An Overview of Air- And Bone-Conducted CE-Chirp Stimuli

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Learner Objectives

- After this course, participants will be able to:
  - understand differences between air- (AC) and bone-conducted (BC) CE-Chirps and traditional click stimuli.
  - understand differences between AC CE-Chirp Octave Band stimuli and traditional tone burst stimuli.
  - describe similarities/differences in ABRs to CE-Chirps and CE-Chirp Octave Band stimuli versus traditional click and tone burst stimuli.

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Webinar Overview

- Introduction
- The CE-Chirp® Versus Click Stimulus
- The CE-Chirp® Octave Band Versus Tone Burst Stimulus
- Stimulus Parameter Effects:
  - CE-Chirp®
  - CE-Chirp® Octave Band Stimuli
- Clinical Applications
- Questions

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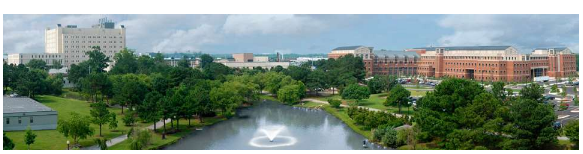

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Some history…

Human Auditory Evoked Potentials: Possible Brain Stem Components Detected on the Scalp

subjects. These waves all have shorter latencies and apparently greater consistency than those of the earliest potentials recorded by Mendel and Goldstein (3), which in turn are reported to be more stable than waves with latencies of 50 msec or greater. Control records (Fig. 2A) taken with the ears plugged showed an absence of electrical artifact beyond the first fraction of a millisecond. There was no reversal of the polarity of the evoked potential with stimulus reversal, indicating that no part of the cochlear microphonic was detected. The first detectable wave had a magnitude of about 100 nanovolts, approached the level of run-to-run variation in the base line (see Fig. 1C; compare with Fig. 1, B

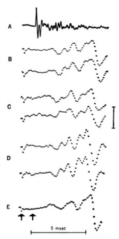

Fig. 1. (A) Sound stimulus showing time of arrival at the ear. Downward deflection indicates compression. (B–D) Two recordings from each of three subjects, vertex-neck, approximately 75-db sensation level. (E) Recording vertex-neck from subject in D, 65-db sensation level. Vertical calibrations: A, 14 μbar; B–E, 0.5 μv. In B–E and in Fig. 2, upward deflection indicates positivity at the first electrode; earphones were energized at the first arrow; sound wave arrived at the ear at the second arrow.

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- In 1970 Jewett, Romano, & Williston first describe auditory brainstem response (ABR) in humans.

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A year later…

- Jewett & Williston (1971) reported a systematic study ABR in humans.
  - "…the early auditory field potentials presented here *may have considerable use for empirically based clinical and experimental work…*" (p. 685).

Brain (1971) **94**, 681–696.

AUDITORY-EVOKED FAR FIELDS AVERAGED FROM THE SCALP OF HUMANS

BY

DON L. JEWETT AND JOHN S. WILLISTON
(From the Departments of Physiology and Neurological Surgery, University of California, San Francisco, California 94122, U.S.A.)

INTRODUCTION

AVERAGING, when used to extract extremely small signals from relatively high levels of background noise, allows detection of evoked potentials at surprisingly large distances from the site of neuronal activity. In animals, volume-conducted potentials from brain-stem auditory structures can be recorded throughout the brain (Grinnell, 1963; Bullock *et al.*, 1968; Jewett, 1970) and even from the scalp (Jewett, 1970). In humans, auditory-evoked potentials can be detected at the vertex due to neural activity from subcortical structures (Jewett, Romano and Williston, 1970) as well as from primary cortical areas (Vaughan and Ritter, 1970). Under the conditions of skull and scalp boundaries and intracranial inhomogeneities, recordings from a single electrode position offer little indication as to the location of a wave's neural generator(s), whereas multiple recording sites may be more informative.

We have found it useful to borrow concept and terminology from engineering to distinguish between two parts of the volume-conducted field: the *near field* and the *far field*. Operationally defined, for biological systems, the near field is characterized by significant differences in wave shape (i.e. in amplitude, polarity, or both) at electrode positions a short distance apart. In contrast, far field electrode positions short distances apart show no significant differences in wave shape, assuming that there is no boundary, no other extreme inhomogeneity, no anisotropism, etc.

Differential recording between closely spaced electrodes is useful for locating a neural generator since such a recording configuration can only detect near fields and is uninfluenced by the far fields of distant generators. Far field recordings (which imply that the generator is at a distance) offer advantages in that the position of the electrode is not critical for obtaining satisfactory recordings and in that potentials from widely spaced generators can be detected at a single electrode. Both of these advantages can be seen in the work presented here, where far field potentials evoked by auditory click stimuli are recorded from the scalps of humans. On the basis of some indirect evidence, it is possible to deduce the location of the

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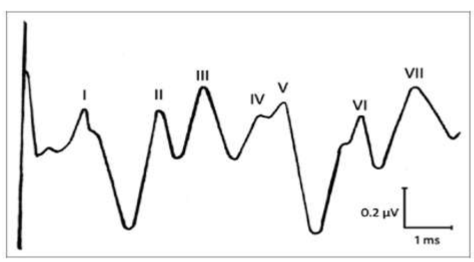
What is the ABR?

- The ABR "reflects bioelectrical potential arising from the auditory nerve and brainstem in response to acoustic short-duration sounds (*transient signals*)."
  - ASHA (2004)

- A normal ABR waveform recorded from adults consists of a series of 5 to 7 peaks that occur within the first 10 ms after the onset of a *transient stimulus*.



Sampath et al. (2016). Brainstem auditory evoked potentials for intraoperative neurophysiological monitoring. J Neuroanaesthesiol Crit Care 2016;3, Suppl S1:1-3

Clinical Applications of ABRs

- Differential Diagnosis/Evaluations
  - Integrity of auditory nerve and brainstem pathway
  - Auditory processing
- Newborn Hearing Screening
- Estimation of Behavioral Thresholds

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Why A Transient Stimulus?

- The ABR is an onset response.
- The rapid onset of the transient stimulus is key in generating the synchronous firing of numerous auditory 8th nerve fibers and brainstem neurons that underlies the response.
- The "click" is the most commonly used transient signal.

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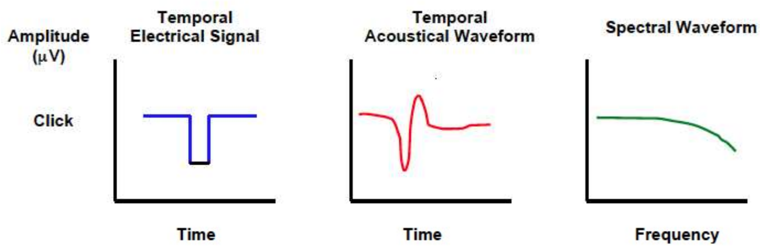
Typical Air-conducted Click

(Hall, 2015)



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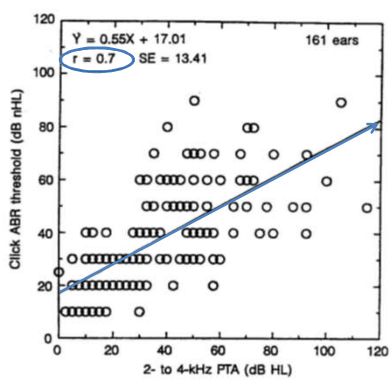
What's Good About The Click?

