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Human Auditory Evoked Potentials: Possible Brain Stem Components Detected on the Scalp

Abstract. *Auditory potentials recorded from the vertex of humans by a modified averaging technique have very short latencies and are probably generated by brain stem structures located at a considerable distance from the recording point. The evoked waves, which show considerable detail and consistency within and across subjects, may be clinically useful in evaluating subcortical function.*

The use of averaging techniques in the study of the human auditory system has been limited to auditory nerve potentials recorded from the ear canal (*1*), and to waves, recorded from the scalp, which may reflect cortical activity (*2*). Recently, waves with peak latencies as short as 7.6 msec have been recorded from the scalp (*3*). We now report a method which can record from the scalp electrical activity within the interval which the previous methods have not studied. Thus, a combination of our method with the ear canal method (*1*) should allow study of the electrical activity of most parts of the auditory system, including brain stem components, in intact, unanesthetized humans. Such recordings could be used to determine the neural level of dysfunction in clinical conditions such as severe brain damage and space-occupying lesions, since it is likely that wave components can be related to specific neural structures, as is the case in the cat (*4*), bat (*5*), and chinchilla (*6*). Our recordings show that in man, as in cats (*4*), averaging techniques can now be used to detect neural signals at such distances that the electrical activity from any brain location within the skull should be detectable at the scalp, given a satisfactory method of synchronizing the activity with the averager.

Three adult male subjects were studied at rest in an electrically grounded metal enclosure, in a seated position with the head supported and the neck muscles relaxed. The subject was grounded by the earlobe or wrist. The signal was led from electroencephalograph (EEG) disk electrodes to, in succession, a Grass P9 preamplifier, a high-pass filter (bandpass of system approximately 300 hz to 2 khz at 6-db points), a Tektronix 3A3 amplifier in a 565 oscilloscope, and a Princeton Applied Research TDH-9 waveform eductor (a 100-channel capacitor-storage "averager"). The TDH-9 was used on-line in a manner which minimized the nonlinear summation of the instrument by a sweep speed of 100 microseconds per point and a 100-second capacitor time-constant; these settings gave, with maximal input voltages and 2000 repetitions, signal outputs of 50 to 100 mv peak-to-peak, approaching the performance limit of the TDH-9. A Tektronix 162 waveform generator, carefully set at a frequency which canceled 60-hz power-line interference (*4*), triggered the TDH-9 at about 16 hz and, after a delay, an Exact 303 square-wave generator which in turn delivered a 0.5-volt, 0.1-msec pulse to an Audiovox 9C earphone attached by a Y tube to stethoscope earpieces for binaural stimulation. Click intensity, measured in a quiet room by using a power attenuator box with properly matched impedances, was never greater than 75 db above the subject's subjectively determined threshold for this stimulus. The click waveform (Fig. 1A) was transduced to the oscilloscope by a 12.5-mm condenser microphone with a Bruel and Kjaer Type 2203 sound level meter through a 2-cm³ coupling chamber.

Recordings were made between the vertex and the lateral-posterior neck; similar results were obtained with the earlobe or chin as reference point. For all recordings 2000 clicks were delivered. Auditory responses (Fig. 1, B–D) showed a series of waves between 2 and 7 msec after the arrival of the stimulus at the ear, which were surprisingly consistent within and between subjects. These waves all have shorter latencies and apparently greater consistency than those of the earliest potentials recorded by Mendel and Goldstein (*3*), which in turn are reported to be more stable than waves with latencies of 50 msec or greater. Control records (Fig. 2A) taken with the ears plugged showed an absence of electrical artifact beyond the first fraction of a millisecond. There was no reversal of the polarity of the evoked potential with stimulus reversal, indicating that no part of the cochlear microphonic was detected. The first detectable wave had a magnitude of about 100 nanovolts, approached the level of run-to-run variation in the base line (see Fig. 1C; compare with Fig. 1, B

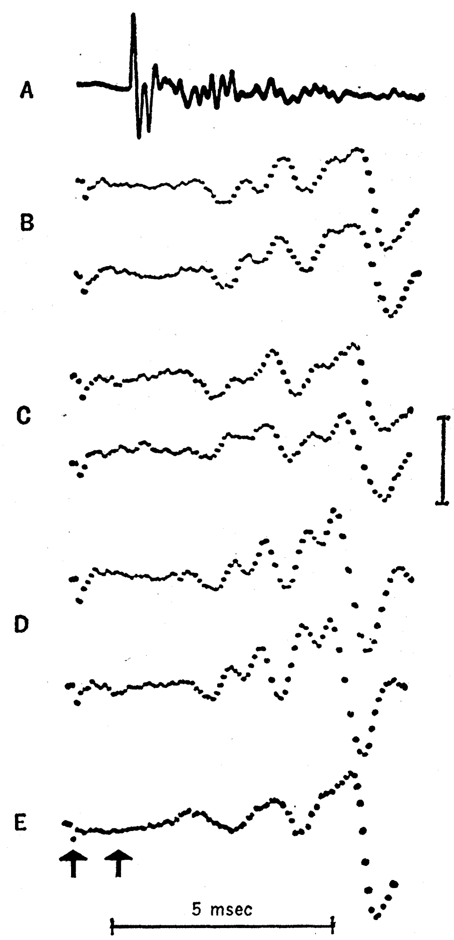

Fig. 1. (A) Sound stimulus showing time of arrival at the ear. Downward deflection indicates compression. (B–D) Two recordings from each of three subjects, vertex-neck, approximately 75-db sensation level. (E) Recording vertex-neck from subject in D, 65-db sensation level. Vertical calibrations: A, 14 μbar; B–E, 0.5 μv. In B–E and in Fig. 2, upward deflection indicates positivity at the first electrode; earphones were energized at the first arrow; sound wave arrived at the ear at the second arrow.

