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VARIATIONS IN EARLY AND LATE EVENT-RELATED COMPONENTS OF THE AUDITORY EVOKED POTENTIAL WITH TASK DIFFICULTY [1]

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Several evoked potential components have been described which are sensitive to psychological variables (see Donchin et al. 1978 for a review). These so-called 'endogenous' or 'event-related' components include N_2 (Ford et al. 1973), N_A (Ritter et al. 1982), P_3 (Sutton et al. 1965), P_{3a} (Squires et al. 1975), P_4 (Stuss and Picton 1978), as well as an attention-related enhancement of N_1 (Hillyard et al. 1973). Recently we reported the existence of another of these event-related potentials, the P_{165}, and suggested that it was an early manifestation of a sequence of neural events initiated by the presentation of an infrequent target stimulus (Goodin et al. 1978). This sequence was presumed to include the N_2 component and to culminate with the P_3 component.

The assumption that the P_{165}, N_2 and P_3 components comprise a functional sequence was based upon the fact that they appear in similar circumstances. As yet no attempt has been made to test the affinity of these 3 components by experimental manipulation. In this study the difficulty of an auditory discrimination was varied in an effort to determine how the 3 components would be individually affected.

A number of investigators have reported that the latency of the P_3 component varies as a function of task difficulty or complexity and have noted correlations between P_3 latency and behavioral reaction time (RT) (Ritter et al. 1972; Ford et al. 1976; Kutas et al. 1977; Squires et al. 1977; Roth et al. 1978; McCarthy and Donchin 1981). On the basis of such results it has been suggested that the P_3 latency is directly related to processes of stimulus evaluation (Squires et al. 1977). More recently, Ritter et al. (1979) noted that the latency of N_2 is at least as well correlated with RT as is P_3 (see also Ford et al. 1976) and stated that the reason P_3 latency 'can be used to assess the temporal occurrence of stimulus evaluation is because it is related in time to N_2.' It was our interest to further evaluate this contention, along with the additional possibility that the latencies of both the N_2 and P_3 components passively reflect changes in the earlier P_{165} component.

Method

Fourteen subjects (8 females, 6 males) ranging in age from 24 to 38 years were tested. All reported normal hearing. Three of the subjects were familiar with the aims of the study and four had previously participated in a similar experiment.

Blocks of 400 pre-recorded binaural tone bursts (1000 Hz, 50 msec) were presented at a rate of 1/sec through earphones. Two series of tones were used. In both series, 85% of the tones had an intensity which was 60 dB above the threshold for a jury of normal-hearing subjects. The intensity of the remaining 15% of the tones was 40 dB in one series, and 57 dB in the other series. The order of rare (40 dB or 57 dB) and frequent (60 dB) tones was random with the constraint that no two rare tones occurred in succession, and the sequence of rare and frequent tones was identical in the two series.

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Each series was presented to each subject under two different attentional conditions. In one condition the subject was instructed to ignore the tones and read a magazine (Ignore). In a second condition the subject was instructed to count and keep a mental record of the number of rare tones and to report the number at the end of the block (Attend). The subjects were not informed of the correct number of rare tones until the end of testing. Thus, there were two levels of stimulus discriminability, Easy (40 dB vs. 60 dB) and Difficult (57 dB vs. 60 dB), and two attentional conditions, Attend and Ignore.

Prior to data recording, a series of approximately 100 tones from the Easy condition was presented in order to familiarize the subject with the tone sequence. Four blocks were then presented in the order of Easy-Ignore, Easy-Attend, Difficult-Ignore and Difficult-Attend, with a 5 min rest period between blocks. For 11 of the subjects the 4 blocks were presented a second time in the reverse order.

Silver disc electrodes were affixed to the scalp with collodion at F_z, C_z and P_z and referred to linked mastoids. Additional electrodes were positioned superior and lateral to the right eye in order to monitor eye-related potentials. When time-locked potentials in the eye monitor channel were encountered, the block of trials was discarded. The EEG was amplified approximately 10,000 times with a bandpass of 0.3–250 Hz.

