醫工學會誌 : 第 3 卷, 第 2 號 1982
J. of KOSOMBE: Vol. 3, No. 2

研 究 論 文
82—3—06

Effects of Carrier Wave on the Brain Stem Electric Response (BER) in Scala Tympanic Electrode Array

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=Abstract=

Using electronic cochlear implant system, we studied in cats the difference in the response of the brain stem evoked response(BER) during the stimulation with the acoustic signals and the electric signals.

These brain stem electric responses were analyzed using the integral pulse frequency modulation method of the auditory nervous system.

Animal experimental results and the analysis show that the carrier wave has improved the frequency specificity. of the electronic auditory prosthesis.

1. Introduction

Various electronic prosthetic devices have been utilized for the deaf with sensory neural problems. These cochlear implant devices could produce noise sensation or frequency differentiation to assist lip reading. However, their full application for clinical usuage requires further quantitative evaluations, especially in the area of signal processing of the implanted electrode array[1,5].

The final objective of the implant devices would be to produce neural responses similar to those from natural acoustic stimuli.

In the present study, we evaluated the Brain Stem Electric Response Audiometry (BERA) responses to the scala tympanic electrical stimuli with and without amplitude-modulated carrier waves. Then, we compared the electrically-induced responses to the acoustic BERA responses in five cats experiments.

Since the pathways from the VIIIth nerve to the auditory cortex involved in producing BERA responses are common to both electrical and acoustical stimuli, any differences in BERA responses must be attributed to peripheral factors.

In acoustic stimuli, these peripheral factors include the mechanical oscillation of the basilar membrane (first filter) and its fine stimulation of the hair cell, and finally the VIIIth nerve.

Therefore, the evaluation of various modes of electrical stimuli and their different BERA responses, in comparison with the acoustic BERA responses, will be useful for evaluating the design of optimal electrode array and,

<1982. 12.26. 접수>

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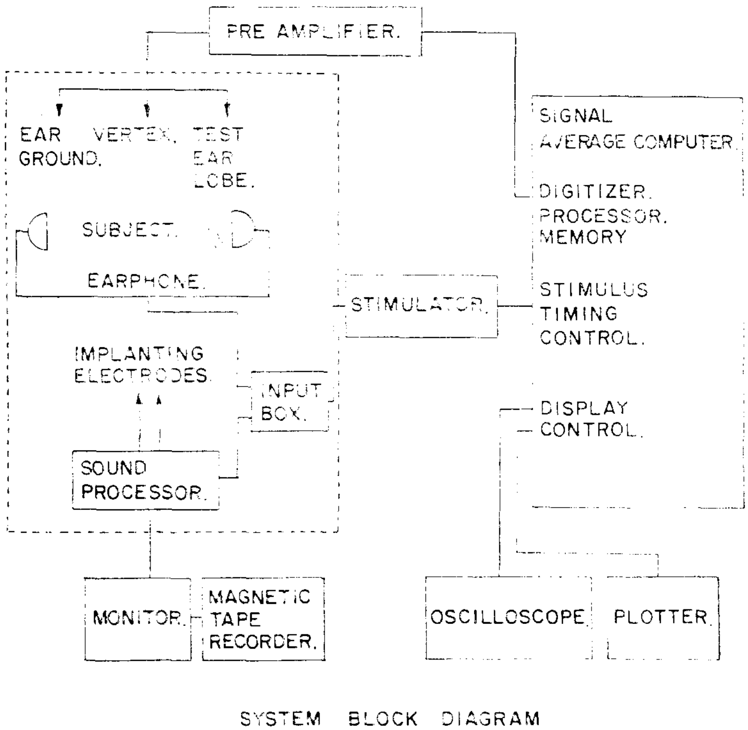


Fig. 1. Experimental system block diagram.

also, for the study of peripheral sensory mechanisms.

