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Objective auditory threshold estimation using sine-wave
derived responses

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A derived response method of acquiring frequency specific auditory evoked potentials that utilizes a pure tone in combination with a toneburst is applied to the measurement of hearing sensitivity in guinea pigs, chinchillas and pocket gophers. Two experiments which demonstrate that thresholds acquired via tone-derived responses are 10 to 15 dB more sensitive than thresholds to solitary tonebursts are described. The derived potentials approximate behaviorally acquired thresholds at frequencies of 0.5 kHz and above. This technique may provide a more rapid means of assessing hearing sensitivity in laboratory animals than by behavioral means.

Auditory brainstem response; Action potential; Threshold; Tonebursts; Sinusoids; Guinea pig; Chinchilla; Pocket gopher; Animal hearing

Introduction

Acquiring behavioral thresholds to sine waves in
laboratory animals can be a time-consuming proce-
dure. Although electrophysiological recording methods
provide an objective measure and may be less time
consuming, these procedures can be invasive and lack frequency specificity. Continuous sine waves cannot elicit synchronous discharges sufficient to measure ac-tion potentials and tonebursts with fast rise times usu-ally fail to generate responses closer to tonal threshold than 15 to 20 dB. In addition, the energy of fast-rise tonebursts is spread across a considerable region of the cochlea, thus limiting frequency specificity (e.g. Davis et al., 1984; Gorga et al., 1988).
Various methods have been suggested to overcome some of the spectral problems. These methods include high-pass masking of clicks (Don and Eggermont, 1978; Don et al., 1979) and presentation of tonebursts in notched noise (Picton et al.,
nation with a toneburst (Berlin et al.,

1990.

Briefly, derived responses are obtained by subtracting an evoked action potential acquired to a low-intensity toneburst from a combination of a toneburst plus a low-level sine wave centered at the same frequency

TEST CONDITIONS

St~rnulus Response
Toneburst Alone I

Derived Res~onse I
Cornb~nation Condition

Donor Condition

(same as Toneburst Alone)

Derived Response
(Combinaflon Condlllon
minus oonor conerio")

Fig. 1. Test stimuli and responses for the toneburst and derived response evoked potential test conditions described in this study. Stimuli are at 8 kHz and responses shown were obtained from one of the guinea pig subjects. Vertex positive is upward in this and all

(see Fig. 1). Consistent with the nomenclature sug-gested by Berlin et al. (1990, the two conditions con-tributing to the derived responses are noted as the donor (toneburst) and combination (toneburst plus continuous tone) conditions. Subtracting the donor re-sponse from the combination response yields the de-rived response. The utility of this technique in deriving frequency-specific action potentials at the round win-dow has been reported recently (Salt and Vora, 1990). Our purpose here was to investigate the feasibility of applying the non-invasive derived response tech-nique to surface-recorded frequency-specific auditory brainstem responses. Such a technique would provide a baseline measure for longitudinal threshold studies as well as a method for quickly acquiring threshold data in animals who would then participate in other audi-tory studies. In this paper we report two experiments which demonstrate that derived responses provide a more sensitive measure of hearing than tonebursts alone and that they approximate behaviorally acquired thresholds for the frequencies between 0.5 and 32 kHz.

Experiment 1

Surface-recorded auditory brainstem responses were obtained from guinea pigs for solitary tonebursts and for tonebursts interleaved with continuous tone combi-qatiohs. Thresholds obtained by the toneburst and derived response methods were then compared to be-havioral hearing thresholds reported in the literature for guinea pigs (Heffner et al., 1971; Prosen et al.,
1978).

Subjects

Eleven adult pigmented guinea pigs weighing be-
tween 200 and 300 g were subjects for this study. Each
animal was sedated with chloral hydrate (up to 0.0076

cc/g of 5% chloral hydrate) for the duration of the 3 testing and body temperature was maintained near
! 37°C using a rectal probe and an isothermic heating pad.

Methods

Two procedures were compared for their ability to
produce thresholds approximating those obtained be-haviorally. The first involved acquisition of intensity
series for tonebursts alone centered at 13 frequencies from 0.25 to 18 kHz. Tonebursts had cosine-squared envelopes with 1 ms rise and fa11 times and a minimal plateau at 1 kHz and above; one cycle rise and fall times were used for 0.25 and 0.5 kHz. Tonebursts were generated by a SM700 Multi-Signal Generator compo-nent of a Nicolet Pathfinder I1 Evoked Potential Sys-

tem and were presented at levels well above threshold (approximately 70 dB peak sound pressure: SP) to just below threshold in 10 dB steps. The second method involved the derived response, which is the focus of this report. To obtain the derived responses two stimu-lus types were used: (1) a toneburst presented at a constant intensity of either 55 dB peak sound pressure or a level that was at least 20 dB above toneburst threshold (donor condition) and (2) a continuous tone presented at intensities that varied from below thresh-old to approximately 20 dB above derived response threshold (combination condition). Toneburst stimuli were centered at the frequency of the pure tones. The tonal stimuli used in the second stimulus condition

were generated by a separate waveform generator (Hewlett-Packard Model

20 f1hsrlT1_0 1 Tf 20 f1hsrlT16 Tc 10.75 0 0 10.625 471.124.9602 Tm ((2))Tj ET70d (20-0.0d (20 f1hWidrated)Tj -0.093 T129 Td (thRange49 Tc 1.072 (obtain)Oscilla-ated)Tj -0.09316 T17 Tc 3.751 0 T((116 Tc 116 Tc -19.713 -1tely)T116 Tc 1.317 09 Td (the void 0.0233 Tc 2 0 Td (thsithase-locking)1 Tdbetweeneburst)TTc 1.31Tc 17frequency)Tj -0.0698 Tc 4.264 0

