Changes in auditory evoked brain potentials during ultra-low frequency whole-body vibration of man or of his visual surround*

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Summary. Auditory evoked brain potentials (AEP) were recorded from nine healthy male subjects during three types of condition: A - subject and visual field stationary; B - subject vibrated (z-axis, 0.6 Hz, 1.85 ms−2 rms), visual field stationary; C - subject stationary, visual field vibrated (as for B). The visual surround was confined to a checkerboard pattern in front of the subject. Auditory stimuli (1000 Hz, 86 dB, inter-stimulus interval 7 s) were delivered via headphones to evoke AEP. Vibration-synchronous activity in the EEG was eliminated by a subtraction technique. In comparison with condition A, conditions B and C caused an attenuation of P2 and N1P2 components of AEP together with an increased latency of N1. Effects of conditions B and C did not differ. Direct vestibular stimulation and mechanisms specific for whole-body vibration were rejected as modes of action. The AEP-changes and the subjective evaluation of experimental conditions, arousal and performance, as well as symptoms of kinetosis (motion sickness) suggest a sensory mismatch, leading to a "latent kinetosis" with de-arousal, as the dominating mechanism by which the processing of information was affected. This suggestion was supported by an additional pilot study. Under real working conditions a similar effect can be expected during relative motion between the driver and his visual surround, i.e. even with perfect vibro-isolation of the driver's seat.

Key words: Whole-body vibration – Auditory evoked brain potentials – Information processing – Sensory interactions – Kinetosis

Introduction

Effects of very low-frequency (v.l.f.) whole-body vibration (WBV), i.e. WBV below 1 Hz, are of practical significance in the work place, since they can induce symptoms of kinetosis (motion sickness) affecting performance (Dupuis and Zerlett 1986). Previous investigations have shown effects of WBV on the processing of information reflected by auditory evoked brain potentials (AEP). Exposure to WBV in the longitudinal direction at 4 Hz, 0.57–3.2 ms−2 rms, caused a significant decrease of the N1-P2 amplitude and a shortening of the latency of P2 at the low intensity of WBV (Ullsperger and Seidel 1980). In another experiment, Ullsperger et al. (1986) found a systematic dependence of WBV-induced AEP changes on the frequency and intensity of WBV. The N1-P2 amplitude decreased with the frequency of WBV decreasing from 8 to 1 Hz; this amplitude also decreased with increasing intensities of WBV that were equivalent at different frequencies, according to the weighting of the International Standards Organisation [(ISO) 1985]. In a study published recently (Seidel et al. 1990), the effects of WBV with 0.6 and 1 Hz were examined under different visual conditions. Compared with control, the N1 and N1-P2 amplitudes significantly decreased during WBV, while the latencies of N1 and P2 increased. Since the visual conditions "bright visual field" and "darkness" exhibited no systematic effect on the AEP vs “normal vision”, a dominance of vestibular-auditory interactions was suggested, compared with visual-auditory ones. However, the mechanism underlying WBV-induced changes of AEP discussed by Ullsperger et al. (1986) still remains an open question.

The present experiments were performed in order to answer the question as to whether the effects of WBV on AEP are coupled with a direct stimulation of the vestibular system. For this purpose, the effects of passive movement of the whole body by v.l.f.-WBV were compared with an identical movement of the visual surround, while the body remained motionless. The examination of this problem is of practical significance also. New developments of “active seats” can reduce vibration transmission drastically but, at the same time, they can cause considerable relative low-frequency movements between the driver and his visual surround.

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Methods

Subjects. Nine healthy males (aged between 22 and 27 years, mean 23 years; height 169–187 cm, mean 181 cm; body mass 63–90 kg, mean 74.5 kg) volunteered for the experiment. The subjects had no earlier experience in vibration experiments.

Vibration exposure and visual conditions. Vertical sinusoidal WBV in the longitudinal a,-direction with a frequency of 0.6 Hz and acceleration of 1.85 ms⁻² rms was generated by an electronically-controlled electrohydraulic vibrator (Fa. Schenck, Darmstadt, FRG). In addition to electronically-controlled limits for acceleration and displacement, the maximal force was restricted mechanically by means of an adjustable ‘multi-valve’ (Fa. Schenck, Darmstadt, FRG), thus preventing accelerations beyond 1 g. The displacement and acceleration were measured simultaneously at the seat.

