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Somatosensory-Evoked Potentials and Vibration

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Summary. Vibratory stimuli (250 Hz) with amplitudes between 50 and 200 μm were delivered to the middle finger knuckle of 15 human subjects. The cortical-evoked potentials and psychophysical magnitude estimations were simultaneously recorded. Only the large, late components of the evoked cortical potentials showed significant correlation to the stimulus intensity.

While the psychophysical response showed a slight positive acceleration, the evoked potential stimulus-response relations were slightly nonlinear with negative acceleration. The early components of the evoked potential were well localized over the contralateral, postcentral hand area; the late components showed a wide distribution over both hemispheres. The late, bilateral components resembled the alpha rhythm in frequency and distribution.

It is concluded that late components resembling alpha rhythm may be due to stimulus-synchronized oscillations of alpha generators. The underlying neuronal events are probably of less importance for perception. By contrast, the important neuronal activity in the first 100 ms after arrival of the impulses at the cortex does not appear in the scalp-recorded evoked potential.

Key words: Evoked potentials – Vibration – Man – Perception.

Introduction

A fundamental concept of psychophysics—the neuronal basis of sensory perception—has been studied in the last two decades by a number of scientists utilizing the evoked potential as a possible key (Keidel and Spreng, 1965; Libet et al., 1967; Franzèn and Offenloch, 1969). The accent has been on the late components, a similar correlation in amplitude of the evoked potential as well as perception to the stimulus has been interpreted as at least an indication of coherence, although not, of course, necessary dependency.

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The experimental evidence for this hypothesis is, however, open to criticism. Moreover, in an experimental situation in which the sensory events from the receptor to the cortex, including perception of stimulus magnitude, were better understood (step indentation of the skin), the findings conflicted with the earlier assumptions (Johnson et al., 1975). In this paper the experiments were extended to another important group of somatic receptors: the vibratory receptors which, at 250 Hz and small amplitudes, are probably identical to the pacinian corpuscles (Talbot et al., 1968).

While vision is concerned with stimulus location, orientation and movement, and audition with frequency discriminations (translating location on the basilar membrane into frequency), somatic sensation yields both stimulus location and a rough, local frequency analysis (serving surface exploration), using three populations of receptors that give the zeroth and the first and second derivative of skin indentation: depth, velocity, and acceleration (Kornhuber, 1972). The acceleration or vibration receptors have the lowest indentation threshold of these three and yet are located subcutaneously. This apparent contradiction may be explained by the fact that their threshold is lowest at frequencies (around 250 Hz) which coincide with optimal tissue conductance. These receptors are not designed to localize stimuli but rather to detect small, distant mechanical shocks.

Methods

A vibration stimulus (250 Hz) amplitude-modulated with a ramp of slow, constant velocity (5 mm/s, see Fig. 1) was applied via a mechanostimulator (Burchard et al., 1967) to the dorsal bony prominence at the base of the middle finger of 15 normal, awake human subjects (7 females, 8 males between 19 and 49 years of age). This location was chosen due to the thin, hairless skin and the good contact thereby achieved between the probe and the bone where a large number of pacinian receptors are stimulated almost exclusively. The stimulator was used in the position-controlled modus. The precision of the probe position was ± 1 μm.

Stimulus intensities (in 4 categories, 128 repetitions each) were randomly distributed between 50 and 200 μm peak-to-peak and given at random intervals (at least 4 s). The stimulus probe had a contact diameter of 1 mm, and the start position was adjusted automatically prior to the individual stimuli. Auditory artifacts were masked continuously with a 250 Hz tone so that there was no auditory sensation of the vibration stimuli and no evoked potential without skin contact. The ramp at the start of each stimulus was too slow to be perceived at the middle knuckle without the vibration and also led to no evoked potential. The stimulus ramp and vibration together were readily perceived, however. The ramp was also chosen because it was slow enough not to stimulate the slowly adapting Merkel cells, the rapidly adapting Meissner receptors, and the hair follicle receptors. The vibration was, however, fast enough to stimulate neither of these receptors, thus exciting the pacinian corpuscle exclusively. Off-effects were avoided by maintaining the stimulus beyond the analysis and estimation times. Prediction of stimulus onset and possible associated potentials were eliminated by randomizing the post-estimate intervals.

