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Reticular formation influences on primary and non-primary auditory pathways as reflected by the middle latency response

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Ongoing studies are aimed at identifying the neural pathways responsible for the middle latency response (MLR). These studies involve the analysis of surface and intracranial potentials following pharmacologic inactivation (with lidocaine) of discrete regions of the guinea pig brain. Previous investigations have shown that MLR surface waves recorded over the temporal lobe originate from pathways anatomically and functionally distinct from those that generate MLR waves recorded over the midline, and that both primary and non-primary auditory thalamo-cortical pathways contribute to the guinea pig MLR. The present investigation examines the role of the mesencephalic reticular formation (mRF) in the MLR generating system. Inactivation of the mRF was associated with disruption of the midline response. These waves have been shown to reflect activity from non-primary subdivisions of the thalamo-cortical pathway. Components recorded over the temporal lobe were also affected, consisting of amplitude reduction and latency prolongation without changes in response morphology. Changes in temporal MLR components with mRF inactivation were smaller than those associated with direct inactivation of primary and non-primary subdivisions of the medial geniculate body. These findings indicate that mRF input is essential for normal generation of those components of the MLR thought to reflect both primary and non-primary auditory pathway activity.

INTRODUCTION

Ongoing studies in our laboratory are aimed at identifying the neural pathways responsible for the middle latency response (MLR). Recent investigations involve the analysis of surface and intracranial potentials following pharmacologic inactivation (with lidocaine) of discrete regions of the guinea pig brain [21,25,26]. The present investigation examines the role of the mesencephalic reticular formation (mRF) in the MLR generating system.

Several lines of evidence point to the reticular formation as an important contributing source in the generation of the auditory middle latency response. Buchwald and colleagues [1] provide considerable experimental evidence that human MLR wave P1 is generated by thalamic nuclei receiving essential input from the midbrain reticular activating system. In the cat, ablation experiments and correlations between intracranial and surface recordings point to the ascending RF as a generating source for a component occurring at 22 ms [3,16]. Both this wave and human P1 show decreases in amplitude during slow wave sleep with increases during REM sleep [6,11]. Furthermore, human and cat waves share similar rate/recovery cycles [12] and appear to be generated by cholinergic neurons [2,8].

There is little direct evidence linking the RF with human MLR wave Pa. Studies of the Pa generating system in humans and animal models have emphasized the contributions of the auditory afferent thalamocortical pathways [18]. Yet, wave Pa is affected by arousal state (sleep) and is thus tied by inference to the reticular formation [7,9,19,30].

Further linking the RF to the MLR are data suggesting that the RF exerts modulatory influences on the MLR both during sleep and during classical conditioning and appears to include neurons capable of reducing thalamic inhibitory responses [28,29]. Additionally, the 40 Hz response, consisting partially of MLR activity, is affected by sleep and has thus been tied to the reticular formation [13].

Midline and temporal components of the MLR generating system

Certain MLR components in the guinea pig have been tied to the auditory thalamo-cortical afferent

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pathways and are likely to correspond to human Pa. One of the goals of the present study was to examine how the mRF contributes to these components.

The guinea pig model is well suited for delineating the various contributing sources and physiological properties underlying the MLR. Two distinct MLR

