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Measurement of human body surface vibrations induced by complex low-frequency noise composed of two pure tones

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To clarify the mechanical responses of the human body to airborne vibrations, six male subjects were exposed to eight kinds of low-frequency noise stimuli: airborne white noise, two pure tones (31.5 and 50 Hz), and five complex noises composed of pure tones. The vibrations induced on the body surface were measured at five locations: the forehead, the right and left anterior chest, and the right and left anterior abdomen. It was found that the vibration acceleration levels of both the 31.5- and 50-Hz components in the chest vibration increased as an approximately linear function of the sound pressure levels of each corresponding frequency component in the noise stimulus. No clear interference was found between the 31.5- and 50-Hz components in the chest vibration. Similar characteristics were also found in the vibrations induced at the forehead and abdomen. These findings suggest that within the limited range of frequency and sound pressure level used here, the human body acts as a mechanically linear system in response to airborne vibrations induced by complex low-frequency noise.

Key words: low-frequency noise; complex low-frequency noise; noise-induced vibration; body surface; vibration acceleration level; independence in induction; linear response

1. INTRODUCTION

Low-frequency noise, which is noise in the frequency range below 100 Hz, is commonly generated in living and working environments [1]. In particular, in the working environment, various machines such as blowers, air compressors, large engines and the like generate high-level low-frequency noise, the sound pressure levels of which occasionally exceed 100 dB(SPL).

Mechanical vibrations are induced in the human body when a person is exposed to high-level, low-frequency noise [2, 3]. These vibrations (noise-induced vibrations) are an interesting subject for researchers who study the mechanical responses of the human body to vibration. If a person is exposed to vertical vibrations in one direction, the whole body is uniformly vibrated in the same direction as the stimulating vibration. In the case of noise-induced vibrations, however, it is expected that the human body is exposed to approximately isotropic pressure changes because the wavelength of low-frequency noise (approximately 6.8 m for 50-Hz noise, for example) is longer than the human being. Thus, it is speculated that his abdomen and back, for example, are forced to move in opposite directions. This isotropic characteristic distinguishes noise-induced vibrations from other vibrations in which the human body is excited in only one direction. To the authors' knowledge, however, there have been few studies to investigate in detail the characteristics of noise-induced vibrations.

In our previous study [2], we used pure tonal stimuli in the 20- to 50-Hz range and measured noise-induced vibrations on the body surface. We found that the increment in the vibration acceleration levels of the noise-induced vibrations agreed well with the increment in the sound pressure levels of the noise stimuli, implying that the human body is a mechanical system that responds linearly to airborne vibrations generated by pure tones in the low-frequency range.

However, low-frequency noises generated in real environments are not pure tones but complex noises whose frequency spectra are spread over a wide range. If the human body responds linearly to complex low-frequency noise, it is expected that (1) the vibrations at different frequencies are induced independently of each other, and (2) the vibrations are induced as a linear function of the magnitude of the corresponding frequency component in the noise stimulus, regardless of the magnitude of the other noise component.

The aim of the present study was to clarify the mechanical responses of the human body to airborne vibrations generated by complex low-frequency noise. We measured noise-induced vibrations on the body surface using eight kinds of low-frequency noise stimuli.

2. METHODS

Six healthy male subjects whose ages ranged from 19 to 25 yr (mean = 22.8, SD = 2.1) participated in the experiment. Their heights and weights (mean ± SD) were 174.3 ± 4.8 cm and 71.0 ± 8.3 kg, respectively.

The measurements were carried out in a soundproof test chamber with a capacity of approximately 25 m^3 (2.85 m (W) × 3.16 m (D) × 2.80 m (H)) [4] in winter (a dry season in Japan). The temperature in the test chamber was set at 25°C, and the humidity in the chamber was maintained at 40% by a humidifier throughout the measurement period.

We used eight types of low-frequency noise stimuli (Table I). One type was white noise with an approximately flat spectrum within the 4- to 100-Hz range. Two were pure tones with frequencies of 31.5 and 50 Hz, respectively. These pure tones were selected so that we could compare the results of the present study with our previous results [2]. The other five stimuli were complex noises composed of the two pure tones. The source of the noise stimuli was WAV-type data generated at a sampling rate of 48 kHz on a PC. The five complex noises were generated by synthesizing the two source data for the pure tones at a phase difference of zero degrees. All of the source data were D/A converted by an audio data interface (AD216, Nittobo Acoustic Engineering, Japan).

It has previously been shown that the frequency response of the test chamber is not flat over the entire frequency range [4]. In our previous study [2], we did not apply any compensation for the frequency response because we used only pure tonal stimuli at frequencies equal to or below 50 Hz, a range in which sound pressure levels have proven to be closely uniform in the test chamber [4]. In the present study, however, we used several methods to compensate for the frequency response of the test chamber so as to reproduce the complex noise stimuli as precisely as possible. The frequency spectrum of the source data was modified through one of two digital filters generated by a digital

Table 1 *The low-frequency noise stimuli used in the present study*

No.	Combinations and sound pressure levels (dB(SPL))
1	White noise (100 dB)
2	31.5-Hz pure tone (100 dB)
3	50-Hz pure tone (100 dB)
4	Complex noise composed of 31.5-Hz (100 dB) and 50-Hz (100 dB) tones
5	Complex noise composed of 31.5-Hz (100 dB) and 50-Hz (95 dB) tones
6	Complex noise composed of 31.5-Hz (100 dB) and 50-Hz (90 dB) tones
7	Complex noise composed of 31.5-Hz (95 dB) and 50-Hz (100 dB) tones
8	Complex noise composed of 31.5-Hz (90 dB) and 50-Hz (100 dB) tones

audio convolution processor (CP4, Lake Technology, Australia). We prepared five kinds of digital filters, each of which worked appropriately at 110, 120, 130, 140, or 150 cm high, at the center of the test chamber. In the measurement, the height of the measuring location was adjusted at any one of these five heights by setting an appropriate support under a subject. The other digital filter, which was set subsequently to the first filter, was used to eliminate electrical noise at frequencies above 100 Hz. After the compensation for and amplification of the source data, the noise stimulus was reproduced by 12 loudspeakers (TL-1801, Pioneer, Japan) which were installed in one wall of the test chamber.

Figure 1 shows examples of the frequency spectra of the noise stimuli, as measured at the center of the test chamber (120 cm in height). Our results indicate that the desired frequency spectra were obtained for both the white noise stimulus and the complex noise stimulus. It should be noted that the sound pressure levels of both the 31.5- and 50-Hz components in the white noise stimulus were approximately 80 dB(SPL), as the overall sound pressure level was adjusted to 100 dB(SPL). It should also be noted that the sound pressure levels for the white noise stimulus were not uniform along the whole body surface of a subject because the sound pressure levels in the test chamber, as mentioned earlier, lacked uniformity along the vertical direction at frequencies higher than 50 Hz [4].

