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# An Early Event-Related Cortical Potential

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## ABSTRACT

A waveform subtraction procedure, in which evoked potentials to rare tones ( $p=.15$ ) in an Ignore condition were subtracted from the analogous waveforms in an Attend condition, revealed the existence of a previously unreported positive potential with a latency of approximately 165 msec (P165) which is related to cognitive stimulus processing. The potential was absent for frequent background tones. An analysis of latency and scalp distribution data showed that P165 could be differentiated from the stimulus-evoked P200 potential, and experiments in which muscle tension was varied did not change the form of P165, supporting a neurogenic origin. Most likely P165 is an early manifestation of decision processes related to the later N200 and P300 potentials.

**DESCRIPTORS:** Decision-related cortical potentials, P300 wave, Information processing.

Several late components which are sensitive to psychological variables have been identified in the auditory evoked potential waveform (for example, see Squires, Squires, & Hillyard, 1975). Of these event-related potentials, as distinguished from the obligatory stimulus-related potentials, the P300 component (Sutton, Braren, Zubin, & John, 1965) has been the most thoroughly studied. However, because the latency of P300 often exceeds the time required to make a behavioral response (Ritter, Simson, & Vaughan, 1972), and thus appears to reflect cognitive activity subsequent to the primary processes of stimulus identification, stimulus classification and response selection, there has recently been an increased interest in earlier latency potentials. These earlier potentials, such as N200 (Courchesne, Hillyard, & Galambos, 1975; Ford, Roth, Dirks, & Kopell, 1973; Picton, Hillyard, Krausz, & Galambos, 1974; Ritter et al., 1972; Simson, Vaughan, & Ritter, 1976, 1977; Squires, N. et al., 1975; Squires, Donchin, Herning, & McCarthy, 1977), may logically reflect the primary

stimulus processing sequence, as Simson et al. (1977) have proposed. In this study we report the existence of an additional early potential which is dependent on psychological variables, and hence may be related to the event-related potentials previously described.

## Method

Forty-seven normal subjects (25 female, 22 male) ranging in age from 6 to 76 yrs were tested. Four of the subjects were familiar with the experimental design. Subjects were considered "normal" if they were fully employed or attending school. The mental status of the older, retired subjects was assessed using the "Mini-Mental State" test (Folstein, Folstein, & McHugh, 1975) and all who were included in the study scored 29 or 30 out of the 30 possible points. In addition to the 47 subjects tested, 2 other individuals were eliminated from the experiment due to low test scores and 1 was eliminated because of a psychiatric problem.

Four hundred pre-recorded binaural tone bursts (50 msec, 60 dB SL) were presented through earphones at a rate of 1/1.5 sec in each run. Eighty-five percent of the tones had a frequency of 1000 Hz and fifteen percent had a frequency of 2000 Hz. The stimulus sequence was random with the constraint that no two rare tones appeared in succession.

After familiarizing the subject with the tone bursts, the stimulus sequence was presented twice with an intervening 5-10 min rest period. In one condition the subject was instructed to ignore the tones and to read a magazine ("Ignore" condition). In a second condition ("Attend" condition) the subject was instructed to keep a mental

These data were separately analyzed in a previous study of the N200 and P300 potentials, which is reported elsewhere.

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record of the rare, 2000 Hz tones and to report the number at the end of the run. All subjects were able to correctly perform the task.

Silver disk electrodes were affixed to the scalp 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. The EEG was amplified 10,000 times with a bandpass of 0.3 to 70 Hz. Evoked potentials were averaged for 768 msec following stimulus onset.

Evoked potential waveforms were computer averaged (TN-1500) separately for the rare and frequent tones in each condition. In addition to the four basic sets of evoked potential waveforms (two tones in two separate conditions), "difference" waveforms were constructed by digital subtraction of the evoked potentials in the Ignore condition from those for the corresponding tone and electrode site in the Attend condition.

In the data reported here all significance levels are at the .05 level or beyond (two-tailed test).

## Results

The four vertex evoked potentials for one subject are shown in Fig. 1. Also shown are the Attend minus Ignore difference waveforms for each tone. The evoked potentials for the frequent tone in both conditions exhibited the typical "vertex potential" waveform with negative and positive peaks with mean latencies of 97 msec (N100) and 186 msec (P200), respectively. The rare-tone waveforms were considerably more complex, containing an additional set of event-related negative and positive potentials, the form of which varied according to whether or not the subject attended to the tones.