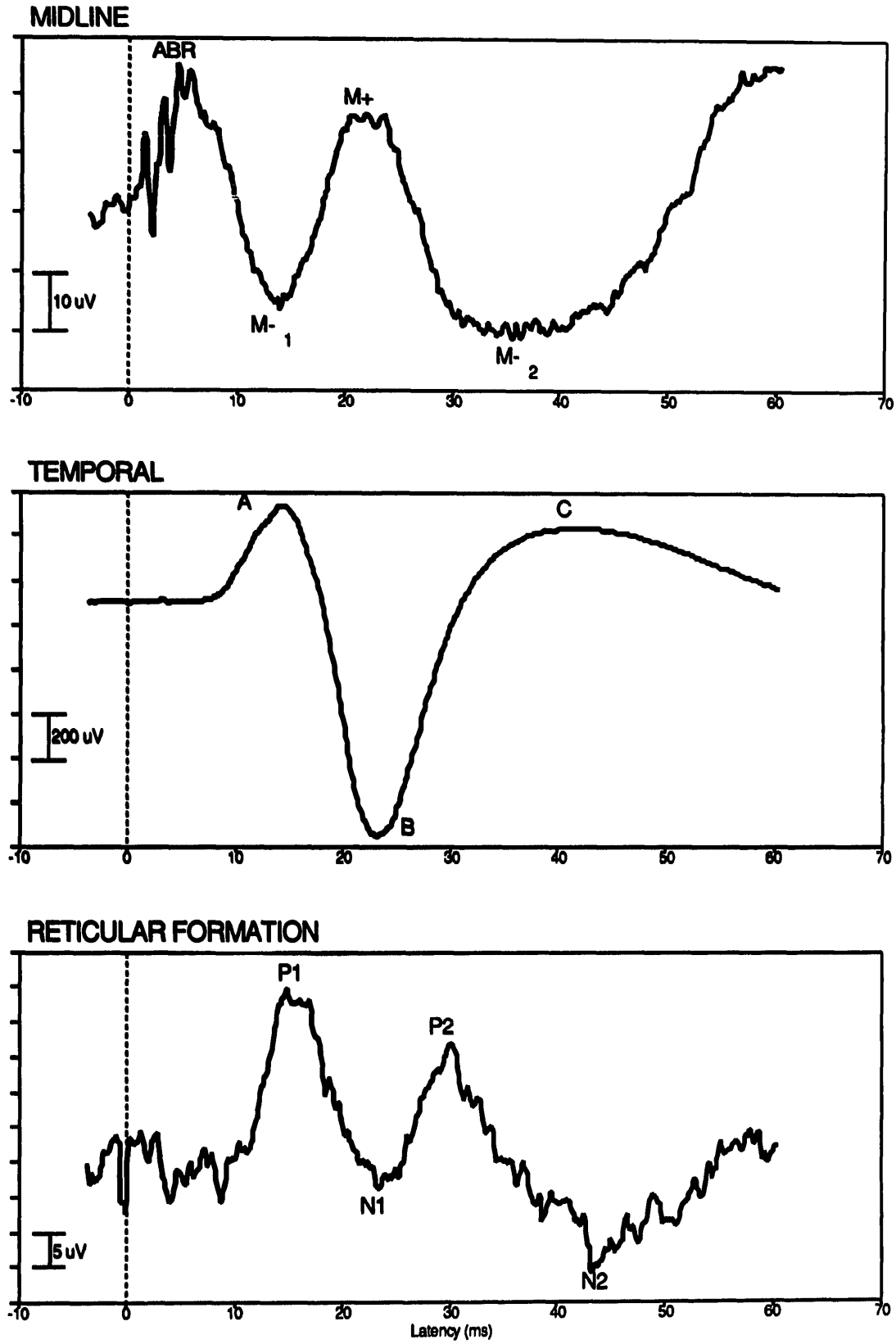

Fig. 1. Representative neural activity recorded from the epidural surface over the midline (top), the temporal lobe contralateral to the stimulated ear (middle) and the intracranial electrode in the mRF (bottom).

morphologies have been identified, one recorded over the temporal cortex and the other recorded over the posterior midline [21]. These occur during a similar time frame, following the ABR. MLRs recorded from the surface of the temporal cortex exhibit a three-component complex A, B, C, while MLRs recorded over the posterior midline are characterized by components $M-_1$, M+, $M-_2$.

These waves, referred to as 'temporal' and 'midline' components, appear to be mediated by distinct generating systems because they differ (in response characteristics) both neuroanatomically and functionally. The midline components have an early developmental time course, are rate resistant and sensitive to anesthetic agents. The midline response also persists following auditory cortex lesions. Temporal components develop later, are larger in amplitude, rate sensitive, resistant to anesthetic agents, affected by auditory cortex lesions, and show significantly more binaural interaction than midline components [22-24]. Furthermore, pharmacologic inactivation of subdivisions of the medial geniculate body (ventral and caudomedial portions, MGv and MGcm, respectively) have revealed that the primary sensory pathway (MGv) selectively contributes to the temporal response, while the non-primary afferent input (MGcm) contributes to both temporal and midline responses [26].

The purpose of the present study was to examine how the mRF contributes to the generation of midline and temporal MLR components in guinea pigs. Part of

