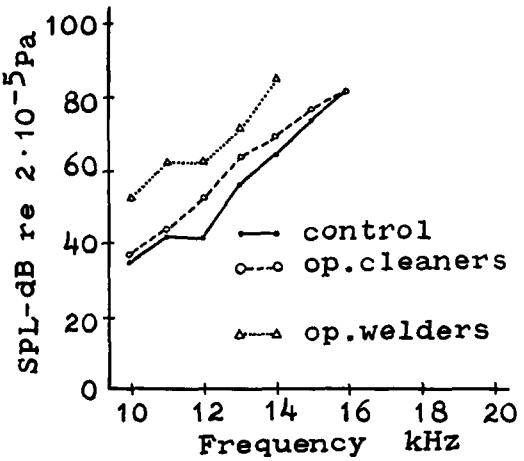

Fig. 5. Mean SPL-dB of control group and Uls-operators. Age group IV (40–49 years)

increased significantly (about 20-25 dB) in the range 10-13 kHz. Also the highest frequency of the hearing range decreases to 16 kHz in comparison to 19 kHz of the control group and the first sub-group with a shorter time on the job.

Age Group IV

The time on the job in this group was up to 7 years. There were 13 operators of cleaners and 4 of welders. Their mean treshold SPL differs about 5-9 dB in the range 10-13 kHz from that of the control group (statistically significant only at 13 kHz7).

Comparing the mean threshold SPL of operators of cleaners and operators of welders separately (Fig. 5), no or only insignificant differences are found between operators of cleaners and the control group. In the case of welder-operators the hearing threshold is elevated about 10-20 dB in the range 10-14 kHz, but only at 10 and 11 kHz is the difference statistically significant. Also a drop of the highest frequency of the hearing range to 14 kHz in comparison to 16 kHz of the control group and cleaner-operators is evident.

Discussion

The results presented determine the age-related hearing threshold in the range 10-20 kHz of persons with no occupational noise exposure and no experience of impaired hearing. Comparing these data with results published by Rosen et al. [12] and Erickson et al. [4], a good agreement could be established.

The auditory function in this range shows an age depending two-segmental hearing threshold. No differences could be found in the range 500-20,000 Hz between right and left ears and males and females, up to an age of 30 years.

The hearing ability of 55 Uls-operators tested revealed a statistically significant elevation of the hearing threshold in the range 10-20 kHz and a decrease of the percentage of persons tested responding at the highest frequency.

Operators of welders and cleaners showed different threshold shifts. This may be explained by specificities of the acoustic spectrum to which the two sub-groups are exposed to. The fundamental frequency of ultrasonic cleaners is 25 or 28 kHz. The sound pressure level measured at the operator's stand point was the highest in the range of the fundamental frequency (100-116 dB), but its sub-harmonic frequency at 12.5 or 14 kHz caused in the range 10-16 kHz sound pressure levels (80-102 dB) exceeding the proposed critical values. This may explain the increase of the threshold SPL of operators of cleaners at 10-13 kHz.

The basic frequency of welders was, in our case, 21 kHz and the highest sound pressure levels, which exceeded critical values, were measured at frequencies of 20 and 16 kHz (106 dB and 90 dB respectively). This burdens the hearing particularly at the highest frequencies and may cause a loss of hearing sensitivity at those frequencies.

Taking into account results related to the two sub-groups of cleaner-operators with a short (up to 7 years) and long (13-17 years) time on the job, it may be concluded that the hearing sensitivity of operators of Uls-devices depends not only on the character of the acoustic spectrum, but also on the time on the job.

The elevation of the mean threshold SPL and decreased responding at the highest frequencies of welder operators in comparison with those of cleaners (with the same time on job) can be explained, besides the somewhat dissimilar acoustic spectra, by different daily exposure time. The nominal daily exposure time of operators of welders is eight-hours, while that of cleaners is much shorter. Even when the Uls-cleaner is in operation a whole work day, there is no need for the operator to stay in the vicinity of the device for eight hours. The sound pressure level at a distance of 2 m from an Uls-cleaner is damped about 8 dB at 8 kHz to 16 dB at 63 kHz [8]. The consequence of this is that operators of cleaners are exposed to a lesser degree than operators of welders. This also means that daily exposure time must be taken into account in hygienic evaluation of the exposure of operators of Uls-devices. It also underlines the need of determining the critical daily exposure dose for frequencies above 10 kHz in the future.

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