(11(2)

Results and Discussion

A toneburst intensity series for 8 kHz at intensities of 0 to 30 dB peak sound pressure is shown in Fig. 2 (left tracings). As expected, the toneburst latency-in-tensity function shows an increase in latency with de-creasing intensity. For comparison, an example of an intensity series for the derived response technique is shown in Fig. 2 on the right. In this series the donor toneburst was presented alone at 55 dB peak sound pressure and in combination with tones from - 10 to 20 dB SP. The donor toneburst response was sub-tracted from the combination response to obtain the derived response. As the intensity of the tone de-creases, the amplitude of the difference trace de-creases. In contrast to the toneburst alone latency-in-tensity series, no shift in latency is observed as the intensity of the continuous tone decreases (refer to Fig. 2).
The lowest intensities eliciting responses were de-termined for each method and plotted as a hearing threshold curve. Criteria for acceptance of a response were replicability, appropriate latency region, decreas-ing amplitude with decreasing intensity, peak-to-peak amplitude of at least 0.05 pV, and response amplitude that exceeded the peak-to-peak amplitude of the pre-stimulus baseline. In addition, the latency of the tone-burst waveforms had to increase in latency at progres-sively lower intensity levels to be acceptable. This la-tency

Electrophysiological thresholds were compared to behavioral data reported in the literature for adult pigmented guinea pigs. Heffner et al. (1971) deter-mined behavioral thresholds for frequencies between 54 Hz and 50 kHz and reported thresholds ranging from of - 10 to 52 dB SPL with best sensitivity at 8 kHz. Prosen et al. (1978) tested the range from 125 Hz to 52 kHz and reported behavioral thresholds ranging from - 11 to 42 dB SPL with best sensitivity in the 8 to 12 kHz region. While differences exist between the behavioral threshold studies, particularly below 8 kHz, the overall configurations of the two audibility curves are similar.
Behavioral and toneburst thresholds are compared in Fig. 4. Toneburst thresholds for most subjects are poorer than behavioral thresholds below 2 kHz and in good agreement from 2 through 4 kHz. However, for 8 through 16 kHz the toneburst thresholds are again less sensitive and miss the area of best sensitivity in the guinea pigs' audibility curve. The derived ,response thresholds are compared to behavioral ,thresholds in Fig. 5. These thresholds are poorer than the behavioral thresholds below 1 kHz in some subjects. The derived response thresholds fell between the behavioral thresh-old curves of Heffner et al. (1971) and Prosen et al. (1978) through 4 kHz and followed the behavioral audibility curve more closely than did the tonebursts for the frequencies up to 16 kHz. To summarize, derived responses were more sensitive than simple responses to tonebursts for all frequencies tested. Both toneburst and derived response thresholds agreed with behavioral thresholds from 0.25 through 4 kHz. De-

.... 1 Heffner et al. I

Frequency in kHz

Fig. 4. Comparison of toneburst thresholds obtained in the present study with behavioral thresholds reported by Heffner et al. (1971) and Prosen et al. (1978) for guinea pigs. Mean and one standard deviation are shown for the tonebursts (N = 11).

.... Heffner et at. ----- - Prosen et at.
Dertved Response

Frequency in kHz
Fig. 5. Comparison of derived response thresholds obtained in the present study with behavioral thresholds reported by Heffner et al. (1971) and Prosen et al. (1978) for guinea pigs. Mean and one standard deviation are shown for the derived responses (N = 11).

rived responses proved more sensitive and followed behavioral thresholds more closely than tonebursts be-tween 6 and 16 kHz.
Procedural differences between the behavioral mea-
sures and the current study existed in three areas that may have contributed to some study

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Derived Response

80 ? i -

Frequency in kHz

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.--0-. Toneburst
Derived Response
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(1) 80

Chinchilla 2

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1 .O1 1 1 10 100
Frequency in kHz

Fig. 7. Comparison of behavioral, toneburst and derived response thresholds obtained from two individual chinchillas.

Pocket gophers
Examples of toneburst and tone-toneburst derived responses are shown in Fig. 8 for a pocket gopher.

Toneburst Derived Response

Fig. 8. Intensity series obtained from a pocket gopher for tonebursts centered at 2 kHz at 20, 30 and 40 dB peak SP (left) and for derived responses at 2 kHz using a 55 dB peak SP toneburst and 10, 20 and 30 dB peak SP tones (right).

. --..p--- Behavioral ..-..*.-- Toneburst
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Frequency in kHz

Fig. 9. Comparison of mean behavioral, toneburst and derived re-sponse thresholds for 9.

for the discrepancy at 16 kHz although some possibili-ties include possible spectral spread associated

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