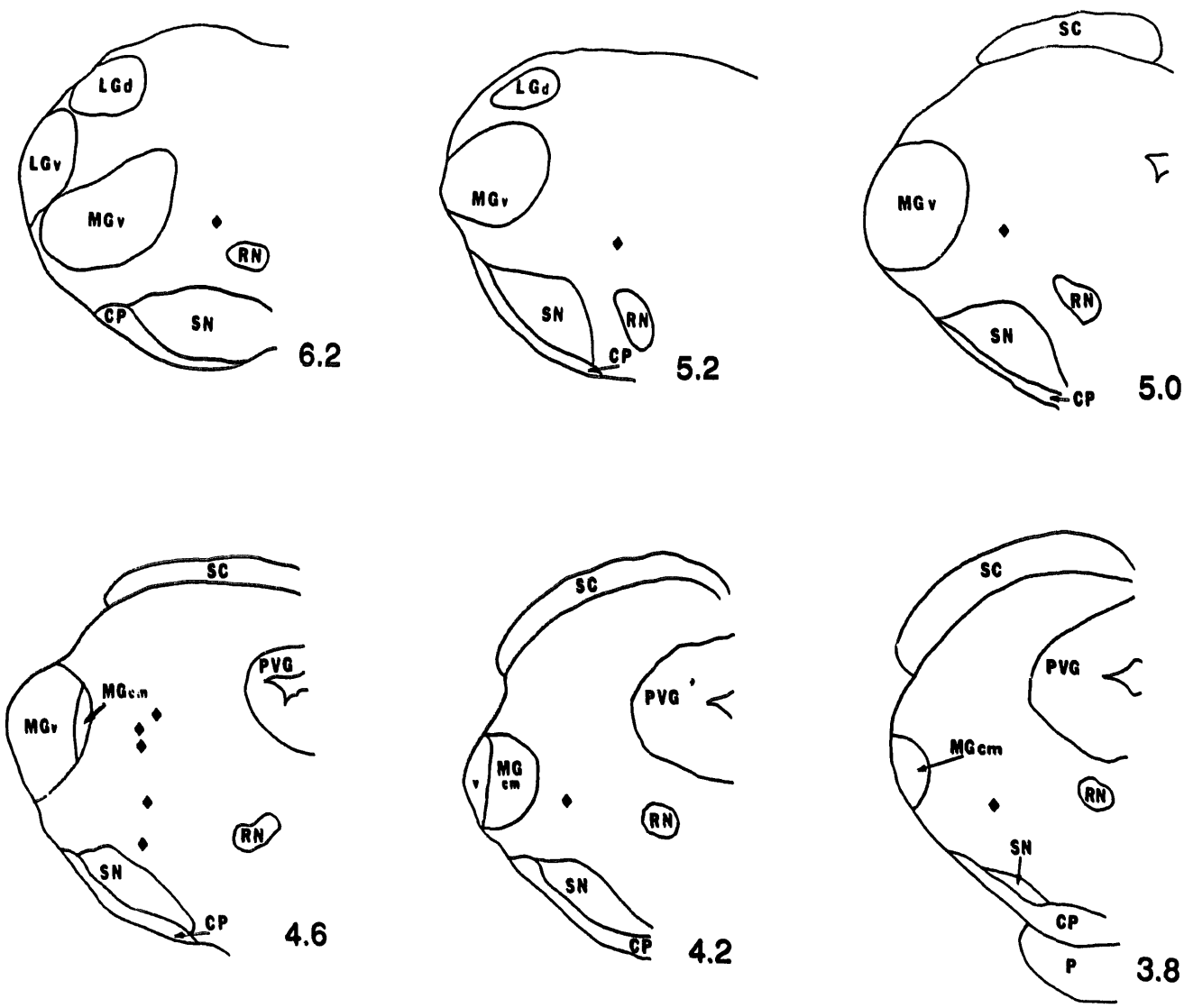

Fig. 2. Schematic of coronal section of the mesencephalon. Histologic reconstruction of injection sites within the mRF are indicated by solid diamonds. Numbers in right hand corner of each schematic denote distance (mm) in a rostral direction from the interaural line. Abbreviations: SC, superior colliculus; PVG, periventricular grey; MGv, ventral subdivision of medial geniculate body; MGcm, caudomedial subdivision of medial geniculate body; SN, substantia nigra; RN, red nucleus; CP, cerebral peduncle; P, pons; LGd, dorsal division of lateral geniculate nucleus; LGv, ventral division of lateral geniculate nucleus.

the investigation compared contributions of the mRF to those of the primary (MGv) and non-primary (MGcm) portions of the thalamo-cortical pathway.

MATERIALS AND METHODS

Ten guinea pigs, weighing approximately 350 g, were used as subjects. Animals were anesthetized with ketamine hydrochloride (100 mg/kg) and xylazine (7 mg/kg). Smaller doses (15 mg/kg of ketamine; 3 mg/kg of xylazine) were administered at 1-h intervals throughout the rest of the experiment. Atropine (0.6 mg/kg) was administered before surgical anesthesia, and every 3 h thereafter.

Electrophysiologic recording. Epidural silver bead electrodes (0.5 mm diameter) were used to record the surface MLR as previously described [21]. Recordings were made over the temporal lobe contralateral to the stimulated ear and over the posterior midline. An electrode placed 15 mm anterior to bregma and 1 mm lateral to the sagittal suture served as a reference. A combination high-impedance micro-electrode and micro-injection needle was positioned stereotaxically in the mRF. Coordinates were 4.5 mm rostral from the interaural line, 2.2 mm left lateral of midline and 8.5 mm ventral.

Monaural, 100 μs click stimuli were presented to the right ear at 70 dB HL at a rate of 3.5/s through Etymotic insert earphones. Recordings were filtered from 10 to 1,500 Hz. Each averaged response consisted of 200 individual responses with a 60 ms time sweep and a 3.25 ms pre-stimulus period.

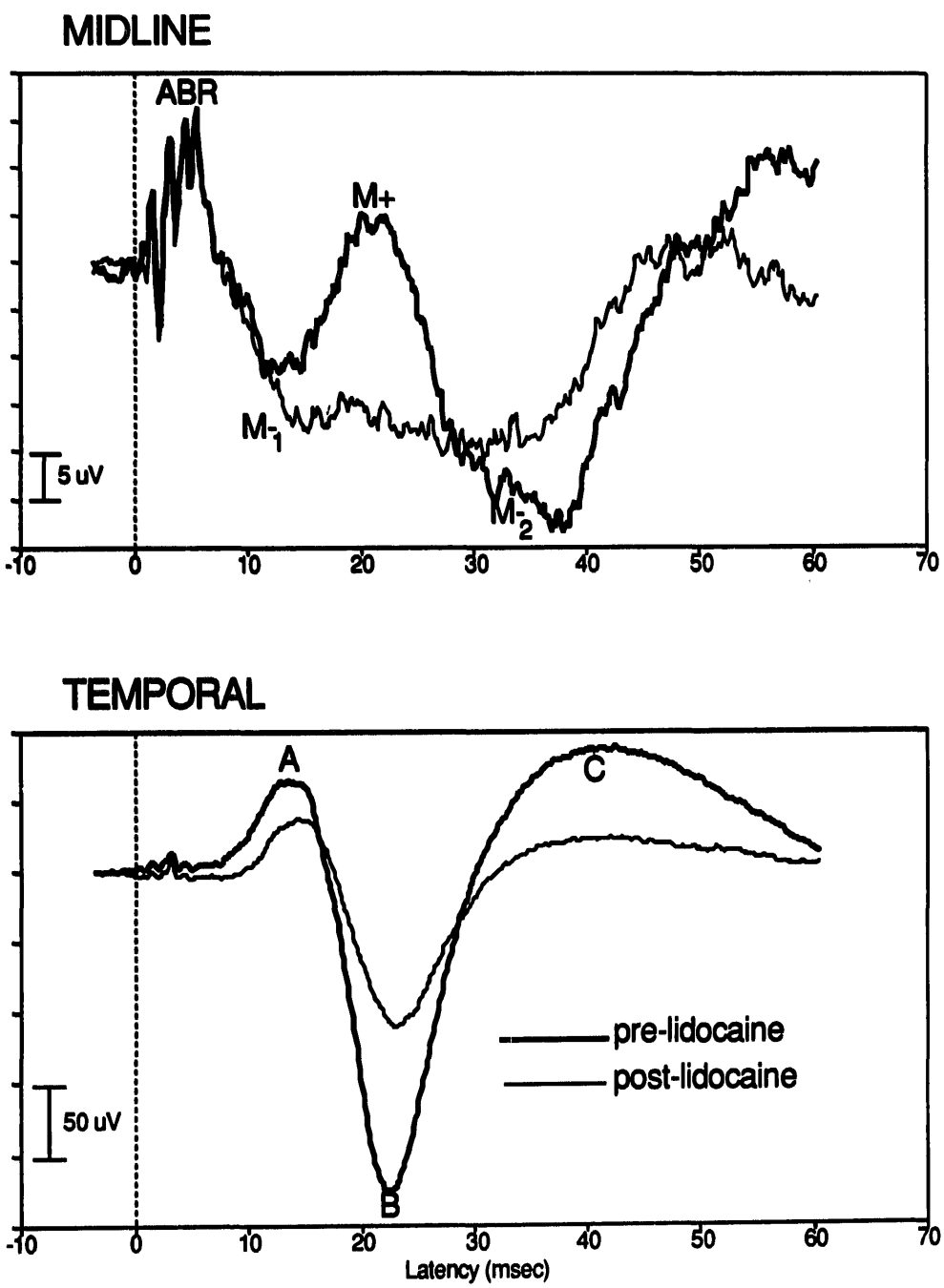

Fig. 3. Midline and temporal surface responses before and after lidocaine injection for a representative animal. Note the disruption of the midline MLR and the reduction in amplitude and latency prolongation in the temporal MLR.