2. Methodology

Five anesthetized cats, weighting 600～800 gr, were used for study. All cats were shown to have normal auditory sensory responses by the Preyer's reflex test. After injection of Pentothal Sodium at 50mg/kg dosage, the head and the tongues were fixed to the animal holders. Additional amounts of Pentothal Sodium (3～5mg/kg) were injected, if required, to maintain steady anesthetic conditions.

The block diagram for the experimental system is shown in Fig.1.

The acoustic stimuli and its BERA responses were used as the control measurement in ipsilateral recording. The acoustic stimulating signals were the logon equivalents of high tone bursts at 2kHz, 4kHz, and 6kHz in order to obtain frequency specific responses[2,4]. The acoustic stimulating spectrum are shown in Fig.2, Fig.3 The acoustic pressure was variable from 0 to 110dB SPL, and was set at 90dB level for all measurements.

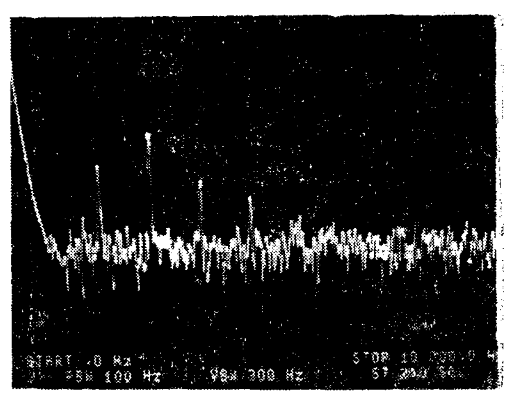


Fig. 2. Acoustic logon signal spectrum (2kHz, 20msec).

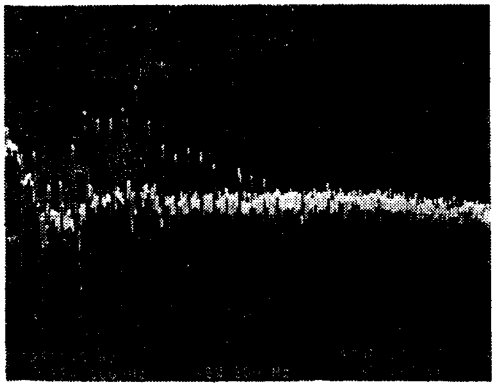


Fig. 3. Acoustic logon signal spectrum (2kHz, 5msec).

The BERA responses were measured using a digital signal averaging compter with averaging of 1024 responses[2,4,7]. In this far field measurement, three needle type electrodes were used, one at the vertex, the second at the testing ear mastoid, and the third one at the opposite mastoid.

The measured signal of 1μV range was amplified using a preamplifier with a gain of 10^4, and the amplifier output was used as the input to the signal averaging computer.

The electrical stimulus signal was provided through the sound processor of Fig. 1. It provided either the cochlear microphonic (CM) type electrical stimuli to the scala tympanic electrode array, or the amplitude modulated CM-type wavefrom with a carrier wave of 50kHz. Both the electrical stimulating signals were synchronized with the acoustic stimulus signal.

The stimulating current level was 200μA, the voltage was variable around 0.6Volts with the modulating ratio of one.

The cochlear implant electrodes were 0.1mm diameter ball-tip type platinum wire, and were coated with silastic materials.

They were located in the scala tympanic area, 0.25cm inside of round window membrane using two micromaupulators and a operating microscope after punching the tympanic membrane.

The monopolar electrode was located at the neck muscle, and, in the case of the bipolar electrode, two electrodes were located inside the scala tympanic area with a tip distance of 0.2mm. Three different modes of electrical stimulating methods were used. Mode 1 consisted of the monopolar electrode with CM-equivalent electrical signals. Mode 2 consisted of the bipolar electrodes with CM-type electric signals, and Mode 3 consisted of bipolar electrodes with amplitude modulated CM-type electric signals with a high frequency carrier wave of 50kHz. During all these electrical stimulations, the non-tested ear's tympanic membrane were broken.

