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Somatosensory-Evoked Potentials and Perception of Skin Velocity

D. Johnson[1], R. Jürgens[2], and H. H. Kornhuber[2]

[1] Present address: Institut für Physiologie, Klinikum der J. W. Goethe-Universität, Theodor-Stern-Kai 7, D-6000 Frankfurt/Main 70, Federal Republic of Germany
[2] Section of Neurophysiology, Universität Ulm, D-7900 Ulm, Federal Republic of Germany

Summary. Mechanical ramp indentations of constant amplitude and randomized velocities to the finger tip of human subjects were used to adequately stimulate the rapidly adapting Meissner corpuscles. The somatosensory-evoked potentials and the subjects' estimations were simultaneously recorded and analyzed off-line.

The magnitude of perception showed a nonlinear, monotone-rising function approximated by a log or power function with respect to ramp velocity. The small, early components of the EP showed little correlation to stimulus velocity. The large, late components (120 ms or more) showed a stimulus response function similar to the psychophysical one. These large, late components resemble the alpha rhythm in frequency and distribution.

It is concluded that although the large, late component of the EP show a similar relation to the psychophysical one, it is unlikely that there is a specific correlation between them.

Key words: Evoked potentials - Perception - Skin indentation.

Introduction

The importance of cortical-evoked potentials with respect to the objective stimulus and subjective (psychophysical) estimations has been a subject of controversy for many years. Few investigations have, however, compared these parameters using adequate stimulations in one and the same experiment.

We have taken advantage of the known frequency response characteristics of the touch receptors to stimulate the rapidly adapting (Meissner) receptors in the finger tip of man as specifically as possible. Because of their adaptation characteristics, time constants about 2 and 40 ms (Kornhuber and Viernstein, 1972),

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Offprint requests to: Dr. D. Johnson

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which may in turn be at least partly due to tissue mechanics—similar time constants (Becker and Kornhuber, 1973)—these receptors are specific for local, dynamic gradients, i.e., they signal the localization of movement on the skin. Their tuning curves show the best frequencies in the monkeys (lowest thresholds) at 20—30 Hz (Talbot et al., 1968). The 1/1 falling slope of the log/log tuning curve with sine wave stimuli indicates that these receptors have constant velocity thresholds. The same receptors have been found in the glabrous skin of the human hand (Knibestöl, 1973). The three response populations that are present in the primate hand (slow, rapid, and very rapid adapting, corresponding to Merkel, Meissner, and Pacini receptors) have also been found in the monkey postcentral gyrus and in a similar quantitative relation (14/80/6) as in the median nerve. Thus the cutaneous frequency analysis forming the zeroth and the first and second derivative of stimulus position by means of the adaptive properties of the three receptor populations (Kornhuber, 1972) is preserved up to the cortical level. The cortical neurons with afferents from Meissner receptors (which are the important ones for this paper) show similar tuning curves like the peripheral receptors with the best frequencies (lowest threshold) around 30 Hz (Mountcastle et al., 1969).

Methods

Ramp indentations (1 mm constant amplitude) with velocities between 17 and 136 mm/s (see Fig. 1) were applied to the right index finger tip of 15 normal, awake, human subjects (11 male, 4 female, between 16 and 27 years of age) as adequate stimulation of the rapidly adapting Meissner receptors in the skin. Stimulus velocities were individually randomized (four categories per subject, 128 repetitions of each). The cylindrical plexiglass probe, with a tip diameter of 1 mm, was driven by a mechanostimulator (Burchard et al., 1967).

Skin contact was automatically detected by the contact of the silver probe tip with a graphite layer sprayed on the finger tip. The probe was automatically reset to subthreshold skin contact prior to the stimuli. The position of the stimulus probe was feedback-controlled with a precision of ± 1 µm. The duration of the stimulus and the interstimulus intervals were also randomized. The next stimulus was given at least 4 s after completion of the psychophysical magnitude estimation. To avoid off-effects and usage of off-information for the magnitude estimations, the stimulus end position was maintained a random time after completion of the magnitude estimation. Alertness was continuously monitored by EEG, verbal communication, and television observation. Beckmann Ag-AgCl electrodes were used to record the EEG (monopolar vs joined ears) in a horizontal row in front and behind C_3 and C_4 according to the 10–20 system (from frontal to parietal and occipital, ipsi and contralateral). At stimulus onset a quartz clock was started and after 500 ms, a time mark was generated and stored on the analog tape on which the EEG was also recorded. At the time of recording the EEG written on paper was continuously scanned for artifacts due to eye, head, tongue and lid movements, and galvanic skin reflexes. All artifacts were marked by electrical code signals on the analog magnetic tape. The averaging analysis was carried out off-line using tape reverse analysis starting with the 500 ms delay pulse so that the recordings contaminated with artifacts were automatically detected and eliminated using the markers added at the time of recording.