Neural activity was recorded simultaneously from the midline and temporal surface and the mRF. Throughout the experiment, auditory brainstem responses (ABR) were monitored to insure the integrity of the peripheral auditory system. Neural inactivation procedures were as previously described [25]. At least ten successive recordings were obtained from all sites prior to the administration of lidocaine. Following this baseline period, 2 μl of 4% lidocaine HCl was injected into the mRF, to reversibly inactivate axonal transmission [15]. To control injection rate, a microinfusion pump delivered the lidocaine at a rate of 2 μl/30 s.

The effect of the drug was observed simultaneously on surface potentials and on the local response, with recordings obtained at intervals of one to two min until the return of baseline waveform morphologies and amplitudes. At the end of the experiment, recording locations were marked electrolytically (30 μA for 10 s). Brains were cut in 17-μ coronal sections and stained with the Kluver stain

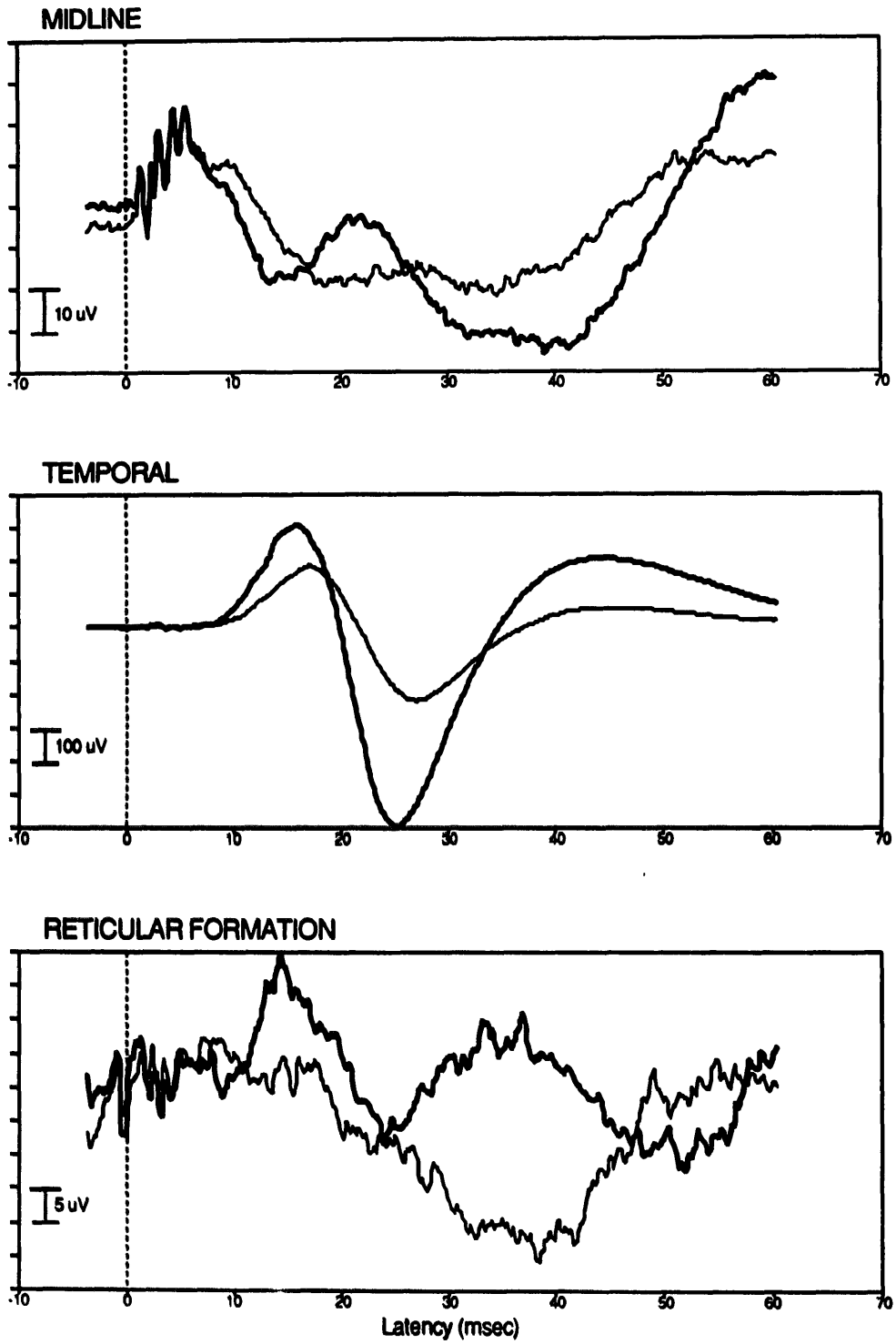

Fig. 4. Surface MLRs (midline and temporal) and intracranial responses from the mRF before and after lidocaine injection in a representative animal. Baseline responses are shown with bold, thick lines; post-lidocaine responses are depicted with lighter lines. Midline waves M+ and M$-_2$ were markedly attenuated; the temporal response retained its original morphology but was again reduced in amplitude and prolonged in latency. All activity beyond 10 ms was disrupted at the mRF.

which permits visualization of cell body and fiber pathways.