- Can provide an assessment of 8th nerve and auditory brainstem integrity.
  - i.e., can rule out possible neurological involvement.
- Click ABR thresholds correlate quiet well with hearing sensitivity in the 2000 to 4000 Hz range.



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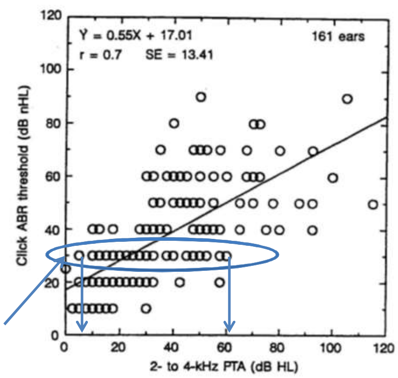
What's Bad About The Click?

- Click ABR thresholds do not provide "a reliable estimate with hearing sensitivity in the 2000 to 4000 Hz range for individual patients."
  - (Stapells & Oates, 1997)



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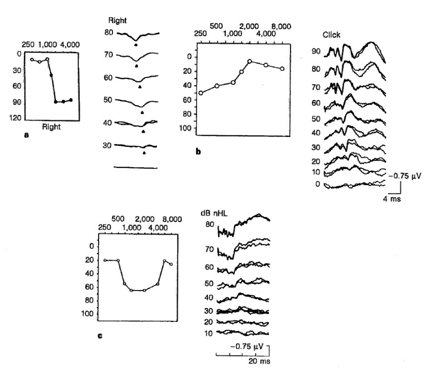

In each case above the ABR threshold was ≤30 dB nHL.

- ABRs to clicks miss hearing loss.
  - (Stapells & Oates, 1997)

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Estimating the Audiogram by the ABR

- "...ABR to tonal stimuli can be successfully recorded in most clinical environments and provide reasonable accuracy estimates of 500 to 4000 Hz pure-tone behavioral thresholds..."
  - (Stapells & Oates, 1997)

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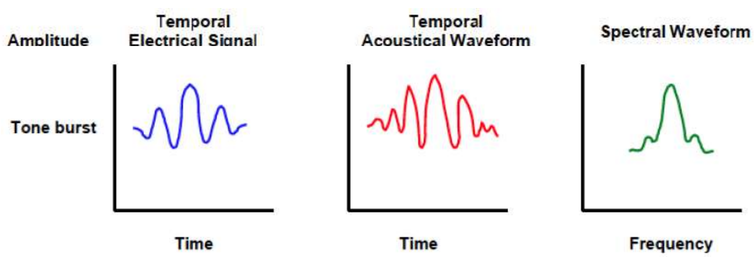
Typical Air-conducted Tone Burst

(Hall, 2015)



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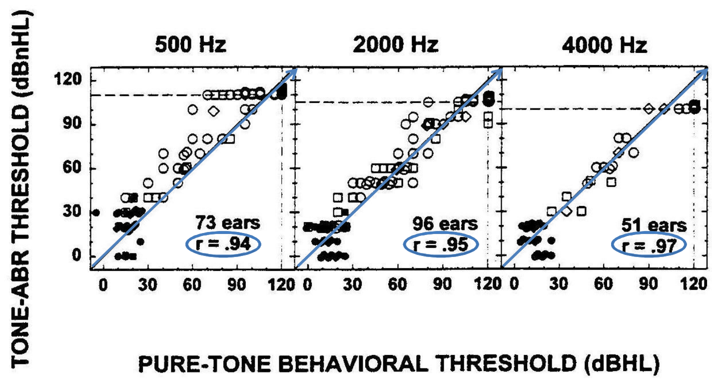
Threshold Estimation Using Tones

(Stapells et al., 1995)



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But can we improve these stimuli?

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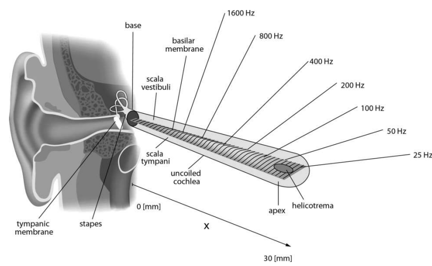
ABRs to Clicks

- The click's broad acoustic spectrum evoked from activity from the whole basilar membrane.



Kern A, Heid C, Steeb W-H, Stoop N, Stoop R (2008) Biophysical Parameters Modification Could Overcome Essential Hearing Gaps. PLoS Comput Biol 4(8): e1000161. doi:10.1371/journal.pcbi.1000161

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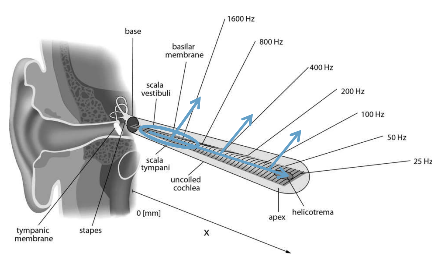
- The different neural units along the cochlear partition are not stimulated at the same time.
- Wave V is dominated by neural activity from high-frequency regions of the cochlea.



Kern A, Heid C, Steeb W-H, Stoop N, Stoop R (2008) Biophysical Parameters Modification Could Overcome Essential Hearing Gaps. PLoS Comput Biol 4(8): e1000161. doi:10.1371/journal.pcbi.1000161

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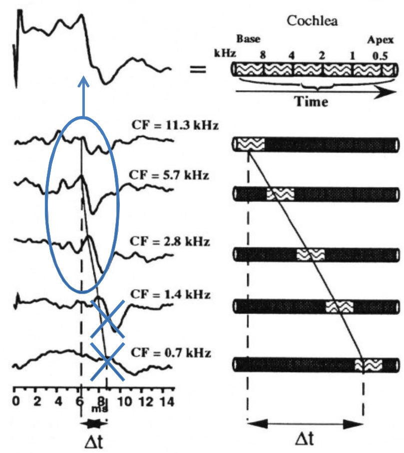
Derived Band ABRs

(Don et al., 1997)

- The frequency components along the basilar membrane are shown from base to apex.
- Each band contributes to the standard ABR.
- But the low frequency components are phase canceled!



