

HUMAN AUDITORY SUSTAINED POTENTIALS. II. STIMULUS RELATIONSHIPS

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The preceding paper demonstrated that it is possible to record from the human scalp an auditory sustained potential that is distinct both from the transient onset and offset potentials, and from the contingent negative variation. The amplitude, duration and morphology of this auditory evoked potential appears to be largely determined by the nature of the eliciting acoustic stimulus. There are only a few reported studies, however, that evaluate such stimulus-response relationships.

Keidel and his colleagues (David et al. 1969; Keidel 1971) have demonstrated that the human auditory sustained potential increases in amplitude with increasing intensity of the acoustic stimulus in a similar manner to the transient response. They have also reported that the duration of this potential is determined by the stimulus duration, and its morphology correlated to the envelope of the stimulus intensity. In studies of inter-modality relationships, they found that simultaneous sustained visual stimulation resulted in attenuation of the auditory sustained potential recorded between vertex and mastoid electrodes (David et al. 1971).

This paper further explores the relationships between the human auditory sustained potential and various physical parameters of the eliciting stimulus. A greater understanding of the stimulus determinants of the auditory

sustained potential is important for 3 reasons. First, a more extensive comparison between the stimulus relationships of the transient evoked potential and of the sustained potential is essential to evaluating their different physiological sources and psychophysical correlates. Second, a better description of which aspects of the acoustic stimulus play a determining role in the generation of the auditory sustained potential should increase our knowledge of the origins of this scalp-recorded potential. Third, these experiments can provide basic normative data for further psychological and clinical studies of the auditory sustained potential.

The selection of which stimulus parameters to evaluate was largely based on previous studies of the stimulus determinants of the slow onset-response components of the auditory evoked potential. These studies have been recently reviewed by several authors: Reneau and Hnatiow (1975); Davis (1976); Keidel (1976); Picton et al. (1977). It was obviously important to evaluate the effects of stimulus intensity, presentation rate and tonal frequency on the sustained potential. An examination of the frequency specificity of the refractory period of the sustained potential using the technique of Butler (1968) was also performed in order to gain some further knowledge of the physiological characteristics of the sustained potential generator. The effect of different stimulus durations was studied because of the sustained rather than transient nature of the response. Finally, the possible effects of monaural and binaural

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stimulation on the symmetry and amplitude of the sustained potential was investigated.

Methods

The subjects were paid volunteers who sat quietly in a sound-attenuated room and read while toneburst stimuli were presented through earphones. The rise and fall times of these tonebursts were 10 msec. Their intensity was calibrated to normal hearing levels (HL) or to 0.0002 dyne/cm² (SPL). The duration of the toneburst was measured between the beginning of the rise and the beginning of the fall in acoustic intensity. Different stimuli were presented in balanced block or random sequence so as to prevent any possible effects of temporal order on the measurements. Except for the last experiment wherein the ear of delivery was varied, all stimuli were presented to the left ear.

All recordings were made using direct-coupled amplification. Except for the last two experiments, the electroencephalogram was recorded between vertex and right mastoid electrodes. In the study of the effects of tone duration, a balanced frontal-mastoid electrode (Cooper et al. 1974) was used to eliminate eye blink artifacts. In the study of the effects of ear of delivery, recordings were taken from the temporal and central regions as well as the vertex, and a balanced non-cephalic chest reference (Stephenson and Gibbs 1951) was used.

In all experiments electro-oculographic signals recorded between the supra- and infra-orbital ridges were simultaneously averaged so as to ensure that there was no electro-ocular contamination of the cerebral evoked potentials. For the study of the effects of ear of delivery, these electrodes were oriented diagonally so as to monitor lateral as well as vertical eye movements.

More complete methodological details are given in the preceding paper. The stimulus parameters specific to each experiment will be described together with the results.

Results

(1) Intensity

Tonebursts of 1 kc/sec frequency and of 1 sec duration were presented every 3 sec at intensities of 10–90 dB HL. With increasing stimulus intensity the amplitudes of the transient onset auditory evoked potential and the sustained potential both increased. The sustained potential was of smaller amplitude than the transient onset response at all intensities. At the lower intensities the amplitude of the auditory sustained potential was about 30% of the amplitude of the N₁ component, but at the higher intensities it reached 50%. Fig. 1 presents sample wave forms from one subject, together with the average amplitude measurements for the 12 subjects evaluated in this experiment.

Regression lines for the N₁ and sustained potential data at the different intensities were obtained according to both a logarithmic and a power relationship of the response to stimulus intensity. For N₁ the logarithmic regression line ($r = 0.61$) was: amplitude in $\mu\text{V} = 0.075$ (intensity in dB) + 2.33. For the sustained potential the regression line ($r = 0.87$) was: amplitude in $\mu\text{V} = 0.05$ (intensity in dB) - 0.05. Exponents of the power functions were 0.13 for N₁ ($r = 0.63$) and 0.23 for the sustained potential ($r = 0.80$). According to both basic models, the sustained potential data were significantly more related to intensity than the N₁ data.