To measure noise-induced vibrations, we used a small (3.56 mm × 6.86 mm × 3.56 mm) and lightweight (0.5 g) accelerometer (EGA-125-10D, Entran, USA). Prior to the present experiment, the accelerometer was calibrated on a vibrating table (AST-11V, Akashi, Japan) the vibrations of which were monitored with a set of a calibrated acceleration pickups (PV-85, Rion, Japan) and a vibration meter (VM-80, Rion, Japan). In the calibration, we investigated the frequency response of the accelerometer in the frequency range below 100 Hz and confirmed that the accelerometer responded linearly to the magnitude of the acceleration of the vibrating table.

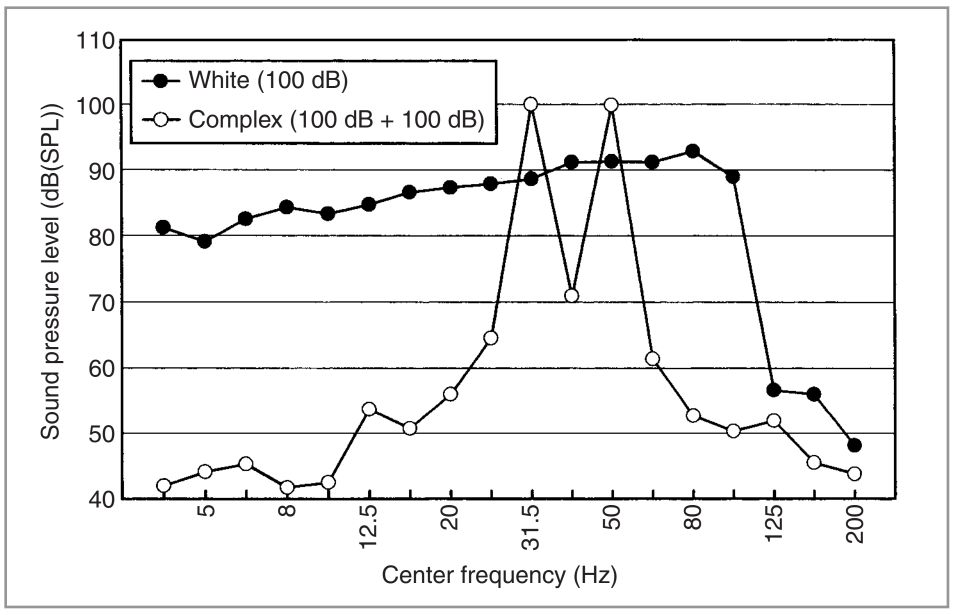

Figure 1 *An example of the frequency spectra of the noise stimuli. The spectra shown are for the white noise stimulus and for the complex noise stimulus composed of a 31.5-Hz, 100-dB tone and a 50-Hz, 100-DB tone. These were measured at the center of the test chamber (120cm in height).*

Noise-induced vibrations were measured at five locations on the body surface: the forehead (2 cm above the level of the eyebrows and on the midline), the right anterior chest (2 cm above the right nipple), the left anterior chest (2 cm above the left nipple), the right anterior abdomen (5 cm below the pit of the stomach and 5 cm to the right of the midline), and the left anterior abdomen (5 cm below the pit of the stomach and 5 cm to the left of the midline). Five sets of an accelerometer and a strain amplifier (6M92, NEC-Sanei Instruments, Japan), each of which corresponded to one measuring location, were arranged. With the accelerometer attached to each measuring location using double-sided adhesive tape and no other supporting material, we detected vibrations perpendicular to the body surface. The detected vibrations were amplified by the strain amplifier and recorded on DAT with a multi-channel data recorder (PC216Ax, Sony Precision Technology, Japan).

Analysis by an FFT analyzer (HP3566A, Hewlett Packard, USA) yielded the power spectrum of the noise-induced vibration. The spectral components at 31.5 and 50 Hz were then transformed to vibration acceleration levels (VALs) defined as:

$$\text{Vibration acceleration level (VAL)} = 20 \times \log_{10} (a_{meas}/a_{ref}) \text{ [dB]},$$

where a_{meas} was a measured acceleration (m/s^2(r.m.s.)) and a_{ref} was the reference acceleration equal to 10^{-6} m/s^2. To eliminate any effects of transient vibrations corresponding to the beginning and end of each 1-min noise exposure, the first and last 10 seconds of each data recording were disregarded and only the remaining 40 seconds were analyzed. It was expected that the measured VAL would be contaminated by inherent vibrations originating in vital body activities [5]. In the above transformation, however, we did not separate the inherent vibrations from the total vibrations measured because the phase relationship between the inherent and the true noise-induced vibrations was unknown.

The measurements were conducted in three sessions (Figure 2). In the first session, the subject stood at the center of the test chamber, and noise-induced vibrations were measured at the right and left chest. In the second session, noise-induced vibrations were measured at the right and left abdomen of the subject standing at the same place. In the last session, noise-induced vibrations were measured at the forehead of the subject who sat on a stool at the center of the chamber. At the beginning of each session, inherent vibrations were recorded (1 min) with no noise stimulus. Eight kinds of noise stimuli were then presented in random order for every session, and noise-induced vibrations were recorded during exposure to each 1 min noise stimulus. Between any two recordings, a 1-minute-long rest period with no noise stimulus was assigned. Throughout the measurements, the subject, who wore no clothes on the upper half of the body to allow the accelerometers to be attached, faced the wall in which loudspeakers were installed. The subjects wore no hearing protectors. We instructed each subject to keep his upper body in a relaxed erect position during the exposure period.

To examine the differences between the VALs of the 31.5-Hz vibration measured under nine noise exposure conditions, including the inherent vibration measured with no noise stimulus, first the Kruskal-Wallis test then the Mann-Whitney test was performed using a statistics software package (SPSS for Windows 10.0J, SPSS Japan, Japan). This test was carried out for every measuring location. The same test was also performed on the VALs of the 50-Hz vibration measured. For these tests, a p-value lower than 0.05 (two-sided) was considered to be statistically significant.