Using two other cats, the following sham experiments were performed to evaluate whether the above BERA responses to the electrical stimuli could be produced due to the surgical artifacts in positioning the electrodes in the round window: (1) BERA measurements with the electrode located inside the round window membrane, with and without acoustic stimuli, (2) the BERA responses after taking out the electrodes, with and without acoustic stimuli.

3. Results

Fig.4 shows a typical BERA response to acoustic stimuli. The electrical stimuli were set at various amplitudes of 2kHz at the rate of 20 pulses/sec.

This figure shows that the smilarity of the BER wavefrom patterns in electrical stimuli compared to the acoustic response is greatest in the case of the amplitude-modulated bipolar electrode stimuli with the high carrier frequency (Mode 3).

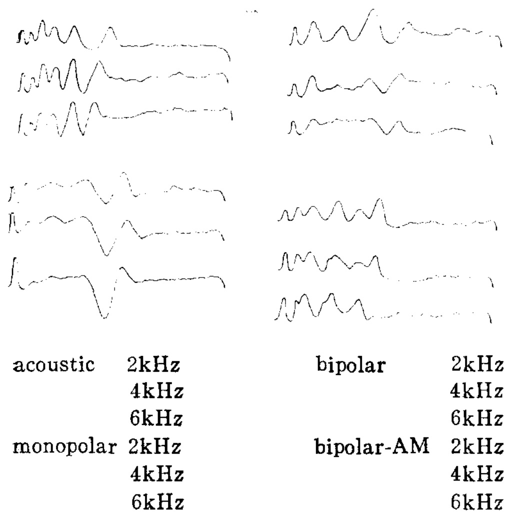


Fig.4. BERA responses of #1 cat.

Frequency specificity of each stimulus mode is demonstrated in Fig.5 (acoustic stimulus), Fig.6 (monopolar stimulation), Fig.7 (bipolar-CM stimulation), Fig.8 (bipolar-AM type stimulation), respectively for BER's Vth peak wave latency.

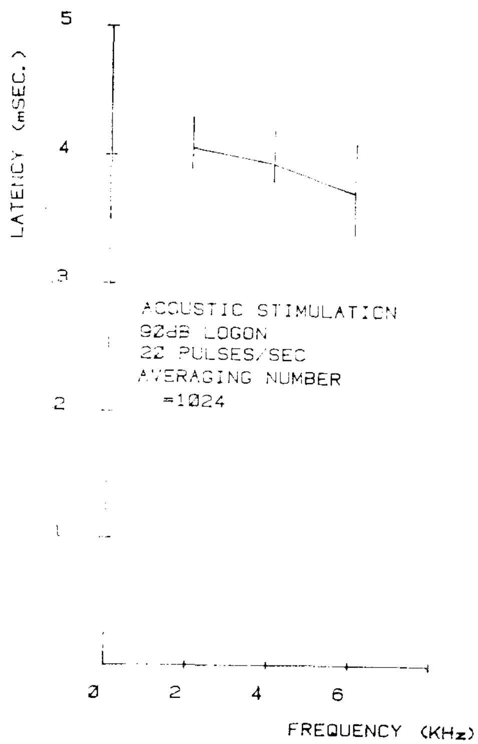


Fig.5. BERA response for acoustic stimuli in 5 cats.