The cerebral-evoked potentials were monopolarly recorded (reference joined ears) over the contralateral and ipsilateral postcentral gyri and surrounding fields using nonpolarizable Beckmann silver chloride scalp electrodes and off-line computer (PDP-12) averaging. The electrodes were placed in a matrix of 12 electrodes around C_3 and C_4 according to the 10–20 system. The distance between the electrodes was 2 cm and the matrix was aligned between the external meatus and a point 10% of the nasalinion circumference behind the vertex on the midline. This matrix ensured coverage of the hand area of the postcentral gyri and beyond. Additional control experiments for artifacts, distribution of the EPs over the skull, and perception of stimulus-related phenomena were performed with a total of 35 subjects prior to the actual experimental series. Artifacts were eliminated by editing via time-reversed analysis. The first author's program written for this analysis gave intraindividual confidence intervals (95%, DECUS 12-98). Each lead was analyzed individually. Only peak-to-peak measurement of the evoked potential components was used, as zero-line references proved to be unstable. Using the method of absolute judgment, the psychophysical estimations of vibration amplitude were simultaneously analyzed and the information transmission was computed (results unpublished).

Results

Two typical evoked potentials from two experimental subjects under identical conditions may be seen in Figure 1. The interindividual variability may be readily seen, especially in the early components. The stimulus is depicted below: the baseline represents skin contact with neither measureable nor perceived indentation nor pressure. The pooled psychophysical stimulus-response curve of all 15 subjects is shown in Figure 2. Although the data may be approximated by a linear function, they show a positive acceleration with increasing amplitude. The maximal amplitude has a standard error of zero due to the normalization of all data to this value.

Figure 3 shows the averaged values for the peak-to-peak amplitudes of the various components of the evoked potentials pooled from all 15 subjects. Good

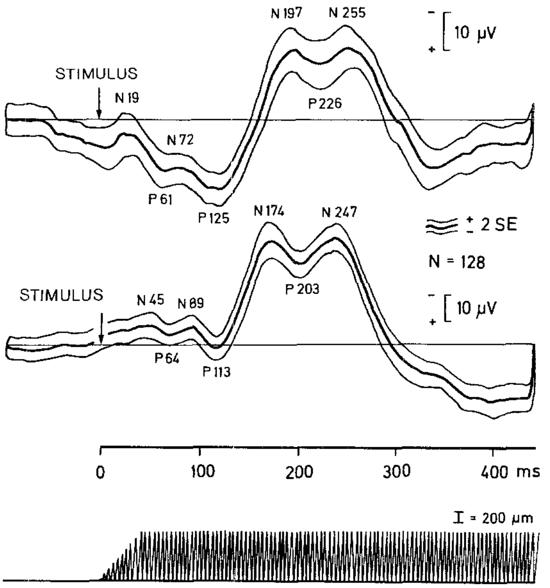

Fig. 1. Typical averaged evoked potentials from two subjects in response to the vibratory stimulus indicated below. Stimulus start (ramp = 5 mm/s, amplitude = 200 µm). A total of 128 stimuli were given to the bony prominence at the dorsal base of the right middle finger. Monopolar recordings vs joined ears, contralateral hand area of the postcentral gyrus. Surface negativity upwards, latencies of peaks in ms. Central curve represents the averages, outer curves the 95% confidence intervals

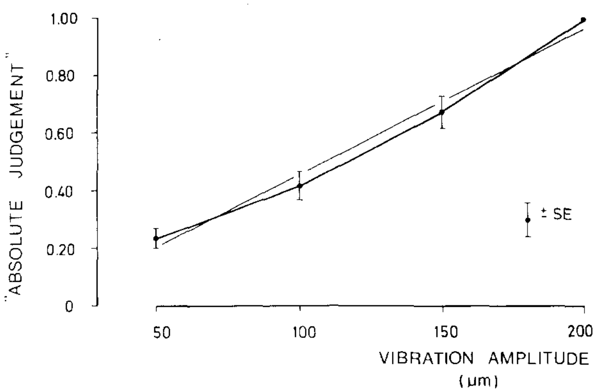

Fig. 2. Psychophysical perception of vibration amplitudes. Estimated magnitudes of stimuli averaged and normalized so that the average responses to maximal stimulus category are equal to unity. Fifteen normal, human subjects with standard errors for all the pooled data (each point from 15 × 128 responses)

