

# Chapter 1

## History of ABR and EABR



**Kimitaka Kaga**

**Abstract** There are multiple types of auditory evoked potentials (AEPs) and they are classified based on the latency and length of their response time and on the stimuli used to provoke them. The types are: electrocochleography (ECoG), auditory brainstem responses (ABRs), middle latency responses (MLRs), the slow vertex response (SVR), mismatch negativity (MMN), and the P300, an event-related potential. Of these AEP types, the ABR has been widely accepted by audiologists and neurologists as a valuable aid in the diagnosis and monitoring of neural activity of the eighth cranial nerve. The emphasis of this chapter is to both show the historical development of AEPs, since the discovery of electroencephalography (EEG) in 1924, and to explain the methodology and the specific value of each of these AEP types.

Electrically evoked auditory brainstem responses (EABRs), recorded from cochlear implants, were initially reported in 1979. Thereafter, EABRs have been incorporated into a practical procedure for programming cochlear implants in young children and in patients with inner ear malformation or cochlear nerve deficiency.

**Keywords** Electrocochleography · ABR · EABR

### 1.1 Auditory Evoked Potentials (AEPs)

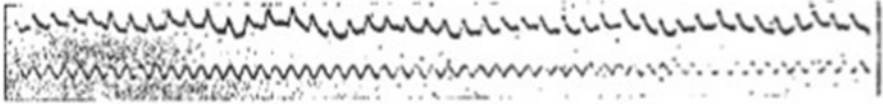
In 1924, a German psychiatrist at Jena University, Hans Berger, described his invention of the electroencephalogram (EEG) recording system and he recorded human EEGs for the first time in history [1] (Fig. 1.1).

In 1930, cochlear microphonic potentials were recorded from the cochlea by Weber and Bray [2]. In Fig. 1.2, the lower trace is the sound stimulus and the upper trace is the resultant cochlear microphonic (CM) which is similar in its pattern to

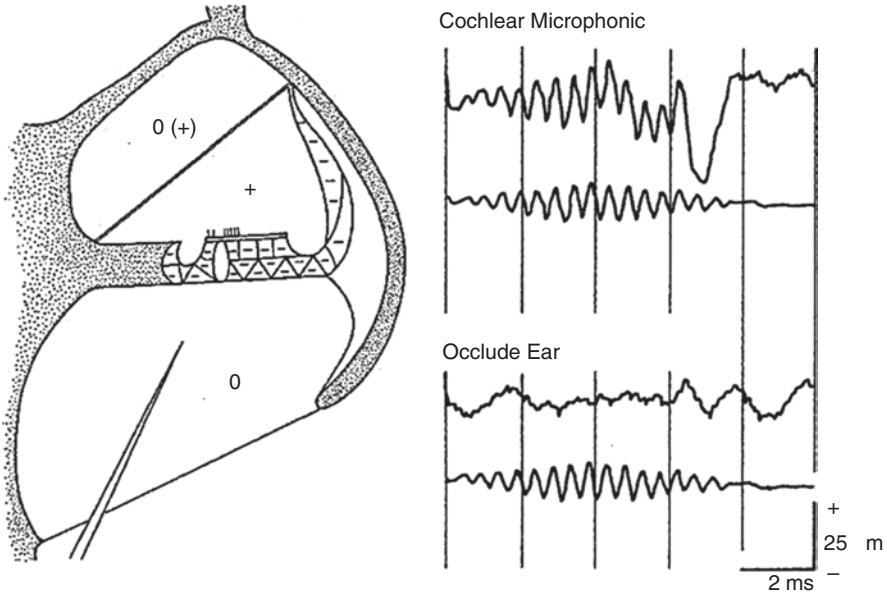
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**Fig. 1.1** The first recordings of the EEG, by Hans Berger in 1924, were taken from epidural electrodes placed directly on the dura of a patient via a local craniotomy [1]



**Fig. 1.2** Cochlear microphonic potentials recorded by Weber and Bray in 1930 [2]

that of the sound stimulus. Stimulation of an occluded ear did not elicit a definable CM.

In 1938, Loomis found a K complex on the EEG which is a cortical response to auditory and touch stimuli or inspiratory interruptions during stage II of sleep [3]. In Fig. 1.3, the EEG tracings change simultaneously with the K complex and two phases following the sound stimuli are evident on the EEG recordings.

In 1939, Davis PA, described V potentials on the EEG provoked by acoustic stimuli [4]. In Fig. 1.4, arrows indicate the acoustic stimuli. The V wave indicates that the brain was also responsive to the stimuli.

The K complex and the V potentials elicited on the EEG were ultimately found to be the same response of these brain waves to acoustic stimulation. In 1947, Dawson reported his finding of a long latency response (LLR) which was illustrated by superimposing each EEG tracing following frequent acoustic stimuli [5]. In Fig. 1.5. The amplitude of the LLR is influenced by the depth of sleep level, Stages II and III, with Stage III eliciting more robust responses. After the discovery of the LLR, Geisler, in 1958 [6], found a middle latency response (MLR) around a latency

