Effects of Age and Sex on Auditory Brainstem Response

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We examined amplitude and latency of the auditory brainstem response (ABR) waveform as functions of chronological age in 182 male and 137 female subjects. Hearing sensitivity was within normal limits in 98 subjects. The remaining 221 subjects had varying degrees of sensorineural hearing loss. Age had a slight effect on both latency and amplitude of wave V. In subjects with normal hearing, latency increased about 0.2 ms over the age range from 25 to 55 years. In the same group, wave V amplitude decreased about 10%. In subjects with sensorineural hearing loss, the latency increase was smaller, but the amplitude decrease was equivalent. Sex also affected the ABR. In both normal and hearing-impaired subjects, female subjects showed consistently shorter latency and larger amplitude at all age levels. Wave V latency was about 0.2 ms shorter and wave V amplitude was about 25% larger in female subjects.

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In less than a decade, auditory brainstem response (ABR) audiometry has assumed a prominent role in clinical audiology. Following the Jewett and Williston[1] report in 1971, numerous investigators have studied the ABR in subjects with normal hearing[2-11] and a range of otologic and neurologic disorders.[12-30] The developmental aspects of the ABR in neonates, infants, and young children are also well established.[3,10,31-35] From birth to approximately 18 months, latency of the ABR, in particular the wave V component, systematically decreases, while amplitude increases.

In contrast to the interest in the developmental changes in the ABR, the potential influence of aging in adults has received remarkably little attention. Age is an important factor in behavioral audiometry. The age-related decrease in pure-tone sensitivity for higher frequencies[36,37] and, in some patients, lower frequencies,[38-40] is well documented. Depressed performance in speech understanding for both single words[37,41-43] and, especially, sentences in competition[40,43] is associated with aging. Age is also a factor in impedance audiometry. Static compliance decreases as a function of age.[44,45] With increasing age, acoustic reflex thresholds usually improve slightly for pure-tone signals, and are elevated for noise signals, even in subjects with normal hearing.[46] Consequently, the noise-tone difference (NTD) is decreased as a function of age.[46,47] Recently, Gersdorff[48] reported decreased amplitudes for crossed (contralateral) and uncrossed (ipsilateral) acoustic reflexes, again, in subjects with normal hearing sensitivity. In view of these documented age effects in other aspects of auditory function, it seems reasonable to suspect an age factor in the ABR.

There is mounting evidence that sex is a factor in both behavioral and impedance audiometry. In older adults, pure-tone sensitivity for high-frequency, pure-tone signals is usually better in women than in men, while sensitivity for low-frequency pure-tone signals is usually better in men than women.[40,49,50] Sex differences in performance on diagnostic speech audiometric procedures have also been reported.[40] Sex is a factor in some impedance audiometry measures. Static compliance tends to be greater in male than in female subjects.[44,45,51] However, a sex effect is not apparently reflected in acoustic reflex thresholds.[44]

Recent evidence suggests that both age[9,52-55] and sex[52,53,55] affect the ABR. We report the effects of age and sex for ABR wave V latency and amplitude.

METHOD

Subjects

The subjects were 319 patients, aged 20 to 79 years, whose clinical records were studied retrospectively. All subjects had received a routine audiologic evaluation at the Methodist Hospital/Neurosensory Center, Houston. There were 182 male and 137 female subjects. In 98 subjects, hearing sensitivity was within normal limits; that is, equal to or better than 20 dB hearing level (HL) for octave frequencies from 250 through 4,000 Hz. The remaining 221 subjects had varying degrees of sensorineural hearing loss. All subjects had normal middle ear function, as defined by impedance audiometry, and no audiometric evidence

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of retrocochlear disorder. In the sensorineural group, ABR latency and amplitude are always reported for the ear with better hearing sensitivity.