A checkerboard pattern (size 100 x 100 cm with black and white squares 10 x 10 cm) was located in front of the sitting subjects at a distance of 35 cm. The visual surround was confined to the checkerboard pattern by instructing the subjects to fix on a stationary point and providing special spectacles limiting the peripheral visual field. Three conditions were tested: A - subject and visual field stationary; B - subject vibrated, visual field stationary; C - subject stationary, visual field vibrated.

Experimental procedure and design. The experiments, lasting for about 1.5 h, were carried out in accordance with the BSI (1973). During the experiments the unrestrained subjects sat on a hard seat. They were instructed to make all bigger movements, blinks, and swallowings in the pauses between experiments only. The three experimental conditions were arranged in triplets and repeated three times per experiment in a permuted sequence. Each experimental condition lasted about 5 min and was followed by a pause lasting for about 3 min. Longer intervals were inserted after each triplet of experimental conditions. During these pauses the subjects filled in questionnaires on annoyance, difficulty to perform the experiment and symptoms of kinetosis. The experimental room was air-conditioned and artificially lit.

Acoustic stimulation. Auditory stimuli were presented via headphones Type DK78 (VEB Funktechnik, Leipzig) to both ears. Parameters of the auditory stimuli were as follows: frequency 1000 Hz, duration 50 ms, ascent and decay time about 5 ms, sound pressure level 86 dB. The auditory stimuli were given with a regular interstimulus interval of 7 s.

Recording of physiological parameters and signal analysis. The EEG signal was recorded from the vertex with the mastoid reference. The Ag/AgCl-electrodes were affixed to the scalp by collodium. The subject was earthed by a midforehead-electrode. The EEG signal was pre-amplified near the electrodes and amplified (frequency band from 0.1 to 15 Hz) by a battery-driven multi-purpose amplifier connected with the computer via glass fibre-optic for electric safety.

The EEG, electro-oculogram (EOG) and the acceleration signal were averaged on-line (sampling interval 2 ms) for epochs of 3334 ms and simultaneously stored on a multitrack FM tape recorder. After excluding artifacts on the basis of excessive amplitudes, the vibration-synchronous activity was automatically eliminated by a subtraction technique similar to that described earlier (Ullsperger and Seidel 1980; Ullsperger et al. 1986). This subtraction method was also performed in runs with experimental conditions A and C in order to have a signal-to-noise ratio comparable to that during condition B. Thirty treated EEG-epochs were averaged to obtain the evoked potential for each run. The peak amplitudes N1 and P2 of the AEP were measured using a computer, against a baseline calculated across a prestimulus interval of 200 ms (component windows: N1 50–200 ms, P2 150–250 ms). The vibration-synchronous activity was eliminated from the baseline also.

Statistical analysis. All data were tested by multifactorial analyses of variance (ANOVA), Newman-Keuls tests and t-tests for paired samples. The significance level was set at 5%.

Additional experiment. Four experimental conditions were tested in an additional pilot study by methods otherwise identical to those above: conditions B and C (see above); D - subject vibrated, bright homogeneous visual field without information on movement; E - subject and visual field synchronously vibrated (“visual stabilization”). Four healthy males participated in the experiment and underwent each condition twice (4 x 4 Latin square design with two repetitions).

Results

Figure 1 shows the AEP grand-mean waveforms for the conditions tested, averaged across all subjects and experiments. There was a distinct decrease in AEP-amplitudes P2 and N1P2 during experimental conditions B and C compared to A. The N1 amplitude occurred later with B and C. The gross AEP waveform remained unchanged. The effects of conditions B and C on AEP exhibited good reproducibility in all three repetitions (Fig. 2). Table 1 presents mean values and standard deviations of AEP amplitudes and latencies. The factor ‘experimental condition’ had a significant effect on the amplitudes P2 and N1-P2 as well as on the latency of N1 (ANOVA) (Table 2). Significant differences were observed between the effects of experimental conditions A vs those of conditions B and C, whereas AEP during B and C did not differ (Table 2). As expected, the amplitudes of AEP became smaller with the repetition of the exposure conditions A-C presented in triplets (factor ‘repetition’ in Table 2), except for condition A where the mean values of the second repetition were highest (Fig. 2, Tables 1, 2).

Figure 3 shows the AEP grand-mean waveforms obtained in the additional experiment by averaging across all four subjects and two repetitions. The statistical analysis did not reveal significant effects of the experi-