Evoked potential wave forms were averaged over 768 msec beginning at tone onset. Separate averages were constructed for the rare and frequent tone in each block. In addition to the 8 basic sets of evoked potential wave forms (2 tones $\times$ 2 levels of discriminability $\times$ 2 attentional conditions), 'difference' wave forms were constructed by digital subtraction of each wave form recorded in the Ignore condition from the corresponding wave form recorded in the Attend condition. The primary data were 4 sets of difference wave forms (2 tones $\times$ 2 levels of discriminability). Only the data recorded at C_z are reported, although the F_z and P_z wave forms were used to help identify the different components. Peak latencies were measured by extrapolating lines from the ascending and descending portions of a wave and measuring the latency at the point of intersection. Peak amplitudes were measured relative to the baseline in the first 50 msec of the difference wave form.

Results

The subjects had no difficulty performing the counting task at either level of difficulty and counting performance was similar at both levels (Easy, 100% and Difficult, 92%).

The evoked potential wave form recorded at C_z for one subject in the two attentional conditions (Attend and Ignore) for the Difficult discrimination condition are shown in Fig. 1. Also shown are the Attend-Ignore difference wave forms for each tone. The evoked potentials elicited by the frequent tone in both attentional conditions exhibited the typical 'vertex potential' characterized by the N_1 (mean latency 86 msec) and P_2 (mean latency 147 msec) components. The rare-tone

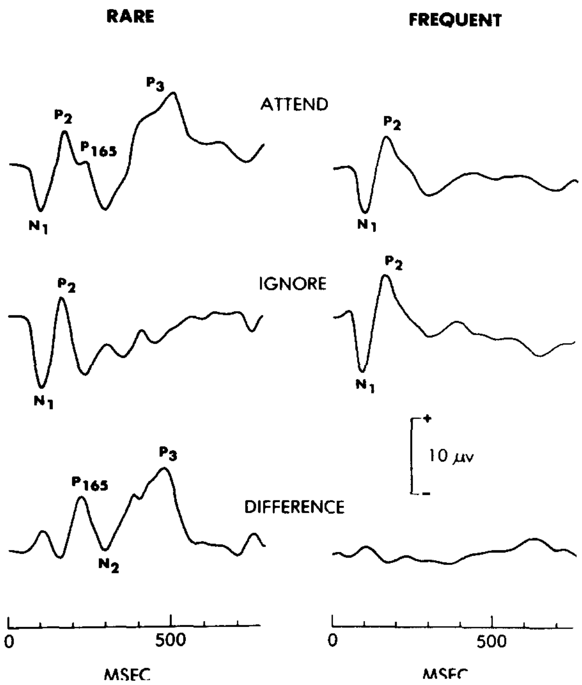

Fig. 1. Vertex evoked potential wave forms for one subject for the two tones and two attention conditions in the Difficult discrimination task. The difference wave forms (Attend minus Ignore) for each tone are also shown.