Data analysis. Wave amplitudes and latencies pre- and post-lidocaine injection were measured. Amplitude was measured from the preceding trough to the peak, or from the preceding peak to the trough. Latencies were measured at the midpoint of the peak or trough. All peaks and troughs occurring in a post-stimulus latency range of 4–40 ms were scored. The means and standard deviations of baseline amplitudes were computed to determine confidence intervals of significant change. A change of more than 2 standard deviations from the baseline mean was considered significant. To compare lidocaine effects across animals, amplitudes were normalized to percentages, with baseline mean defined as 100%. The percentage values were utilized in parametric statistics. Three way split-plot ANOVAs were performed to assess amplitude, latency and recovery effects following mRF injection. Effects of mRF injections were compared with effects associated with inactivation of the MGB [26]. Tests for simple main effects and post-hoc *t*-tests were used to assess specific interactions between MLR waves, midline and temporal recording sites and injection locations.

RESULTS

Definitions of components. Representative surface and intracranial recordings are shown in Fig. 1. As previously reported [20,21], the surface midline MLR (top) includes the rapid peaks of the ABR, followed by a negative wave at 10–12 ms ($M-_1$), a positive wave at 20–25 ms (M+), and a second negativity $M-_2$ at 32–35 ms. MLRs recorded from the surface of the temporal cortex (middle) show a three-component complex, with a positive wave at 12 ms (A), a negative wave at 21 ms (B), and a positive wave at 35 ms (C). The waveform recorded locally from the mRF is characterized by positive waves (P1, P2) at 15 and 30 ms and negative troughs (N1, N2) at 25 and 45 ms (bottom). Lesions were localized in the mRF histologically as shown in Fig. 2 (schematic modified from Redies et al. [31]).

Effects of pharmacologic inactivation of the mRF. The injection of lidocaine into the mRF correlated with changes in both midline and temporal MLR components in all animals. At the midline, the morphology of waves M+ and $M-_2$ was often disrupted. The ABR and the midline negative component following the ABR ($M-_1$) were unaffected. Thereafter, the midline complex typically reappeared with amplitude reductions and latency delays until recovery of baseline values. Changes observed in temporal MLR components generally consisted of amplitude reduction and latency prolongation without changes in the basic ABC complex morphology.

Neural activity recorded from within the mRF was too variable for analysis in 6 animals. In the 4 animals with stable baseline waveforms, significant changes in local activity were observed following lidocaine injection.

Representative midline and temporal responses are shown in Fig. 3 prior to and following lidocaine injection. Shown is disruption of midline waves M+ and $M-_2$. Temporal waves ABC retained their basic morphology but were reduced in amplitude and prolonged in latency. Waveforms representative of pre- and post-lidocaine responses are shown in Fig. 4 for another

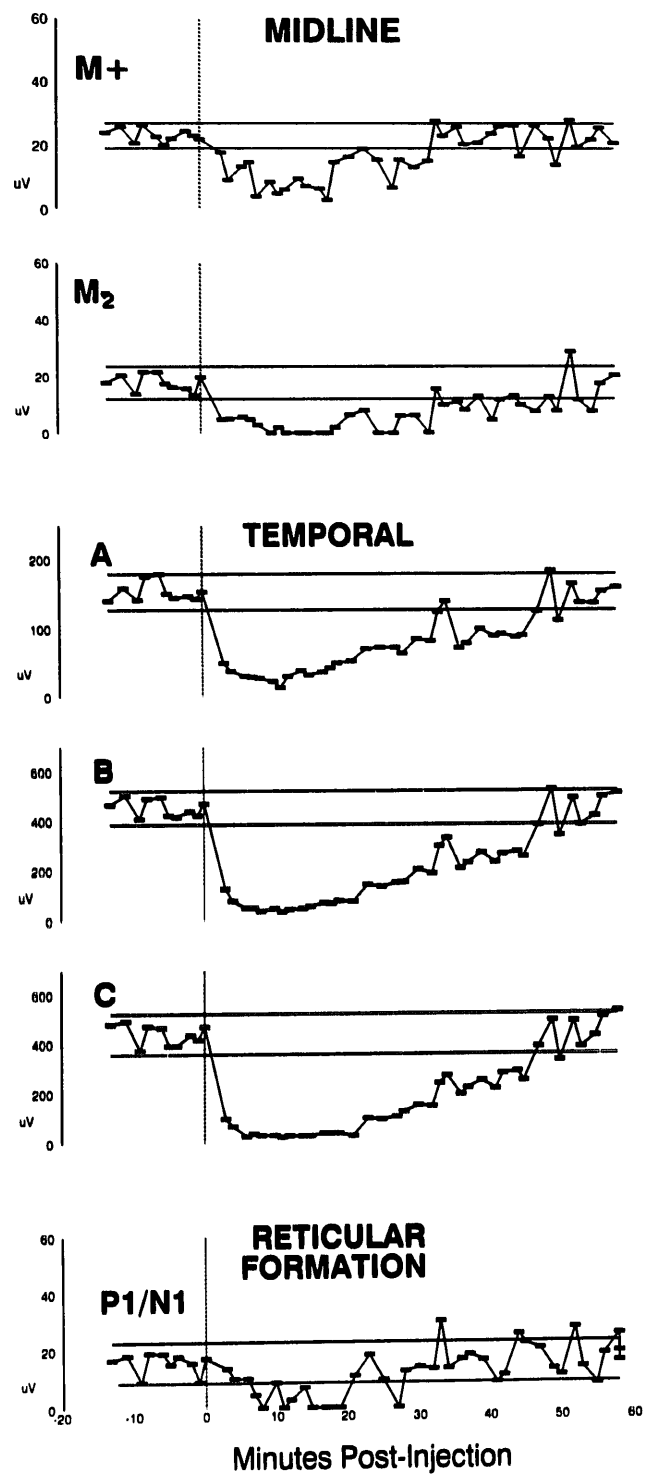

Fig. 5. Effects of lidocaine injection in the mRF on the amplitude of waves from surface temporal and midline electrodes and from within the mRF for a representative animal over the time course of the experiment. Horizontal lines indicate the range of baseline mean ± 2 standard deviations.