At intensities of above 50 or 60 dB HL there was a tendency for the amplitude of the N₁ to saturate, particularly in certain subjects (e.g. subject E.C. in Fig. 1). Four of the 12 subjects had a lower or equal amplitude N₁ at 90 dB compared to 60 dB. On the other hand, all of the sustained potential amplitudes at 90 dB were higher than at 60 dB.

(2) Stimulus repetition rate

Auditory evoked potentials were recorded in response to 1 kc/sec 80 dB HL tonebursts of 1 sec duration that were presented at rates of once every 10, 5, 3 and 2 sec. Both the

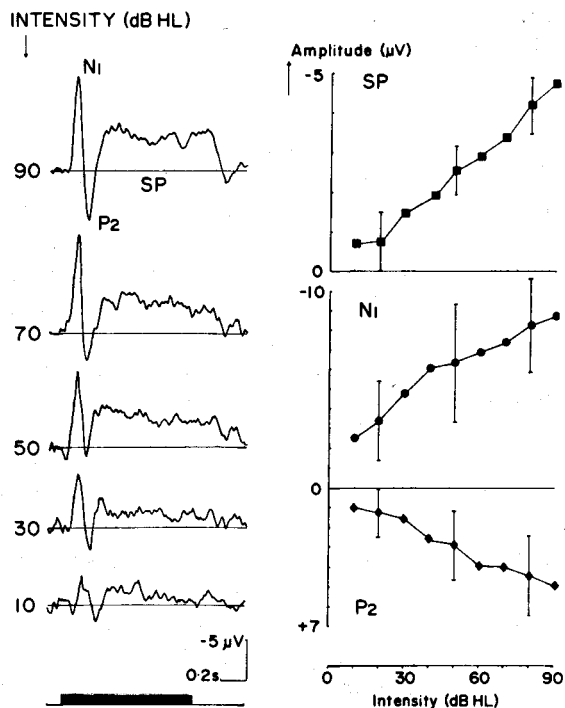


Fig. 1. Effects of stimulus intensity on the auditory evoked potentials. Tonebursts of 1 sec duration and of 1 kc/sec frequency were presented every 3 sec to the left ear. The intensity of the tonebursts was varied between 10 and 90 dB HL in 10 dB steps. The evoked potentials were recorded between the vertex and right mastoid. The evoked potential wave forms from one subject (E.C.) are shown on the left of the figure. Each tracing represents the average of 80 individual trials. The sweep duration was 1.5 sec and there was a 100 msec delay before the stimulus onset. On the upper right of the figure are plotted the mean amplitudes from 12 subjects of the sustained potential (SP) at the different intensities. Below this are plotted the mean values for the N_1 and P_2 components of the onset response. The variability of the data is shown by the plotted ± 1 S.D. range at 80, 50 and 20 dB HL.

transient onset response and the sustained potential decreased in amplitude at higher rates of stimulus presentation, but the N_1 component was significantly more affected than the sustained potential. Fig. 2 illustrates the evoked potential wave forms from two subjects, and the average data from all 10 subjects that were evaluated during this experiment.

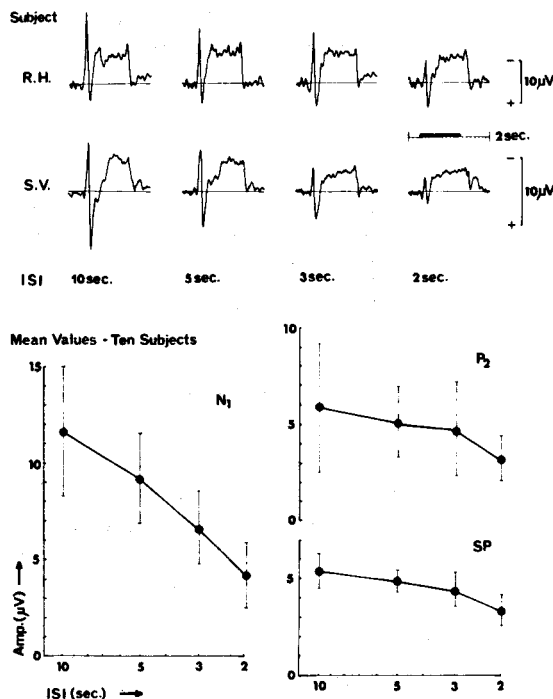


Fig. 2. The effect of stimulus presentation rate on the auditory evoked potentials. Tonebursts of 1 sec duration with an intensity of 80 dB HL and a frequency of 1 kc/sec were presented at rates of once every 10, 5, 3 or 2 sec. Illustrative evoked potential wave forms from two subjects are plotted at the top of the figure. Each wave form is the average of 100 individual responses. In the lower section of the figure the mean values over the 10 subjects evaluated in this experiment are plotted together with the ± 1 S.D. range.