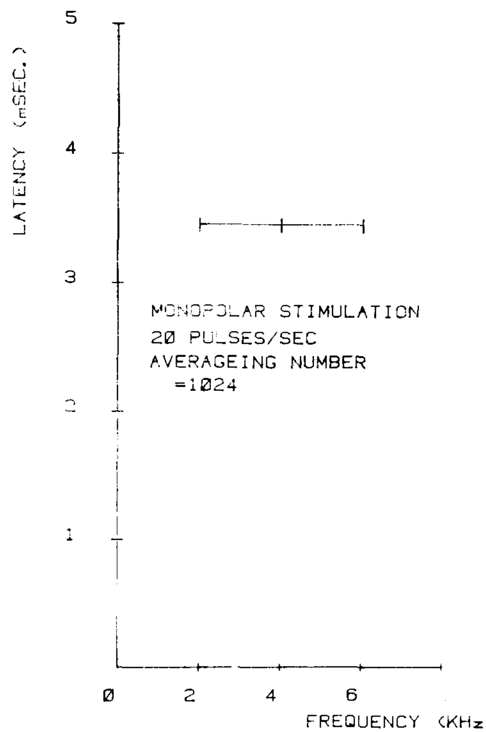


Fig. 6. BERA responses for monopolar electric stimuli in 5 cats.

Also, the ranges of electrical signal amplitude providing the typical BERA response was smaller than the amplitude ranges in the acoustic stimuli (approximately, 25dB in electric stimuli, and 120dB in acoustic stimuli).

The advantage of using the carrier wave is also shown in Fig.9. It demonstrates the difference of the BER's Vth peak wave latency in the case of electrical stimuli as compared with the acoustic stimuli, at the stimulating frequencies of 2kHz, 4kHz, and 6kHz.

The latency difference was smallest in mode 3 with carrier wave. Furthermore, the acoustic response, showing the shorter latency

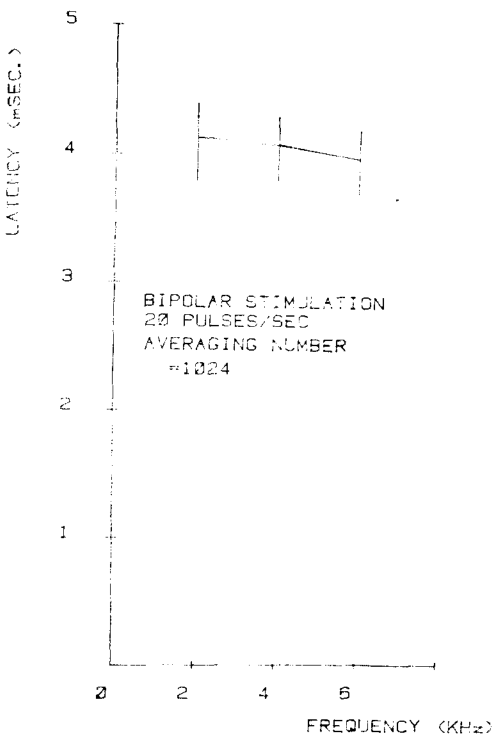


Fig. 7. BERA responses for bipolar electric stimuli in 5 cats.

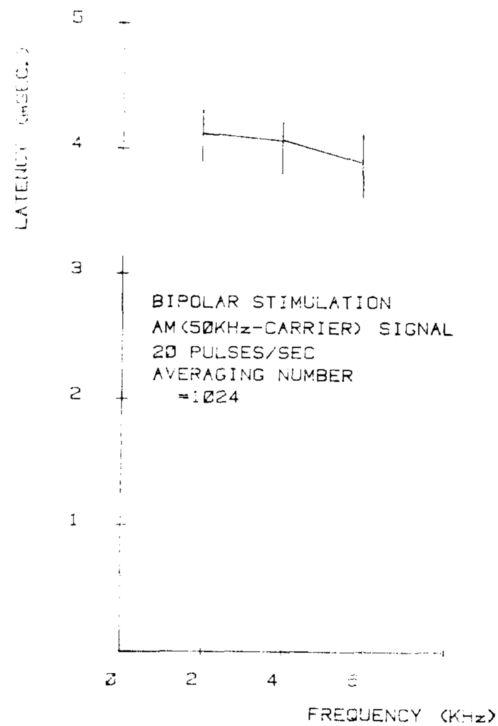


Fig. 8. BERA responses for bipolar AM electric stimuli in 5 cats.

with the higher stimulating frequency was most clearly reproduced in the electrical stimuli with the carrier wave. These results were obtained in all five cats.