The characteristics of these event-related potentials can best be seen by examining the difference waveforms. Since the sequences of tones in the Attend and Ignore conditions were identical, the only

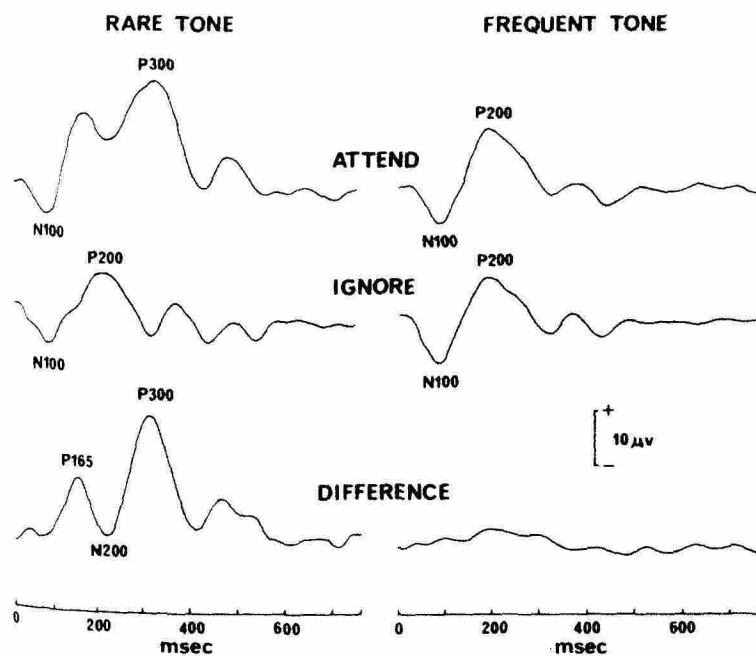


Fig. 1. Vertex evoked potentials for one subject for the two tones and two attention conditions. The difference waveforms (Attend minus Ignore) for each tone are also shown.

experimental variable contributing to the difference waveform was the variation in cognitive activity across the conditions. As can be seen, the rare-tone difference waveform was characterized by prominent negative and positive peaks with latencies of approximately 200 msec (N200) and 300 msec (P300), respectively. These components have been extensively described in previous studies (see Tuetting, in press, for review). The difference waveforms, however, also contained an additional event-related positive peak with a mean latency of 165 msec (SD=14 msec), which we have labeled P165. Normally P165 was preceded by a small negative deflection with a mean latency of 113 msec.

Rare-tone difference waveforms for 15 additional subjects are shown in Fig. 2. These waveforms were selected to illustrate the degree of variability of the event-related potentials, particularly P165, found in this study. The number of waveforms of each general type shown in Fig. 2 is proportional to the number of occurrences of that type waveform among the 47 subjects. For instance, a low amplitude double-peaked component at the latency appro-