The evoked potentials were averaged and the 95% confidence limits were computed and plotted. The amplitude and latency values of the peaks were listed (DECUS 12-98 of the first author) and peak-to-peak amplitudes were measured. The simultaneously recorded psychophysical velocity estimates (method of absolute judgment) were analyzed off-line. With the large university computer the information transmission was calculated (unpublished results).

Results

A couple of contrasting examples of cerebral, evoked potentials from two subjects under identical stimulus conditions are shown in Figure 1. The stimulus is schematized below. The upper curve is typical for the majority of subjects. The degree of interindividual variability may be readily seen. The baseline, used as a reference point for plotting (but not for amplitude measurements) is the average

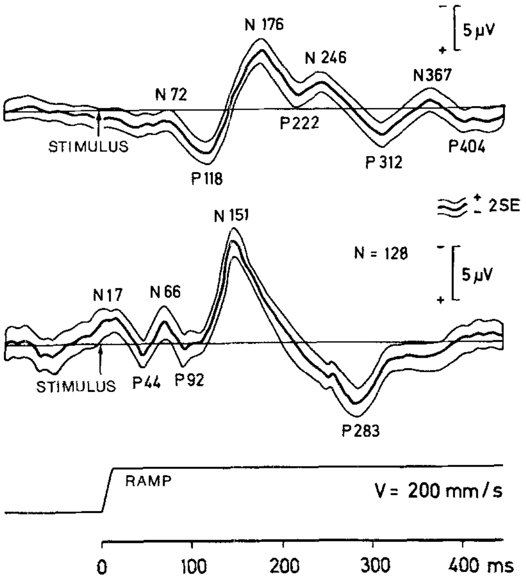

Fig. 1. Two contrasting examples of averaged evoked potentials from different subjects under identical experimental conditions in response to 128 stimuli as shown below (maximal ramp velocity used). Stimulus amplitude = 1 mm applied to the right index finger tip. Recordings are monopolar with reference to joined ears. Negativity upwards, latencies in ms. Each average curve is enveloped by ± 2 SE (intraindividual)

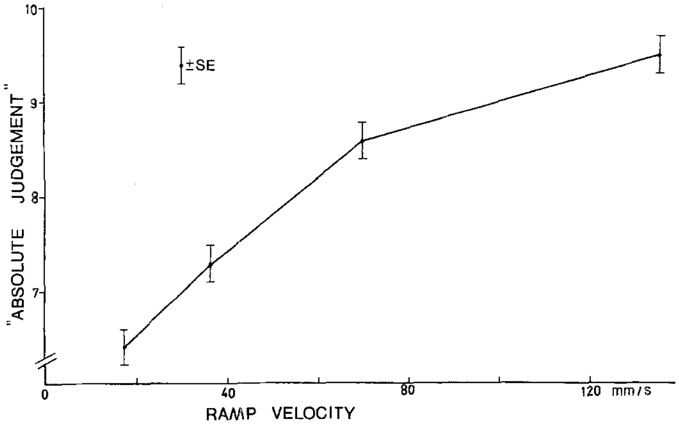

Fig. 2. Psychophysical perception of ramp velocities. Averaged estimates of ramp velocities from 15 subjects with inter and intraindividual standard errors