This effect was further studied using 600 msec tonebursts presented at rates of once every 2 or 1 sec. Again, at shorter interstimulus intervals all the evoked potential components were decreased in amplitude. However, the sustained potential was significantly more resilient to increasing stimulus repetition rates than either the N_1 or the P_2 components of the onset response. At stimulus presentation rates of 1/sec the average auditory sustained potential became almost equal in amplitude to the N_1 component, 5 of the 10 subjects actually showing a larger sustained potential. Fig. 3 shows the evoked potential wave forms from two subjects, together with the average

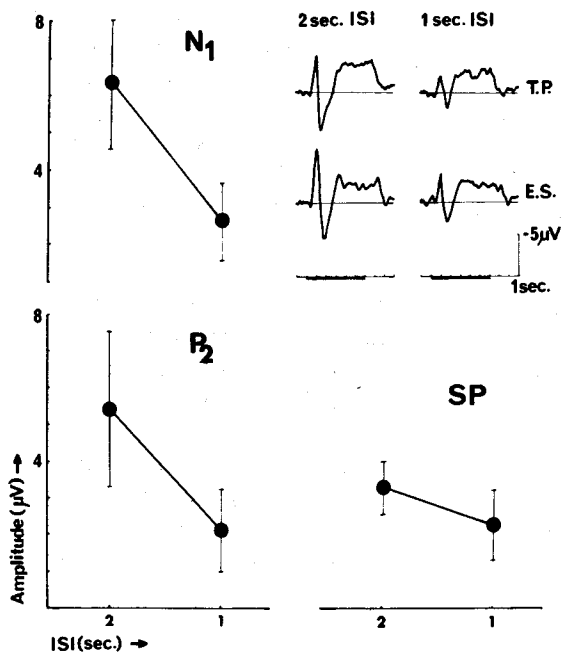


Fig. 3. The effect of rapid stimulus presentation rate on the auditory evoked potentials. Tonebursts of 600 msec duration with an intensity of 80 dB HL and a tonal frequency of 1 kc/sec were presented every 1 or 2 sec. Mean and standard deviation data from 10 subjects are plotted together with illustrative average wave forms from two different subjects. Each evoked potential wave form represents the average of 100 individual responses recorded between vertex and right mastoid, with negativity at the vertex represented by an upward deflection.

data from the 10 subjects studied in this paradigm.

(3) Interactions between intensity and repetition rate

In order to investigate any possible interaction between intensity and stimulus repetition rate, evoked potentials were recorded in response to 600 msec 1 kc/sec tonebursts presented at 50, 70 and 90 dB HL and at stimulus presentation rates of once every 1.5, 3 and 6 sec. These evoked potentials were recorded in 10 subjects who had not been tested in the previous two experiments. The average amplitudes of the N_1 , P_2 and sustained potential components of the evoked potential

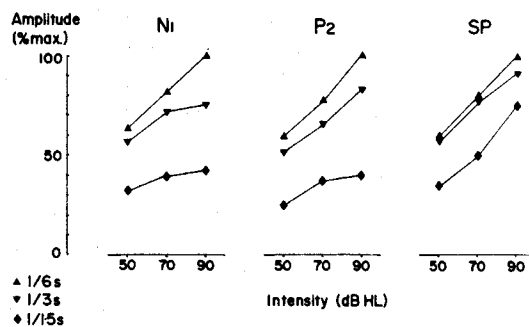


Fig. 4. The interaction between intensity and stimulus presentation rates in the determination of the auditory evoked potential amplitudes. Tonebursts of 600 msec duration and 1 kc/sec frequency were presented at 3 different intensities and at 3 different repetition rates. The mean values for 10 subjects are plotted. The amplitudes of the evoked potential components are plotted relative to the maximum mean amplitude of that component during the experiment. This maximum amplitude was 12.6 μ V for N_1 , 5.7 μ V for P_2 , and 3.6 μ V for the sustained potential. The amplitude of the N_1 component tends to saturate at higher intensities and at faster stimulus presentation rates. This effect is not present in the data for the sustained potential.

are plotted in Fig. 4 as a percentage of their maximum value. The N_1 data showed significant effects of intensity and repetition rate, and a significant interaction between the two effects. This interaction was due to a flattening of the stimulus-response function at the faster stimulus repetition rates, particularly at the higher intensities. For both the P_2 and the sustained potential measurements there were significant intensity and repetition rate effects, but no significant interaction between the two.

(4) Frequency specificity of the refractory period

Evoked potentials were recorded in response to 1 kc/sec 80 dB HL 600 msec tonebursts presented once every 4 sec. In one condition these 'test' stimuli were presented alone. In other conditions 3 'intervening' tonebursts were interjected between the 'test' stimuli so that the overall stimulus presentation rate was 1/sec. The intervening tone-

bursts were of equivalent duration and intensity to the test tonebursts, but were 250, 500, 750, 1000, 1500, 2000, or 4000 c/sec in frequency. The amplitude of the evoked potential components to the test stimuli varied with the frequency of the intervening stimuli. Illustrative wave forms from one subject, together with the average data from 20 subjects, are shown in Fig. 5.

The N_1 component of the evoked potential showed a highly significant frequency specificity effect. It was of smallest amplitude when the intervening stimuli were of the same frequency as the test stimulus, and increased in amplitude as the frequency difference between the test and intervening stimuli increased. The N_1 data in the graph plotted to the left of Fig. 5 show a highly significant

quadratic trend, with no significant linear or cubic trend. The P_2 data showed a similar quadratic trend, although the effect was less definite than for the N_1 component, probably because the P_2 was smaller and more variable in its amplitude.