Instrumentation and Procedure

The instrumentation and procedure used in this study have been described previously.[28(pp 456-457)] In brief, the acoustic signal used to elicit the ABR was a half-cycle of a 3,000-Hz sinusoid. Signal intensity is expressed in HL (ie, decibels above average normal hearing for the click). The ABR was recorded by conventional signal-averaging technique. Standard EEG disk electrodes were attached to the vertex (active) and to each mastoid. The mastoid of the stimulated ear served as reference, and the opposite mastoid served as ground. Prior to electrode placement, the three electrode sites were cleaned with an abrasive gel to reduce interelectrode resistance to less than 4,000 ohms. The EEG signal was preamplified (Grass P511) with a voltage gain of 200,000 and band-pass filtered from 300 to 3,000 Hz (6 dB/octave skirt). The signal averager (Nicolet, 1010) was triggered for a 10-ms sweep at the onset of each signal. A total of 2,048 sweeps was averaged. Half of the signals (1,024) were condensation clicks, and half were rarefaction clicks.

Subjects were seated in a double-walled sound-treated room. Each subject was tested at a high intensity (90 or 100 dB HL) and at 10- to 20-dB intensity decrements until the ABR was no longer observed. However, for this study, only ABRs for signal intensities of 70 to 90 dB HL were analyzed. The latency of wave V (the time, in milliseconds, from signal onset to the positive peak of wave V) and the amplitude of wave V (in microvolts) measured from the peak of wave V to the following trough were determined for each response.

RESULTS

Figure 1 shows mean ABR latency (wave V) as a function of age in both the normal and sensorineural groups. Results for male and female subjects are plotted separately. The average signal intensity was comparable (83 to 85 dB HL) for all groups of subjects. In the normal group, latency increased as a function of age for both sexes. For both male and female subjects, the average latency in the oldest group was 0.20 ms longer than the average latency in the youngest group. However, while the relative age effect was comparable for male and female subjects, there was a distinct difference in the absolute latencies between sexes. In each age group, the average latency of the ABR was longer for male than for female subjects. In male subjects, the latency ranged from 5.70 ms in the youngest group to 5.89 ms in the oldest group. For female subjects, the latency ranged from 5.57 ms for the youngest group to 5.76 ms for the oldest group. Combining all age groups, the average latency for male subjects was 0.14 ms greater than the latency for female subjects.

In the sensorineural group, latency showed little change as a function of age. For male subjects, the average latency in the oldest group was only 0.10 ms longer than the average latency in the youngest group. For female subjects, there was no consistent change in latency as a function of age. In contrast to the small age effect, the difference in absolute latencies between male and female subjects was substantial, ranging from 0.19 ms in the youngest age group to 0.35 ms in the oldest age group. Collapsed across age, the average sex difference was 0.25 ms.

Figure 2 shows mean ABR amplitude (wave V) as a function of age in both groups. Results for male and female subjects are plotted separately. Again, the average signal intensity was comparable (83 to 85 dB HL) for all groups of subjects. In the normal group, wave V amplitude for female subjects showed a very slight decrease (0.025 μV) from the youngest to oldest age groups. For male subjects, the amplitude decrease was twice as great (0.050 μV) from the youngest to the oldest age groups. Compared with the weak age effect on normal ABR amplitude, the sex difference was robust. Female amplitude consistently exceeded male amplitude by amounts ranging from 0.080 μV in the youngest group to 0.120 μV in the oldest group.

In the sensorineural group, there was a slightly greater age effect on wave V amplitude. For female subjects, amplitude decreased by about 0.050 μV. For male subjects, amplitude decreased by about 0.020 μV. Again, a sex difference in wave V amplitude is clearly evident. The amplitude for female subjects exceeded the amplitude for male subjects by up to 0.150 μV (in the 50 to 59 year age group).

In view of the dependence of both amplitude and latency of the ABR on auditory sensitivity in the high-frequency (1,000 to 8,000 Hz) region,[19] it is possible that the sex differences observed in Fig 1 and 2 could be due to subtle differences in high-frequency hearing sensitivity, differences favoring the female group. To investigate this possibility, we calculated the mean and standard deviation of the threshold HL at each test frequency from 250 through 8,000 Hz for each sex. Table 1 summarizes these data for the normal group (40 female and 58 male subjects).