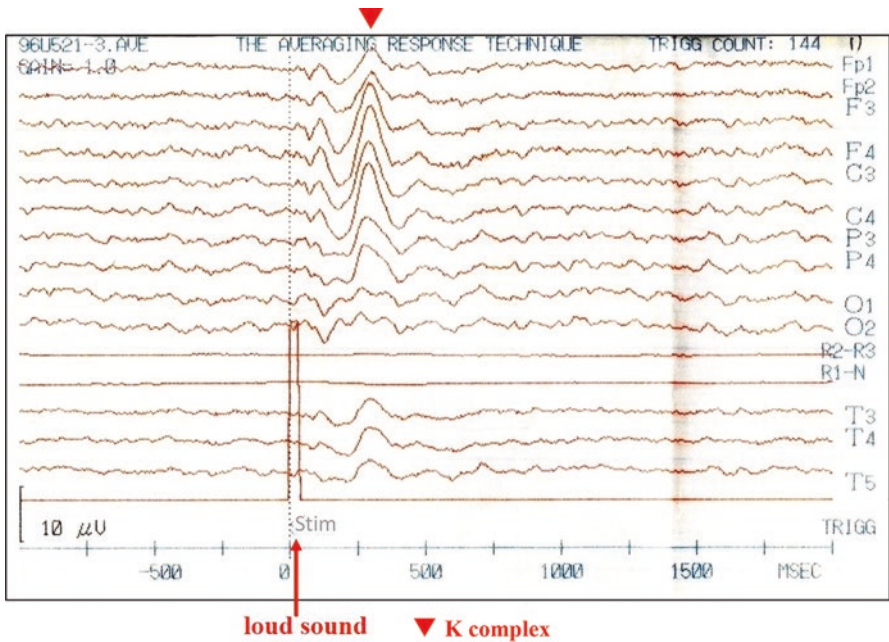


Fig. 1.3 Examples of the K complex in modern EEGs to acoustic stimuli

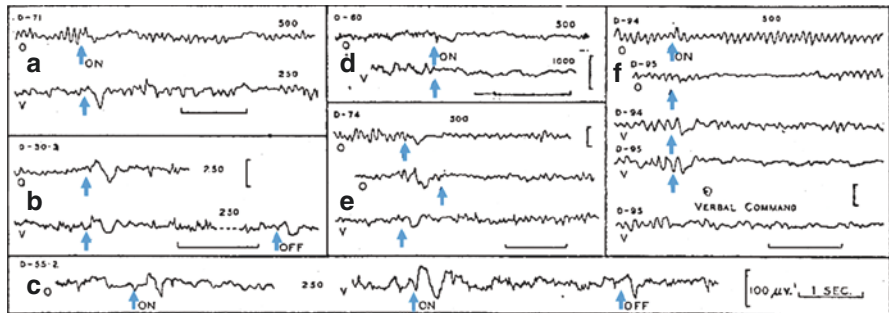
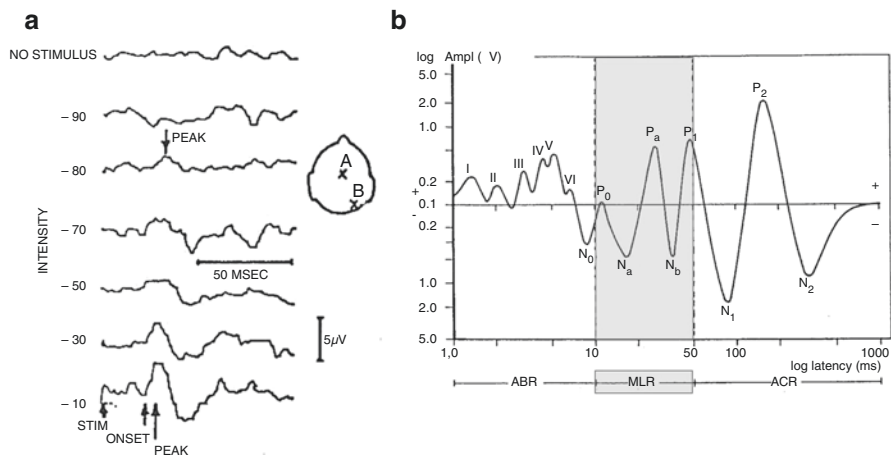
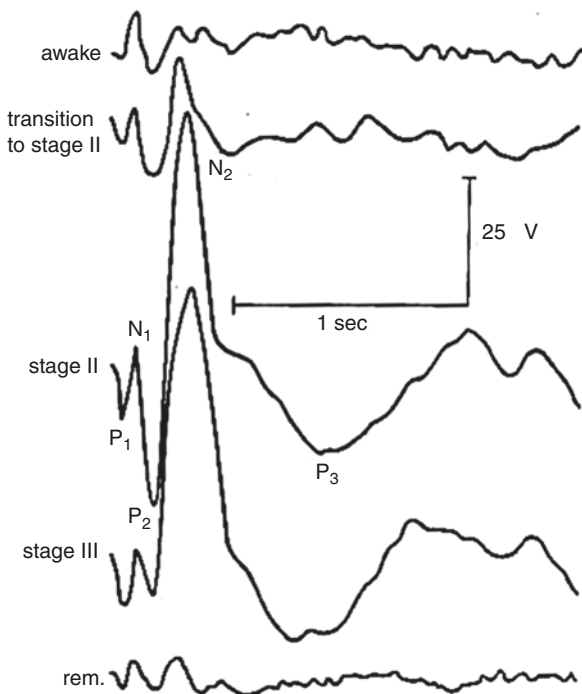


Fig. 1.4 V potentials found on the EEG as reported by Davis, PA [4]. On-effects and modifications of spontaneous rhythms in response to sounds. The frequency employed is indicated in each case. No measurements of loudness were reported. O is the monopolar occipital record; V is the monopolar record from the vertex. The reference electrodes on the ear lobes are connected in parallel. Paired tracings do not represent simultaneous records. Calibrations are for 1 sec. and 100  $\mu$ V. throughout. (a) Resolution of the alpha rhythm and the on-effect in an alpha subject on the alpha rhythm. (b) On- and off-effects in a non-alpha subject. Also, note the resolution of beta waves in the vertex record. (c) The same as in B but in another subject. (d) Resolution of fast (beta) frequencies in another non-alpha subject. (e) Typical on-effects. "Anticipatory" reactions are shown in the second tracing. (f) Resolution of the alpha rhythm and on-effects from a pair of identical twins, D-94 and D-95, and the effect of a verbal command

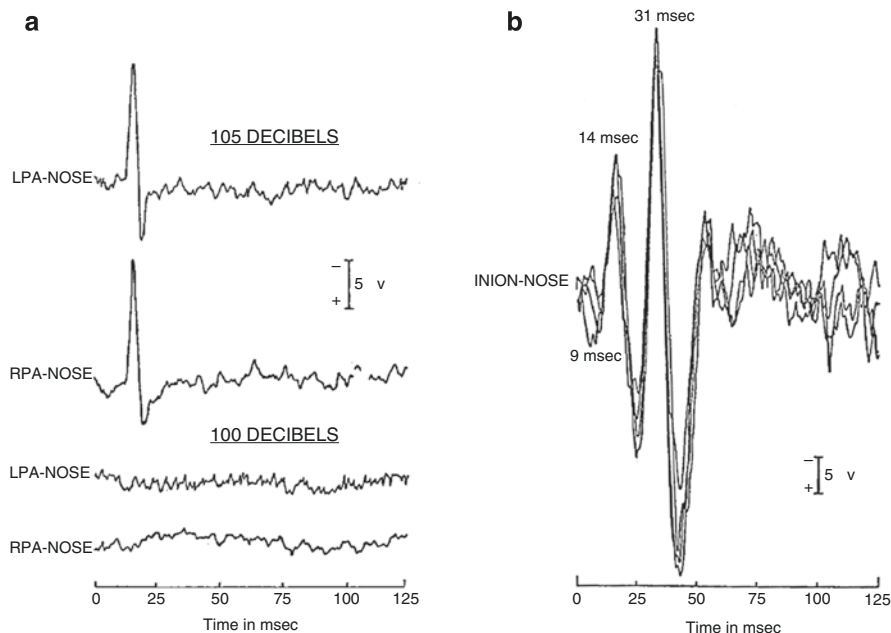
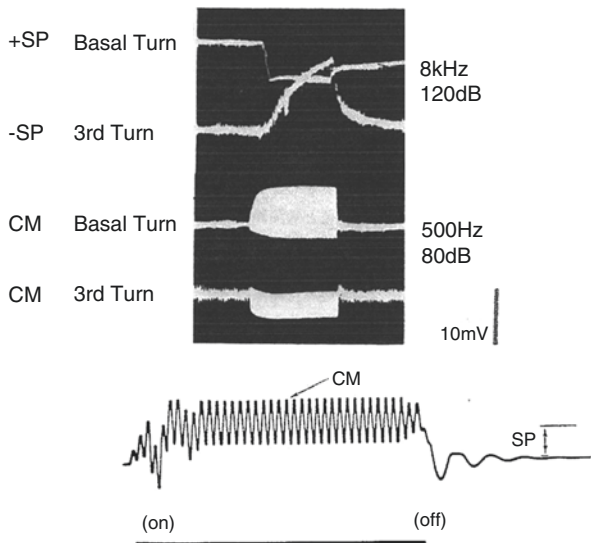
**Fig. 1.5** Changes of LLR as a function in depth of sleep levels [5]