The sustained potential data plotted to the right of Fig. 5 showed no significant linear, quadratic or cubic trends. The sustained potential was significantly reduced in amplitude when intervening stimuli were interjected than when the test stimulus occurred alone. Furthermore, there were significant differences between the effects of intervening stimuli of different frequency. The sustained potential was smallest when the intervening stimulus frequency was 1 kc/sec, this measurement being significantly smaller than the

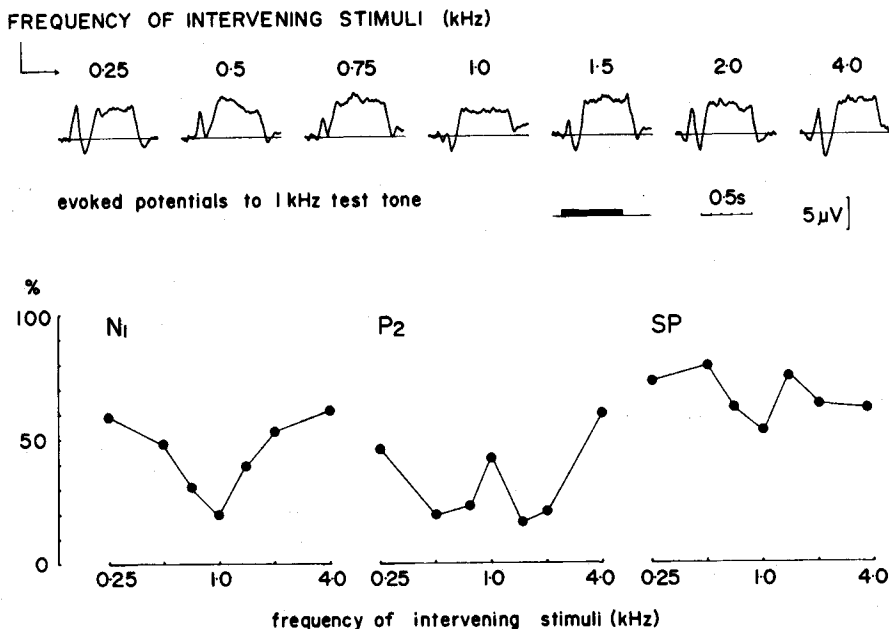


Fig. 5. Frequency specificity of the auditory evoked potential refractory periods. Tonebursts of 600 msec duration, of frequency 1 kc/sec, and of intensity 80 dB HL were presented once every 4 sec as 'test' stimuli. Between these stimuli 3 'intervening' tonebursts, of similar duration and intensity to the test stimulus but of varied frequency, were presented such that the overall stimulus repetition rate was 1/sec. The evoked potentials to the test toneburst in one subject (P.F.) are shown at the top of the figure. Each tracing represents the average of 128 individual responses. At the bottom of the figure are shown the effects of the different intervening stimuli on the various auditory evoked potential components to the test stimulus. The mean data from 20 subjects are plotted. These amplitudes are expressed as a percentage of the amplitude of the component when the test stimulus was presented alone without any intervening stimuli. These amplitudes were 10.8 μ V for the N_1 , 4.1 μ V for the P_2 , and 4.6 μ V for the sustained potential components.

measurements when the intervening stimulus was 500 or 1500 c/sec. The measurements when the intervening stimuli were of frequencies of other than 1 kc/sec were not significantly different from each other. The morphology of the frequency specificity graph can therefore be interpreted as showing a non-specific attenuation of the sustained potential whenever an intervening stimulus of any frequency occurred, and an added further attenuation when the frequency of the intervening stimulus was the same as the test stimulus. Since the sustained potential begins during the latency period of the P_2 component, this second effect might account for the small notch on the P_2 specificity curve at 1 kc/sec.

(5) Frequency

The effect of tonal frequency on the auditory potential was examined by recording the response to 1 sec tonebursts of different frequency presented every 3 sec. The intensity of the 1 kc/sec toneburst was 80 dB HL, while the other tonebursts were presented at an equivalent SPL (87 ± 3 dB) so that the tonebursts were approximately equal in loudness (Fletcher 1953). After the experiment, each subject ranked the stimuli in order of loudness. There was no significant difference between these rankings, indicating that the assumption of equal loudness at these intensities was correct. The wave forms from one subject together with the average measurements from 10 subjects are illustrated in Fig. 6.