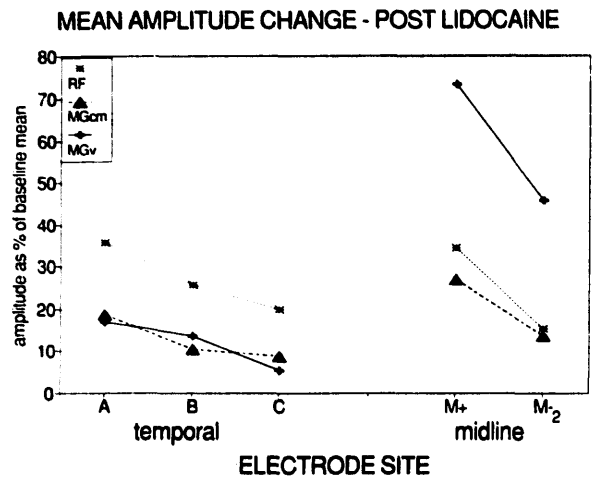

Fig. 6. Mean amplitude change post-lidocaine for midline and temporal waves. Amplitude effects following mRF injections are compared with effects associated with injections into primary and non-primary subdivisions of thalamus (MGv and MGcm). Amplitude reductions were significantly less following mRF injections as compared to injections in the MGB for all temporal waves. All injection sites had minimal effects on midline wave $M-_1$. mRF and MGcm injections had similar effects on midline waves M+ and $M-_2$ amplitude. These amplitude reductions were significantly greater than those associated with inactivation of the primary thalamo-cortical pathway (MGv).

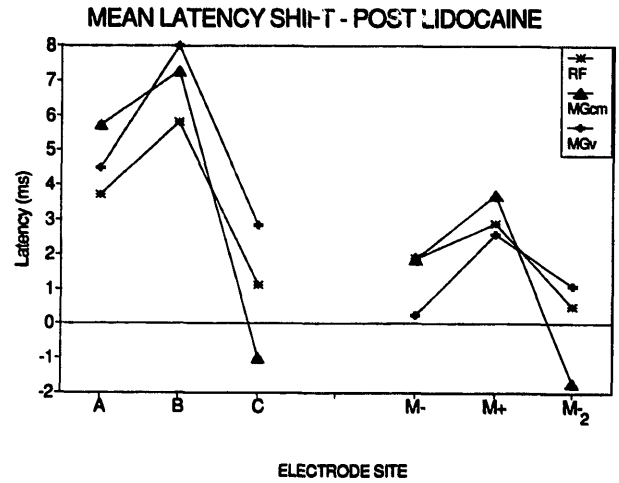

Fig. 7. Mean latency at time of maximum effect after lidocaine injection. No significant differences between injection sites (mRF, MGv and MGcm) were observed. Temporal waves (A and B) showed greater latency shifts than midline waves with lidocaine injections.

animal with stable baseline and stimulus-locked activity within the mRF. Once again the midline response was markedly attenuated; temporal wave amplitudes were reduced with prolonged latencies. Within the mRF, neural activity beyond 10 ms was abolished with lidocaine injection.

Amplitude changes (over the course of the experiment) on midline, temporal and local mRF responses are shown in Fig. 5 for a representative animal. The horizontal lines designate ± 2 S.D. of mean baseline amplitude. Lidocaine was injected at time 0. Significant amplitude changes were observed on midline waves M+ and $M-_2$, temporal waves A, B and C and the local mRF response. The time course of midline changes mirrored the local mRF changes. Temporal components were the last to recover. In all animals, latency shifts were significantly greater for temporal waves than for midline components ($P < 0.01$).

Comparison of mRF and MGB inactivation. Effects of mRF inactivation on the amplitude of midline and temporal surface responses are compared with effects of inactivation of subdivisions of the auditory thalamus. Shown in Fig. 6 is the percent change from the pre-injection baseline amplitude (averaged over 5 post-injection trials where maximal effects occurred).

As reported above, mRF inactivation affected both midline and temporal components. Following mRF inactivation, amplitude reductions of the temporal components were significantly less than the changes observed with injections into either subdivision of the MGB ($F = 7.1$, $P < 0.01$). Lidocaine injection into mRF had a significantly greater effect on midline components M+ and $M-_2$ than did injections into MGv ($F = 24.3$, $P < 0.0001$). At the midline, changes observed with mRF injections resembled those observed with MGcm inactivation with respect to degree of amplitude reduction.

Mean latency changes following mRF, MGv and MGcm injections are compared in Fig. 7. Latency effects were similar irrespective of the injection sites.

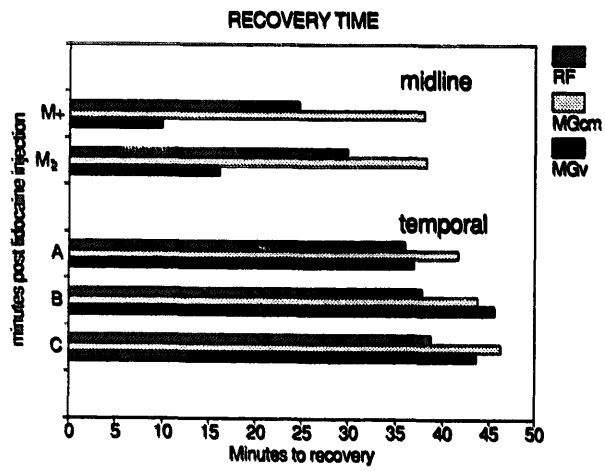

Fig. 8. Mean duration of lidocaine effects from time of injection to recovery of amplitude to baseline values. With mRF injections, midline changes recovered earlier than temporal changes. Amplitude changes associated with injections into mRF and MGv recovered significantly earlier than following MGcm injections. There were no significant differences in the time course of effects following mRF or MGB injections for temporal MLR waves.

Latency shifts were significantly greater for temporal waves A and B than for midline components for all injection sites ($F = 13.4$, $P < 0.01$).