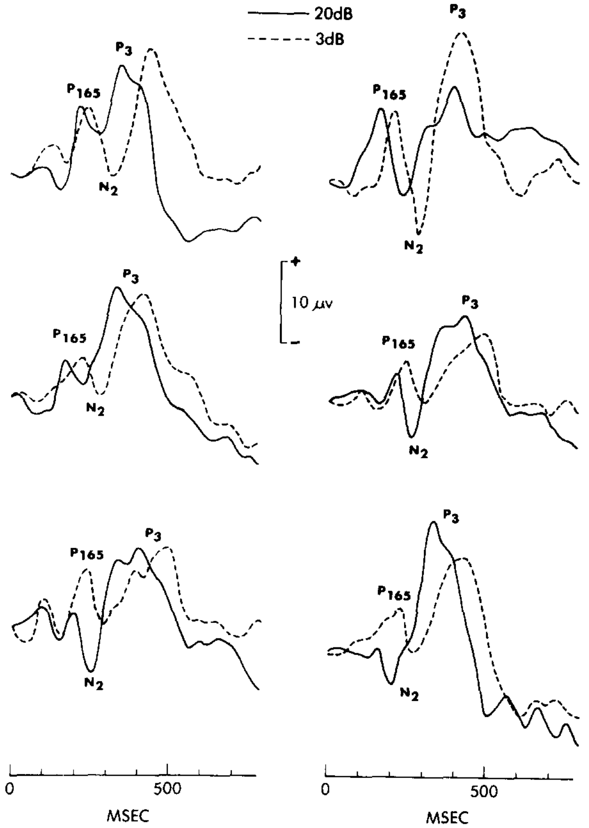

Fig. 2. Difference wave forms for 6 subjects for the Difficult (3 dB) discrimination (dashed lines) and Easy (20 dB) discrimination (solid lines).

evoked potentials, however, were considerably more complex and varied according to whether or not the subject attended to the tone sequence.

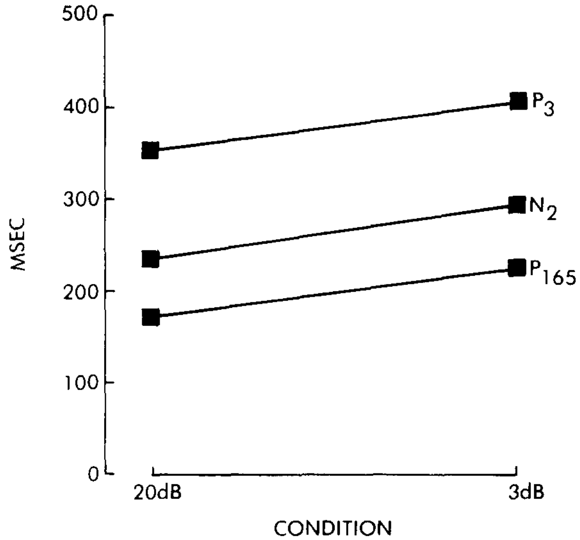

Fig. 3. Mean latencies of the P_{165}, N_2 and P_3 components from the difference wave forms in the Easy (20 dB) and Difficult (3 dB) discrimination conditions.

The variations in the rare-tone evoked potential as a function of attentional condition are most clearly seen in the difference wave forms. In the difference wave forms, the evoked potential components strictly attributable to the sensory input ('exogenous' or 'stimulus-related' components) have been largely removed, since the tone series were identical in the Attend and Ignore conditions. The remaining components can thus be associated with the differences in cognitive processing between the Attend and Ignore conditions.

TABLE I

Peak latencies (msec) for the endogenous components, P_{165}, N_2 and P_3, derived from the difference wave forms. Also shown are the peak latencies of the exogenous potentials derived from unsubtracted wave forms. Means for 14 subjects. The standard deviations are given in parentheses.

Component	Easy	Difficult	Difference (Difficult-Easy)	Significance *
P_{165}	172 (33)	223 (41)	50 (26)	$P < 0.001$
N_2	234 (27)	294 (37)	60 (19)	$P < 0.001$
P_3	354 (34)	408 (31)	54 (15)	$P < 0.001$
N_1 (Rare-Attend)	89 (16)	81 (13)	−8 (16)	N.S.
N_1 (Rare-Ignore)	94 (17)	86 (7)	−8 (18)	N.S.
P_2 (Rare-Ignore)	153 (29)	147 (12)	−6 (26)	N.S.

* Two-tailed t tests for matched pairs.

TABLE II

Peak amplitudes (μV) of the endogenous components derived from the difference wave forms. Means for 14 subjects. The standard deviations are given in parentheses.

Component	Easy	Difficult	Difference (Difficult-Easy)	Significance *
P_{165}	6.2 (10.0)	11.7 (9.0)	5.5 (8.0)	$P < 0.05$
N_2	−2.1 (10.0)	−4.0 (11.0)	−1.9 (11.0)	N.S.
P_3	23.3 (17.0)	22.2 (15)	−1.1 (9.0)	N.S.