Average HLs between sexes differed in excess of 2 dB at only one test frequency; at 250 Hz, the average threshold level was 2.17 dB better for male subjects. At 8,000 Hz, the average level for female subjects was 1.29 dB poorer than the average level for male subjects. It is unlikely that these differences in sensitivity level could produce significant effects on either ABR amplitude or latency. However, if they did, the effects would be in the direction of decreasing amplitude and increasing latency in the group with greater loss, the female group. However, in fact, actual results were reversed. In spite of poorer sensitivity, female subjects showed larger amplitude and shorter latency. Therefore, we conclude that the sex differences in ABR amplitude and latency cannot be accounted for by subtle differences in high-frequency hearing sensitivity in the normal group.

Table 2 summarizes means and standard deviations for wave V latency and amplitude collapsed across age subgroups, along with the probability of α error derived from tests of statistical significance of mean differences in latency and amplitude. For latency, the mean sex difference, collapsed across age, was 0.14 ms. For amplitude, the mean sex difference was 0.088 μV.

In the total sensorineural group (N = 221), there was an inevitable interaction among age, sex, audiometric contour, and the amplitude and latency of ABR. Not unexpectedly,

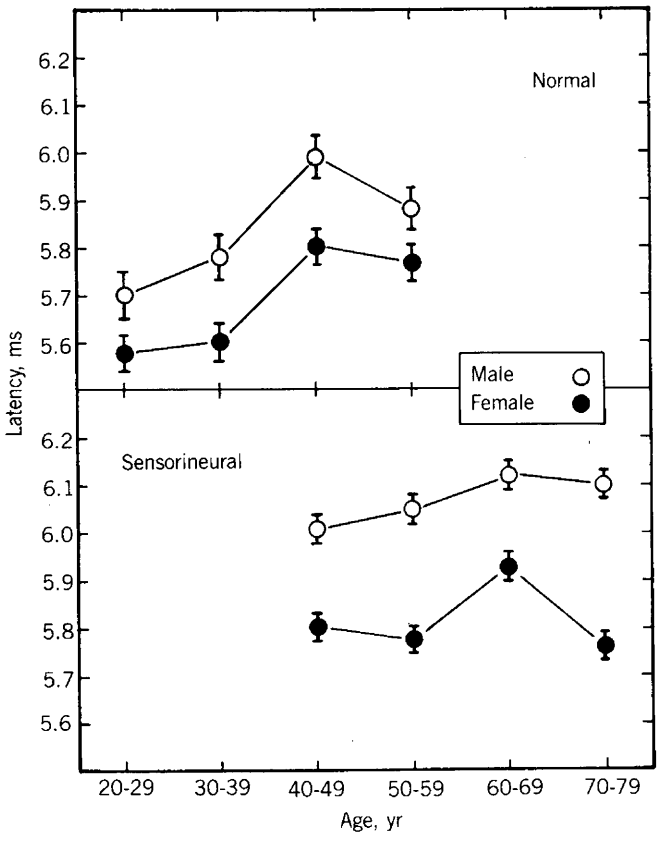

Fig 1.—Mean latency of wave V of auditory brainstem response as function of age for male and female subjects with both normal hearing (N = 98) and sensorineural hearing loss (N = 221). Brackets indicate SEM.

