

A dramatic increase in the auditory middle latency response at very slow rates

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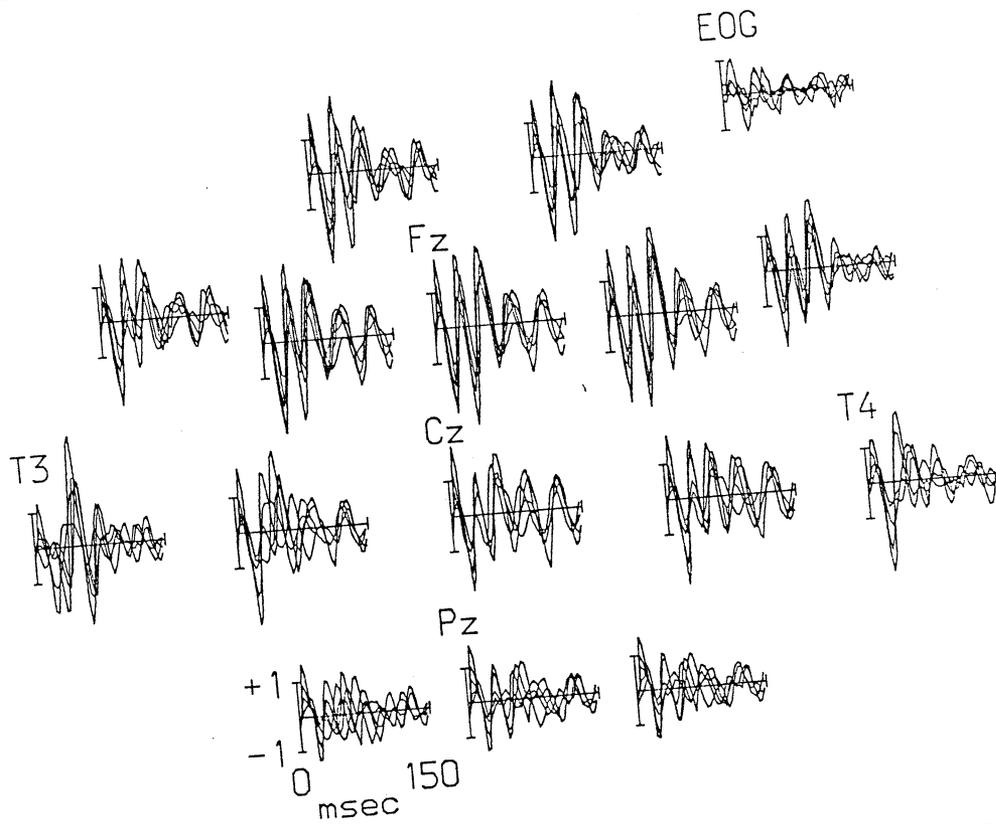
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The term auditory middle latency response (MLR) usually refers to a series of 1-3 bipolar waves with an approximate center frequency of 30-35 Hz occurring in the first 100 ms following an abrupt auditory event. The MLR is most often elicited using clicks presented at rates near 10 s. Although rates as low as 1 s are sometimes used to evoke it, faster rates are often chosen because, (1) responses can be collected more quickly, and, (2) once steady-state equilibrium is reached, responses to 10 s stimulation contain little or no lower-frequency slow waves (P1-N1-P2) which can obscure the MLR in wideband recordings using slower rates of stimulation. In a series of papers, Freedman et al. (1987) have studied the first prominent peak near 50 ms (P50) in the auditory response to clicks delivered at very slow rates (1/10 s). The 1/10 s P50 response has the same polarity and approximately the same latency as positive responses at 1 s (P1) and 10 s (Pb) rates. To test for similarities and differences between MLRs at these widely separated rates, a five-step rates series experiment was performed.

Methods

Clicks (55 dB SL 0.2 ms) were delivered by headphone to the right ear of three normal adult subjects (female 43; male 36; female 61) at five rates (1/10 s, 1/3 s, 1 s, 3 s, 10 s). Responses were collected from 15 channels of the International 10-20 System (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, P3, Pz, P4) referred to a four-lead neck lead electrically balanced to minimize heart-beat artifact. A -16th channel collected the EOG from a pair of electrodes placed diagonally across the right eye. Subjects reclined in a comfortable chair with eyes closed. Responses were collected in runs of 7 minutes. EEG was bandpassed at 0.1-100 Hz, amplified 50,000 times, and converted to 12-bit digital format for computer storage and analysis. The three faster rates were periodic; for instrumental reasons some time jitter (+/- 200

ms) was introduced at the two slowest rates (1/3 s, 1/10 s). To foster wakefulness, subjects were asked to count infrequent auditory target events and report their number at the end of each run. For the two slowest rates, these targets were the click stimuli themselves. At faster rates, the targets were 45 dB SL clicks delivered approximately 1/10 s to the left ear. After the rejection of trials containing eye movements or other abnormally large ($\pm 90 \mu\text{V}$) electrical activity, at least 500 responses to the probe clicks were averaged at each rate.



NORMALIZED MEAN OF 3 SS AT FIVE RATES

Figure 1: Normalized 40 Hz-band click ERPs at five stimulus presentation rates (1/10 s, 1/3 s, 1 s, 3 s, 10 s). Grand means of three subjects. Responses normalized by equalizing RMS amplitude at Cz.