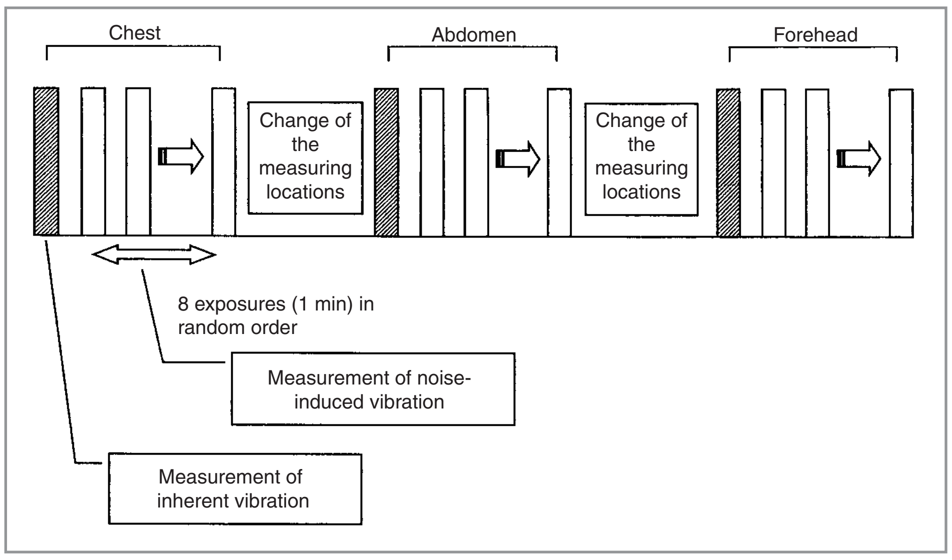

Figure 2 *The procedure of the measurement In the first session, noise-induced vibrations were measured at the chest. In the second and last sessions, noise-induced vibrations were measured at the abdomen and at the forehead, in that order.*

The experiment was approved by the ethics committee of the National Institute of Industrial Health, Japan, and informed consent was obtained from each subject before the measurements were taken.

3. RESULTS

Figure 3 shows the VALs (means ± SD) of the 31.5-Hz component in the noise-induced vibration measured for no noise stimulus, the white noise stimulus, the 31.5-Hz pure tonal stimulus, and the three complex noise stimuli in which the sound pressure level of the 31.5-Hz noise component was 100 dB(SPL). Figure 4 shows the VALs (means ± SD) of the 50-Hz component in the noise-induced vibration measured for no noise stimulus, the white noise stimulus, the 50-Hz pure tonal stimulus, and the three complex noise stimuli in which the sound pressure level of the 50-Hz noise component was 100 dB(SPL). The VALs for the white noise stimulus were measured to be lower than the VALs for the other noise stimuli because the sound pressure levels of the 31.5- and 50-Hz components in the white noise stimulus were approximately 80 dB(SPL). Half the VALs measured for the white noise stimulus (31.5-Hz vibrations measured at the left chest, the right abdomen, and the left abdomen, and 50-Hz vibrations measured at the forehead and the left abdomen) were found not to be significantly different from the VALs of the inherent vibrations measured for no noise stimulus. In contrast, the VALs measured for the pure tonal stimuli and the complex noise stimuli were found to be significantly different from the VALs of the inherent vibration, except for one case (31.5-Hz vibration measured for a complex noise stimulus composed of a 31.5-Hz, 100-dB(SPL) tone and a 50-Hz, 100-dB(SPL) tone. The VALs of the 50-Hz vibration induced by the 50-Hz pure tonal stimulus were found to be higher than those of the 31.5-Hz vibration induced by the 31.5-Hz pure tonal stimulus, a finding which was consistent with our previous results [2, 5].

At all the measuring locations, no statistically significant difference was found between the VALs of the 31.5-Hz vibration measured for four noise stimuli in which

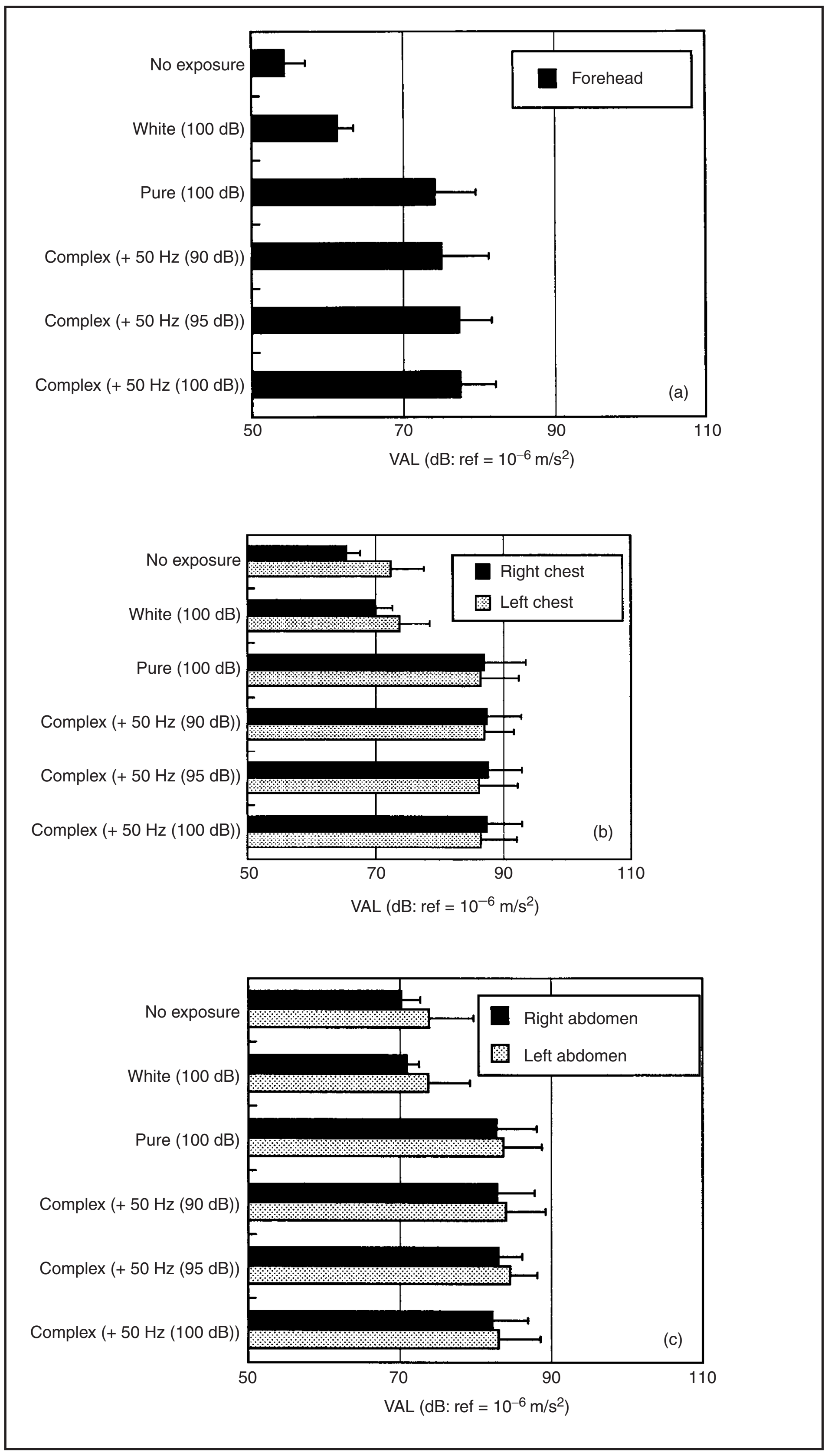

Figure 3 *The vibration acceleration levels (means ± SD) of the 31.5-Hz component in the noise-induced vibration measured for no noise stimulus, the white noise stimulus, the 31.5-Hz pure tonal stimulus, and the three complex noise stimuli in which the 31.5-Hz noise component was set at 100 dB(SPL). They were measured (a) at the forehead, (b) at the chest, and (c) at the abdomen.*