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Temporal Alignment: Output

- One way is to align the activity along the cochlear is to temporally align derived band ABRs.
  - i.e., output compensation
- The Stacked ABR is formed by first generating derived-band ABRs, temporally aligning wave V, and then summing stacked responses.
  - (Don et al., 1997, 2005).
- Aligning the derived-band ABRs eliminates phase cancellation of lower frequency activity.

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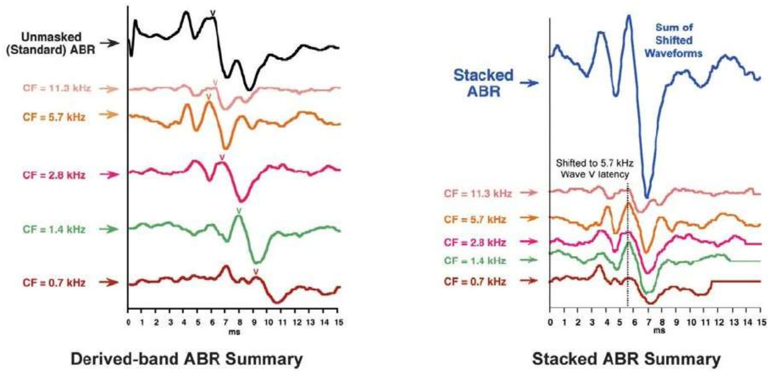
The Stacking Method

(Don et al., 2005)



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Temporal Alignment: Input

- Another way is to align the activity along the cochlear is to time-shifting the different frequency components of the click stimulus.
  - i.e., input compensation
- The order of the frequency components in the stimulus is based on the tonotopic organization of the basilar membrane.

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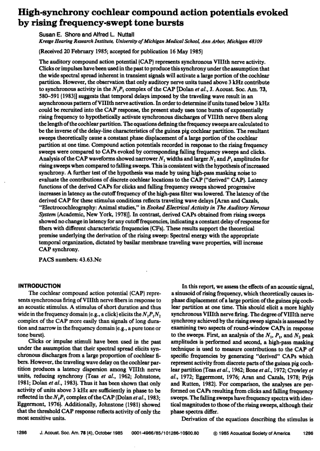
Chirps – A New Stimulus!

- First described by Shore & Nuttal (1985).
- Several chirps have been described.
  - A-Chirp, M-Chirp, O-Chirp
    - Dau et al., 2000; Fobel & Dau, 2004;



High-synchrony cochlear compound action potentials evoked by rising frequency-swept tone bursts

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(Received 20 February 1985; accepted for publication 16 May 1985)

The auditory compound action potential (CAP) represents synchronous VIIIth nerve activity. Clicks or impulses have been used in the past to produce this synchrony under the assumption that the wide spectral spread inherent in transient signals will activate a large portion of the cochlear partition. However, the observation that only auditory nerve units tuned above 3 kHz contribute to synchronous activity in the N_1P_1 complex of the CAP [Dolan *et al.*, J. Acoust. Soc. Am. **73**, 580–591 (1983)] suggests that temporal delays imposed by the traveling wave result in an asynchronous pattern of VIIIth nerve activation. In order to determine if units tuned below 3 kHz could be recruited into the CAP response, the present study uses tone bursts of exponentially rising frequency to hypothetically activate synchronous discharges of VIIIth nerve fibers along the length of the cochlear partition. The equations defining the frequency sweeps are calculated to be the inverse of the delay-line characteristics of the guinea pig cochlear partition. The resultant sweeps theoretically cause a constant phase displacement of a large portion of the cochlear partition at one time. Compound action potentials recorded in response to the rising frequency sweeps were compared to CAPs evoked by corresponding falling frequency sweeps and clicks. Analysis of the CAP waveforms showed narrower N_1 widths and larger N_1 and P_1 amplitudes for rising sweeps when compared to falling sweeps. This is consistent with the hypothesis of increased synchrony. A further test of the hypothesis was made by using high-pass masking noise to evaluate the contributions of discrete cochlear locations to the CAP ("derived" CAP). Latency functions of the derived CAPs for clicks and falling frequency sweeps showed progressive increases in latency as the cutoff frequency of the high-pass filter was lowered. The latency of the derived CAP for these stimulus conditions reflects traveling wave delays [Aran and Cazals, "Electrocochleography: Animal studies," in *Evoked Electrical Activity in The Auditory Nervous System* (Academic, New York, 1978)]. In contrast, derived CAPs obtained from rising sweeps showed no change in latency for any cutoff frequencies, indicating a constant delay of response for fibers with different characteristic frequencies (CFs). These results support the theoretical premise underlying the derivation of the rising sweep: Spectral energy with the appropriate temporal organization, dictated by basilar membrane traveling wave properties, will increase CAP synchrony.

PACS numbers: 43.63.Nc

INTRODUCTION

The cochlear compound action potential (CAP) represents synchronous firing of VIIIth nerve fibers in response to an acoustic stimulus. A stimulus of short duration and thus wide in the frequency domain (e.g., a click) elicits the $N_1P_1N_2$ complex of the CAP more easily than signals of long duration and narrow in the frequency domain (e.g., a pure tone or tone burst).

Clicks or impulse stimuli have been used in the past under the assumption that their spectral spread elicits synchronous discharges from a large proportion of cochlear fibers. However, the traveling wave delay on the cochlear partition produces a latency dispersion among VIIIth nerve units, reducing synchrony (Teas *et al.*, 1962; Johnstone, 1981; Dolan *et al.*, 1983). Thus it has been shown that only activity of units above 3 kHz are sufficiently in phase to be reflected in the N_1P_1 complex of the CAP (Dolan *et al.*, 1983; Eggermont, 1976). Additionally, Johnstone (1981) showed that the threshold CAP response reflects activity of only the most sensitive units.

In this report, we assess the effects of an acoustic signal, a sinusoid of rising frequency, which theoretically causes in-phase displacement of a large portion of the guinea pig cochlear partition at one time. This should elicit a more highly synchronous VIIIth nerve firing. The degree of VIIIth nerve synchrony achieved by the rising sweep signals is assessed by examining two aspects of round-window CAPs in response to the sweeps. First, an analysis of the N_1, P_1, and N_2 peak amplitudes is performed and second, a high-pass masking technique is used to measure contributions to the CAP of specific frequencies by generating "derived" CAPs which represent activity from discrete parts of the guinea pig cochlear partition (Teas *et al.*, 1962; Bone *et al.*, 1972; Crowley *et al.*, 1972; Eggermont, 1976; Aran and Cazals, 1978; Prijs and Rutten, 1982). For comparison, the analyses are performed on CAPs resulting from clicks and falling frequency sweeps. The falling sweeps have frequency spectra with identical magnitudes to those of the rising sweeps, although their phase spectra differ.