In the sham experimets, we could not reproduce any typical BERA response,suggesting that the above experimental results showing the advantages of the carrier wave cannot be produced by the surgical or other artifacts.

4. Discussion

It is shown in five cats experimemts that the Vth wave latency and the frequency specificity in the BERA response to the acoustic stimuli could be most closely reproduced by bipolar electrode stimulation with amplitude-modulated CM-type signals. The conventional stimulating methods of CM-type signals through monopolar or bipolar electrodes could not reproduce the typical acoustic BERA response.

The above observations may be explained using the integral pulse frequency modulation (IPEM) method of signal transmission from the scala tympani electrodes to the Ⅷth nerve[3)], since the continuous stimulating signals are converted to pulse train signals during this transmission stage. The IPFM communication system is shown in the block diagram of Fig.10.

The output pulse trains are related to the magnitudes of the input signal (a), the frequency of modulating signal (f_m), the thresh-

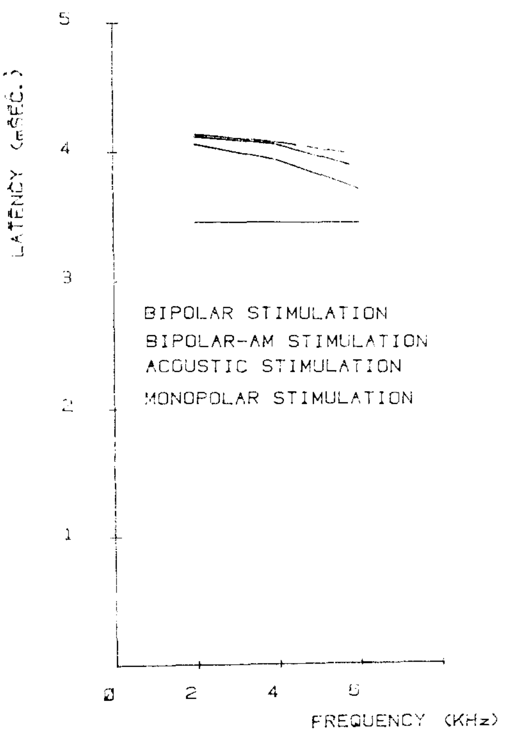
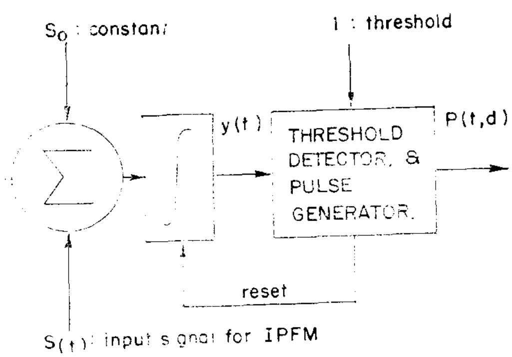


Fig. 9. Comparison of average BERA responses for various stimulation methods.



$S(t)=a\cdot\cos(2f_mt+\phi)$, l : threshold level
f_o : resting state frequency, d : time delay
$p(t,d)$: pulse train, $y(t)$: charging function

Fig. 10. IPEM system block diagram.

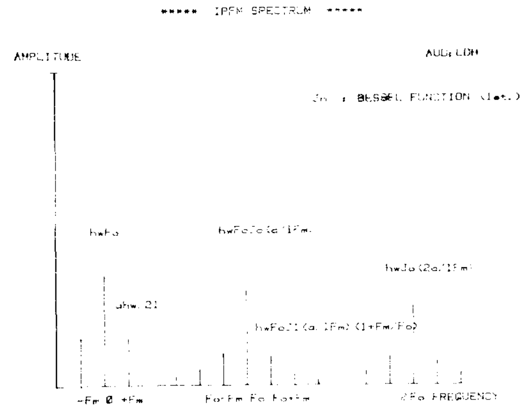


Fig. 11. Spectrum fo IPFM system

old level(l), and the resting state frequency (f_0) as shown in eqs. (1), (2), (3)