**Fig. 1.6** (a) MLR responses as reported by Geisler in 1958 [6] (b) Under the rubric of AEPs, the shadowed area outlines the MRL

of 10–50 msec following acoustic stimulation (Fig. 1.6). At that time, the auditory brainstem response (ABR) had yet to be discovered. Almost half a century later, the MLR contributed to the finding of an auditory steady-state response (ASSR). In the same year, 1958, Davis H described a summing potential (SP) which was mixed in with and preceded the CM recordings [7] (Fig. 1.7). The polarity of SPs was positive at the basal turn of the cochlea and negative at the third turn of the cochlea.

**Fig. 1.7** Summating potentials (SP) were found in cochlear microphonic (CM) recordings by Davis H in 1958 [7]



**Fig. 1.8** (a) The postauricular response was reported by Kiang, N in 1963 [8]. (b) Inion response. Both responses are identical to the postauricular muscle response

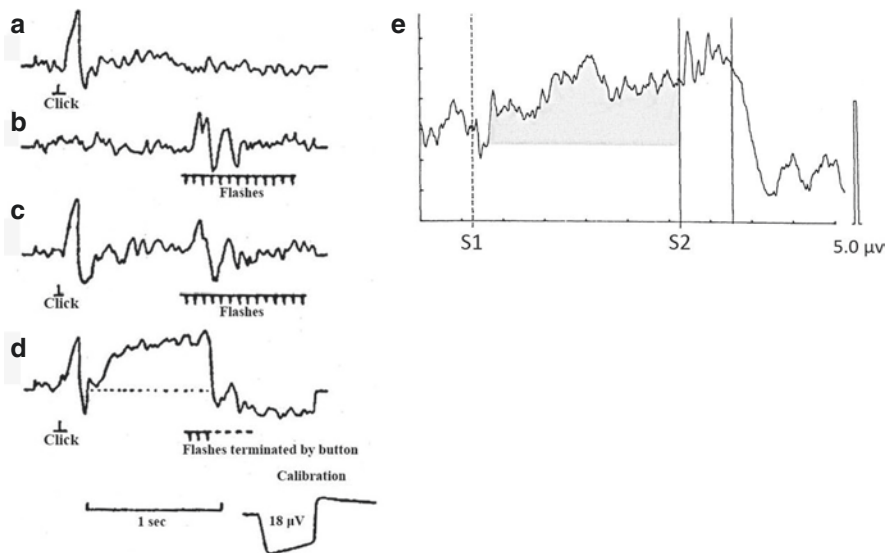
In 1963, Nelson Kiang discovered a postauricular response to sound stimuli [8] evoked by a loud click (Fig. 1.8). Another name given to this response was the inion response. This response was forgotten immediately but has recently been appreciated as a vestibular-evoked myogenic potential (VEMP).

In 1964, Walter described a contingent negative variation (CNV) response which can be regarded as a type of event-related potential [9] (Fig. 1.9). An irregular but predictable pattern of auditory stimuli is presented to the subject who is tasked to predict the next presence or absence of the next auditory stimulus to which he/she is presented following a visual flash. The subject's expectation of the next auditory stimulus generates the cortical CNV. The CNV was an epoch-making potential that is evoked by activity of higher brain functions involved in perception, judgement, or decision-making.

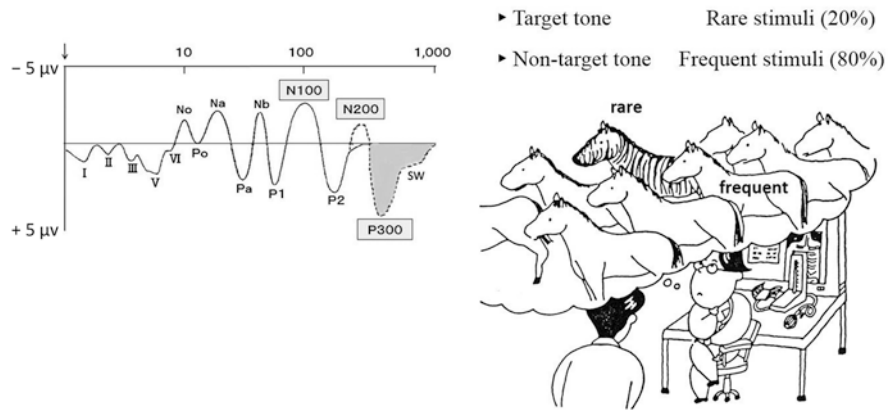
In 1967, Sutton described a P300 evoked wave, an event-related potential, which is a positive wave occurring 300 msec following a discrete auditory stimulus [10]. Two different stimuli (tones) are presented to a subject. One is a target tone presented rarely, 20% frequency, and a nontarget tone presented frequently, 80%. In Fig. 1.10, the black trace shows the response to frequent stimuli and the dotted trace shows a largely positive response around 300 msec to the rare stimuli [11].

Figure 1.11 shows typical P300 responses comparing rare stimuli with frequent stimuli from a normal hearing subject. The upper trace (a) indicates when each button is pushed button by the right-hand finger, the middle trace (b) shows when each button is pushed button by the left-hand finger. The lower trace (c) is the mentally counted number of rare stimuli. There are recorded P300s to rare stimuli in the three tasks but not to frequent stimuli.

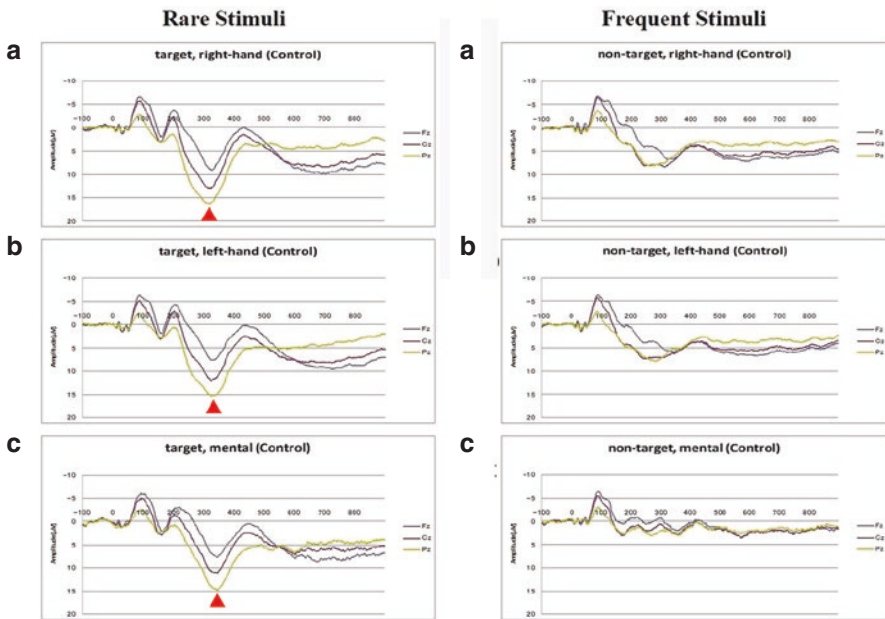
In 1967, an electrocochleographic response (the ECoG) was described simultaneously by Yosie, in Japan [12] and Portman, in France [13]. In Fig. 1.12, the upper trace shows the wave configuration of rarefaction and condensation wave of the