Derivation of the equations describing the stimulus is

1286 J. Acoust. Soc. Am. 78 (4), October 1985 0001-4966/85/101286-10$00.80 © 1985 Acoustical Society of America 1286

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The Claus Elberling -Chirp®

(Elberling et al, 2007, 2010; Elberling & Don, 2008, 2010)

- Designed using a delay model based on derived-band ABR latencies.
- The electrical CE-Chirp® has a flat amplitude spectrum within five octave-bands ranging from 350 to 11,300 Hz.
- Four octave-band filtered versions of the CE-Chirp® are also implemented with the center frequencies 500, 1000, 2000, and 4000 Hz.
  - The octave-band chirps are obtained by decomposing the broad-band CE-Chirp®.

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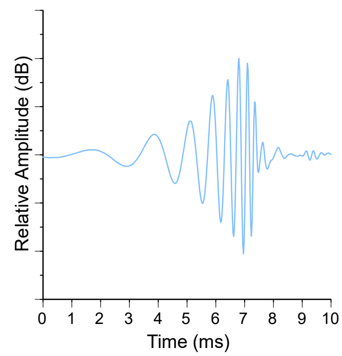
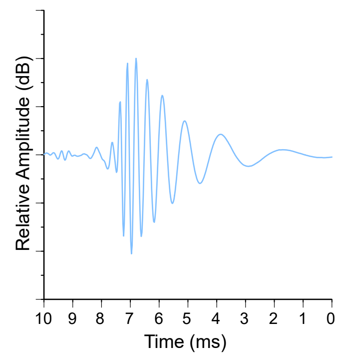
The CE-Chirp®





A rising frequency or "low-frequency leading" stimulus that compensates for the cochlear traveling wave delay!

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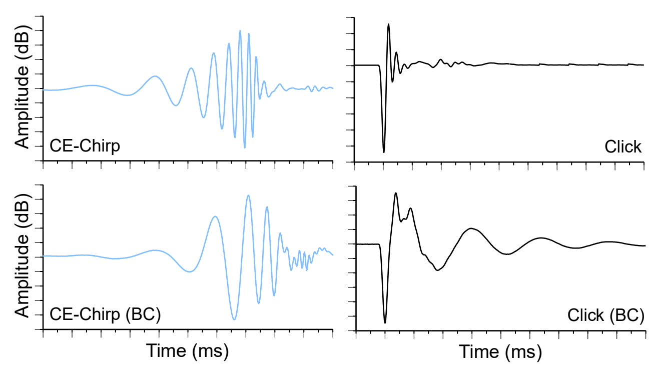
CE-Chirp® & Click Time/Amplitude Waves



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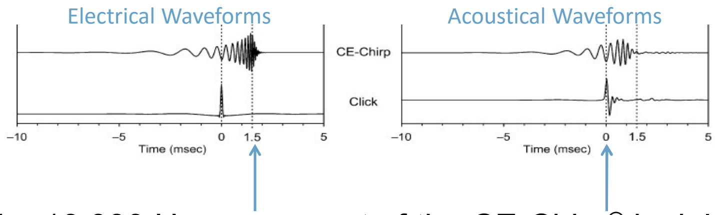
Some Temporal Issues

(Kristensen & Elberling, 2012)



- The 10,000 Hz component of the CE-Chirp® is delayed by 1.5 ms to align ABR latencies to the chirps with the latencies to the click in normal-hearing subjects.
- The 0 ms point on the time axis for the acoustical waveforms indicates the start of the data collection and also the temporal reference for all latency measures.

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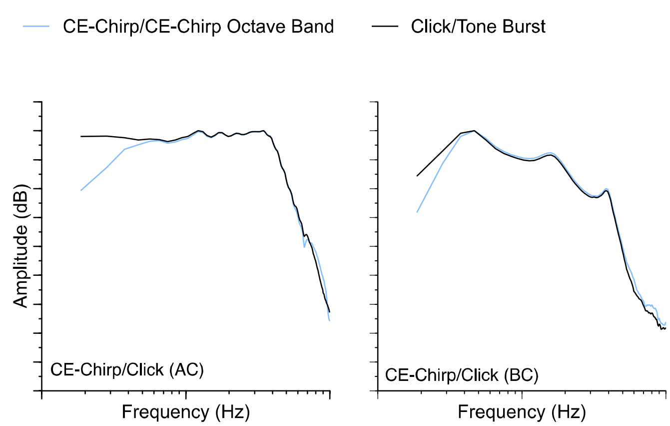
CE-Chirp® & Click Stimuli Spectra



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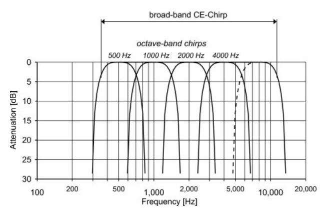
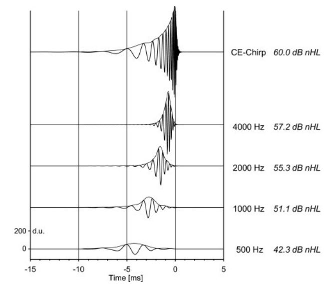
Decomposing The CE-Chirp®

(Elberling et al., 2010)

Amplitude Frequency



Waveform and Envelope



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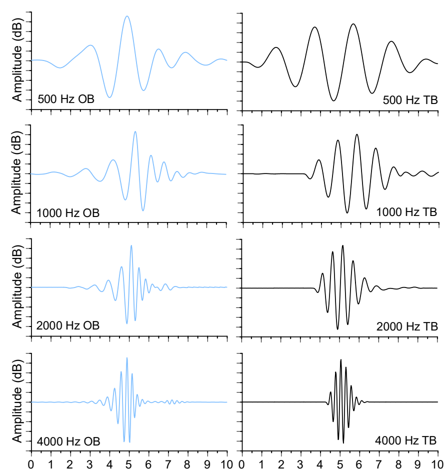
CE-Chirp® Octave Band and Tone Burst & Click Time/Amplitude Waves



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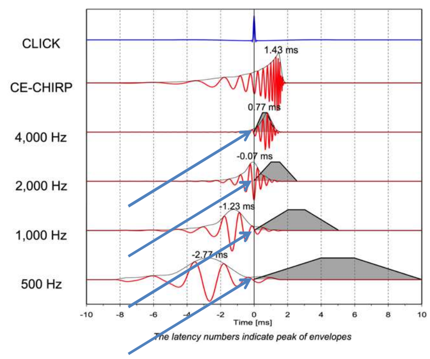
CE-Chirp® Octave Band: Temporal Characteristics (GSI, 2013)



- The timing of each CE-Chirp® Octave Band stimulus is derived from the timing of the same component in the CE-Chirp®.
- *Notice that the tone burst presentation starts at 0 ms, while the CE-Chirp® Octave Band stimulus presentation precedes 0 ms.*