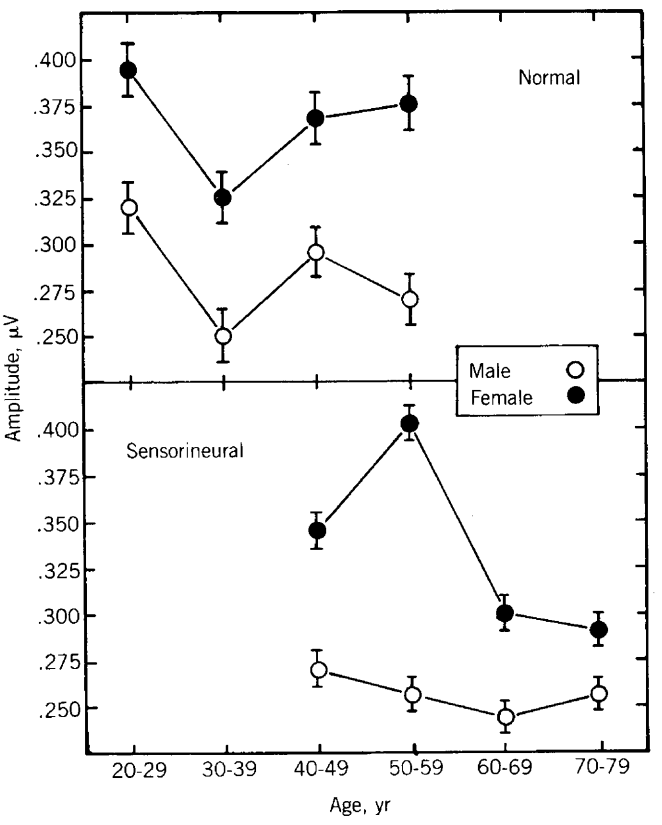

Fig 2.—Mean amplitude of wave V of auditory brainstem response as function of age for male and female subjects with both normal hearing (N = 98) and sensorineural hearing loss (N = 221). Brackets indicate SEM.

male subjects, especially in the older age groups, had more high-frequency sensitivity loss than female subjects. To control for this factor, we formed two matched subgroups of 35 male and 35 female subjects from the total sensorineural pool. The subgroups were selected in such a way that average age and average audiometric contour were matched as closely as possible. Table 3 summarizes average audiometric threshold HLs for these male and female subgroups. At all test frequencies, average threshold levels for the two sexes were within 3 dB, except at 8,000 Hz, where female subjects were actually 12 dB poorer than male subjects. Again, if this difference at 8,000 Hz had an effect on the ABR, it would be in the direction of penalizing female subjects. Thus, shorter latency and larger amplitude in the female subgroup cannot be attributed to audiometric contour.

Table 4 summarizes mean latency and amplitude measures for these two matched sensorineural subgroups. Wave V latency was an average of 0.250 ms shorter in the female group, and wave V amplitude was an average of 0.069 μV larger.

COMMENT

Two conclusions seem warranted. First, there is a slight age effect on the ABR. In subjects with normal hearing, latency increased about 0.20 ms over the age range from 25 to 55 years, and amplitude decreased about 0.050 μV. Beagley and Sheldrake[53] noted a similar but smaller effect in 70 normal subjects. In the sensorineural group, age had relatively little effect on latency, but amplitude showed the same 0.050-μV decrease. The age effect, albeit relatively modest, should be taken into account in ABR audiometry. Slightly delayed wave V latency, and smaller wave V amplitude, must be expected in older patients.

Second, there is a pronounced sex effect in the ABR. In subjects with normal hearing, female subjects showed consistently shorter latency and larger amplitude at all age levels. Beagley and Sheldrake[53] noted a similar effect on latency in their 70 normal subjects. In contrast to the influence of age, the differential effect of sex on the ABR seems to be slightly enhanced by sensorineural loss.

The clinical implications of the age and sex effects in the ABR are important. For example, the proportion of male to female subjects in normative data groups is a prime consideration. Many audiology facilities, especially in university settings, find it convenient to test young, normal-hearing female subjects during the standardization process.

Values derived from such groups must be regarded as highly suspect when used as a normal standard for evaluation of the clinical population. In fact, in evaluating the ABR in older, adult male subjects, the use of such normal values could easily con-

Table 1.—Means and Standard Deviations of Threshold Hearing Levels in Normal Group*

Sex	No.	Measure	Frequency, Hz 250	500	1,000	2,000	4,000	8,000
M	40	Mean	8.54	8.23	5.23	3.45	10.30	11.50
		SD	7.81	6.12	5.55	6.13	7.04	15.88
F	58	Mean	10.71	7.43	5.80	3.91	9.18	12.79
		SD	10.60	9.71	6.18	6.63	7.6	15.05

*N = 98.

Table 2.—Sex Differences in Wave V Latency and Amplitude for 98 Subjects With Normal Hearing

Measure	Index	Sex M	Sex F	Sex Difference	P*
Sample size	No.	40	58	...	...
Age, yr	Mean	39.0	40.0	...	...
Wave V latency, ms	Mean	5.83	5.69	0.14	.020
	SD	0.34	0.30	...	...
	SEM	0.05	0.04	...	...
Wave V amplitude, μV	Mean	0.284	0.372	0.088	< .003
	SD	0.081	0.124	...	...
	SEM	0.013	0.016	...	...