**Fig. 1.9** Contingent Negative Variation (CNV), as a type of event-related potential, was reported by Walter, WG in 1964 [9]. (a) Auditory evoked potential stimulated by click, (b) Visually evoked potential stimulated by flash 1 sec after click, (c) Evoked potential (a+b), (d) CNV evoked by click and flashes terminated by button (a+b), (e) CNV evoked by click (S1) and flash (S2) terminated by button in a 15-year-old patient with auditory agnosia. CNV is evoked after click (S1)



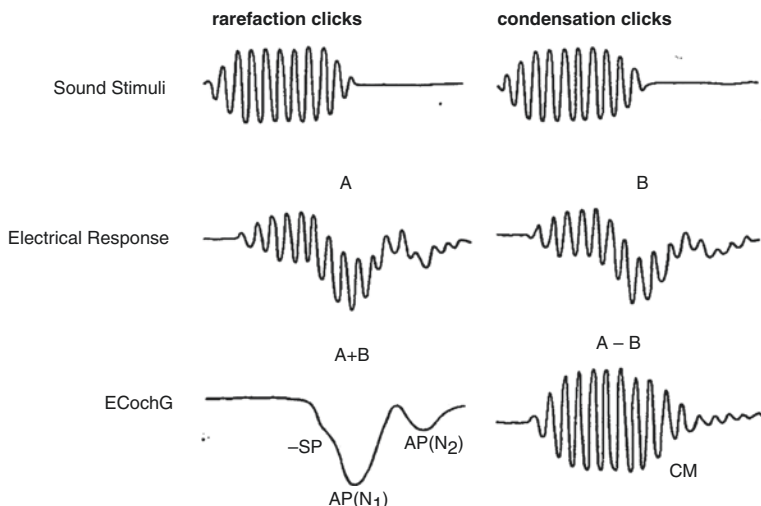
**Fig. 1.10** P300, as an event-related potential, was reported by Sutton S in 1967. Two different tones of rare stimuli and frequent stimuli are presented to the listener [10]



**Fig. 1.11** Grand average of P300s recordings from Fz, Cz, and Pz are superimposed following rare stimuli and frequent stimuli in normal subjects [11]. ▲: P300

auditory stimulus. The middle trace shows the evoked responses to these rarefaction and condensation stimuli. The lower trace shows the ECoG by A + B and CM by A - B. The finding of the ECoG soon led to the discovery of the ABR.

1970 was the most important year in the history of the ABR. Jewett, in the USA, and Sohmer, in Israel, concurrently reported, for the first time, their discovery of the ABR [14, 15]. Figure 1.13 shows our examples of human and cat ABRs. Figure 1.14



**Fig. 1.12** The ECoG as first reported by Yosie, N in Japan and Portman M in France in 1967 [12, 13]

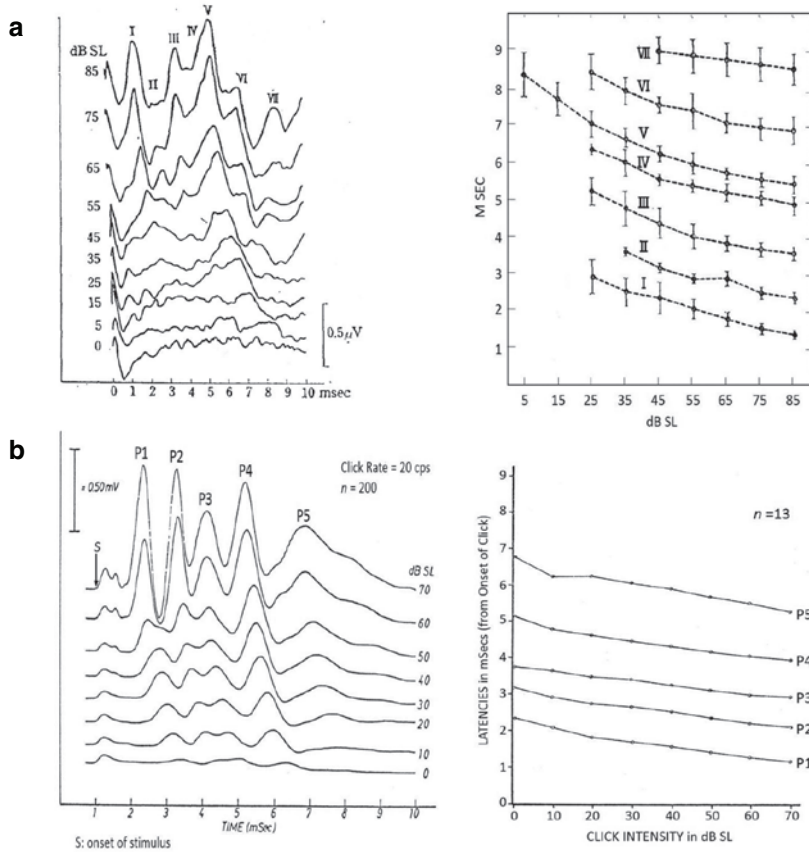
illustrates a human ABR (a) and a cat ABR (b) as published by Sohmer. Both the human and the cat ABR waves are similar in shape. As a result of these publications, Jewett and Sohmer have been regarded as the pioneers of ABR.

The ABR became a new and extremely valuable tool for localizing and diagnosing neuropathology within the eighth cranial nerve and along its' length from the cochlea to the pons. This far-field recorded response is generated acoustically by presenting, via earphones, a number of sharp clicks (around 2000) to the subject. The recorded responses to each of these clicks are summed and computer averaged to eliminate the background EEG signals. The recording window is 10 msec long. The summed and averaged responses over this 10 msec reveal up to seven prominent waves, in a normal hearing subject. The generators of each of these waves have been determined neurophysiologically [14, 16], which delineates the localization of brainstem pathologies. In Fig. 1.15, the left figure shows ABRs recorded from a cat. The distribution and amplitude of each wave are a function of the nuclei through which the neurological response traverses [16]. The right figure further illustrates the neurological substrate underlying each ABR wave.