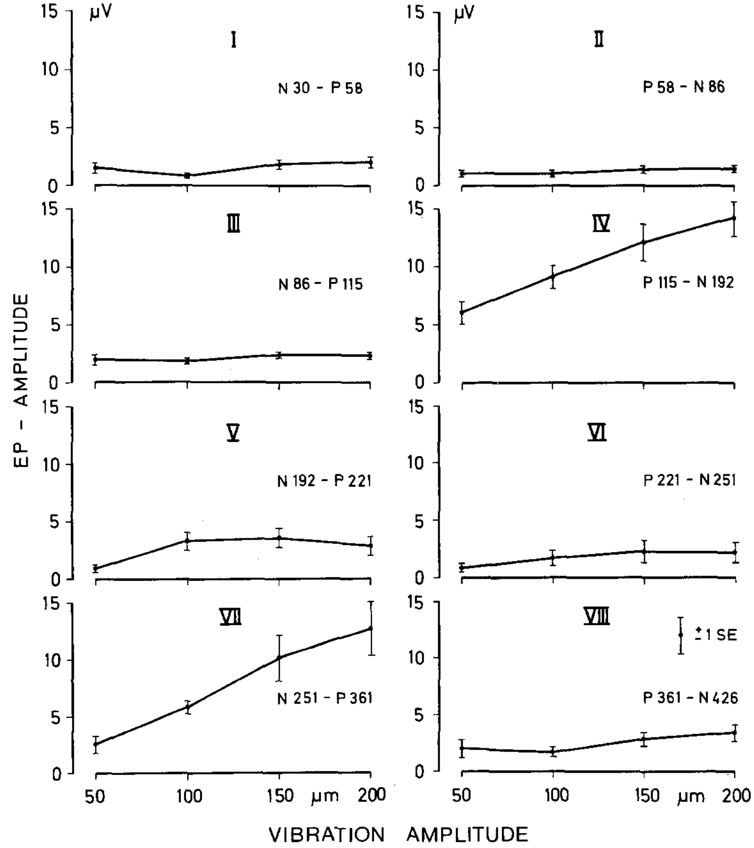

Fig. 3. Amplitudes curves for the various components of the cortical-evoked potential in response to mechanical vibration of the right hand. Each component is labeled according to polarity (N = negativity, P = positivity) and average peak-to-peak latencies in ms. Averaged values from 15 subjects, 128 repetitions each with 95% confidence limits (interindividual)

correlations between evoked potential amplitude and magnitude of perception are found only for the large, late components IV and VII. Although IV and VII may also be fitted to a linear function, they tend to show a curvature with negative acceleration and a better fit to a power function with an exponent slightly less than unity in contrast to the perceptual function (Fig. 2). The small early components up to 120 ms latency show a contralateral localization over the hand area, whereas the large, late components are found bilaterally over the whole scalp (no significant differences as tested at the 95% confidence level in 35 control experiments).

Discussion and Conclusions

At first glance our data appear to agree with Talbot et al. (1968) and Stevens (1968), since the psychophysical perception of vibration amplitude may be approximated by a linear function. Our own data (Fig. 2) nonetheless clearly show a curvature with positive acceleration. This difference is probably due to the different locations of the stimuli: in our case, at the knuckle bone; in the first case, in the soft skin of the finger tip pad. The amplitudes of the large, late components IV and VII of the cortical-evoked potential also show a definite correlation to vibration amplitude; the form, however, is negatively accelerated which is also reflected in the smaller, late components V and VI (Fig. 3). The difference between the stimulus response characteristics of the evoked potential and perception does not support the hypothesis that the magnitude of perception is linearly reflected in the EP amplitude, although a nonlinear correlation is not excluded. This agrees with the results from similar experiments in which the slowly adapting Merkel receptors were stimulated in the finger tip of man (Johnson et al., 1975). In 1968, Talbot et al. stimulated the Merkel receptors in the finger tip with a step stimulus as did Johnson et al. in 1975. Former researchers recorded, though, from the nerve and in the cortex (in the monkey) and found in both cases a linear relationship. In parallel experiments with man, perception of magnitude showed a similar linear relationship. In 1975, we confirmed the latter finding but the EP did not reflect this situation.