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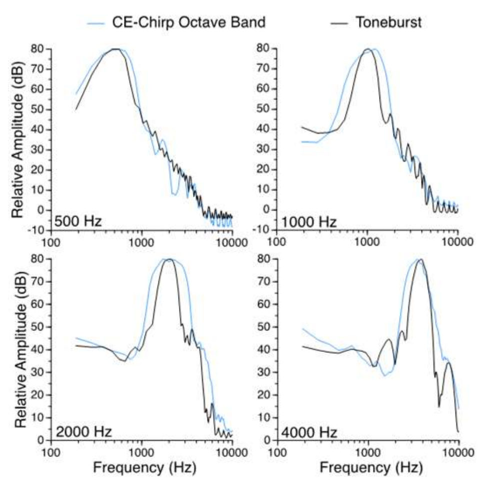
CE-Chirp® Octave Band & Tone Burst Spectra



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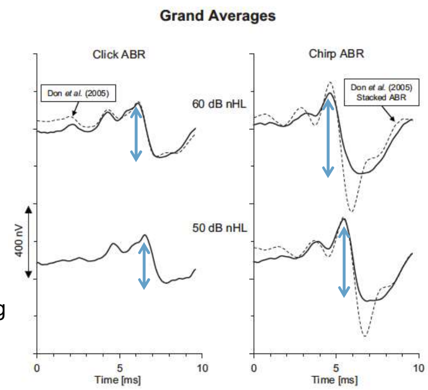
Why Use the CE-Chirp®?

- Using a CE-Chirp® has been shown to <u>*increase the amplitude of the ABR in adults*</u> compared to the amplitude in response to a click.
  - Elberling et al, 2007; Elberling and Don, 2008; Don et al, 2009; Elberling et al, 2010; Cebulla and Elberling, 2010; Elberling and Don, 2010; Kristensen & Elberling, 2012; Elberling et al., 2012



(Elberling & Don, 2008)

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ECU & The CE-Chirp®

- We were interested in using the CE-Chirp® with neonates:
  - Compare neonate ABRs to air- (AC) and bone-conducted (BC) CE-Chirp® and click stimuli.
  - Compare neonate ABRs to AC CE-Chirp® octave band and tone burst stimuli.
  - Compare neonate and adult ABRs to AC CE-Chirp® and CE-Chirp® octave band stimuli.

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Effect of Stimulus and Number of Sweeps on the Neonate Auditory Brainstem Response

Andrew Stuart and Kensi M. Cobb

Test-retest reliability of auditory brainstem responses to chirp stimuli in newborns

JSLHR

Research Note

Auditory Brainstem Response Thresholds to Air- and Bone-Conducted CE-Chirps in Neonates and Adults

Kensi M. Cobb[a] and Andrew Stuart[a]

Neonate Auditory Brainstem Responses to CE-Chirp and CE-Chirp Octave Band Stimuli I Versus Click and Tone Burst Stimuli

Kensi M. Cobb and Andrew Stuart

Neonate Auditory Brainstem Responses to CE-Chirp and CE-Chirp Octave Band Stimuli II: Versus Adult Auditory Brainstem Responses

Kensi M. Cobb and Andrew Stuart

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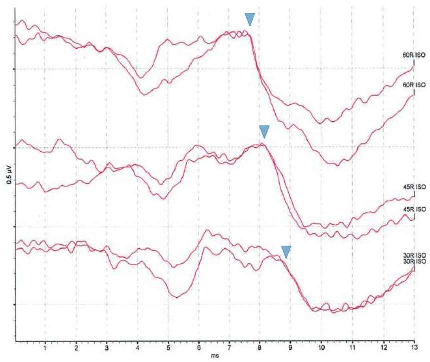
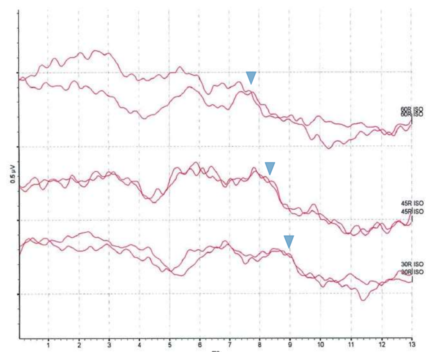
AC Intensity: CE-Chirp® vs. Click

CE-Chirp®: 60, 45, & 30 dB nHL @ 57.7/s



Click: 60, 45, & 30 dB nHL @ 57.7/s



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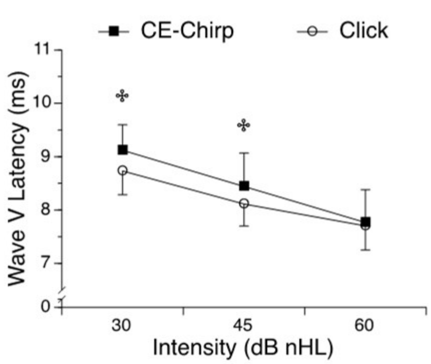
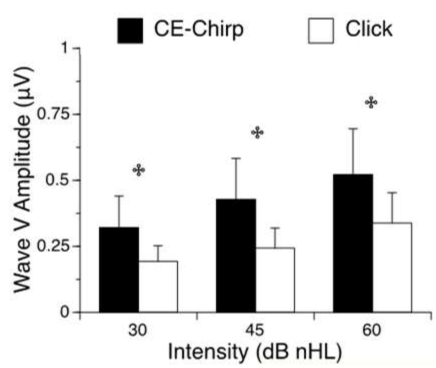
AC Intensity: CE-Chirp® vs. Click

Latency



Amplitude



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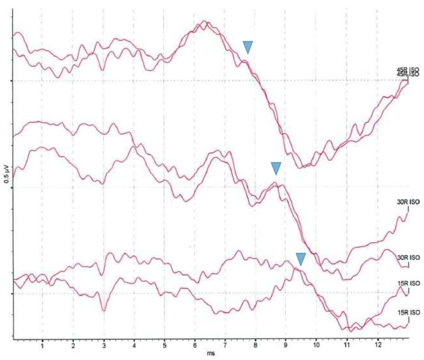
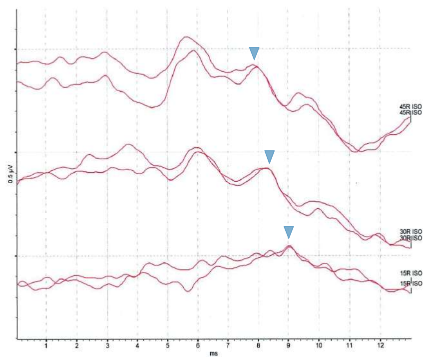
BC Intensity: CE-Chirp® vs. Click