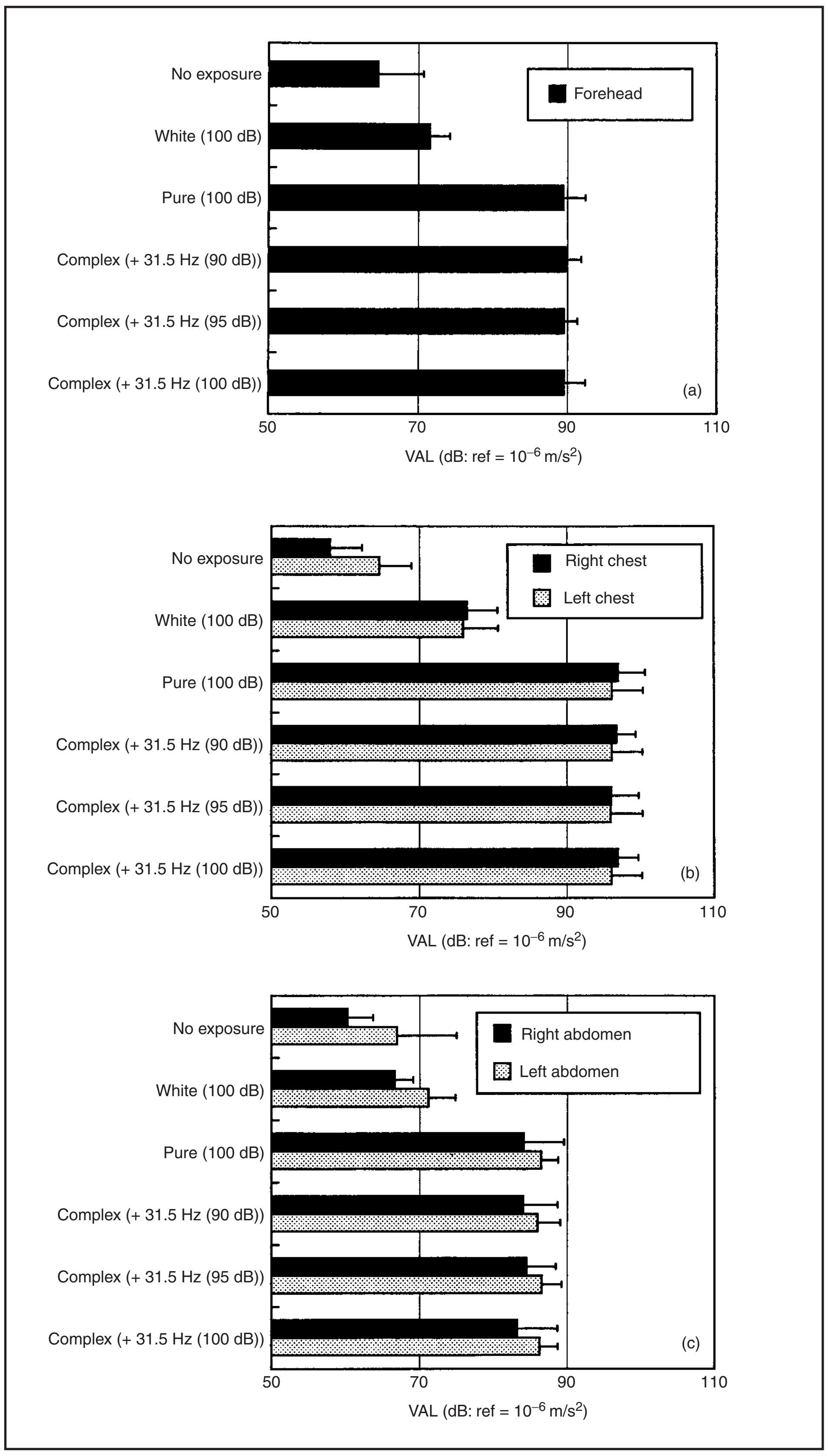

Figure 4 *The vibration acceleration levels (means ± SD) of the 50-Hz vibration measured for no noise stimulus, the 50-Hz pure tonal stimulus, and the three complex noise stimuli in which the 50-Hz noise component was set at 100 dB(SPL). They were measured (a) at the forehead, (b) at the chest, and (c) at the abdomen.*

the 31.5-Hz noise component was set at 100 dB(SPL). Similarly, with respect to the 50-Hz vibration, no statistically significant difference was found between the VALs measured for four noise stimuli in which the 50-Hz noise component was set at 100 dB(SPL). Thus, no clear interference was found between the 31.5- and 50-Hz vibrations induced by complex low-frequency noise stimuli, which suggested that noise-induced vibrations at two frequencies were induced independently of each other.

Figure 5 shows the VALs (means ± SD) of the 31.5-Hz vibration measured for three complex low-frequency noise stimuli in which the sound pressure level of the conjugate (50-Hz) noise component was 100 dB(SPL). In the figure; the VALs of the 31.5-Hz vibration are depicted by black circles and plotted as a function of the sound pressure level of the corresponding (31.5-Hz) noise component. The solid line and expression incorporated in the figure represent a regression line calculated with these three VALs. The value attached to the expression (r^2) is the coefficient of determination obtained in the calculation. In Figure 5, the VAL (mean ± SD) of the 31.5-Hz vibration measured for the white noise stimulus is also depicted by a white square on the assumption that the sound pressure level of the 31.5-Hz noise component in the white noise stimulus is accurately equal to 80 dB(SPL). In addition, the mean VAL of the inherent vibration is shown by a horizontal dashed line. Figure 6 provides a similar treatment for the VALs of the 50-Hz vibration.

Although the regression was not highly significant because of the small number of VALs used in the calculation, the coefficients of determination were very close to 1 at all the measuring locations and at both frequencies. At the forehead and chest, the slopes of the regression lines were nearly equal to 1, indicating that the increment in the VALs of the noise-induced vibration was in good agreement with the increment in the sound pressure levels of the corresponding noise component in the complex noise stimulus. These results suggest that the body surface vibration is induced as a linear function of the sound pressure level of the corresponding noise component, regardless of the sound pressure level of the conjugate noise component. In contrast, at the abdomen, the slopes of the regression lines were found to be smaller than 1 at both frequencies.