Both the N_1 and the SP components were smaller at higher frequencies. The morphologies of the relationships were, however, quite different. The N_1 component was quite stable up to 2 kc/sec and then fell off sharply in amplitude, the measurements at 4 kc/sec and 8 kc/sec being significantly smaller than all other measurements. The sustained potential decreased monotonically with stimulus frequency, with the 250 c/sec measurement being larger than both the 4 and 8 kc/sec measurements but no other differences reaching

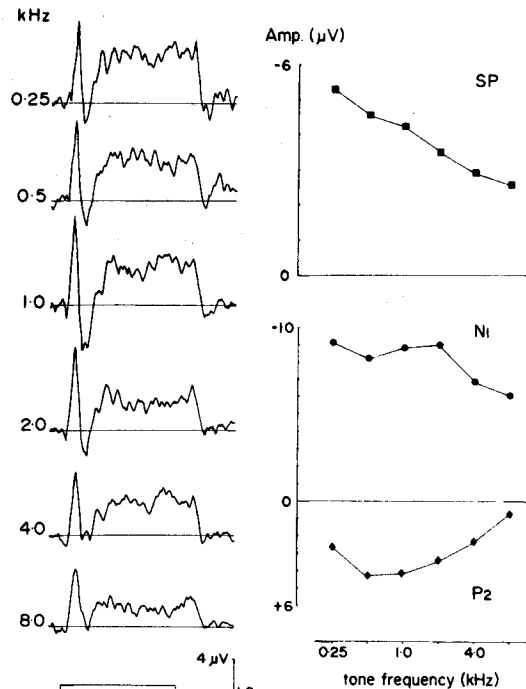


Fig. 6. The effect of tonal frequency on the auditory evoked potentials. Tonebursts of 1 sec duration were presented to the left ear every 3 sec. The frequency of the tonebursts was varied from 0.25 to 8.0 kc/sec. The intensity of the tonebursts was 87 ± 3 dB SPL. At this intensity the tonebursts were of approximate equal loudness across the frequency range. On the left of the figure are shown the evoked potential wave forms from one subject (R.H.) during this experiment. Each tracing is the average of 120 single responses. On the right of the figure are shown the mean amplitudes of the different components of the auditory evoked potential from the 10 subjects in this experiment.

the 0.01 level of significance. The somewhat unusual relationship to tonal frequency seen for the P_2 component can probably be related to the partial overlapping of this component by the sustained potential.

(6) Duty cycle and adaptation effects

In order to evaluate the possibility of adaptation, evoked potentials were recorded to 1 kc/sec 80 dB HL tonebursts presented once every 10.24 sec with durations of 1, 3, 5 and 9.24 sec. For this experiment, a balanced

frontal-mastoid reference was used to compensate for blink artifacts and averaging was performed continuously. As the tonebursts became longer, the amplitude of the auditory sustained potential measured in the 1 sec after its onset decreased. Measurements taken during the tonebursts showed that there was no significant change in amplitude of the sustained potential during the 3 sec toneburst, but that there was a significant attenuation in

amplitude during the course of the 5 sec toneburst. For the 9 sec toneburst the measurements became too small to allow meaningful assessment of adaptation during the stimulus. Fig. 7 shows the evoked potential wave forms from one subject and the average sustained potential data from the 10 subjects evaluated during this experiment.