Recovery. Mean time to recovery of pre-injection amplitudes is shown for all waves in Fig. 8. Following mRF injections, recovery was significantly faster for midline than for temporal components ($F = 31.9$, $P < 0.01$). The faster midline vs. temporal MLR recovery is also apparent in Fig. 5 for an individual animal. For midline waves, recovery time course was longer for MGcm than for mRF and MGv injections ($F = 9.8$, $P < 0.01$). There were no significant differences in the recovery time of temporal waves with respect to injection site (mRF, MGv or MGcm).

DISCUSSION

Summary of results. MRF inactivation affects MLR components recorded from both midline and temporal surface locations. At the midline, waves M + and $M-_2$ were disrupted and/or markedly reduced in amplitude. Over the temporal lobe, effects consisted of amplitude reduction and latency prolongation of waves A, B and C, with preservation of basic response morphology. The amplitude reductions in the temporal response observed with mRF inactivation were significantly less than reductions associated with inactivation of either the primary or non-primary subdivisions of the auditory thalamus. The marked disruption of the midline MLR associated with mRF injections resembled changes seen with MGcm inactivation. Both mRF and MGcm inactivation were associated with large changes in the midline response in contrast to the minimal midline response changes observed following MGv inactivation.

Latency changes were more pronounced for temporal waves than for midline waves, irrespective of inactivation site. That is, latency changes accompanying mRF and thalamic inactivation were indistinguishable.

Recovery from mRF inactivation occurred earlier at the midline than over the temporal lobe. The time course of local changes observed in the mRF mirrored the time course seen for midline waves. The mRF and MGB recovery courses were not significantly different for temporal responses. For midline waves, the recovery time course was longer for MGcm than for mRF and MGv injections.

Midline and temporal generating systems. This investigation builds upon previous work delineating the neurophysiologic networks reflected by the temporal and midline components of the guinea pig MLR [20,21,24-26]. Two increasingly well-defined aspects of the MLR generating system emerge:

(i) The midline system develops early and appears to be functionally more generalized than its temporal counterpart. In comparison to the temporal response, the midline system is more labile, more affected by anesthetic agents, and not particularly sensitive to acoustic stimulus properties as evidenced by its resistance to stimulation rate and relatively weak binaural interaction qualities. With respect to the neural generating system, critical contributing sources are the non-primary subdivision of thalamus (MGcm) and the mesencephalic mRF. A subcortical origin is further supported by resistance of the midline response to auditory cortex lesions.

(ii) The temporal system is later developing and appears to be functionally more specialized. It is robust and is sensitive to acoustic stimulus properties as evidenced by the fact that the response is highly stimulus-locked, rate-sensitive and reflects binaural interaction. In terms of the underlying generating system, the temporal response predominantly reflects primary auditory pathway activity as evidenced by its exquisite sensitivity to pharmacologic inactivation of MGv and to auditory cortex lesions. In addition, MGcm and mRF input is shared by both midline and temporal components.

Possible relationships between human and animal MLR

Waves $M-_1$/Na. The negative trough following the ABR in animals and wave Na in humans are thought to receive important contributions from the midbrain inferior colliculus [5,10,14,17,18,25]. The present investigation is consistent with the view that the mRF does not contribute to this MLR component.

Waves P1 and Pa. A combination of experiments on humans and animals has led to the notion that the mRF contributes heavily to human MLR wave P1 (reviewed in Introduction). The present data concur, in that all MLR waves beyond $M-_1$ were affected by mRF inactivation.

Generating sources attributed to wave Pa include the auditory cortex and auditory thalamo-cortical pathways [18]. Evidence supporting input from the reticular formation into this system has been lacking. In the guinea pig, it appears that **all** MLR components receive important contributions from the mesencephalic reticular formation as well as from the non-primary subdivisions of the auditory thalamus. The current study supports the concept that all MLR components receive critical input from the mRF, with this input functioning, perhaps, as a power supply or amplifier to both systems. This is consistent with the scheme proposed by Yingling and Skinner [32] in which the mRF inhibits other inhibitory nuclei within the RF, thereby

creating an excitatory effect on thalamus. Specifically, pharmacologic inactivation of mRF may permit those inhibitory nuclei to operate, resulting in a decrease in MLR amplitude.

Evidence for two neuroanatomically and functionally distinct MLR systems in animals allows for speculation that similar systems may exist in humans. It may be possible to distinguish components of the MLR generating system topographically in humans, although not as clearly as in the animal model. Human wave Pa is largest in amplitude over frontal cortex (Fz) and is measured from widespread areas of the cortical surface [22]. Another wave, TP41, occurring roughly in the same time frame (about 5–10 ms later than Pa), is highly localized over the temporal lobe [4]. The present study supports the notion that the mRF contributes substantially to all MLR components recorded in the animal model. By inference, human Pa and TP41 may sustain similar inputs and can be expected to be state dependent. Investigations are underway to determine whether the primary and non-primary generating systems observed in the guinea pig may be distinguished in humans on the basis of topography, acoustic stimulus processing and maturational time course.

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REFERENCES

1 Buchwald, J., Animal models of cognitive event-related potentials. In J. Rhorbaugh, R. Parasuraman and R. Johnson, (Eds.), *Event-related Brain Potentials*, Oxford University Press, NY, 1990, pp. 57–75.

2 Buchwald, J., Rubenstein, E., Schwafel, J. and Strandburg, R., Midlatency auditory evoked responses: differential effects of a cholinergic agonist and antagonist, *Electroenceph. Clin. Neurophysiol.*, 80 (1991) 303–309.

3 Buchwald, J.S., Hinman, C., Norman, R.S., Huang, C.M. and Brown, K.A. Middle- and long-latency auditory evoked potentials recorded from the vertex of normal and chronically lesioned cats, *Brain Res.*, 205 (1981) 91–109.

4 Cacace, A.T., Satya-Murti, S. and Wolpaw, J.R., Human middle-latency auditory evoked potentials: vertex and temporal components, *Electroenceph. Clin. Neurophysiol.*, 77 (1990) 6–18.