Figures 5 and 6 show that if we estimate the VAL induced by a corresponding noise component at 80 dB(SPL) by extrapolating the VALs measured for the noise stimuli at higher sound pressure levels, the estimated VAL coincides with the VAL measured for the white noise stimulus, except for the one case shown in Figure 5 (a). At sound pressure levels equal to or below 80 dB(SPL), the influence of the inherent vibration on measurement of noise-induced vibrations is considered to be significant. Taking the contamination by the inherent vibration into account, it is considered that the VAL corresponding to a noise at 80 dB(SPL) is well estimated by the above extrapolation.

4. DISCUSSION

In the present study the VAL of the 31.5-Hz vibration induced by the 31.5-Hz, 100-dB(SPL) pure tone was measured to be 87.0 ± 6.6 dB at the right chest, while the corresponding VAL was measured to be 87.6 ± 2.4 dB in our previous study [2]. With respect to the 50-Hz vibration induced by the 50-Hz, 100-dB(SPL) pure tone, the VAL was measured to be 97.0 ± 3.7 dB in the present study and 96.9 ± 3.1 dB in the previous study. At the other measuring locations, the VALs measured under the same exposure conditions were consistent across the two studies. These results indicate that the sound pressure levels of the noise stimuli reproduced in the test chamber were not influenced by the compensation we introduced in the present study.

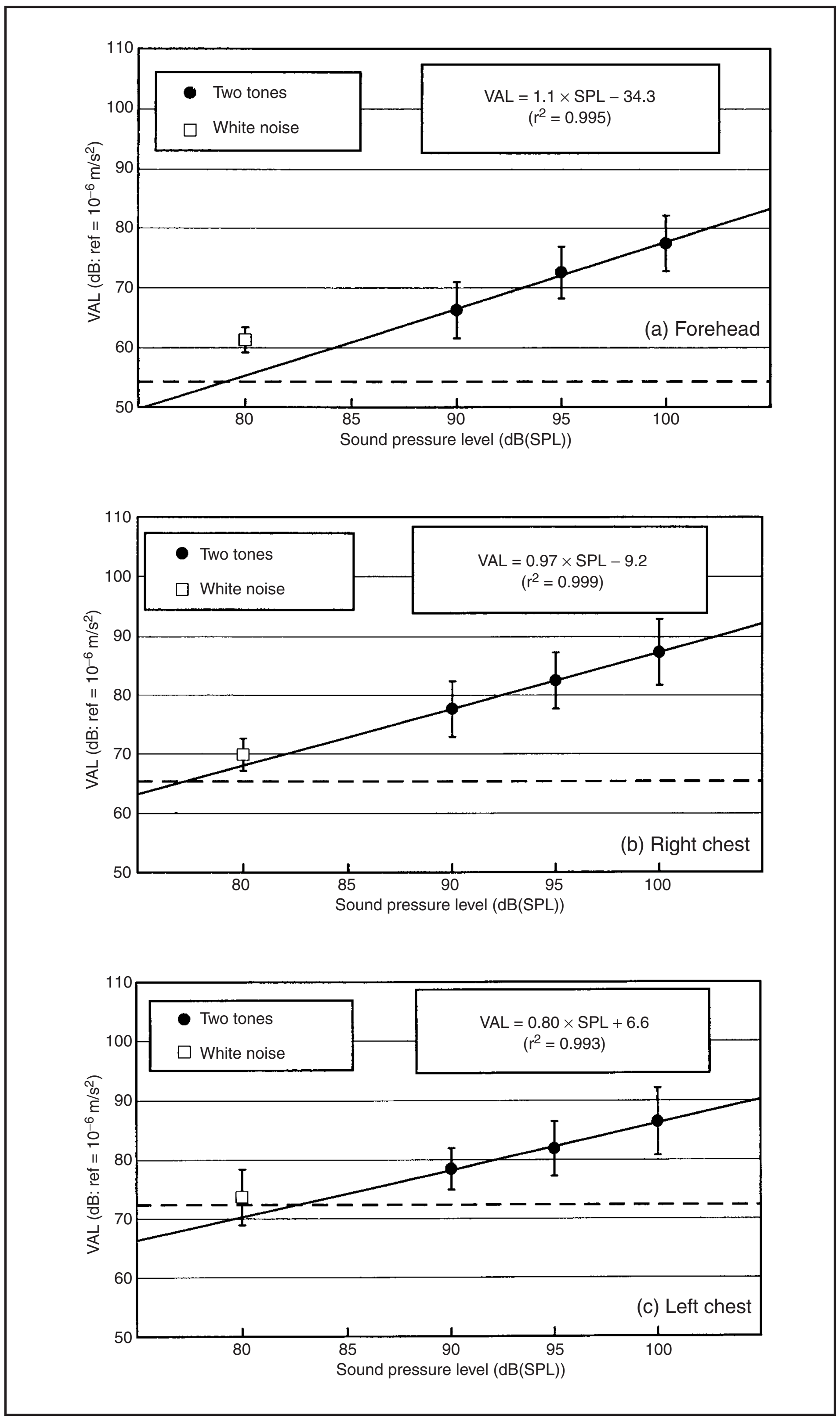

Figure 5 *The vibration acceleration levels (means ± SD) of the 31.5-Hz component in the noise-induced vibration measured for the three complex noise stimuli in which the 50-Hz noise component was set at 100 dB(SPL). They (black circles) were measured (a) at the forehead, (b) at the right chest, (c) at the left chest, (d) at the right abdomen, and (e) at the left abdomen. Please refer to the Results section for more details*