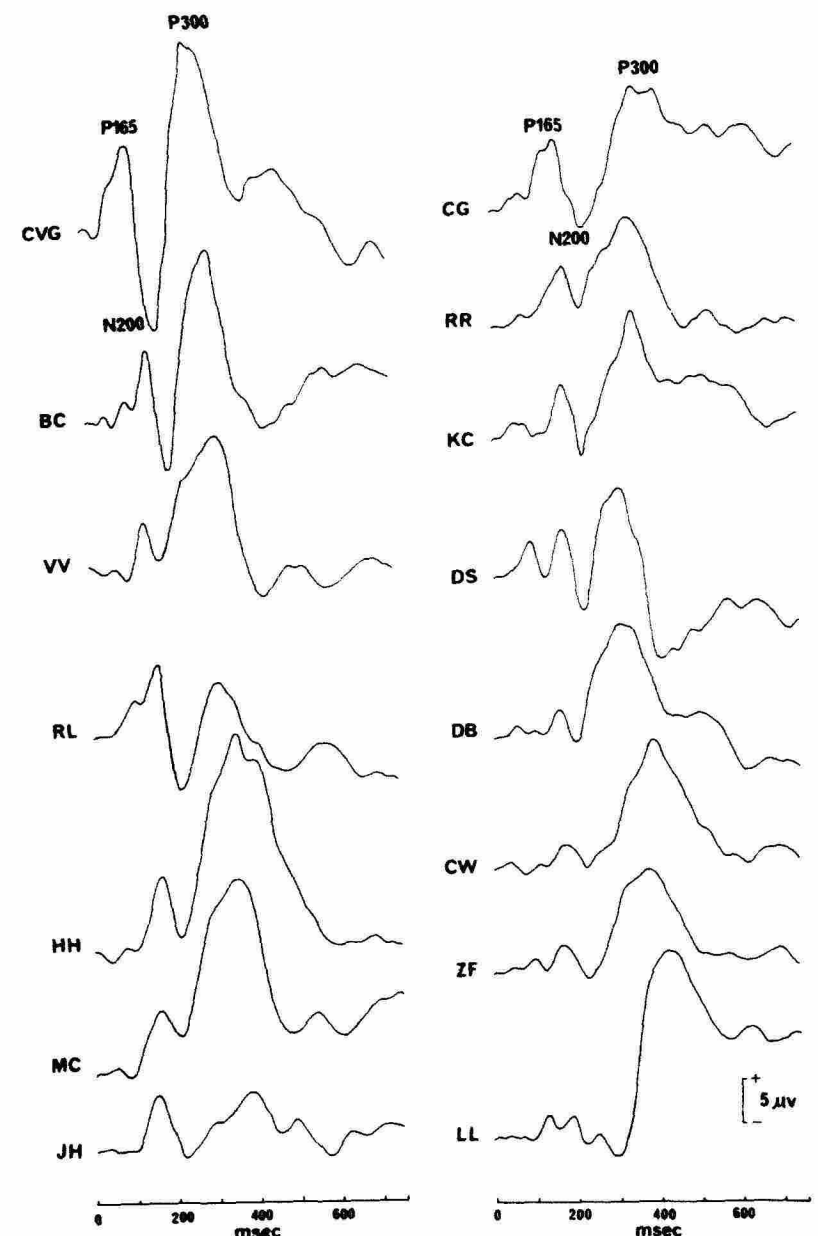


Fig. 2. Vertex difference waveforms for rare tones for 15 subjects.

appropriate for P165, as seen for subject LL, occurred in less than ten percent of the cases (4 out of 47). In the large majority of cases the P165 was extremely distinct. The corresponding difference waveforms for the frequent tones did not contain such event-related potentials (see Fig. 1).

Repeated testing of one subject over a two-month period was carried out to assess the reproducibility of the difference waveform. The ten rare-tone difference waveforms from this series of tests are superimposed in Fig. 3. For this subject the mean peak latency of P165 was 169 msec, with a standard deviation of 13 msec, and the mean P165 amplitude was  $10.2 \mu\text{V}$  with a standard deviation of  $4.3 \mu\text{V}$ . Comparable variations in peak amplitudes and latencies were found for N200 and P300 in this series (N200 latency,  $226 \pm 11$  msec, P300 latency,  $310 \pm 13$  msec, N200-P300 amplitude,  $17.5 \pm 4.5 \mu\text{V}$ ).

Across all subjects the mean amplitude of P165 (measured relative to the preceding negative peak) was  $5.48 \mu\text{V}$  ( $\pm 3.53 \mu\text{V}$ ), compared to a mean peak-to-peak amplitude of N200-P300 of  $13.3 \mu\text{V}$  ( $\pm 7.8 \mu\text{V}$ ). Thus, in the difference waveform P165 was comparable in amplitude to N200 and P300. However, because of the latency relationships of P165, N200 and P300 to the earlier, stimulus-evoked N100 and P200 potentials, the effect of P165 on waveform morphology was much less distinct than for the other two event-related potentials. This undoubtedly accounts for the fact that P165 has not been previously recognized. A comparison of standard peak amplitude and latency waveform measures for the rare-tone evoked potential in the two attention conditions, though, does reveal several small but consistent variations in the N100-P200 complex which may be attributed to the presence of P165. The latency of the *apparent* rare-tone P200 potential in the Attend condition occurred significantly earlier (8.2 msec,  $t(45)=3.19$ ) than the rare-tone P200 in the Ignore condition (see Fig. 1). It was, however, significantly later than the P165 latency derived from the difference waveform (10.5 msec,  $t(45)=3.61$ ). These results are consistent with two overlapping potentials having slightly different latencies (P165 and P200) summing to yield a peak of intermediate latency. The analogous comparison for the frequent tone showed that the latency of the Attend P200 did not differ significantly from that for the Ignore P200. No significant changes were seen in the N100 latencies for either tone.