With increasing stimulus duration the amplitude of the onset transient response

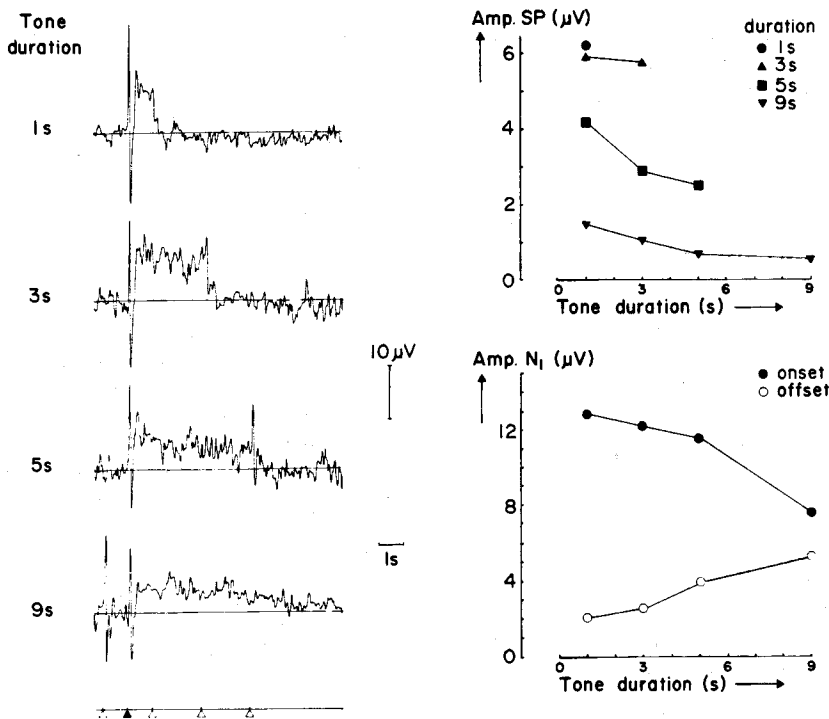


Fig. 7. The effects of stimulus duration and duty cycle on the auditory evoked potentials. Tonebursts of 1, 3, 5 and 9.24 sec were presented at a rate of 1/10.24 sec. The tonebursts had an intensity of 80 dB HL and a frequency of 1 kc/sec. Evoked potentials were averaged continuously throughout the whole period of stimulation. On the left are plotted the evoked potential wave forms from one subject (H.K.). This subject had evoked potentials that were about twice the average in amplitude. Each tracing represents the average of 96 individual responses. The tonebursts began 1.25 sec after the onset of the averaging sweep (dark triangle). The toneburst ceased at the points in time represented by the open triangles. The 9 sec toneburst was actually 9.24 sec in duration so as to allow a 1 sec offset time. This toneburst therefore ceased 0.25 sec after the onset of the averaging sweep. In the right upper portion of the figure is plotted the sustained potential amplitude over the course of the toneburst at each different tone duration. The amplitude of the sustained potential was measured during the 0.5 sec preceding the time point plotted. With increasing stimulus duration, the sustained potential becomes smaller. There is also adaptation over the course of the 5 sec and 9 sec toneburst. In the bottom right of the figure is plotted the amplitude of the N_1 component of the transient response at the different durations of stimuli. The offset N_1 was measured relative to the immediately preceding sustained potential value. With increasing tone duration the onset response gets smaller but the offset response gets larger.

decreased, and the amplitude of the offset transient response increased. This effect is illustrated in the evoked potential wave forms in the left half of Fig. 7 and plotted graphically in the lower right portion of that figure.

(7) Ear of delivery

Evoked potentials were recorded to 1 kc/sec tonebursts of 1 sec duration presented every 3 sec to the left ear, to the right ear, and to both ears. The intensity of the stimuli was 80 dB HL and no compensation was made for the threshold differences obtained when the stimuli were presented binaurally. Recordings were made from T₃, C₃, C₂, C₄, and T₄ electrodes referred to a chest reference. The evoked potential wave forms from one subject, together with the average data from 10 subjects, are illustrated in Fig. 8.

There were significant effects of electrode location, but no significant differences in N₁ or P₂ amplitude among the left, right, or binaural conditions, nor any interaction between scalp distribution and ear of delivery. Because asymmetries of the auditory transient evoked potential with ear of delivery have been reported in the literature (Vaughan and Ritter 1970), we felt justified in specifically evaluating this possibility despite the lack of significance on the overall analysis of variance. The average C₃/C₄ ratio for the N₁ component was 1.01 for the left ear and 1.20 for the right ear which was significantly different at the 0.01 level. There was no significant ear-related asymmetry in the scalp distribution of the P₂ component, the C₃/C₄ ratio being 1.02 for the left ear and 1.17 for the right ear.

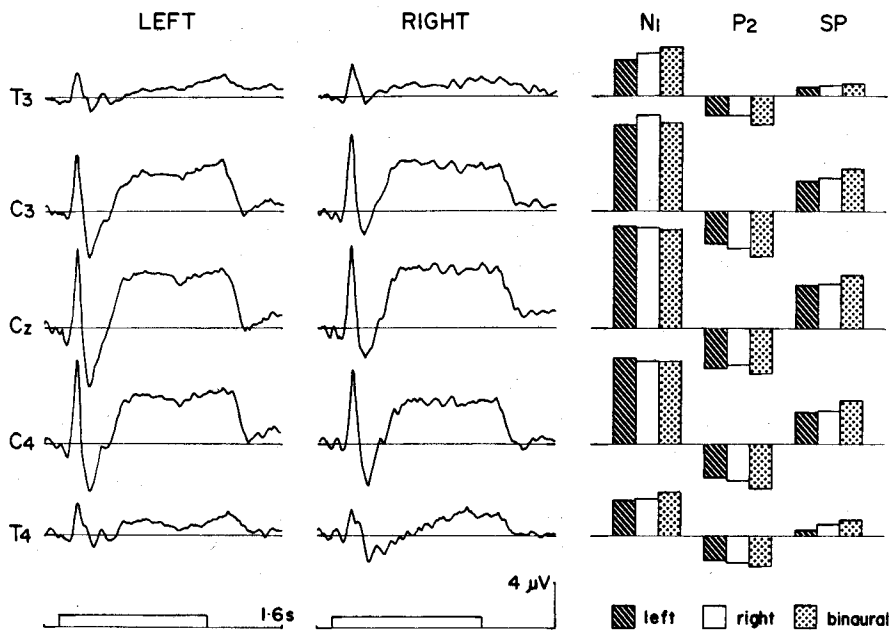


Fig. 8. The effect of ear of stimulation on the auditory evoked potentials. Tonebursts of 1 sec duration, of frequency 1 kc/sec and of 80 dB HL were presented once every 3 sec to the left ear, the right ear, or to both ears. Evoked potentials were recorded from coronal electrodes referred to a chest reference. In the left and center columns of the figure are shown the evoked potential wave forms from one subject (T.P.) in response to left and right ear stimulation. Each tracing represents the average of 200 individual responses. In the right column of the figure are plotted the average components at each of the 5 electrodes for the 10 subjects evaluated during this experiment. The N₁ component shows a slight ear-related scalp distribution asymmetry, but no difference in overall amplitude among the 3 conditions of stimulation. The sustained potential, on the other hand, shows no asymmetry but a definite increase in amplitude with binaural stimulation.