*Probability of incorrectly rejecting null hypothesis (α error).

Table 3.—Means and Standard Deviations of Threshold Hearing Levels in Matched Sensorineural Loss Subgroups

Sex	No.	Measure	Test Frequency, Hz 250	500	1,000	2,000	4,000	8,000
M	35	Mean	17.50	16.70	19.00	23.77	46.87	39.59
		SD	10.69	11.23	14.09	17.68	12.47	20.93
F	35	Mean	19.80	19.00	17.97	28.13	45.67	51.93
		SD	12.82	10.18	9.08	13.84	14.47	18.51

Table 4.—Sex Differences in Wave V Latency and Amplitude for 70 Selected Subjects With Sensorineural Hearing Loss

Measure	Index	Sex M	Sex F	Sex Difference	P*
Sample size	No.	35	35	...	...
Age, yr	Mean	55.0	55.5	...	...
Wave V latency, ms	Mean	5.99	5.74	0.25	< .002
	SD	0.31	0.34	...	...
	SEM	0.05	0.06	...	...
Wave V amplitude, μV	Mean	0.268	0.328	0.069	.026
	SD	0.088	0.136	...	...
	SEM	0.015	0.023	...	...

*Probability of incorrectly rejecting null hypothesis (α error).

tribute to inaccurate clinical interpretation. For example, at a signal intensity of 85 dB HL, the average wave V latency in our young female subjects was less than 5.6 ms. At the same signal intensity, the average wave V latency in our male subjects of 40 to 49 years was greater than 6.0 ms. Since the standard deviation for the wave V latency in the young female group was about 0.20 ms, the latency of the older male subjects would, in comparison, appear abnormally delayed.

We have stressed that both age and sex must be routinely considered in the generation of normal values for the ABR. Since the Jewett and Williston[1] 1971 report, abundant data on the normal ABR have been reported in the literature. We hypothesized that by compiling these normal data, and examining them for age and sex effects, we might augment the present findings. With this objective in mind, we surveyed 37 studies reporting ABR data for 617 normal adults, published from 1971 to 1978. In general, information on subject age and sex was rarely reported. Only 6% of the studies reported ABR data as a function of age. Of the remaining studies, 56% reported only the age range of subjects; 36% provide no age data. Subject sex was noted in 67% of the studies. The ABR data were reported as a function of subject sex in only two studies (6% of the total). Thus, although normal data for the ABR have been reported for at least 617 subjects, the effects of age and sex are accounted for in only 120 or 19%. Clearly, the potential influences of age and sex on the ABR have been grossly unappreciated.

The age effect on the ABR was not unexpected. Anatomic and physiologic changes in the peripheral and central auditory system have long been associated with aging.[56-59] It is not unreasonable to expect that the ABR would reflect such changes. What, then, is the basis of the sex difference in the ABR? We can only speculate with Stockard et al[55] that, due to the relatively smaller dimensions of the female CNS, neural transmission time of the ABR is reduced. The actual basis for the conspicuous sex difference deserves further investigation.