The amplitude of the apparent rare-tone P200 peak in the Attend condition was significantly larger than in the Ignore condition ( $1.83 \mu\text{V}$ ,  $t(45)=2.86$ ), as was the apparent N100 peak ( $.22 \mu\text{V}$ ,  $t(45)=2.76$ ). Also, the slope of the N100-P200 excursion for the rare stimulus was greater in the Attend

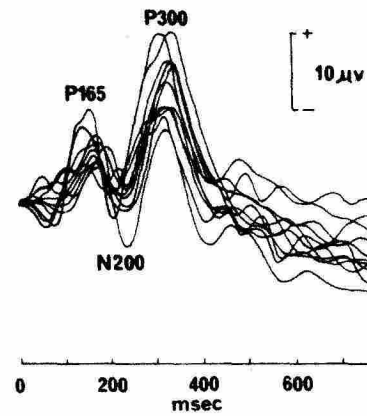


Fig. 3. Superimposed vertex difference waveforms for rare tones for one subject (also shown in Fig. 1). Results of 10 replications over a two-month period.

than in the Ignore condition ( $t(45)=2.089$ ). No significant changes in amplitude or slope were found, however, for the peaks associated with the frequent tones.

A separate analysis of these data had indicated that there were quite striking age-related changes in the characteristics of the N200 and P300 potentials (Goodin, Squires, Henderson, & Starr, 1978). Consequently the amplitude and latency measures for P165 were examined for similar properties. As was the case for N200 and P300, the latency of P165 tended to increase with increasing age, however the trend was nonsignificant. The major age-related change in P165 was its scalp distribution. In Fig. 4a, the mean amplitudes at  $F_z$ ,  $C_z$  and  $P_z$  are plotted for five age groups. The groupings were selected such that each contained approximately equal numbers of subjects. As can be seen, there was a systematic shift from a centro-parietal scalp distribution for children (ages 6-14) to a more frontal distribution for adults. This was due to the fact that while P165 amplitude remained relatively constant with age at  $F_z$ , there was a significant decrease in amplitude with age at  $P_z$  ( $\rho = -0.374$ ). At  $C_z$  the amplitude change was less than at  $P_z$ . From Fig. 4b, where the  $P_z/F_z$  amplitude ratio is plotted as a function of age, it appears that the scalp distribution reaches its final form by approximately the mid twenties.

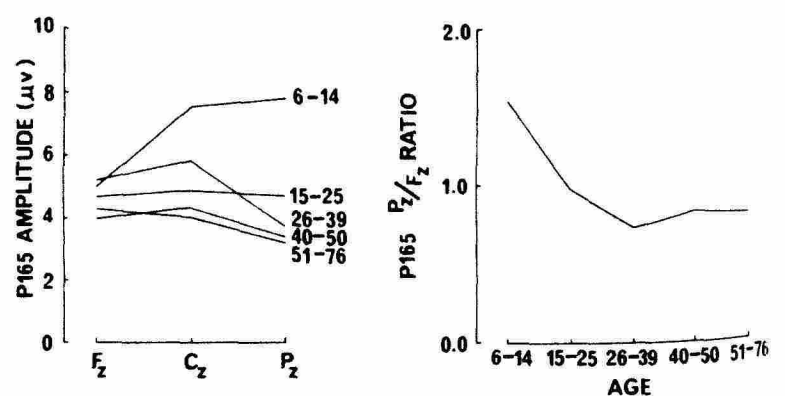


Fig. 4. a) Mean scalp distributions for P165 amplitude derived from the rare-tone difference waveforms for five age groups. b) Mean ratio of P165 amplitude at the  $P_z$  and  $F_z$  electrode sites for the five age groups.