* Two-tailed *t* test for matched pairs.

Accordingly, we considered the residual components to be event-related.

The difference wave form for the frequent tone in all cases was essentially a flat line, suggesting that there was little variation in the cognitive activity associated with the frequent tone in the two attentional conditions. The rare-tone difference wave form, however, was characterized by two prominent positive peaks, labeled P_{165} and P_3 in Fig. 1, separated by a negative peak, N_2. A mixed labeling convention has been used for convenience, with N_2 and P_3 labeled according to polarity and ordinal position, and P_{165} labeled according to polarity and mean latency determined in the previous study (Goodin et al. 1978). The latency variations of these components will be a major consideration in the remainder of the paper.

The effect of discrimination difficulty on the event-related components is illustrated in Fig. 2. Here the difference wave forms for 6 subjects for the Difficult discrimination (dashed lines) are superimposed on the corresponding difference wave forms for the Easy discrimination (solid lines). With increasing task difficulty, there was a systematic shift in the event-related components to longer peak latencies. The mean latencies of the P_{165}, N_2 and P_3 components for the two levels of task difficulty are plotted in Fig. 3. The mean latency changes for P_{165}, N_2 and P_3 were essentially identical; 50, 60 and 54 msec, respectively (Table I). An analysis of variance revealed no significant interactions.

In order to insure that no spurious effects of stimulus variables on the latency of the event-related components were present that might account for the latency variations of P_{165}, N_2 and P_3, the change in peak latency of the stimulus-related N_1 and P_2 components was also analyzed (Table I). The rare tone N_1 and P_2 latencies were actually earlier in the Difficult condition, reflecting the higher intensity of the rare tone in that condition (57 dB vs. 40 dB). The rare tone P_2 latency in the Attend condition could not be analyzed because the P_2 component temporally overlapped the event-related P_{165} component. Thus, the increased latencies of the event-related potentials in the Difficult condition are not spurious reflections of changes in the stimulus-related components.

The amplitudes of the event-related potentials in the two discriminability conditions are presented in Table II. There was no significant change in the amplitudes of either the N_2 or the P_3 component with the change in task difficulty. The P_{165} component, however, significantly increased in amplitude with the more difficult discrimination. An analysis of the N_1 amplitude for both tones and of the P_2 amplitude for the frequent tone revealed no significant effects of either task difficulty or attentional condition.

Discussion

The results of this study are consistent with those of previous studies demonstrating variations in N_2 and P_3 latency with changes in task difficulty (Ritter et al. 1972; Ford et al. 1976; Kutas et al. 1977; Squires et al. 1977; Roth et al. 1978; McCarthy and Donchin 1981). In this study, the latency increments of the N_2 and P_3 components with increasing task difficulty were essentially identical (60 and 54 msec). Ritter et al. (1979) have reported similar findings and have suggested that the change in the P_3 latency passively reflects the change in the N_2 latency. In view of the intensity with which the P_3 component has been scrutinized in recent years in relation to cognitive processing, they suggest that more attention should be paid the characteristics of the N_2 potential.

Our results indicate that this notion can be taken one step further and suggest that the changes in both the N_2 and P_3 latencies passively reflect the change in the P_{165} component latency. Accordingly, variations in the latencies of the N_2 and P_3 components may not reflect variations in the processes actually underlying those components, but rather reflect a change in earlier neural events preceding N_2 and P_3 by a constant time interval. A component which passively reflects changes in a prior neural event should show latency but not amplitude changes. This is the finding for N_2 and P_3 in the present study. The increase in amplitude of P_{165} with increased task demands suggests that this component's change is not passive.

It is conceivable that the N_2 and P_3 components on individual trials actually were larger in the Difficult condition, just as was the P_{165} potential, but that a greater latency variability of the N_2 and P_3 components in the Difficult condition resulted in an attenuated averaged wave form. There was, however, no tendency for the N_2 and P_3 peaks to be broader in the Difficult condition (Fig. 2), which would be expected if the peak latencies were indeed more variable in that condition. Also, the latency variability of the P_{165}, N_2 and P_3 potentials across subjects and across replications was approximately equal for all components in both conditions, so that amplitude changes due to averaging should have been equal for all 3 components.