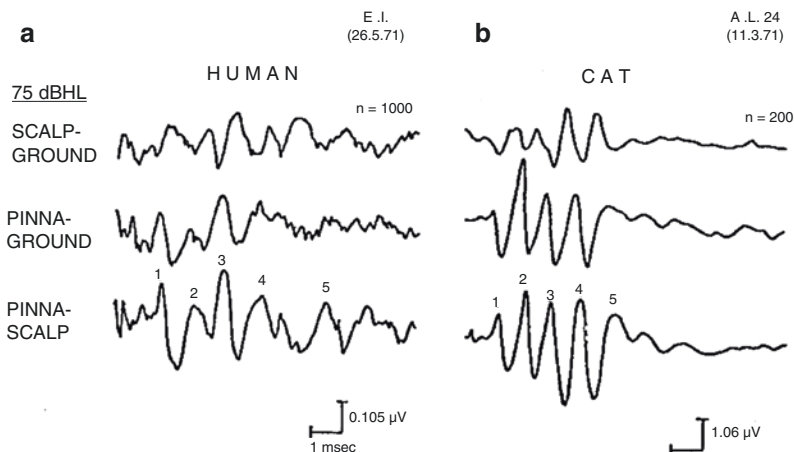
Since the ABR was discovered by Jewett and Sohmer, many subsequent researchers have applied different names to the ABR, as shown in Fig. 1.16. In 1979, at the US-Japan ABR Seminar in Hawaii, Professor Jun-Ichi Suzuki of Teikyo University in Japan proposed choosing the best nomenclature, among 6, to the participants. They voted and chose ABR and it is now used universally to describe this technique.

In 1978, a new potential was discovered by Kemp [18] (Fig. 1.17) and he called it a transient-evoked otoacoustic emission (TOAE). In the following year, Kemp subsequently described another OAE which he called a distortion product otoacoustic emission (DPOAE) [19] (Fig. 1.18). DPOAEs have since been routinely used in clinical practice and they have contributed to establishing the concept of auditory neuropathy (AN) which was reported by Starr [20] and Kaga [21] simultaneously in 1996.

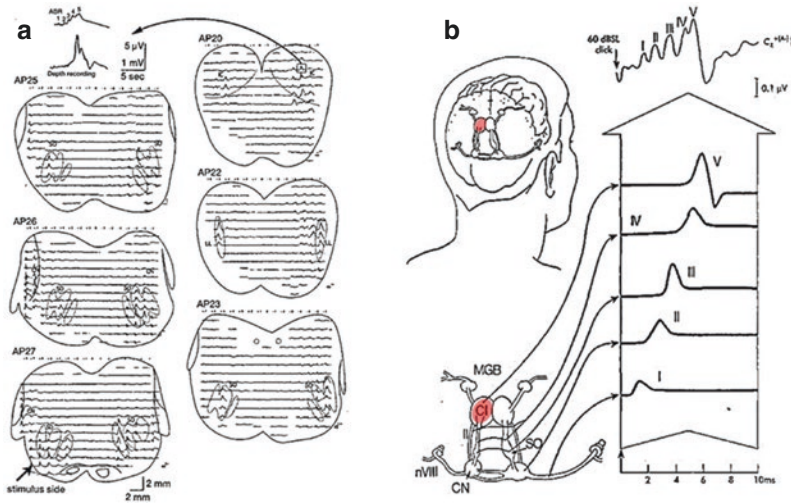




**Fig. 1.13** Recordings of the ABR were initially published by Jewett, DL in 1970 [14]. Examples of human and cat ABRs. (a) Human ABRs as a function of stimulus intensity, (b) Cat ABRs as a function of stimulus intensity



**Fig. 1.14** Simultaneously, Sohmer in 1970 published his ABRs [15]: (a) human, (b) cat



**Fig. 1.15** (a) The distribution of auditory evoked potentials in the brainstem of a cat [16]. (b) is a Schema of the origins of each peak of the human ABR [16, 17]

In 1978, another new potential was discovered by Näätänen in Finland [22] (Fig. 1.19). He called it a mismatch negativity (MMN) potential and it also is a type of event-related potential, which is automatically elicited by any discriminable change in a repetitive sound or sound pattern. Two different auditory stimuli are presented to a subject. However, button-pushing or mental counting is not used as a task. Deviant and standard stimuli are presented and, automatically, the brain discriminates the amplitude difference between the two. The N200 amplitude is more robust to deviant stimuli than it is to standard stimuli. This difference in response amplitude quantifies the MMN as an index of central auditory system plasticity.

In 1981, Galambos described a 40-Hz ASSR (Auditory Steady-State Response) [23]. The ASSR is somewhat similar to the ABR in that both are electrophysiologic responses to rapid acoustic stimuli, presented via earphones or ear inserts, and these responses are recorded from external electrodes arranged in a particular montage on the scalp. The difference between the two techniques lies in the rate of the presented stimuli. The ASSR sound stimuli are repeatedly presented at a high repetition rate whereas the ABR stimuli are presented at a relatively lower rate. Also, the identification of the evoked ASSR responses (waves) uses a mathematical algorithm to identify these waves, increasing the objectivity in the analysis of these responses. The lower recording, illustrated in Fig. 1.20, shows the stimulus sound wave, called the sinusoidal amplitude modulation, and the upper recording shows the 40-Hz sinusoidal evoked potentials.

In 1992, a vestibular-evoked myogenic potential (VEMP) was discovered by Colebatch and Halmagyi in Australia [24]. This wave configuration is remarkably similar to the postauricular muscle response (Fig. 1.21) [24, 25].

In 1995, several reports of clinically obtained multiple-frequency ASSRs were published in the literature by Picton's Canadian and Australian groups

### US-JAPAN ABR Seminar in Hawaii, Jan. 1979

The various names of the ABR prior to the accepted one (ABR).

- BSR : Brain Stem Response
- BSER: Brain Stem Evoked Response
- BAER: Brainstem Auditory Evoked Response
- BERA: Brainstem Electric Response Audiometry
- BAEP: Brainstem Auditory Evoked Potential