The scalp distribution for P165 is compared with that for P200 (relative to a baseline voltage over the first 50 msec of the waveform) and for the N100-P200 peak-to-peak amplitude in Fig. 5. Here the amplitudes for each subject have been normalized in terms of the largest value for each measure in order to compensate for amplitude differences between the potentials. (Equivalent results were found using absolute amplitudes.) Only the data for adults over 40 yrs of age are included in order to avoid the complications of age-related distributional changes. As can be seen, the P200 potential was distributed more centrally than P165. The frontal to parietal amplitude ratio for P165 was significantly greater than for P200 ( $t(45)=2.41$ ). Likewise, the combined N100-P200 amplitude was also largest at the vertex, and the frontal-central ( $F_z/C_z$ ) and parietal central ( $P_z/C_z$ ) ratios were both significantly different from those for P165.

The scalp distributions were further examined by testing one subject with an array of lateral electrodes referenced to an electrode situated at the tip of the nose. As in previous reports in which this derivation was used (Kooi, Tipton, & Marshall, 1971; Peronnet, Michel, Echallier, & Girod, 1974; Vaughan & Ritter, 1970), N100 and P200 inverted in polarity across the supratemporal plane. The polarity of P165, however, remained positive at all leads. Thus the scalp distributional data strongly suggest that different neural sources underlie P165 and N100-P200.

Several procedures were used to determine whether P165 might arise from an artifactual source such as the ocular region or scalp musculature. A careful examination of the difference waveforms for the eye-artifact channel provided no evidence for an ocular origin. Since myogenic potentials with frontal distributions have been reported (Goff, Matsumiya, Allison, & Goff, 1976; Streletz, Katz, Hohenberger, & Cracco, 1977), one subject was tested with sustained frontalis muscle tension. The experiment failed to either enhance P165 or alter the waveform. The analogous experiment with sustained neck extension and clenched teeth also failed to enhance P165. Occasionally earlier peaks (at approximately 110 msec) were seen which resembled the myogenic potentials reported by Goff et al. (1976). However, even when those potentials were seen, the P165 potential was clearly distinct and had a substantially longer latency.

A final control condition was run to ensure that P165 did not result from the order in which the experimental conditions were run. In most cases the Ignore condition was run prior to the Attend condition since as a practical matter naive subjects often find it difficult to ignore the auditory stimuli after having been exposed to the Attend condition. Con-

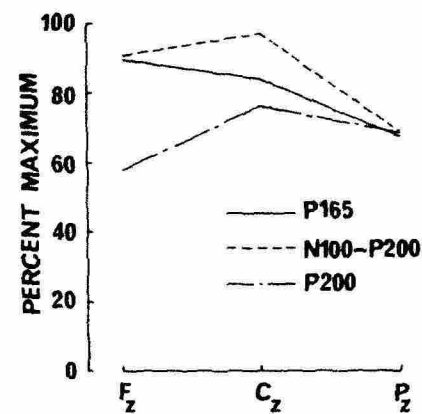


Fig. 5. Mean scalp distributions for P165 amplitude derived from the rare-tone difference waveform, compared to the distributions of P200 and N100-P200 amplitudes derived from the frequent tone in the Ignore condition. The amplitudes have been scaled as a percent of the largest value for each subject and each measure. All subjects greater than 40 yrs of age.

sequently the subject whose data is shown in Fig. 3 was repeatedly tested with the Attend condition preceding the Ignore condition. The waveforms for the two orders of testing were compared and no systematic differences could be found.

### Discussion

The results of this study provide evidence for the existence of a previously unreported event-related potential, P165, which is associated with rare, attended tones. This potential is very difficult to visualize unless subtraction procedures are used, because it has a latency which is coincident with the steep positive slope of the N100-P200 complex. Thus, depending upon the exact relationships between the latencies of N100, P165 and P200, the effect of P165 on the morphology of the N100-P200 complex was quite variable across subjects. The subtraction procedure used here, where only potentials associated with identical stimuli in identical sequences (Squires, Wickens, Squires, & Donchin, 1976) and from identical electrode sites were compared, however, rendered the P165 quite clear for all but about 10 percent of the subjects.