Results

The frequency spectrum of the first 200 ms of the responses at four rates each contained a peak near 40 Hz. To separate the circa 40 Hz and slow-wave components of the responses, all five responses were band filtered using a symmetric FIR bandpass filter with a center frequency of 39 Hz and a rolloff of approximately 12 dB per octave. The filtered responses consisted of a burst of approximately 5 biphasic waves beginning with a scalp-positive peak at the latency of wave V of the brainstem response. At the standard MLR rate (10 s) these resembled a normal MLR (V, Na/Pa, Nb/Pb). Figure 1 superimposes the grand mean response of three subjects at each of the five rates. To avoid domination by larger responses, individual subject responses were equalized for amplitude before averaging, by dividing each by its RMS burst amplitude at the vertex. The figure shows that in frontal and central channels, the phase/latency of the MLR peaks hardly varied over the entire range of rates (1/10 s - 10 s). Figure 2, however, shows that the RMS amplitude of the bursts rose dramatically at the slowest rates, increasing by a factor of about 10 between 10 s and 1/10 s, with the greatest increase between 1 s and 1/10 s.

Discussion

It is not generally recognized that the MLR sequence increases dramatically in size without change in latency at rates below 1 s. In a further experiment on one of the subjects, both the amplitude and duration of the 1/10 circa 40 Hz MLR response were found to increase further as click intensity was raised. This suggests that the MLR sequence may consist in part of an *evoked rhythmicity* with a center frequency in the range 30-50 Hz. The RMS amplitude scalp distribution of the 1/10 s MLR sequence had a distinct maximum between Cz and Fz; examination of the topographic distribution of the responses suggests that the 10 s MLR was more frontal, and more widely distributed. I speculate that in addition to the specific cortical generators which have been shown to contribute to the early MLR peaks (Makela & Hari, 1987), one or more oscillatory response generators may also be involved, and at very slow rates (near 1/10 s) these may come to dominate the response recorded at the scalp.

At slower stimulus rates, the bandpass-filtered responses of Figure 1 ride on larger, lower-frequency slow waves (P1/P50, N1/N100). When the MLRs above are subtracted from the wideband data, these peaks remain. Näätänen and Picton (1987) summarize evidence for a slow-rates N1 (sub)component which they suggest

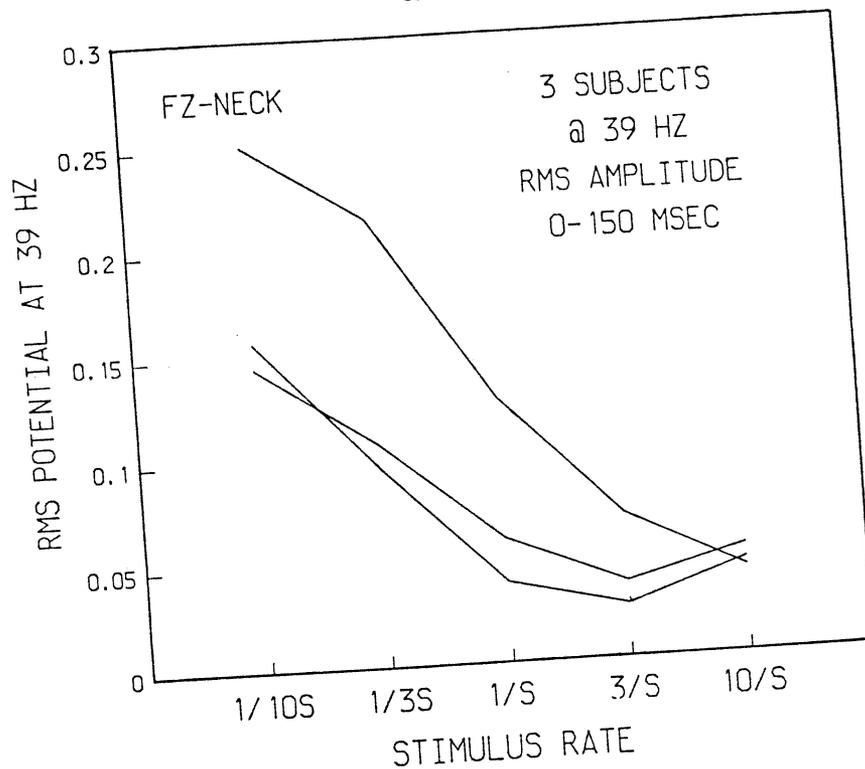


Figure 2: RMS amplitude of the 3 individual subjects' responses at Fz, prior to normalization.

may be generated in frontal motor or premotor cortex. In the rates series data, scalp distributions of the low-pass 1/10 s P50 and 1/10 s N1 were nearly indistinguishable. Furthermore, subtracting the low-pass 1/3 s responses from the low-pass 1/10 s responses produced P1 and N1 difference waves whose scalp distributions were very similar: greatest for both responses at vertex and posterior sites. This suggests that the large, central slow-rates N1 response may be preceded by a slow-rates P1 response, forming a slow-rates P1-N1 complex. Data from more subjects will be necessary to determine the relation of the scalp distributions of slow-rates high-pass MLR and low-pass P1/N1 responses. However, scalp distribution of the low-pass P50/P1/Pb peak was observed to shift from central/prefrontal (at 1/10 s) to ipsilateral/temporal (near 1 s), suggesting that the generators of the low-pass P1 responses at these two rate ranges may not be identical.

Though the concept of the *evoked rhythmic response* has been little used in ERP research (Makeig & Galambos, 1982) these data suggest that it may be appropriate to model the enlargement and prolongation of the auditory MLR at very slow rates. The physiologic implications of the concept are not precise - response rhythmicity may in part reflect the presence of a heterogeneous sequence of similar time and

distance constants in the various brain structures involved in producing the evoked response. However, response rhythmicity may also derive from fundamental principles of brain physiology (Llinas, 1988) and dynamics (Freeman & Skarda, 1985; Grey, Konig, Engel & Singer, 1989).

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