CE-Chirp®: 45, 30, & 15 dB nHL @ 57.7/s



Click: 45, 30, & 15 dB nHL @ 57.7/s



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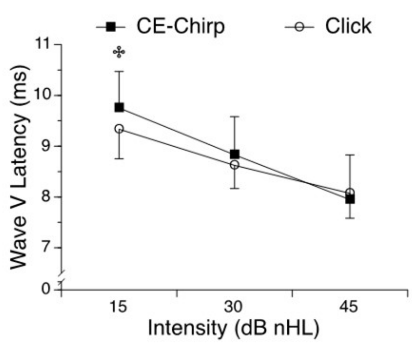
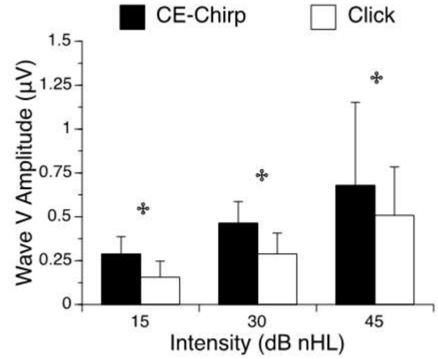
BC Intensity: CE-Chirp® vs. Click

Latency



Amplitude



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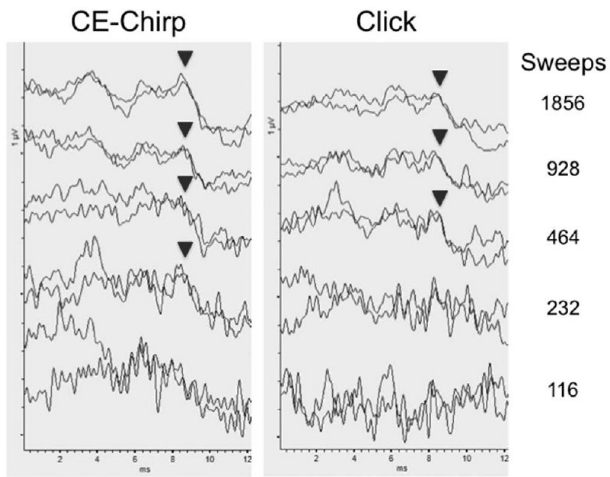
AC Sweeps: CE-Chirp® vs. Click

30 dB nHL @ 57.7/s



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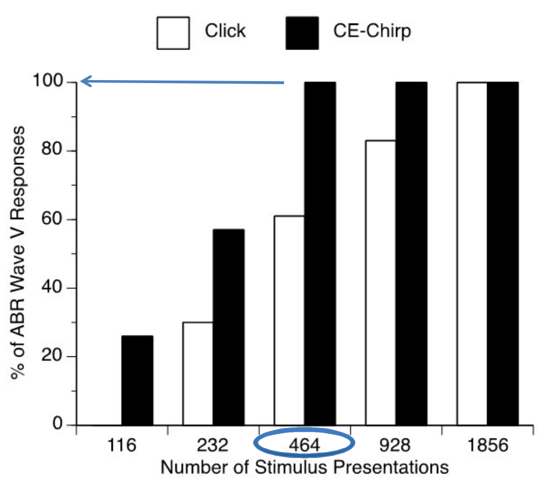
AC Sweeps: CE-Chirp® vs. Click

30 dB nHL @ 57.7/s



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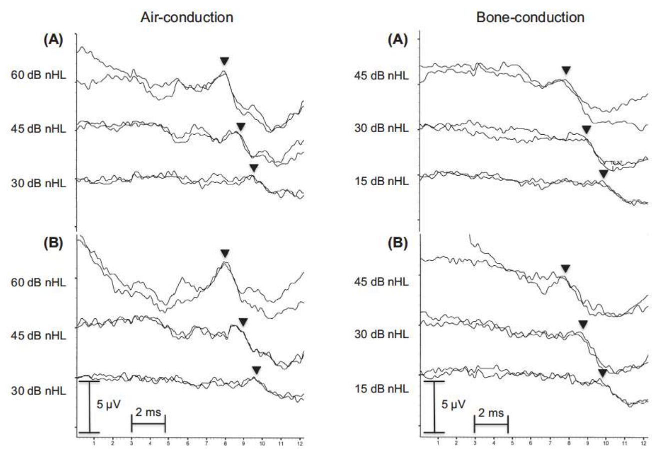
AC & BC Test-Retest Reliability: CE-Chirp®



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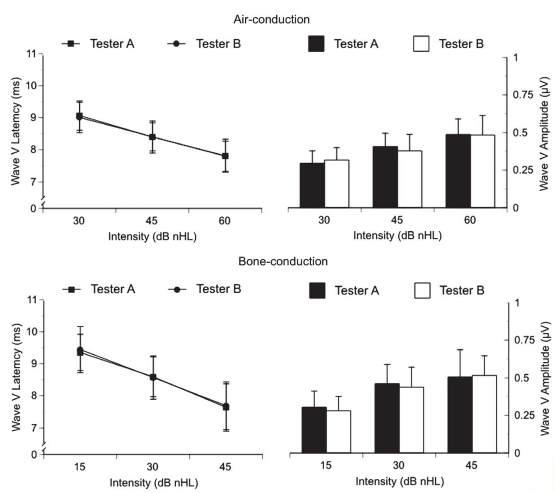
AC & BC Test-Retest Reliability: CE-Chirp®



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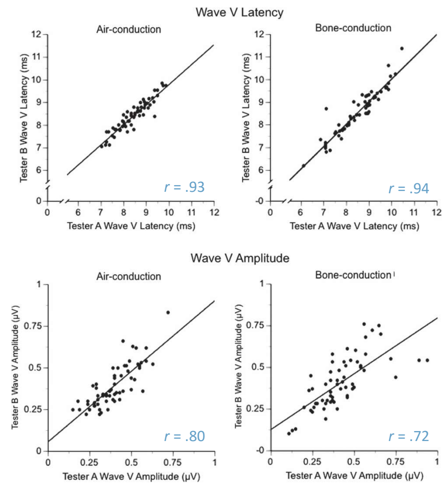
AC & BC Test-Retest Reliability: CE-Chirp®



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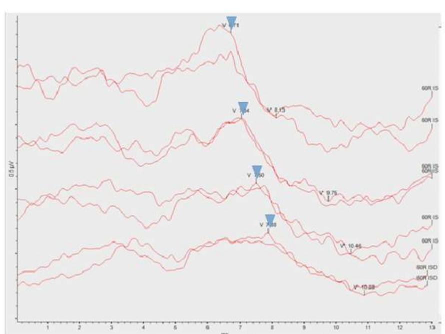
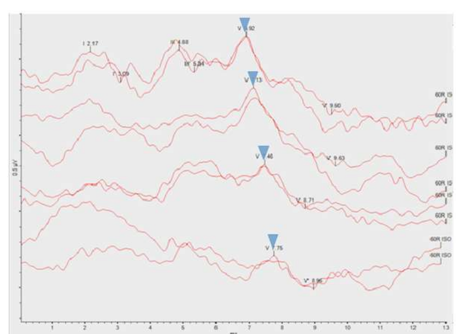
AC Rate: CE-Chirp® vs. Click