In certain subjects a small negative component occurring after the N_1 component could be recognized in the temporal regions. This is evident in Fig. 8 in the right temporal area, particularly when the stimulus was presented to the right ear.

The auditory sustained potential showed significant effects of electrode location, and of the ear of delivery, with no interaction between the two. Unlike the N_1 and P_2 components binaural stimulus presentation evoked a significantly larger sustained potential than either of the monaural presentation modes. There was no ear-related asymmetry in the scalp distribution of the sustained potential, the C_3/C_4 ratio being 1.03 for the left ear and 0.95 for the right ear.

Discussion

The human auditory sustained potential increases in amplitude with increasing stimulus intensity. This stimulus-response relationship is, like that of the transient onset response N_1 component, adequately described by either a logarithmic or a power function. At the present time the regression of such amplitude data on the stimulus intensity according to logarithmic or power functions is most helpful for descriptive or comparative purposes. Since the nature of the evoked potential generation is little understood, the physiological basis and psychological meaning of any such hypothetical stimulus-response functions will remain unclear. The effect of stimulus intensity on the transient auditory evoked potentials has recently been extensively reviewed by Keidel (1976). For the N_1 component the exponent of the fitted power function varies between 0.07 and 0.28 depending upon the rate of stimulus presentation (Rau 1968). Our derived exponent of 0.13 is somewhat smaller than Rau's exponent of 0.20 for a similar stimulus repetition rate, this probably being related to our data extending further into the higher intensity range where the exponent

tends to decrease. The data for the sustained potential are significantly more correlated to stimulus intensity than the N_1 component, and show a somewhat larger exponent on the power function — 0.23.

At higher intensities, particularly in certain subjects, there appears to be a definite saturation of the N_1 component of the auditory evoked potential. This effect has been reported to occur at intensities of above 50 dB HL (Butler et al. 1969; Moore and Rose 1969), and to be more apparent at higher rates of stimulus presentation (Picton et al. 1970; Beagley and Kellogg 1971). Individual differences in evoked potential intensity-response functions have been correlated with differences in perceptual style or strategy (Buchsbaum 1976) but the meaning of such a correlation remains unknown. It is difficult to determine whether this represents actual generator saturation, or derives from overlapping fields from different generators activated at higher intensities. Despite these changes in the transient onset response, the auditory sustained potential amplitude does not saturate at higher intensities even at the higher rates of stimulus presentation. The auditory sustained potential therefore appears to be more directly coupled to stimulus intensity than the transient evoked potential components.

Since the amplitudes of both the transient and sustained auditory evoked potentials are related to stimulus intensity, they are also related to the perceived loudness of the acoustic stimuli. A better evaluation of this relationship could be obtained if the perceived loudness was reported for each stimulus, and the evoked potentials averaged according to this loudness rating rather than according to stimulus intensity. At the present time such studies have not been systematically performed using auditory stimuli. Although the auditory evoked potential amplitudes are related to perceived loudness through stimulus intensity, many findings dissociate the two phenomena. The tonal frequency of the stimulus, for example,

affects the amplitude of the response independently of any change in loudness. High frequency tonebursts evoke smaller responses than low frequency stimuli of equal loudness.

The auditory sustained potential is much more resistant to increasing stimulus presentation rate than is the transient response. One of the major difficulties in correlating the transient response to sensory processes has been this sensitivity to stimulus presentation rate (Donald 1978). When a stimulus is repeated after a brief interval, the second stimulus, although it is perceived similarly to the first, evokes a smaller transient response. The transient response might reflect the activation of the processes necessary to the evaluation of incoming sensory information, such processes remaining active for a period of time equivalent to the relative refractory period of the transient response (Picton et al. 1978a). The analysis of a second similar stimulus occurring during this period would only require partial reactivation of these processes. The auditory sustained potential, which is much more resilient than the transient response to increasing rates of stimulus presentation, might therefore be more closely related to the actual cerebral processes involved in sensory analysis.

The frequency specificity of the refractory periods of the evoked potential components is most easily interpreted in terms of overlapping receptive fields for the generator processes at each frequency (Butler 1968; Picton et al. 1976). An intervening stimulus will activate the generator of the test stimulus-evoked potential to the amount that the receptive field of the test stimulus generator extends to the frequency of the intervening stimulus. When the test stimulus-evoked potential generator is then activated by the actual test stimulus it will be partially refractory. The graphs of this frequency specificity effect, as shown in Fig. 5, are therefore representations of the receptive fields of the evoked potential generators in the domain of tonal frequency. The N_1 component has a well-defined receptive field. The frequency

specificity effects for the auditory sustained potential are much more complex. If there had been no overlap between the different receptive fields, i.e. if the sustained potential generators were extremely specific to each frequency, there would have been a flat line at the level of the 1/4 sec response and a sharp notch at 1 kc/sec. If there was complete overlap between the receptive fields, i.e. complete non-specificity of the generators, one would have obtained a flat line at the level of the 1/sec 1 kc/sec toneburst. The graph obtained is difficult to interpret because of the small amplitude differences involved, but it appears to represent a combination of these two possibilities. Therefore, there might be two distinct generator processes for the auditory sustained potential, one quite non-specific in its frequency receptive field, and one quite specific.