References

1. Jewett DL, Williston JS: Auditory-evoked far fields averaged from the scalp of humans. *Brain* 94:681-696, 1971.
2. Terkildsen K, Osterhammel P, Hius in't Veld F: Electrocochleography with a far-field technique. *Scand Audiol* 2:141-148, 1973.
3. Hecox K, Galambos R: Brainstem auditory evoked responses in human infants and adults. *Arch Otolaryngol* 99:30-33, 1974.
4. Picton TW, Hillyard SA, Krausz HI, et al: Human auditory evoked potentials: I. Evaluation of components. *Electroencephalogr Clin Neurophysiol* 36:179-190, 1974.
5. Yamada O, Yagi T, Yamane H, et al: Clinical evaluation of the auditory evoked brain stem response. *Auris Nasus Larynx* 2:97-105, 1975.
6. Hyde ML, Stephens SDG, Thornton ARD: Stimulus repetition rate and the early brainstem responses. *Br J Audiol* 10:41-50, 1976.
7. Don M, Allen AR, Starr A: Effect of click rate on the latency of auditory brainstem responses in humans. *Ann Otol* 86:186-195, 1977.
8. Goff WR, Allison T, Lyons W, et al: Origins of short latency auditory evoked potentials in man. *Prog Clin Neurophysiol* 2:30-44, 1977.
9. Rowe MJ III: Normal variability of the brainstem auditory evoked response in young and old adult subjects. *Electroencephalogr Clin Neurophysiol* 44:459-470, 1978.
10. Salamy A, McKean CM, Pettett G, et al: Auditory brainstem recovery processes from birth to adulthood. *Psychophysiology* 15:214-220, 1978.
11. Chiappa KH, Gladstone KJ, Young RR: Brainstem auditory evoked responses: Studies of waveform variations in 50 normal human subjects. *Arch Neurol* 36:81-87, 1979.
12. Robinson K, Rudge P: Auditory evoked responses in multiple sclerosis. *Lancet* 1:1164-1166, 1975.
13. Robinson K, Rudge P: Abnormalities of the auditory evoked potentials in patients with multiple sclerosis. *Brain* 100:19-40, 1977.
14. Starr A, Achor LJ: Auditory brainstem responses in neurological disease. *Arch Neurol* 32:761-768, 1975.
15. Stockard JJ, Rossiter VS, Wiederholt WL, et al: Brainstem auditory evoked responses in suspected central pontine myelinolysis. *Arch Neurol* 33:726-728, 1976.
16. Chiappa KH, Norwood AE: A comparison of the clinical utility of pattern-shift visual evoked responses and brainstem auditory evoked responses in multiple sclerosis. *Neurology* 27:397, 1977.
17. Chiappa KH, Norwood AE: Brainstem auditory evoked responses in clinical neurology: Utility and neuropathological correlates. *Electroencephalogr Clin Neurophysiol* 43:518, 1977.
18. Clemis JD, Mitchell C: Electrocochelography and brainstem responses used in the diagnosis of acoustic tumors. *J Otolaryngol* 6:447-459, 1977.
19. Coats AC, Martin JL: Human auditory nerve action potentials and brainstem evoked responses: Effects of audiogram shape and lesion location. *Arch Otolaryngol* 103:605-622, 1977.
20. Daly DM, Roeser RJ, Aung MH, et al: Early evoked potentials in patients with acoustic neuroma. *Electroencephalogr Clin Neurophysiol* 43:151-159, 1977.
21. Gilroy J, Lynn GE, Riston GE, et al: Auditory evoked brainstem potentials in a case of "locked-in" syndrome. *Arch Neurol* 34:492-495, 1977.
22. Rosenhamer HJ: Observations on electric brainstem responses in retrocochlear hearing loss. *Scand Audiol* 6:179-196, 1977.
23. Selters WA, Brackman DE: Acoustic tumor detection with brainstem electric response audiometry. *Arch Otolaryngol* 103:181-187, 1977.
24. Selters WA, Brackmann DE: Brainstem electric response audiometry in acoustic tumor detection, in House WF, Leutje CM (eds): *Acoustic Tumors*. Baltimore, University Park Press, 1979, vol 1, pp 225-235.
25. Stockard JJ, Rossiter VS: Clinical and pathologic correlates of brainstem auditory response abnormalities. *Neurology* 27:316-325, 1977.
26. Stockard JJ, Stockard JE, Sharbrough FW: Detection and localization of occult lesions with brainstem auditory responses. *Mayo Clin Proc* 52:761-769, 1977.
27. Terkildsen K, Hius in't Veld F, Osterhammel P: Auditory brainstem responses in the diagnosis of cerebellopontine angle tumors. *Scand Audiol* 6:43-47, 1977.