► **ABR : Auditory Brainstem Response**



Fig. 1.16 US-Japan ABR Seminar in Hawaii, Jan. 1979

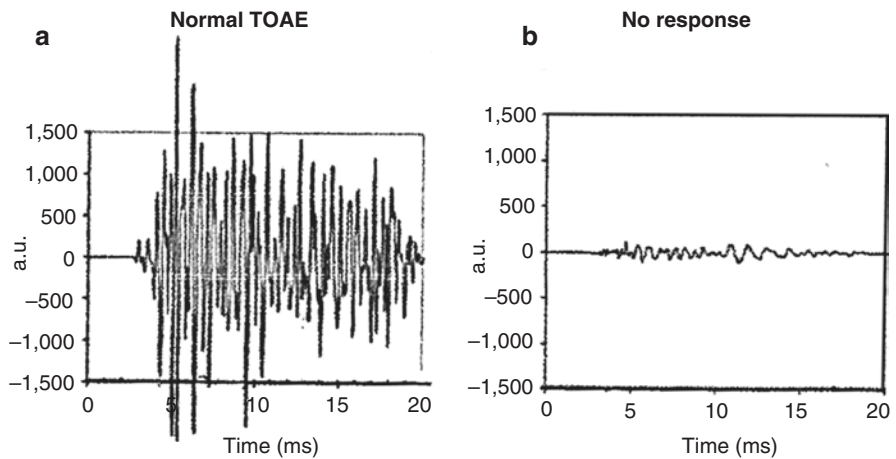
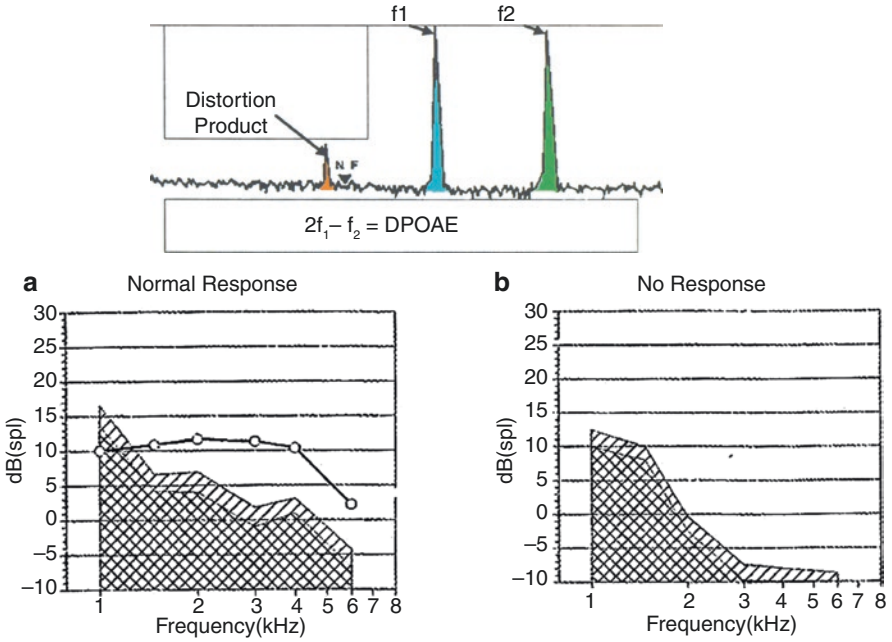
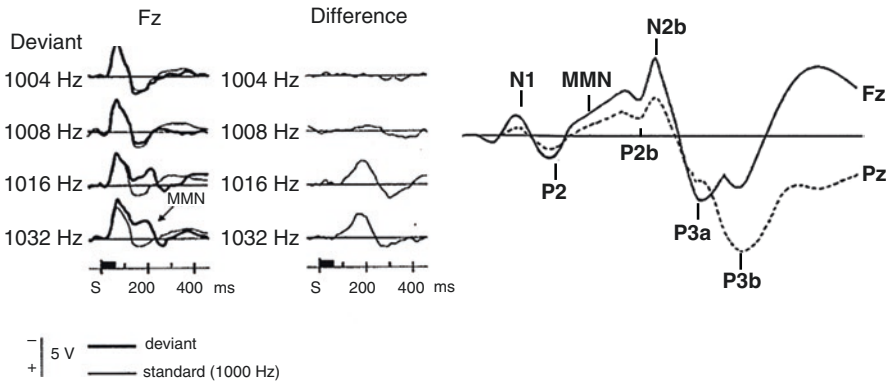


Fig. 1.17 Transient otoacoustic emissions (TOAEs) were discovered by Kemp, DT in 1978 [18] Examples of normal TOAE (a) and no response of TOAE (b)



**Fig. 1.18** Distortion product OAEs (DPOAEs) were also discovered by Kemp, DT in 1979 [19] and they have been used clinically in the evaluation of cochlear function. Examples of normal DPOAE (a) and no response DPOAE (b)

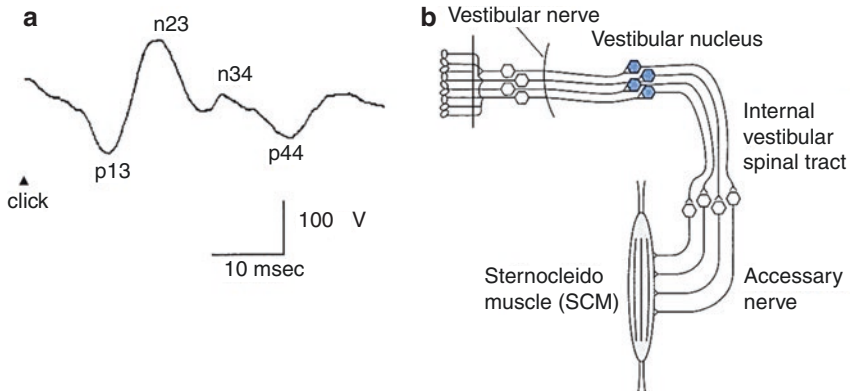
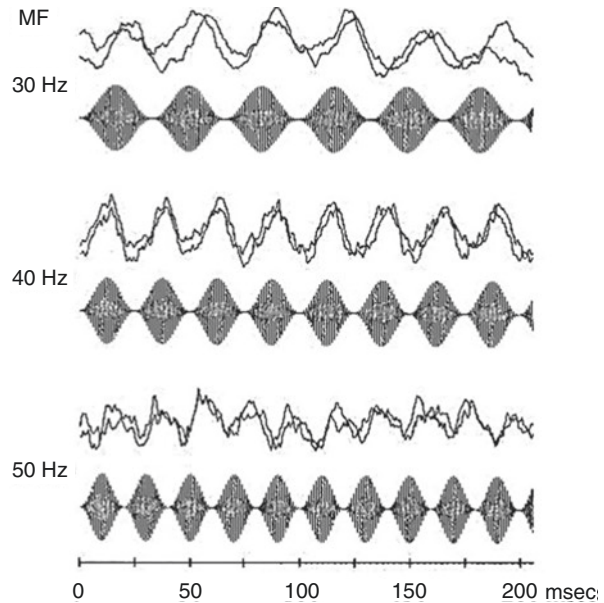
**MMN as a function of frequency change**



Sams, *et al.*,(1985)