A nonlinear response to vibration amplitude was also found by Talbot et al. when recording from single pacinian receptors. They could, therefore, only conclude that the magnitude of vibration must be encoded by a multitude of receptors—in other words recruitment of a receptor population. At the level of the cortex they found no adequate correlation to stimulus amplitude.

Our present results cannot be clearly compared to cortical firing as yet. In general, a linear relationship between EP amplitude as recorded from the scalp and single unit firing frequency in the cortex is perhaps unlikely (although still possible) due to the neuronal and physical complexity (simultaneous activation and inhibition of many cortical neurons, for example). One could just as easily develop parallel arguments for the relation between perception and stimulus amplitude. These inherent weaknesses of the technique must be kept in mind with all such studies.

As has been found by previous investigators in the auditory (Keidel and Spreng, 1965) and somatosensory systems (Franzèn and Offenloch, 1969; Johnson et al., 1975; and the present study) the amplitudes of strictly the late components show a reasonable relation to the stimulus and to the magnitude of perception. However, not all of the late components do so—only the large ones. This is true for both investigations in which the individual components have been measured (the latter two). The larger components have, of course, a better signal-to-noise ratio, a fact which could alone explain their better correlation, i.e., the correlation is not hidden so much in the noise. Therefore, they may have little to do with cerebral information processing. Furthermore, the late components of the evoked potential show a regular rhythm with a frequency of about 10 Hz and the first subharmonic thereof (5 Hz, see Fig. 1) and are, in contrast to the earlier components, widely distributed over both hemispheres. This suggests that these late components consist of an average alpha rhythm which was transiently blocked by the arrival of the afferent impulses. Following the blockade period, the thalamocortical alpha generators begin oscillating again with a relatively constant latency (phase shift). Since it is known that the alpha waves appear when the subjects are in a relaxed state, it seems likely that the reappearance of these waves after the stimulus expresses at least diminuition if not cessation of this information processing.

This hypothesis does not, of course, exclude the possibility that other components hidden in the late potentials may be of some significance for perception. The relationship between the evoked potentials and the alpha rhythm has been conjectured by numerous researchers. Since 1940 some of the most relevant work has been done: evoked and spontaneous activity probably involve parallel, but separate paths (Dempsey and Morison, 1942); secondary EPs are abolished by corticothalamic lesions (Chang, 1950), a definite relation exists between EPs and subsequent alpha frequency (Levonian, 1966); and variations in average EPs as a function of the alpha phase (Rémond and Lesèvre, 1967). Since we also know that EP and alpha rhythm originate at least partially in the same cell population and since we know from clinical cases with hemispheric lesions that neither the occipital, frontal, nor ipsilateral hemisphere is required for tactile perception, we feel that the generalized, bilateral late potentials resembling alpha rhythm are less important than earlier activity for perception.

Other arguments for a long, intracerebral processing time as the postulated basis of conscious experience are also inconclusive. Libet et al. (1967) found that electrical stimuli of the skin are perceived only if they give rise to cortical-evoked potentials with late components. However, there was a marked difference as well in the early components. Arguments based on a long utilization time or on masking by subsequent stimuli (Libet, 1967) are also inconclusive; they do not prove that neuronal events underlying the early components of the cortical evoked potentials are irrelevant for perception nor do they prove that only the late components are relevant. In general, in all threshold experiments there are statistical noise problems, the solution of which requires temporal summation.

A comparison of our results with those of the only other group which also compared the effects of vibration amplitude on the EP and on perception of magnitude is unfortunately impossible for at least two reasons. Both Fruhstorfer (1966) and Ehrenberger et al. (1966) used a short baseline (± 20 ms) in the midst of the ongoing activity as a reference point for all measurements. They also applied the stimuli at the finger tip and used a short risetime and a Gaussian-shaped impulse (200 Hz) which undoubtedly stimulated all three receptor groups. The power functions they found for both the EP and the psychophysical curves differ markedly from our results. This is probably because of the above-mentioned differences in stimulation and measurement techniques.

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