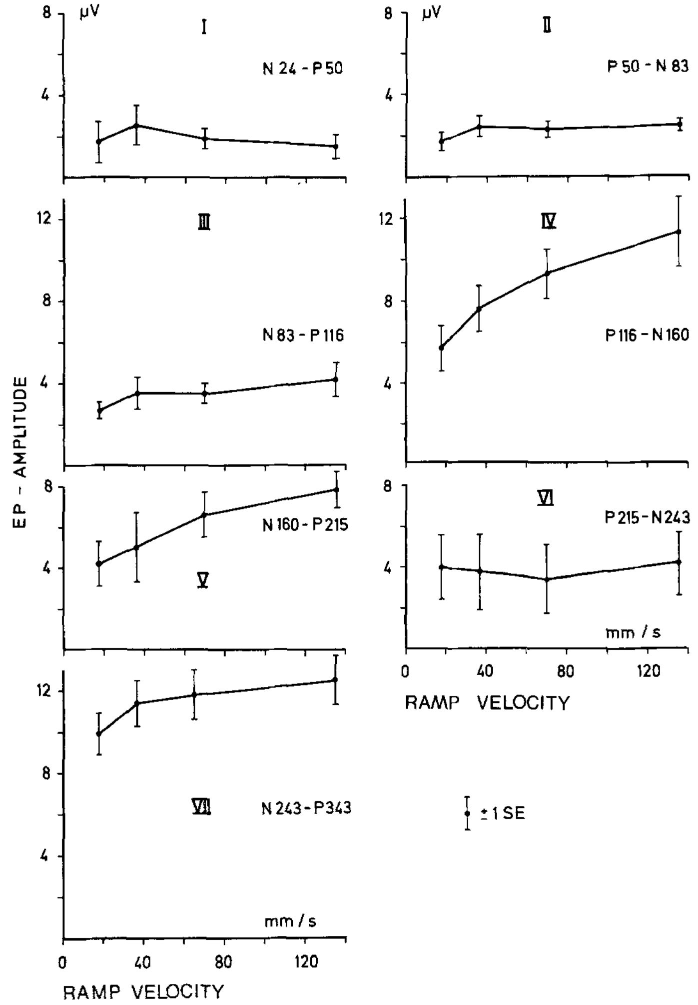

Fig. 3. Amplitude curves of the various components of the somatosensory cortical-evoked potentials with respect to velocity of mechanical ramp stimuli applied to the right index finger tip. Negativity = *N*, positivity = *P*, average latencies in ms of peak-to-peak measurements. Averages of 15 subjects with interindividual standard errors

level of EEG during the 110 ms prior to stimulus onset. The mean response is exhibited with the 95% confidence limits as envelope.

The average of the psychophysical estimates of the given stimulus velocities for the 15 subjects is plotted in Figure 2 with standard errors. The mean values may be fitted to a log or power function. The log function is $I_s = 0.61 \log_{10} V - 0.3$. The correlation coefficient $K = 0.995$. The power function is $I_s = 0.16 V^{0.38}$. The correlation coefficient $K = 0.998$. The difference between the two fittings is insignificant.

The relations of the amplitudes of the various components of the evoked potential to stimulus velocity are shown in Figure 3. The similarity in form of components IV, V, and VII (the three largest components) to Figure 2 may be readily seen and the data may also be fitted to a log or power function ($I_0 = 0.53 \log V - 0.14$, where the correlation coefficient $K = 0.998$ or $I_0 = 0.21 V^{0.32}$, where the correlation coefficient $K = 0.993$ for component IV). In other words, the evoked potential components P116–N160 bear a similar relation to velocity as does the subjective perception.

While the early components of the evoked potential with peak latencies up to about 120 ms are localized strictly over the contralateral, postcentral, hand area, the later components appear widespread over both hemispheres. In half of the subjects, the amplitudes of the late components were somewhat larger over the contralateral hemisphere, while in the other half they were equal on both sides.

A latency decrease for all wave peaks was also measured with increasing ramp velocity. The maximal decrease was about 20 ms. It seems remarkable, however, that the general form of the evoked potential remained similar despite considerable change in stimulus velocity. This relative constancy of the wave form of the evoked potential is probably due to the triggering of a brain-inherent rhythm by the stimulus onset—the alpha rhythm (see Discussion).

Discussion

We found good agreement between the psychophysical stimulus-response relation and the stimulus-response relation of some of the late components of the evoked potential. However, we believe that no conclusion should be drawn regarding the neuronal activity during these late waves as a possible background for perception for the following reasons: first, not all the late potentials are correlated to stimulus magnitude (not component VI, for instance); instead only the large components show a reasonable relation to the stimulus magnitude. This, however, should be expected for purely statistical reasons, since the smaller the signal amplitude, the larger the influence of noise. Second, the late waves of the evoked potential resemble the alpha rhythm in frequency and bilateral distribution over the brain, while the early components are well localized over the contralateral, postcentral hand area. With peak latencies of more than 120 ms, the late waves probably consist of averaged alpha rhythm. The fact that these waves are larger than the averaged alpha rhythm prior to stimulus onset may be explained by a partial synchronization of thalamocortical alpha oscillation after alpha block due to the stimulus. Third, since alpha rhythm is normally associated with a subject in a relaxed state, it would be surprising if alpha rhythm in the evoked potential should be a sign of intensive, cortical, information processing underlying perception. Fourth, the similarity of the psychophysic and neurophysiologic (evoked potential) stimulus response relations in the case of ramp stimuli of the skin must be regarded as coincidental, since in two parallel studies (step and vibration stimuli) there was no such correlation (Johnson et al., 1975; Johnson et al., 1980). Because of such coincidental similarity the neuronal activity underlying the late (and not the early) components of the evoked potential has been considered to be the 'specific' basis for perception.

The discussion above shows that this assumption is probably erronous. Indeed, other results from this laboratory show that the time delay due to intracortical information processing for motor regulations may be 10 ms in the case of arm movement. The intracortical delay may be as short as 10—20 ms for human saccadic eye movements. Others have found that neurons in the primary cortical sensory fields transmit most of the information within the first hundred ms after arrival of the sensory input.

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