**Fig. 1.19** Mismatch negativity (MMN), an event-related potential, was found by Näätänen in 1978 [22]

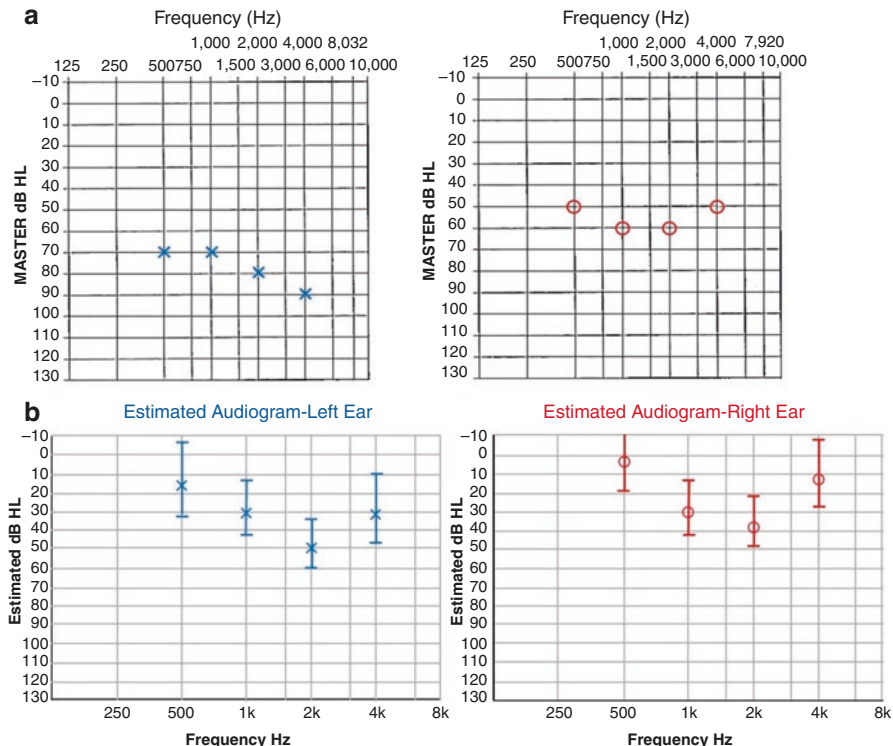
**Fig. 1.20** When using stimuli of 30 Hz, 40 Hz, and 50 Hz, the sinusoidal peak amplitude of 40 Hz is larger than the others (Galambos R, 1981) [23]



**Fig. 1.21** (a) Example of a typical VEMP, (b) A reaction of the vestibular neural myogenic pathway [24, 25]

simultaneously. Pure tone audiograms were generated by multiple-frequency ASSRs [26]. In Fig. 1.22, the upper ASSR displays a simple audiogram such as a pure tone audiogram. However, the lower ASSR shows an estimated audiogram generated by the algorithm.

Table 1.1 is a chronological presentation illustrating the development of auditory evoked potentials over time. Many years have passed since the discovery and recording of the EEG by Hans Berger in 1924.



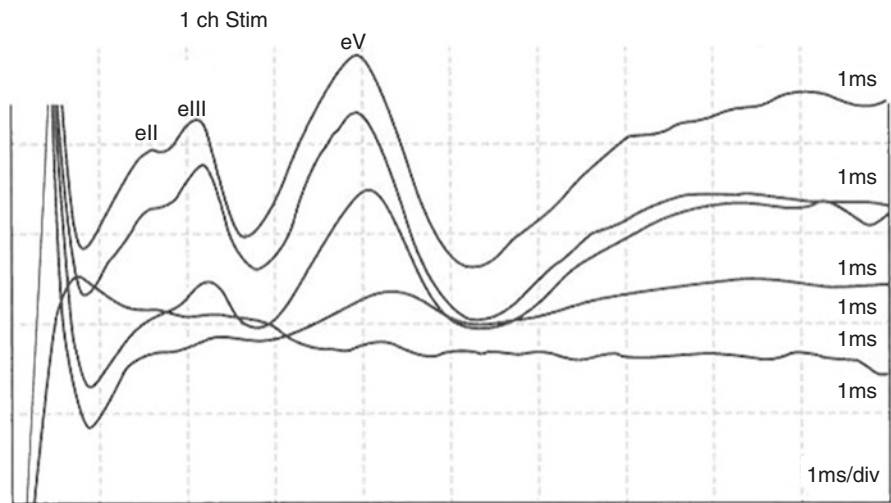
**Fig. 1.22** Examples of audiograms (a, b) generated by multiple-frequency ASSR [26]

**Table 1.1** The year of publication of various evoked potentials

Year	Author	Name	Journal
1929	Berger	Electroencephalograph	Archiv für Psychiatrie und Nervenkrankheiten
1930	Weber & Bray, et al	Cochlear microphonic	Proc Natl Acad Sci, USA
1938	Loomis, et al	K complex	J Neurophysiol
1939	Davis PA	V potential	J Neurophysiol
1947	Dawson	Long latency response	J Neurol Neurosurg Psychiat
1958	Geisler, et al	Middle latency response	Science
1958	Davis H, et al	Summating potential	Am J Physiol
1963	Kiang, et al	Postauricular response	Mass Inst Technology
1964	Walter, et al	Contingent negative variation	Nature
1967	Sutton, et al	P300	Science
1967	Yosie et al. Portman et al.	Electrocochleography Electrocochleography	Laryngoscope Rev. Laryngol (Bordeaux)
1970	Jewett, et al. Sohmer & Feinmesser	Auditory brainstem response Auditory brainstem response	Science Isr J Med Sci
1978	Kemp	Otoacoustic emission	J Acoust Soc Am

**Table 1.1** (continued)

Year	Author	Name	Journal
1979	Kemp	DPOAE	Arch Oto-rhino-laryngol
1978	Näätänen, et al	Mismatch negativity	In a book edited by Kimmel, et al.
1981	Galambos, et al.	40 Hz ASSR	Proc Natl Acad Sci USA
1992	Colebatch & Halmagyi	VEMP	Neurology
1995	Lins, Picton TW, et al	Multiple ASSR	Electroencephalogr Clin Neurophysiol



**Fig. 1.23** Typical EABRs recorded from an apical electrode of a cochlear implant (MED-EL)

## 1.2 Electrically Auditory Brainstem Responses (EABRs)

In 1979, the electrically evoked auditory brainstem response (EABR) was first recorded by Starr and Brackman [27] from scalp electrodes in response to biphasic square-wave electrical stimuli of implanted electrodes of the single channel cochlear implant within the cochleas of three patients. Since then, and for over the last 40 years, many clinical studies describing the applications of EABRs of the multi-channel cochlear implant have been reported to evaluate the integrity of cochlear implants during surgery and for later auditory rehabilitation.

In 1985, Gardi presented intracochlear EABRs from three patients who rested quietly on a hospital bed in a darkroom, showing that they could be reliably recorded [28].

The EABR can be used to functionally evaluate the integrity of the auditory brainstem tracts during the initial activation of the cochlear implant and during its long-term use [29].

The evoked positive peaks, eII, eIII, and eV, of the EABR have a slightly different nomenclature than those of the ABR (Fig. 1.23). However, the familiar positive

peaks of I, VI, and VII of acoustically evoked ABRs are not discerned in the EABR. Wave I of the ABR is masked by the stimulus artifact. Waves VI and VII of the ABR originate from the brachium of the inferior colliculus and medial geniculated bodies. This discrepancy in nomenclature, i.e., why eVI and eVII have not been recorded in the EABR, is an ongoing research endeavor. Waveforms produced during the EABR are evoked as the result of electrical stimuli to the cochlear nerve and thus differ from acoustic stimuli presented to the ear via headphones or insert earphones. The eV wave latency represents the total transmission time through the brainstem from discreet electrical stimuli of the cochlear nerve. This transmission time is essentially identical to the interpeak latency (IPL) interval (brainstem transmission time) as measured in the click-evoked ABR.