Stimuli of lower tonal frequency evoke larger transient and sustained responses than do high frequency stimuli. This effect has been previously recorded for the transient evoked potential (Antinoro et al. 1969; Rothman 1970). The auditory sustained potential is similarly decreased at higher stimulus frequencies, but this effect is much more evident at the middle frequencies than with the transient response. There are several possible explanations for the effect of tonal frequency on the auditory evoked potential amplitudes. Because of the dynamics of the travelling wave in the cochlea, low frequency sounds tend to activate a larger number of neurons. Also, the brain responses to tonebursts of different frequencies are generated in separate, although adjacent areas, and the scalp distributions of the potentials generated from these separate areas might be quite different (Picton et al. 1978b). At the present time it is impossible to determine which of these or other reasons explain the observed effects of tonal frequency on the auditory evoked potentials, or the difference between the transient and sustained potential.

When a toneburst is continued over a duration of 3 sec, the sustained potential shows

adaptation in amplitude. Such adaptation is quite common in recordings of auditory unit activity, and appears to be a general characteristic of sensory systems. The time course of adaptation of the sustained potential is much more consistent with it being a sensory evoked potential, than with it being an expectancy wave which should increase towards the end of the stimulus. The small amplitudes of the sustained potential when the tone is on for the greater proportion of the duty cycle help explain why it is possible to recognize a small relative negativity during a brief pause in a continuous tone (Järvilehto and Fruhstorfer 1973).

The N_1 component of the auditory evoked potential shows some scalp distribution asymmetry related to the ear of delivery, as noted in previous reports (Vaughan and Ritter 1970). There is, however, no significant change in the amplitude of the response when both ears are stimulated together. The asymmetry indicates that the generators activated by stimuli presented to the left or right ears are to some extent distinct, despite a large amount of overlap either in the generator or in the resultant electrical field. The absence of any increase in amplitude with binaural as opposed to monaural presentation suggests that there might be some inhibitory interaction between the ears in the generation of the binaural transient response. The auditory sustained potential is quite symmetrical in its scalp distribution. Moreover, it is of significantly greater amplitude when the stimulation is binaural rather than monaural. These sustained potential data suggest that right ear stimuli and left ear stimuli activate underlying generators that are to some extent separate and additive, but which have similar electrical field distributions at the scalp. Peronnet and Michel (1977) have similarly reported that the auditory sustained potential is symmetrical in its scalp distribution.

The human auditory sustained potential is distinct from the other components of the auditory evoked potential both in its underlying generator processes, and in its relationship

to the acoustic stimuli. It is possible, therefore, that further evaluation of this sustained potential might contribute to a greater understanding of normal and abnormal human sensory function. In evoked potential audiometry, the auditory sustained potential might provide a useful adjunct to the slow transient evoked potential in the evaluation of thresholds, and a possible means of evaluating abnormal auditory adaptation in retrocochlear hearing loss. In neurology, it is possible that the auditory transient and sustained evoked potentials might be differentially affected by different disease processes. In psychology, the sustained potentials might allow further understanding of the cerebral processes occurring during perception rather than just at its onset.

Summary

The auditory sustained potential recorded from the human scalp increases in amplitude with increasing stimulus intensity. At rapid rates of stimulus presentation its amplitude decreases but proportionately less so than the amplitude of the transient onset auditory evoked potential. The frequency specificity of this rate effect is complex, suggesting that there may be two underlying components of the scalp-recorded auditory sustained potential. The amplitude of the auditory sustained potential is smaller when the tonal frequency of the stimulus is higher. With prolonged stimulus durations there is some adaptation of the amplitude of the auditory sustained potential. This potential is larger in amplitude when sounds are presented binaurally than monaurally, and has a symmetrical coronal scalp distribution that is unaffected by the ear of stimulation.

Résumé

Potentiels auditifs de longue durée chez l'homme. II. Relation avec le stimulus

Le potentiel auditif de longue durée enregistré sur le scalp chez l'homme augmente en

amplitude avec l'augmentation de l'intensité du stimulus. A des vitesses rapides de présentation du stimulus, son amplitude diminue mais proportionnellement moins que l'amplitude du potentiel évoqué auditif transitoire au début du stimulus. La spécificité de cet effet de vitesse sur la fréquence est complexe, suggérant qu'il puisse exister deux composantes sous-jacentes du potentiel auditif de longue durée enregistré sur le scalp. L'amplitude du potentiel auditif de longue durée est moindre lorsque la fréquence tonale du stimulus est plus élevée. Avec des durées de stimulation prolongée on note une certaine adaptation de l'amplitude de ce potentiel auditif de longue durée. Ce potentiel est d'amplitude plus grande pour les présentations binaurales que monaurales des sons; sa distribution coronale sur le scalp est symétrique et n'est pas affectée par le côté de l'oreille stimulée.

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