5 Caird, D.M. and Klinke, R., The effect of inferior colliculus lesions on auditory evoked potentials, *Electroenceph. Clin. Neurophysiol.*, 68 (1987) 237–240.

6 Chen, B.M. and Buchwald, J.S., Midlatency auditory evoked responses: differential effects of sleep in the cat, *Electroenceph. Clin. Neurophysiol.*, 65 (1986) 373–382.

7 Collett, L., Duclaux, R., Challand, M.J. and Revol, M., Effect of sleep on middle latency response (MLR) in infants, *Brain Dev.*, 10 (1988) 169–173.

8 Dickerson, L. and Buchwald, J., Midlatency auditory evoked responses: effect of scopolamine in the cat and implications for brainstem cholinergic mechanisms, *Exp. Neurol.*, 112 (1991) 229–239.

9 Dieber, M., Ibanez, V., Bastuji, H., Fischer, C. and Mauguiere, F., Changes in middle latency auditory evoked potentials during natural sleep in humans, *Neurology*, 39 (1989) 806–813.

10 Dieber, M.P., Ibanez, V., Fischer, C., Perrin, F. and Mauguiere, F., Sequential mapping favors the hypotheses of distinct generators for Na and Pa middle latency auditory evoked potentials, *Electroenceph. Clin. Neurophysiol.*, 71 (1988) 187–197.

11 Erwin, R. and Buchwald, J.S., Midlatency auditory evoked responses: differential effects of sleep in the human, *Electroenceph. Clin. Neurophysiol.*, 65 (1986) 383–392.

12 Erwin, R. and Buchwald, J.S., Midlatency auditory evoked responses: differential recovery cycle characteristics, *Electroenceph. Clin. Neurophysiol.*, 64 (1986) 417–423.

13 Galambos, R., Makeig, S. and Talmachoff, P.J., A 40 Hz auditory potential recorded from the human scalp, *Proc. Natl. Acad. Sci. USA*, 78 (1981) 2643–2647.

14 Hashimoto, I., Ishiyama, Y., Yoshimoto, T. and Nemoto, S., Brainstem auditory-evoked potentials recorded directly from the human brainstem and thalamus, *Brain*, 104 (1981) 841–859.

15 Hille, B., Common mode of action of three agents that decrease the transient change in sodium permeability in nerves, *Nature*, 210 (1966) 1220–1222.

16 Hinman, C.L. and Buchwald, J.S., Depth evoked potential and single unit correlates of vertex midlatency auditory evoked responses, *Brain Res.*, 264 (1983) 57–67.

17 Kileny, P., Paccioretti, D. and Wilson, A.F., Effects of cortical lesions on middle-latency auditory evoked responses (MLR), *Electroenceph. Clin. Neurophysiol.*, 66 (1987) 108–120.

18 Kraus, N. and McGee T., Electrophysiology of the human system. In A. Popper and R. Fay (Eds.), *The Auditory System, Vol 2*, Springer-Verlag (1992) in press.

19 Kraus, N., McGee, T. and Comperatore, C., MLRs in children are consistently present during wakefulness, stage 1 and REM Sleep, *Ear Hear.*, 10 (1989) 339–345.

20 Kraus, N., Smith, D.I. and Grossmann, J., Cortical mapping of the auditory middle latency response in the unanesthetized guinea pig, *Electroenceph. Clin. Neurophysiol.*, 62 (1985) 219–226.

21 Kraus, N., Smith, D.I. and McGee, T., Midline and temporal lobe MLRs in the guinea pig originate from different generator systems: a conceptual framework for new and existing data, *Electroenceph. Clin. Neurophysiol.*, 70 (1988) 541–558.

22 Kraus, N. and McGee, T., Color imaging of the human middle latency response, *Ear Hear.*, 9 (1988) 159–167.

23 Kraus, N., Smith, D.I., McGee, T., Stein, L. and Curtee, C., Development of the auditory middle latency response in an animal model and its relationship to the human response, *Hearing Res.*, 27 (1987) 165–176.

24 Littman, T., Kraus, N., McGee, T. and Nicol, T., Binaural stimulation reveals functional differences between midline and temporal components of the middle latency response in guinea pigs, *Electroencephalogr. Clin. Neurophysiol.*, in press.

25 McGee, T., Kraus, N., Comperatore, C. and Nicol, T., Subcortical and cortical components of the MLR generating system, *Brain Res.*, 544 (1991) 211–220.

26 McGee, T., Kraus, N., Littman, T. and Nicol, T., Contributions of medial geniculate body subdivisions to the middle latency response, *Hearing Res.*, in press.

27 McGee, T., Özdamar, Ö. and Kraus, N., Auditory middle latency responses in the guinea pig, *Am. J. Otolaryngol.*, 4 (1983) 116–122.

28 Molnár, M., Karmos, G. and Csépe, V., Laminar analysis of intracortical and evoked potentials during the wakefulness–sleep cycle of the cat, *Int. J. Psychophysiol.*, 3 (1986) 171–182.

29 Molnár, M., Kramos, G., Csépe, V. and Winkler, I., Intracortical and evoked potentials during classical aversive conditioning in cats, *Biol. Psychol.*, 26 (1988) 339–350.

30 Osterhammel, P.A., Shallop, J.K. and Terkildsen, K., The effect of sleep on the auditory brainstem response (ABR) and the middle latency response (MLR), *Scand. Audiol.*, 14 (1985) 47–50.

31 Redies, H., Brandner, S. and Creutzfeldt, O., Anatomy of the auditory thalamocortical system of the guinea pig, *J. Comp. Neurol.*, 282 (1989) 489–511.

32 Yingling, C.D. and Skinner, J.E., Gating of thalamic input to cerebral cortex by nucleus reticularis thalami. In J.E. Desmedt (Ed.) *Attention, Voluntary Contraction and Event-Related Cerebral Potentials*, Prog. Clin. Neurophysiol. Vol 1, Karger, Basel, 1977, pp. 70–96.