EABRs have been helpful as a practical method in the programming of cochlear implants in young children and in evaluating patients with inner ear malformations or cochlear nerve deficiencies [30].

EABRs, using cochlear implant electrodes mediated stimuli, have also been used to evaluate auditory neuronal responses in the brainstem of patients with or without an inner ear malformation [31–33]. EABRs are a reliable and effective way to objectively confirm cochlear implant function and the implant-responsiveness of the peripheral auditory neurons up to the level of the brainstem in patients with inner ear malformations and cochlear nerve deficiencies.

## References

1. Berger H. Über das Elektroencephalogramm des Menschen. *Arch Psychiatr Nervenkr.* 1929;87:527–70.
2. Weber EG, Bray CW. Action currents in the auditory nerve in response to acoustical stimulation. *Proc Natl Acad Sci U S A.* 1930;16:344–50.
3. Loomis AL, Harvey EN, Garret A, Habart III. Distribution of disturbance-patterns in the human electroencephalogram, with special reference to sleep. *J Neurophysiol.* 1938;1(5):413–30.
4. Davis PA. Effects of acoustic stimuli on the waking human brain. *J Neurophysiol.* 1939;2:494–9.
5. Dawson GD. Cerebral responses to electrical stimulation of peripheral nerves in man. *J Neurol Neurosurg Psychiatry.* 1947;10:134.
6. Geisler CD, Frickkopf LS, Rosenblith WA. Extracranial response to acoustic clicks in man. *Science.* 1958;128:1210–1.
7. Davis H, Deatherage BH, Eldredge DH, Smith CA. Summating potentials of the cochlea. *Am J Phys.* 1958;195(2):251–61.
8. Kiang N, Grist AH, French MA, Edward AG. Postauricular electric response to acoustic stimuli in human. *Mass Inst Technology.* 1963;68:218–25.
9. Walter WG, Cooper R, Aldridge VJ, Mccallum WC, Al W. Contingent negative variation: an electric sign to sensorimotor associated and expectancy in the human brain. *Nature.* 1964;203:380–4.
10. Sutton S, Braren M, Zubin E, John ER. Information delivery and the sensory evoked potential. *Science.* 1967;155:1436–9.
11. Kaga K, Fukami T, Masubuchi N, Isikawa B. Effects of button pressing and mental counting on N100, N200, and N300 of auditory-event-related potential recording. *J Int Adv Otol.* 2014;10:14–8.
12. Yosie N, Ohashi T, Suzuki T. Non-surgical recording of auditory action potentials in man. *Laryngoscope.* 1967;77:76–85.



13. Portmann M, Le Bert G, Aran J. Potentiels cochleaires obtenus chez l'homme en dehors de toute intervention chirurgicale. Note: Preliminaire Rev Laryngol (Bord). 1967;88:157–64.
14. Jewett DL, Romano MN, Williston JS. Human auditory evoked potentials: possible brainstem components detected on the scalp. *Science*. 1970;167:1517–8.
15. Sohmer H, Feinmesser M. Cochlear and cortical audiometry conveniently recorded in the same subject. *Isr J Med Sci*. 1970;6:219–23.
16. Kaga K, Shinoda Y, Suzuki J-I. Origin of auditory brainstem responses in cats: whole brainstem mapping, and a lesion and HRP study of the inferior colliculus. *Acta Otolaryngol*. 1997;117(2):197–201.
17. Donkelaar HJ, Kaga K. Chapter 7. The auditory system. In: Hans J Donkelaar ed, *Clinical Neuroanatomy*, 2nd Edition, Springer Nature, Switzerland; 2020. p. 373–407.
18. Kemp DT. Stimulated acoustic emissions from within the human auditory system. *J Acoust Soc Am*. 1978;64:1386–91.
19. Kemp DT. Evidence of mechanical nonlinearity and frequency selective wave amplification in the cochlea. *Arch Otorhinolaryngol*. 1979;224:37–45.
20. Starr A, Picton TW, Sininger Y, Hood LJ, Berlin CI. Auditory neuropathy. *Brain*. 1996;119:741–53.
21. Kaga K, Nakamura M, Shinogami M, Tsuzuku T, Yamada K, Shindo M. Auditory nerve disease of both ears revealed by auditory brainstem responses, electrocochleography and otoacoustic emissions. *Scand Audiol*. 1996;26:233–8.
22. Näätänen R, Gaillard AW, Mäntysalo S. Early selective-attention effect on evoked potential reinterpreted. *Acta Psychol*. 1978;42(4):313–29.
23. Galambos R, Makeig S, Taimachoff PJ. A 40-Hz auditory potential recorded from the human scalp. *Proc Natl Acad Sci U S A*. 1981;78(4):2643–7.
24. Colebatch JG, Halmagyi GM. Vestibular evoked potentials in human neck muscles before and after unilateral vestibular deafferentation. *Neurology*. 1992;42:1635–6.
25. Murofushi T, Kaga K, editors: *Vestibular evoked myogenic potential. Its basics and clinical applications*. Springer, Tokyo; 2009.
26. Lins OG, Picton TW. Auditory steady-state response to multiple simultaneous stimuli. *Electroencephalogr Clin Neurophysiol*. 1995;96(5):420–32.
27. Starr A, Brackman DD. Brain stem potentials evoked by electrical stimulation of the cochlea in human subjects. *Ann Otol Rhinol Laryngol*. 1979;88(4):550–6.
28. Gardi JN. Human brainstem and middle latency responses to electrical stimulation: preliminary observations. In: Schinder RA, Merzenich MM, editors. *Cochlear implants*. New York: Raven; 1985. p. 351–63.
29. Shallop JK, Beiter AL, Goin DW, Mischke RE. Electrically evoked auditory brain stem responses (EABR) and middle latency responses (EMLR) obtained from patients with the nucleus multichannel cochlear implant. *Ear Hear*. 1990;11(1):5–15.
30. Brown CJ, Abbas PJ, Fryauf-Bertschy H, Kelsay D, Gants BJ. Intraoperative and postoperative electrically evoked brain stem responses in nucleus cochlear implant users: implications for the fitting process. *Ear Hear*. 1994;15(2):168–76.
31. Papsin BC. Cochlear implantation in children with anomalous cochleovestibular anatomy. *Laryngoscope*. 2005;115(S106):1–26.
32. Yamazaki NY, Fujiwara K, Moroto S, Yamamoto R, Yamazaki T, Sasaki I. Electrically evoked auditory brainstem response-based evaluation of the spatial distribution of auditory neuronal tissue in common cavity deformities. *Otol Neurotol*. 2014;35(8):1394–402.
33. Kaga K, Minami S, Enomoto C. Electrically evoked ABRs during cochlear implantation and postoperative development of speech and hearing abilities in infants with common cavity deformity as a type of inner ear malformation. *Acta Otolaryngol*. 2020;140(1):14–21.