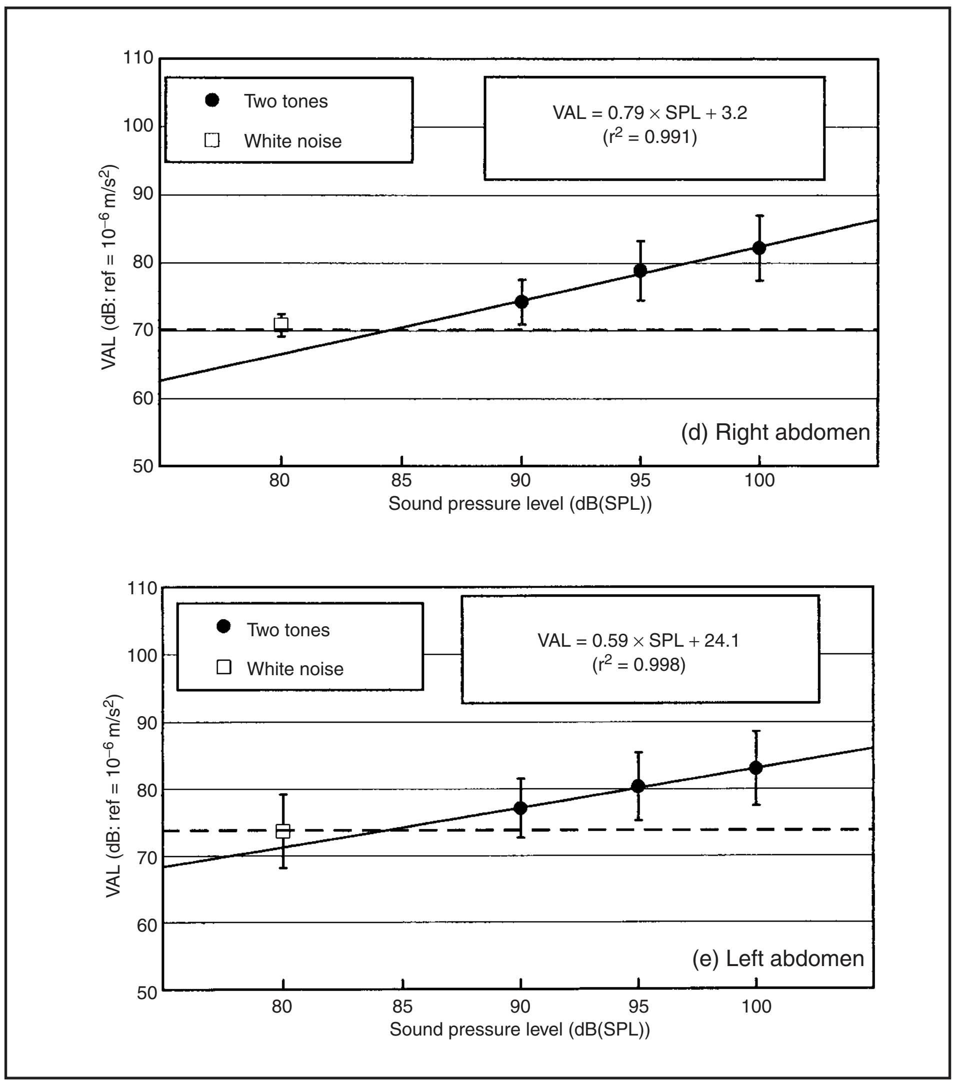

Figure 5 *Continued.*

At all the measuring locations, the 31.5- and 50-Hz components in the noise-induced vibrations appeared to be induced independently of each other. The independence in the induction of noise-induced vibrations at the two frequencies lends support to the idea that the human body acts as a mechanically linear system in response to airborne vibrations generated by complex low-frequency noise. Moreover, we found that the VALs of both the 31.5- and 50-Hz components increased approximately as a linear function of the sound pressure level of the corresponding noise component, regardless of the sound pressure level of the conjugate noise component. We also found that the VALs induced by the noise at 80 dB(SPL) was well-estimated by extrapolating the VALs measured by the noise stimuli at higher sound pressure levels. These results provide additional support for the idea that the human body responds linearly to airborne vibrations generated by complex low-frequency noise.

At the abdomen, the gradients of the VALs of noise-induced vibrations with the sound pressure levels were found to be smaller than 1 (Figures 5 and 6). It is considered likely that this result is primarily due to contamination caused by the vibrations inherent in the human body. As shown in Figures 5 (d) and (e), the VALs of the 31.5-Hz vibration measured for the white noise stimulus were at levels equal to or just above those of the inherent vibrations. Because the

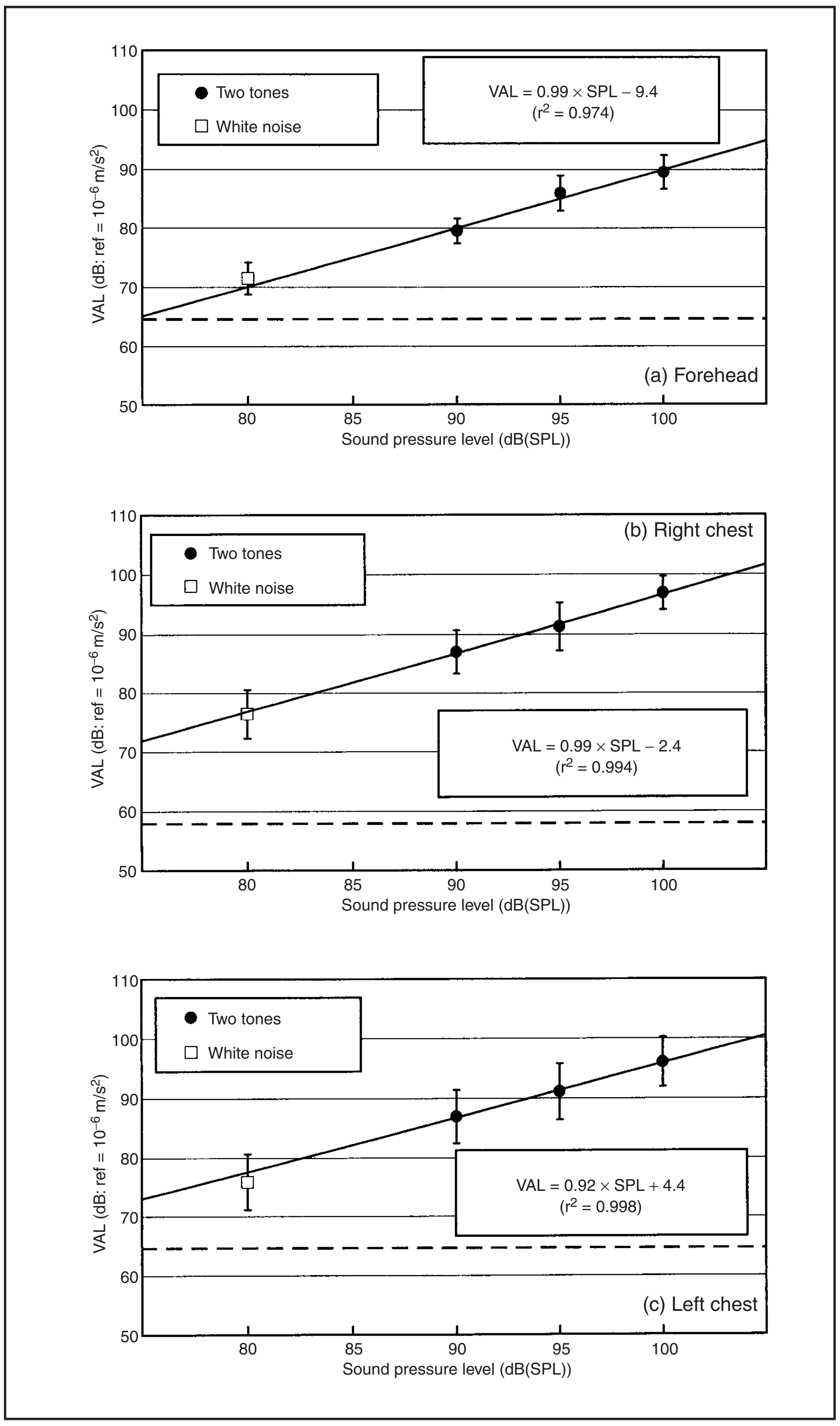

Figure 6 *The vibration acceleration levels (means ± SD) of the 50-Hz component in the noise-induced vibration measured for the three complex noise stimuli in which the 31.5-Hz noise component was set at 100 dB(SPL). They (black circles) were measured (a) at the forehead, (b) at the right chest, (c) at the left chest, (d) at the right abdomen, and (e) at the left abdomen. Please refer to the Results section for more details.*