$$P(t,d)=hwf_o+hw\frac{a\cdot\sin(\pi wf_m)}{\pi lwf_m}\times\cos(2\pi f_m t-\pi wf_m+\phi)$$

$$+2hwf_o\sum_{k=1}^{\infty}\sum_{n=-\infty}^{\infty}J_n\left(\frac{k\cdot a}{f_m\cdot l}\right)\cdot\frac{\sin\{\pi w(kf_o+nf_m)\}}{\pi wkf_o}$$

$$\times\cos\{2\pi(kf_o+nf_m)t-\pi(kf_o+nf_m)w+2kf_od+n\phi-\frac{k\cdot a}{lf_m}\sin(-2f_md)\}\cdots\cdots\cdots(1)$$

$$\frac{a}{lf_m}\cdots\cdots\cdots\cdots\cdots\cdots(2)\quad\frac{f_m}{f_o}\cdots\cdots\cdots\cdots\cdots(3)$$

Where w is the fixed pulse width of the output signal, h is the fixed pulse height of the output signal.

The frequency spectrum of the pulse train output is shown in Fig. 11.

Using the above spectral characteristics of the IPEM system, the effects of the carrier waves on the pulse train output and its effect on the BERA response can be described by two possible mechanisms.

One mechanism relies on the fact that the spectrum of the pulse train can be adjusted depending upon the relative ratios in the magnitudes and frequencies of the modulating and resting state frequency (eqs. (2), (3))

As shown in Fig. 11, IPFM spectrum can

be adjusted for its distribution of the spectrl components and magnitudes. Based upon this mechanism, the carrier waves can cause the changes in the spectral characteristics of the scala tympanic signals such that the pulse trains in the Ⅷth nerve have similar spectrum as the acoustic stimuli case with intact hair cells and basilar membrane.

This effect will be especially useful in eliminating any artifacts produced in the scala tympani electrode fields caused by the interaction, spreading, and dispersion of the electric fields.

The other possible mechanism is due to the fact that the original CM-type signal can be more accurately reconstructed after the low pass filtering process of the higher auditory nervous system, if the frequency spectrum of the original CM-type signals can be placed far from the resting state frequency component due to the carrier wave effect, as shown in Fig. 11.

Then, the frequency specificity of the BERA response arising in the auditory cortex may respond more closely to the case of normal acoustic stimuli. However, the conditions satisfying the first and second mechanism may be much more complex than described.

These mechanisms may also be related to the parallel processing pathways for simple and modulated complex sounds in auditory system[6].

The present experimental results show that the bipolar method (especially bipolar-AM method) is more desirable than monopolar method for frequency specificity. It also shows that there is a comparatively small dyramic range of electrical stimuli amplitudes (approximately 25dB) which can provide the typical BERA response, as compared with wide dynamic range of acoustic stimuli (approximately 120dB)

In summary, the present analysis of evaluating the BERA responses to electrical stimuli in comparison with acoustic stimuli may provide a quantitative method for designing a frequency sensitive hearing aid with a small numbers of electrodes located in the scala tympanic areas. Another method of utilizing this information is in the analysis of the communicating mechanisms of the peripheral sensory systems from the basilar membrane to the Ⅷth nerve.

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▨ 국문 초록 ▨

Scala Tympani 전극 배열에서 搬送波가 腦幹 誘發性 電位에 미치는 효과

임덕환 · 민병구 · 이충웅 · 노관택

본 연구에서는 전자 청력 재생 시스템을 이용해서, 음향신호와 전기신호 사이의 차이점을 뇌간 유발성 전위(BER)를 통해 비교했다. 이 BER은 청신경 전달 시스템에서의 integral pulse frequency modulation방식에 의해 분석되었으며, 동물 실험의 결과 캐리어 웨이브가 첨가 된 bipolar-AM 방법이 Scala Tympani 전극 배열에서 수파수에 예민한 특성을 보였다.