Since the paradigm used here was similar to that used in a number of previous studies it was at first puzzling that the presence of P165 was not noted previously. Most of those studies, however, did not use a subtraction procedure. When a subtraction was used (Simson et al., 1977), peaks were identified from grand average waveforms across all subjects. Such an averaging procedure would tend to obliterate a high frequency (short duration) potential such as P165 while leaving lower frequency potentials such as N200 and P300 relatively intact. Missing-stimulus procedures have also been successfully used to study N200 and P300 (Barlow, 1969; Sutton, Tueting, Zubin, & John, 1967; Klinke, Fruhstorfer, & Finkenzerler, 1968; Picton, Hilliard, & Galambos, 1976; Ruchkin & Sutton, 1973;

Simson et al., 1976), but they again are suitable only for relatively long duration potentials, as are factor analysis procedures which rely on there being a minimum of latency variability relative to the duration of each potential (Squires, K. et al., 1977). In one experiment by Squires, Donchin, Squires, and Grossberg, (1977), in which potentials elicited by identical stimuli were subtracted though, potentials remarkably similar to P165 can be seen (see their Fig. 5).

The data strongly support a neural origin for the P165 potential since no traces of it were seen in the difference waveforms for the eye-monitor channel and variations in tension of the scalp and neck musculature had no effect on the peak. Also the latency of P165 is substantially longer than the longest latency non-neural potentials previously observed for auditory stimuli (Goff et al., 1976). The facts that P165 was absent for frequent tones and varied in scalp distribution with age are also very difficult to reconcile with a non-neural hypothesis.

Since the latency of P165 is quite similar to that of P200 it was necessary to investigate the possibility that P165 might be related to the well known attention-related enhancement of the stimulus-evoked N100 and P200 components (cf. Picton & Hillyard, 1974). An enhancement of, in particular, P200 in the Attend condition relative to the Ignore condition would be expected to yield a positive peak in our subtraction procedure. Indeed, apparent enhancements of both N100 and P200 for rare-tones in the Attend condition were found, however, the amplitude enhancement for P200 was also associated with a shift to a shorter latency. This is more consistent with the addition of two separate potentials with slightly different latencies (P165 and P200) than it is with an enhancement of P200. Furthermore, analogous attention-related shifts in latency or increases in amplitude for the N100 and P200 potentials associated with the frequent tone were not found, ruling out the possibility of a simple attention-related change in P200. These results differ somewhat from previous studies where attention-related enhancements of N100 were found, however that phenomenon is most robust when stimuli are presented at a rapid rate with random interstimulus intervals and the task is difficult enough to thoroughly challenge the subject (Hillyard, Hink, Schwent, & Picton, 1973; Picton & Hillyard, 1974; Schwent, Hillyard, & Galambos, 1976). Those conditions were not met in this experiment.

Additional, strong evidence differentiating P165

from P200 comes from the scalp distribution data. The fact that P165 and P200 are distributed differently, when referenced to either the nose or mastoids, indicates that P165 and P200 arise from different neural sources. Finally, the rate of change in P165 latency as a function of age was substantially different from that previously reported for P200 (Goodin et al., 1978).

Thus a number of factors mitigate against the possibility that the P165 potential in the difference waveform is the result of a simple enhancement of P200 in the Attend condition. However, complex variations in two or more components in the latency range of 100–200 msec which would yield a peak in the difference waveform can not be totally excluded. Likewise, the addition of a positive potential (P165) in one condition can not be distinguished from the absence of a negative potential (N165?) in another. It is evident, however, that *some* type of waveform change is occurring in the latency range in question, and that it is specific to rare stimuli and is related to variations in cognitive processing. Our interpretation is that the increased processing of the rare tone in the Attend condition is manifested as an additional positive potential, P165.

The functional significance of P165 remains to be determined. Since P165 occurs earlier than P200 but is not present for all tones, as P200 is, P165 must represent a branch in the stimulus processing sequence. In that respect P165 resembles the later potentials, N200 and P300, which are also elicited by only certain stimuli or by omissions of stimuli in situations where subjects must process stimulus information. The degree to which P165 is related to N200 and P300, though, also remains to be determined. If, however, the event-related potentials as a group represent a unitary branch of the stimulus processing sequence which is activated only by rare, attended stimuli, the point in time at which the branching occurs clearly must precede P165.

A reasonable hypothesis at this time is that P165 is an early manifestation of neural events related to the processing of target stimuli. Moreover, since reaction times to rare tones in analogous experiments exceed 350 msec (Squires, N. et al., 1977) and since it is estimated that approximately 80–100 msec is needed for motor cortex activity to culminate in a switch closure (Ritter et al., 1972), it is possible that the neural events underlying P165 (and N200) are early enough to be involved in the primary processes of stimulus identification and classification or response selection.

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