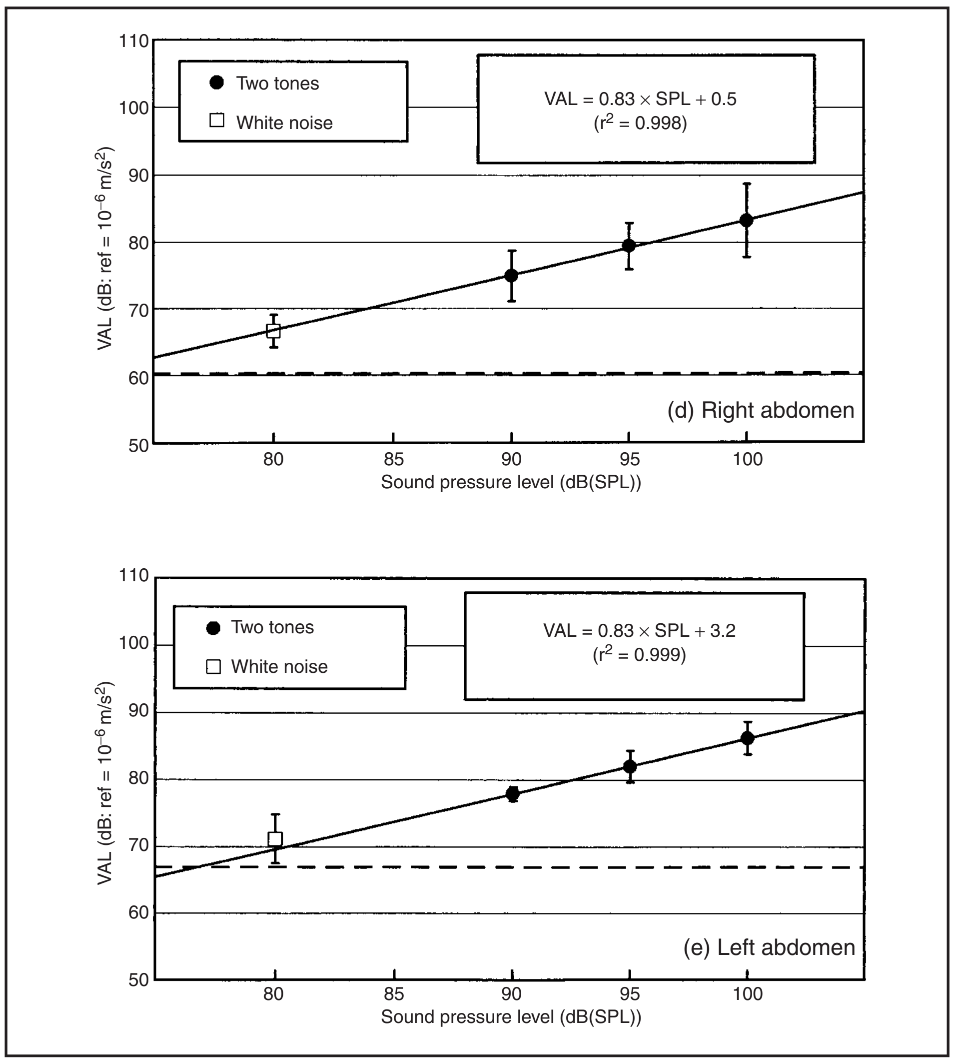

Figure 6 Continued.

noise notes

CLUBS V. RESIDENTS

Planning officers have denied they are failing to enforce planning restrictions in Wimbledon town centre as friction between residents and businesses continues. Residents said their lives were being made a misery by increasing noise levels and that Merton Council has done little or nothing to stop the offenders. But the authority said it was aware of the problems, was taking steps to resolve them and in one case has even called in the Environment Agency to investigate. Trinity ward Councillor Chris McLaughlin said: 'This goes to the heart of the relationship between a residential area, containing properties paying significant council tax and expected to pay significantly more in the future, and operators of clubs and restaurants.' Perhaps it is time for a complete review of licensing and regeneration practice along and around Wimbledon Broadway. But Steve Clark, Merton Council's head of planning and public protection, said: 'In town centres, where residents and businesses exist in such close proximity, the council always tries to reach a compromise for local businesses and residents. Wimbledon town centre has prospered greatly over the last decade or two, but unfortunately this sometimes results in problems such as more late night noise. Residents should rest assured we will be monitoring the situation of all these issues and will respond to any further problems as they arise.' Grievances include loud music and noisy collection of bottles and restaurant waste.

inherent vibrations were not eliminated from the total noise-induced vibration measured, the VALs measured for the noise stimuli at lower sound pressure levels were possibly higher than they were naturally. This undesirable effect is expected to be greater at lower frequencies and at lower sound pressure levels for noise stimuli [5], which results in gentler gradients of the VAL with sound pressure levels. However, the 50-Hz vibrations at the abdomen were found to be higher than the 31.5-Hz vibrations, and the slopes of the regression lines for the 50-Hz vibrations were closer to 1 than those for the 31.5-Hz vibrations (Figures 5 and 6). These results imply that if the inherent vibrations are eliminated, the increment in the 31.5-Hz noise-induced vibration is in good agreement with the increment in the sound pressure levels of the 31.5-Hz noise component.

Because we measured noise-induced vibrations under limited experimental conditions, it is unclear whether or not the human body responds linearly to airborne vibrations in a wide range of frequency and sound pressure levels. With respect to vibrations induced in the head, for example, Håkansson et al. [6] have reported that the human skull responds linearly to vibration stimuli at frequencies above100 Hz. Their results suggest that the human head responds linearly to airborne vibrations generated by low-frequency noise at frequencies higher than 100 Hz.In their study, however, they excited the head with a miniature vibrator attached near the right ear and detected the induced vibrations with a miniature accelerometer attached near the left ear. In contrast, we excited the whole body by approximately isotropic pressure changes induced by low-frequency noise. To clarify the effective range of frequency and sound pressure levels where the human head responds linearly to airborne vibrations induced by low-frequency noise, further studies are needed using noise stimuli in a wider range of frequency and sound pressure levels. Similarly, further investigations are needed for vibrations induced at the chest and abdomen.