CE-Chirp®: 60 dB nHL @ 8.7, 27.7, 57.7, & 77.7/s

Click: 60 dB nHL @ 8.7, 27.7, 57.7, & 77.7/s





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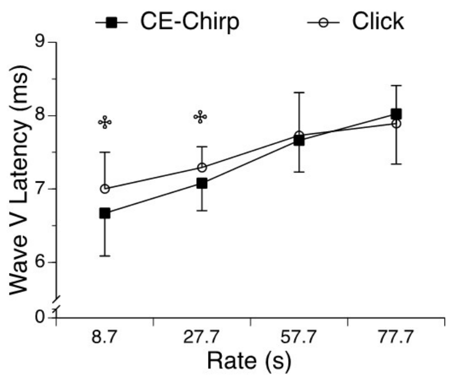
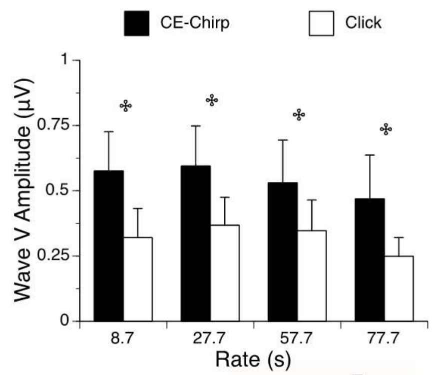
AC Rate: CE-Chirp® vs. Click

Latency



Amplitude



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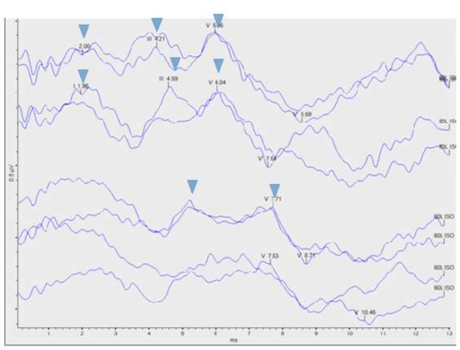
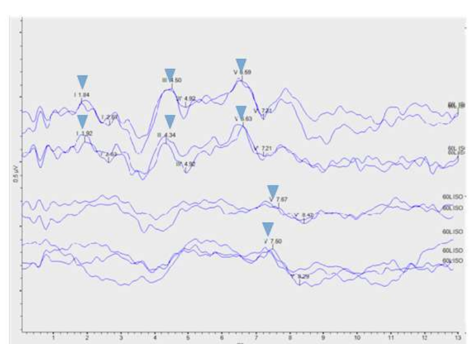
AC Polarity: CE-Chirp® vs. Click

CE-Chirp®: 60 dB nHL @ 8.7, & 77.7/s (Condensation/Rarefaction)



Click: 60 dB nHL @ 8.7, & 77.7/s (Condensation/Rarefaction)



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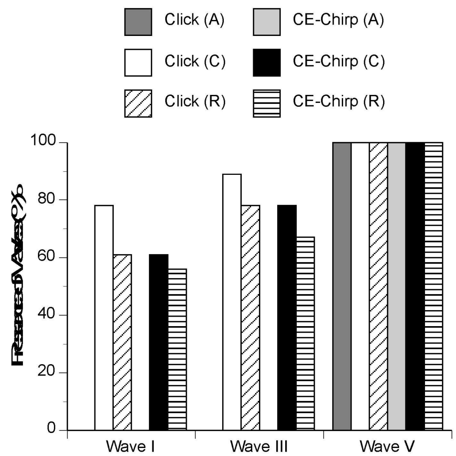
% Presence of Waves I, III, & V

(60 dB nHL @8.7/s)



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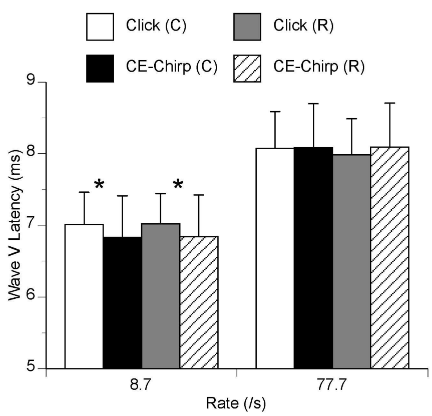
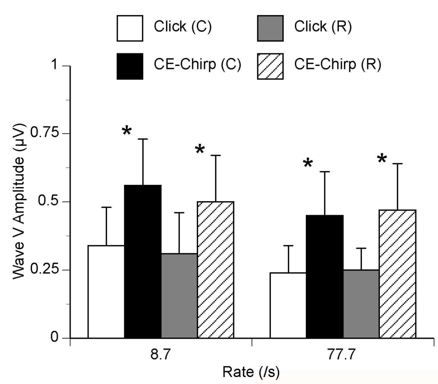
AC Polarity: CE-Chirp® vs. Click

Latency



Amplitude



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CE-Chirp® Observations

- Wave V amplitudes to AC and BC CE-Chirp® are significantly larger than those evoked to standard click.
- Wave V latency differences exist between the AC and BC CE-Chirp®.

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- AC and BC ABRs can be reliably evoked with low intensity 30 dB nHL CE-Chirp® and a fast rate of 57.7/s, similar to the current parameters of newborn hearing screenings.
- With the CE-Chirp®, wave V can be detected with 1/4 the amount of stimulus presentations required for the click.

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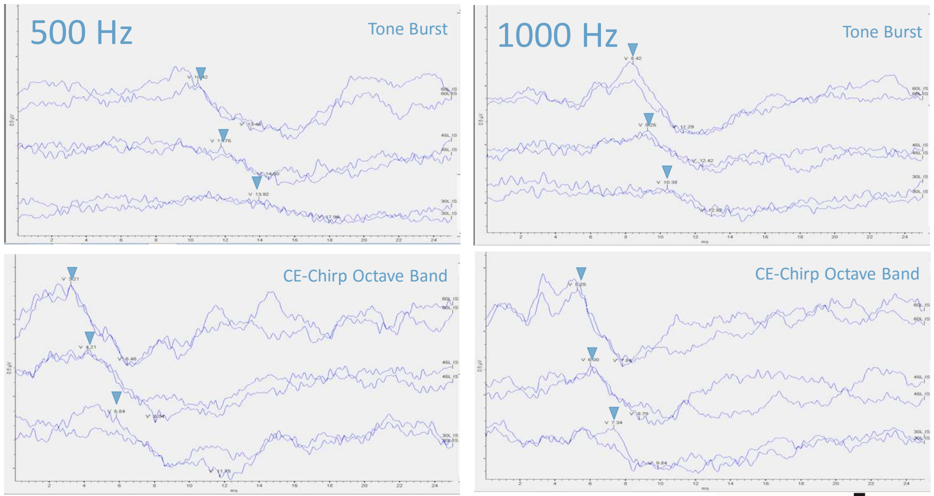
ABR Waveforms: Tonal Stimuli