It is likewise conceivable that our results could be interpreted to reflect a primary change in the N_2 peak latency in the difficult condition. If, on the one hand, the P_{165} and P_3 components were stable, then as N_2 moved away from the P_{165} component and underneath the P_3 component, the P_{165} would increase in latency and amplitude, the P_3 would increase in latency and decrease in amplitude, and the N_2 would increase in latency but have an unpredictable amplitude change. If, on the other hand, the N_2 and P_3 components moved together with a stable P_{165} component, then an increased amplitude of P_{165} would be accompanied by a comparably increased negativity of N_2. These interpretations are improbable, however, since we observed no change in either the N_2 or the P_3 amplitude to support them.

Recently there has been much interest in several negative components that occur at relatively short latencies and which have been related, either to selective attention or to the discrimination and classification of stimuli (Näätänen and Michie 1979; Hansen and Hillyard 1980; Näätänen et al. 1980; Ritter et al. 1982). The only event-related negativity, however, measured in these experiments was the N_2 component. Many of these earlier negativities have been elicited only using fast rates of stimulus presentation (Schwent et al. 1976) and would therefore not be seen in these experiments where the interstimulus interval was long (1 sec). Ritter et al. (1982) have reported two negative components in the latency range of the N_2 component but their demonstration required two separate subtraction procedures to reveal them. In our experiments a single subtraction procedure was used and the resulting single N_2 component may well be made up of more than one component. Nevertheless, this component (or group of components) behaves in a manner which suggests that its latency shift is passive under our experimental conditions.

These results, thus, are consistent with the idea that the P_{165}, N_2 and P_3 components comprise a functional sequence in the sensory processing of infrequent auditory stimuli. Further our amplitude data suggest that the P_{165} may initiate this sequence. Unfortunately, the nature of the function(s) reflected by these potentials is unknown. Presumably they do not reflect sensory discrimination per se since accurate discrimination and initiation of a motor response can precede all of these potentials (Goodin and Aminoff 1983). One attractive hypothesis is that they reflect mental processes, which follow the discrimination of targets from non-targets and are involved in the subject's expectations of and preparations for future events (Squires et al. 1973; Donchin 1975).

This, however, is only speculative and must be the subject of future investigation. The major conclusion of the present study is that the P_{165} component, like the more extensively studied 'event-related' N_2 and P_3 components, is sensitive to changes in task difficulty and that the entire series of 'event-related' potentials may reflect a functional sequence of neural events following the discrimination of infrequent target tones.

Summary

A variation in the difficulty of an auditory discrimination was used to investigate the relationship between the event-related P_{165}, N_2 and P_3 components of the auditory evoked potential. Equivalent increases in the latencies of all 3 components were found with increased task difficulty. The P_{165} component, however, could be differentiated from the two later components since it increased in amplitude with increased task demands while the N_2 and P_3 amplitudes remained constant. It is suggested that the P_{165}, N_2 and P_3 components comprise a functional sequence in the processing of rare events and possibly involved in a subject's preparations for the future.

Résumé

Les composantes précoces et tardives liées à l'événement, du potentiel évoqué auditif dépendent de la difficulté du test

Une discrimination auditive dont la difficulté variait a été utilisée pour rechercher la relation entre les composantes liées à l'événement P165, N2 et P3 du potentiel évoqué auditif. Des augmentations équivalentes des latences des 3 composantes ont été trouvées avec l'accroissement de la difficulté du test. La composante P165 pouvait toutefois être différenciée des deux autres composantes plus tardives car son amplitude augmentait avec l'exigence du test alors que celle de N3 et P3 demeuraient constantes. Il est suggéré que les composantes P165, N2 and P3 traduisent une séquence fonctionnelle dans le traitement des événements rares, et éventuellement impliqués dans une préparation du sujet au futur.

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