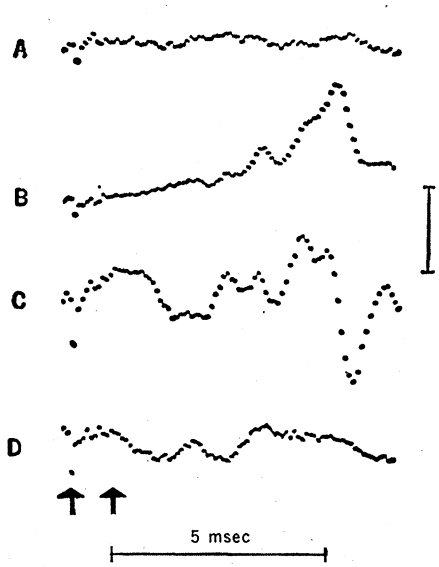

Fig. 2. Recordings from same subject as in Fig. 1D, at 75-db sensation level. (A) Vertex-neck with ears plugged. (B) Vertex-neck recorded at bandpass at 10 hz to 2 khz. (C) Vertex-wrist. (D) Neck-wrist. Vertical calibrations: A, C, D, 0.5 μv; B, 1.1 μv.

and D), and was usually a negative wave with a peak latency of about 2.4 msec from the arrival of the stimulus at the ear. When allowance is made for intensity and air conduction time, this wave has about the same peak latency as the second wave of Yoshie *et al.* (*1*) recorded from the external ear canal. This latency is so short as to strongly suggest that the potential is generated in the brain stem. In anesthetized cats, Jewett (*4*) has shown that a volume-conducted positive potential recorded at the scalp, but synchronous in time with N_2 recorded at the round window, is generated in the vicinity of the cochlear nucleus. If this is analogous to the first negative wave in the human record, then subsequent waves may indicate sequential contributions from successive neurons, as they do in the cat (*4*). While it may thus be possible to associate a given wave with activity in a distinct portion of the auditory system, it seems unlikely that any but the earliest of the waves will represent exclusively the activity of specific nuclei or tracts; potentials from both ascending and descending fibers can occur simultaneously, and postsynaptic slow waves can have durations extending over the time of several waves (*4*). We wish to defer the labeling of the waves until a nomenclature based upon some clearly defined reference point (such as N_1) can be developed.

The evoked potentials of Fig. 1 were obtained by means of a bandpass filter which effectively reduced the EEG "noise" at the input to the TDH-9. This filtering makes direct interpretation of the potential difficult, owing to the differentiating property of the filter and the phase-lead introduced. Recordings made without the filter (bandpass 10 hz to 2 khz) showed that all of the waves, except possibly the first, were positive at the vertex with respect to the neck (Fig. 2B). The positivity is consistent with the interpretation that these waves are generated, at least in part, by action potentials traveling toward the vertex (*4*).

The contribution of the neck reference to the waveform was studied by recording vertex-wrist and neck-wrist (Fig. 2, C and D). Neck-wrist recordings showed none of the later waves, but may have shown the first wave (Fig. 2D); however, the electrocardiographic artifact caused variability in the waveform of a similar magnitude. Simultaneous recordings will be necessary to determine the potential distribution of this initial wave. Some workers (*7*) have offered evidence that, under certain conditions, evoked responses to very intense auditory stimulation may be generated by the musculature of the head, particularly the neck. Three lines of evidence argue against such an origin for the potentials described in this report: (i) neck-wrist recordings do not show the waves as would be expected if the generators were in the neck; (ii) the potentials were recorded with sensation levels of 65 db (Fig. 1E), much lower than the reported threshold for the muscular response (*4*); (iii) the latency of the earliest wave is so short that, given conduction velocities and lengths comparable to that of the auditory nerve plus synaptic delay, there is insufficient time for impulses to leave the skull. Electromyogenic potentials in the middle ear muscles have a latency of about 10 msec with intense stimulation (*8*), so they are unlikely to be the generator of any of the waves reported here.

When the click intensity was reduced, the response showed an increased latency (Fig. 1E), as has been reported for the auditory nerve response N_1 (*1*). Since the latency of the later waves was increased only by the same amount as the early waves, it would appear that this effect on latency is less prominent in later synapses. It is also evident (Fig. 1E) that a decrease in stimulus intensity changes the waveshape and lowers the size of the early waves while the later biphasic wave remains at about the same magnitude.

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Denver Earthquakes

Simon (*1*) states in her abstract that "it appears unnecessary to explain the Denver earthquakes in terms of pressure induced by the introduction of waste fluid." In the light of the data that she presents, such a statement is unwarranted and extremely misleading. As she has concluded, her data do indicate that present-day broad patterns of seismicity in Colorado agree with those deduced from historical records, and that there was therefore some degree of tectonic strain in basement rocks of the Denver area prior to the injection of waste fluids at the Rocky Mountain Arsenal well. But her data also indicate that very numerous (1698 of magnitude $\gtrsim 1$ over the period from 1962 to 1968) earthquakes in the Denver area *began* at the time waste fluid was first injected at the Arsenal well. This frequency of seismic events and the resultant concentration of energy release are not in accord with historical records. In addition, Simon cites pumping tests conducted by Army Engineers in 1968 in which an attempt to withdraw fluids from the well resulted in numerous small shocks. Simon's data in effect substantiate the work of Evans (*2*) and