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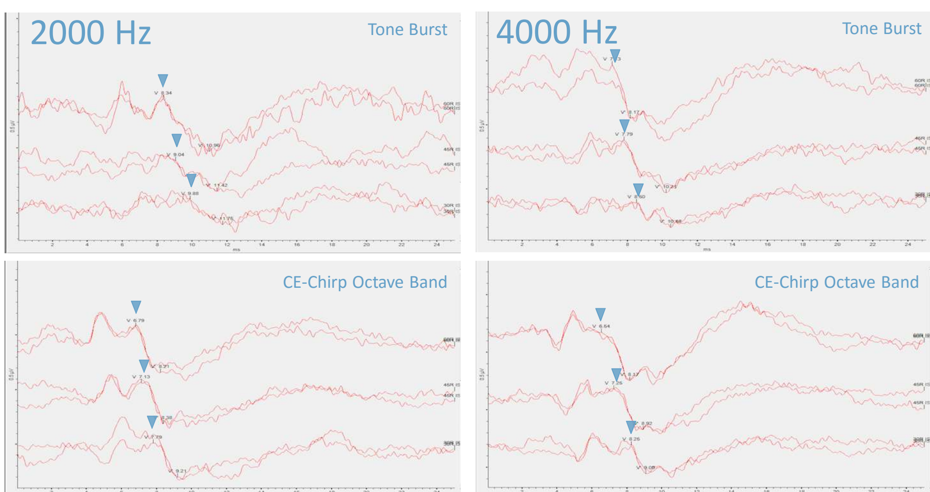

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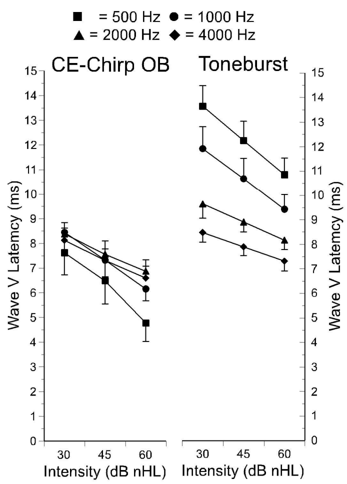
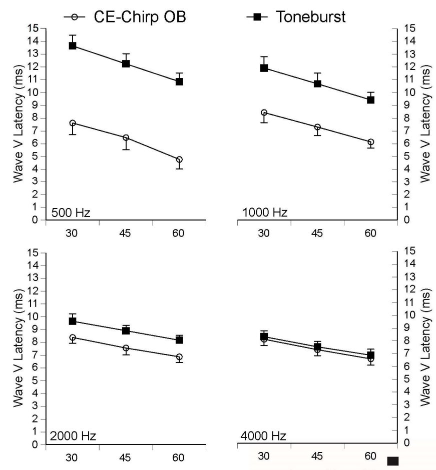
ABR Wave V Latency





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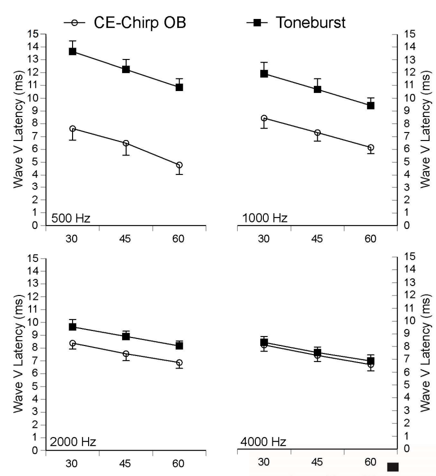
CE-Chirp® Octave Band Observations: Wave V Latency

- Wave V latencies significantly earlier to CE-Chirps® Octave Bands versus tone bursts.
  - Related to input delay for "rising frequency" chirp.
    - (Cebulla et al., 2014; Kristensen & Elberling, 2012)



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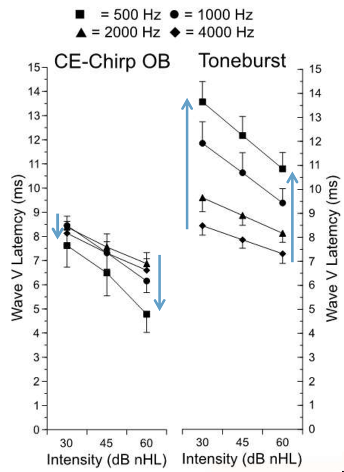
Latency/Frequency Reversal!

- Wave V latencies *increase with decreasing tone burst frequency*.
  - Rodrigues et al. (2013)
- Wave V latencies *decrease with decreasing frequency* of CE-Chirps® Octave Band.



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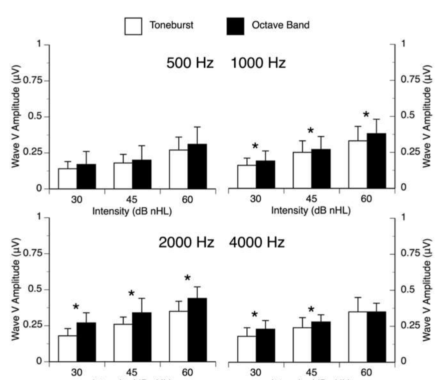
ABR Wave V Amplitudes



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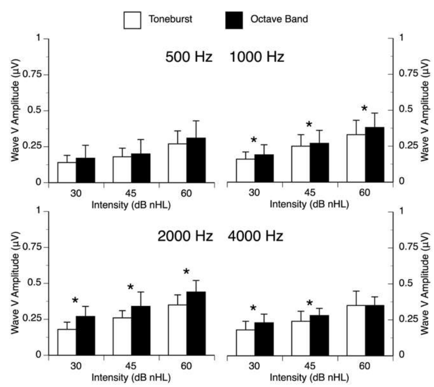
CE-Chirp® Octave Band Observations: Wave V Amplitudes

- Amplitude
  - Wave V amplitude was significantly larger at all intensities for CE-Chirps® Octave Bands at 1000 and 2000 Hz and 4000 Hz at 45 and 30 dB nHL.
    - Related to wider spectral widths?
      - (Bell et al., 2002)



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Clinical Applications of ABRs to CE-Chirp® Stimuli

- Differential Diagnosis/Evaluations
  - Integrity of auditory nerve and brainstem pathway
  - Auditory processing
- Newborn Hearing Screening
- Estimation of Behavioral Thresholds

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Conclusions

- Wave V amplitudes to AC and BC CE-Chirp® stimuli are significantly larger than traditional stimuli.
- Wave V latency differences exist between CE-Chirp® stimuli and traditional stimuli.
- Test time can be reduced.
- ABRs to AC and BC CE-Chirp® stimuli are reliable.

Acknowledgements

- Vidant Medical Center Audiology (Greenville, NC)
- GSI:
  - Sherrie Weller & staff for equipment and technical assistance.
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Questions