As for the experimental conditions used in the present study, there are some other points to be discussed. First, each subject was exposed to each noise stimulus for only 1 min. It is considered that the extent of human psychological responses to noise would be influenced by the duration of the exposure. However, the magnitude of the noise-induced vibration was expected to be independent of the duration of the exposure, because the noise-induced vibration is a mechanical response of the human body to low-frequency noise stimuli. This is the reason why we set the duration of each exposure at 1 min only and did not use longer durations. Secondly, we used only young male subjects in the present study. Due to the difference in the amount of body fat, for example, it is considered that the physical characteristics of the female body are different from those of the male body. This may possibly be a confounding factor for our experiments. Similarly, the difference between the physical characteristics of older persons and those of younger persons are expected to be another confounding factor. To minimize the effects of these possible confounding factors, we did not use female or older subjects. However, it is important to verify whether or not the characteristics of noise-induced vibration depend on sex difference and age. It is desirable to conduct further studies under a variety of experimental conditions, and on a variety of experimental subjects.

We did not measure the transfer function from the low-frequency noise stimulus to the noise-induced vibration, as it was considered that the signal-to-noise ratio in the measured noise-induced vibration was poor due to contamination by inherent vibrations, especially at 31.5 Hz. Wodicka and Shannon [7] introduced a white noise stimulus into the mouth with an approximately flat spectrum in the 100- to 1000-Hz range and measured the amplitude of sound transmitted from the mouth to two sites on the posterior chest wall. Their results showed the transfer function of the transmission as having a single peak around 150 Hz and as decreasing with increasing frequencies. Although their results should not be compared directly with our present results due to differences in measuring methods, they suggest that the amplitude of noise-induced vibrations at the chest decreases at higher frequencies. It is not clear whether or not noise-induced vibrations at the head and abdomen behave in a similar manner. Because the transfer function is an important quantity in studying the mechanical response of the human body, further studies are needed to measure the transfer function for noise-induced vibrations.

In addition, we did not measure the phase relationship between the 31.5- and 50-Hz components in the noise-induced vibration. Provided that the noise-induced vibration is induced depending only on the atmospheric pressure change at the body surface, the phase relationship between two vibration components should be approximately the same as the relationship in the noise stimuli, except for the effect of the acoustical properties of the test chamber. However, if the pressure change in the inner body interactively contributes to the induction of noise-induced vibrations, the phase relationship between two vibration components on the body surface is possibly more complicated. Lu et al. [8] injected a broadband noise stimulus in the 300- to 1600-Hz range into the mouth and measured the vibrations induced on the chest wall. They estimated the phase-delay of the transmitted sound and reported a tendency for sounds at higher frequencies to reach the chest wall faster than that at lower frequencies. If lung pressure changes due to sound being transmitted through the airways, thus influencing the induction of noise-induced vibrations, some discrepancies may occur between the phases of different frequency components in the noise-induced vibration measured at the chest. This point also remains to be investigated in the future.

Peters et al. [9] exposed sheep to 100-dB airborne broadband noise and measured the intra-abdominal sound pressure by a hydrophone located within the abdomen, revealing that the sound pressure of the noise within the abdomen was less attenuated at frequencies below 100 Hz. Similar frequency-dependent transmission of intra-abdominal vibration has been reported in other studies in which the abdomens of sheep were exposed to be mechanical vibrations by a shaker, not to airborne vibration by airborne sound [10-12]. These results suggested that transmission of vibrations in the inner body is frequency-dependent and the vibration is less attenuated at lower frequencies. In the present study we measured noise-induced vibrations in a limited range of frequency and only on the body surface. Although the effects of noise-induced vibration on vibrations within the body remain unclear, there is a good possibility that the noise-induced vibration on the body surface is transmitted deeply into the inner body.

Provided that detailed characteristics of the transmission of the noise-induced vibration within the human body are clarified, these findings may be helpful in the study of adverse health effects caused by low-frequency noise. Castelo Branco et al. [13-15] have reported that long-term exposure to high-level, low-frequency noise causes vibroacoustic disease involving some extra-aural pathologies such as pericardial thickening, pulmonary fibrosis, and so on. Although they presume that noise-induced vibrations are associated with vibroacoustic disease, the mechanisms by which vibroacoustic disease develops have not yet been investigated in detail. To assess the effects of low-frequency noise from a medical viewpoint, noise-induced vibrations should be measured not only on the body surface but also in the inner body, and the characteristics of noise-induced vibration must be quantitatively related to the prevalence and/or stages of adverse health effects such as vibroacoustic disease. Already, some frequency-weighting curves, such as the LF-weighting curve [16] and the G-weighting curve [17], have been proposed. Because they have been designed on the basis of the human psychological and perceptual responses to low-frequency noise, they are considered to be useful and effective in assessing perceptions of noise. However, it is difficult to use these frequency-weighting curves to assess in an appropriate fashion the possible physical effects caused by low-frequency noise. A quantity related to noise-induced vibrations could be useful in establishing a new evaluating method for the adverse health effects caused by low-frequency noise.

CONCLUSIONS

The results of the present study suggest that the human body acts as a mechanically linear system in response to airborne vibrations generated by complex low-frequency noise. Nonetheless, some points remain to be investigated: i.e., the effective range of frequency and sound pressure levels at which this linear response occurs, the transfer function between noise stimuli and noise-induced vibrations, and so on. To clarify the details of mechanical responses of the human body to complex low-frequency noise, further studies should be conducted using noise stimuli within a wider range of frequency and sound pressure levels.

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noise notes

INDIAN CONTROL NORMS

From October 1, emission control norms will become tighter in India. Getting Pollution Under Control (PUC) certificates will become that much more difficult, for cars will not only be tested for the smoke they emit, but also the noise they make. In a first-of-its-kind move, a recent notification from the Union Ministry of Road Transport makes noise pollution tests mandatory for all vehicles.

RAIL FOOT CROSSING

A railway crossing where a man was killed trying to rescue his dog may be closed in a row over noisy trains. Rail bosses are considering shutting the foot crossing at Cardross, near Helensburgh, nine months after George Clark, 56, was hit by a passenger train. The closure debate has been sparked by complaints about train drivers sounding their horns as a warning as they approach the crossing near Cardross Station. Mr Clark, a self-employed builder, died last May just 100 yards from his home in the Bainfield estate. It's believed he ran onto the crossing to retrieve his pet Boxer dog, Honey, but slipped on wire mesh and fell on to the track in front of a train. Hours after the horror accident locals were again using the crossing, which is a short-cut from the estate to the shore. Since the tragedy train drivers have sounded their horns more frequently as they approach the scene. However, people living near the line have complained about the noise of the blasts throughout the day and late into the evening.