28. Jerger J, Mauldin L: Prediction of sensorineural hearing level from the brainstem evoked response. *Arch Otolaryngol* 104:456-461, 1978.
29. Jerger J, Mauldin L, Anthony L: Brainstem evoked response audiometry. *Audiol Hear Ed.* June/July 1978, pp 17-19.
30. Thomsen J, Terkildsen K, Osterhammel P: Auditory brainstem responses in patients with acoustic neuromas. *Scand Audiol* 7:179-183, 1978.
31. Lieberman A, Sohmer H, Szabo G: Cochlear audiometry (electrocochleography) during the neonatal period. *Dev Med Child Neurol* 15:8-13, 1973.
32. Salamy A, McKean CM, Borda FB: Maturational changes in auditory transmission as reflected in human brainstem potentials. *Brain Res* 96:361-366, 1975.
33. Schulman-Galambos C, Galambos R: Brainstem auditory-evoked responses in premature infants. *J Speech Hear Res* 18:456-465, 1975.
34. Salamy A, McKean CM: Postnatal development of human brainstem potentials during the first year of life. *Electroencephalogr Clin Neurophysiol* 40:418-426, 1976.
35. Mokotoff B, Schulman-Galambos C, Galambos R: Brainstem auditory evoked responses in children. *Arch Otolaryngol* 103:38-43, 1977.
36. Bunch CC: Age variations in auditory acuity. *Arch Otolaryngol* 9:625-636, 1929.
37. Goetzinger CP, Proud GO, Dirks D, et al: Study of hearing in advanced age. *Arch Otolaryngol* 73:662-674, 1961.
38. Saxén A: Inner ear in presbycusis. *Acta Otolaryngol* 41:213-227, 1952.
39. König E: Pitch discrimination and age. *Acta Otolaryngol* 48:473-489, 1957.
40. Hayes D, Jerger J: Aging and hearing aid use. *Scand Audiol* 8:33-40, 1979.
41. Gaeth JH: *A Study of Phonemic Regression in Relation to Hearing Loss*, thesis. Northwestern University, Evanston, Ill, 1948.
42. Pestalozza G, Shore I: Clinical evaluation of presbycusis on the basis of different tests of auditory function. *Laryngoscope* 65:1136-1163, 1955.
43. Jerger J: Audiologic findings in aging. *Adv Otorhinolaryngol* 20:115-124, 1973.
44. Jerger J, Jerger S, Mauldin L: Studies in impedance audiometry: I. Normal and sensorineural ears. *Arch Otolaryngol* 96:513-523, 1972.
45. Hall JW: Effects of age and sex on static compliance. *Arch Otolaryngol* 105:153-156, 1979.
46. Jerger J, Hayes D, Anthony L, et al: Factors influencing prediction of hearing level from the acoustic reflex. *Contemp Monogr Audiol* 1:1-20, 1978.
47. Hall JW: Predicting hearing level from the acoustic reflex: A comparison of three methods. *Arch Otolaryngol* 104:601-605, 1978.
48. Gersdorff MC: Modifications du reflexe acoustico-facial chez l'homme en fonction de l'age, par etude impedancemetrique. *Audiology* 17:260-270, 1978.
49. Bunch CC, Raiford TS: Race and sex variations in auditory acuity. *Arch Otolaryngol* 13:423-434, 1931.
50. Corso JF: Aging and auditory thresholds in men and women. *Arch Environ Health* 6:350-356, 1963.
51. Hall JW: Impedance audiometry in a young population: Effects of age, sex, and minor tympanogram abnormality. *J Otolaryngology*, to be published.
52. Thomsen J, Terkildsen K, Osterhammel P: Auditory brainstem responses in persons with acoustic neuromas. *Scand Audiol* 7:179-183, 1979.
53. Beagley HA, Sheldrake JB: Differences on brainstem response latency with age and sex. *Br J Audiol* 12:69-77, 1978.
54. Fujikawa SM, Weber BA: Effects of increased stimulus rate on brainstem electric response (BER) audiometry as a function of age. *J Am Audiol Soc* 3:147-150, 1977.
55. Stockard JJ, Stockard JE, Sharbrough FW: Nonpathologic factors influencing brainstem auditory evoked potentials. *Am J EEG Technol* 18:177-209, 1978.
56. Schuknecht HF: Presbycusis. *Laryngoscope* 65:402-419, 1955.
57. Kirikae I, Sato T, Shitara T: A study of hearing in advanced age. *Laryngoscope* 74:205-220, 1964.
58. Kirikae I: Auditory function in advanced age with reference to histological changes in the central auditory system. *Int Audiol* 8:221-230, 1969.
59. Hanson CC, Reske-Nielsen E: Pathological studies in presbycusis. *Arch Otolaryngol* 82:115-132, 1965.