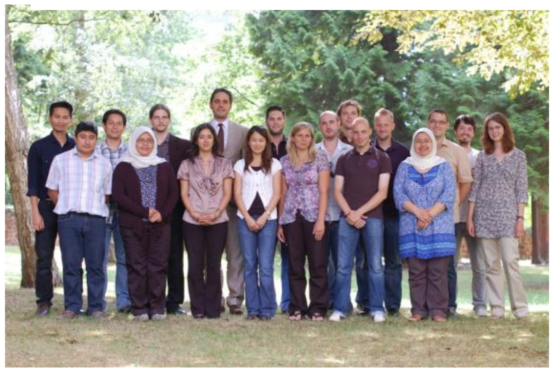
Systems Neuroscience &
Neurotechnology Unit

Neurocenter, Saarland University Hospital



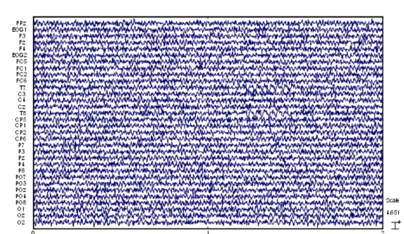
Auditory Processing and Perception

BMT 925, Course 2013

Theme 3: Evoked potentials, Stimulation procedures.

Farah I. Corona-Strauss

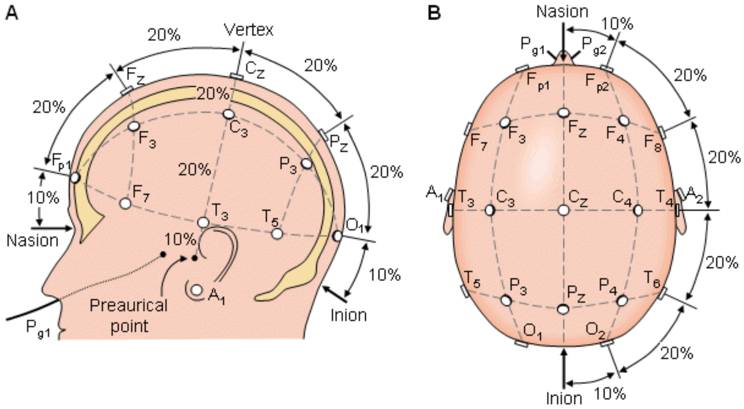
Electroencephalography (EEG)



EEG measures electrical potential at the scalp arising primarily from synchronous neuronal activity of pyramidal cells in the brain.

Methods: the 10-20 system

The 10-20 system is a method of electrode placement, which describes the location of scalp electrodes



The international 10-20 system seen from (A) left and (B) above the head. A=Ear lobe, C=central, Pg=nasopharyngeal, P=parietal, F=frontal, Fp=frontal polar, O=occipital.

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Evoked Potentials

Evoked Potentials (EPs)

Evoked potentials

EPs are EEG measurements which are time locked to a stimulus event.

EPs are voltage changes recorded from the human scalp that are time-locked to a sensory, motor, or cognitive process and therefore provide an electrophysiological window on to brain function during cognition (Mangun & Hillyard, 1995)

EPs can be used to assess whether a brain is functioning normally and how it analyses information.

Advantages & Disadvantages of the EP Technique

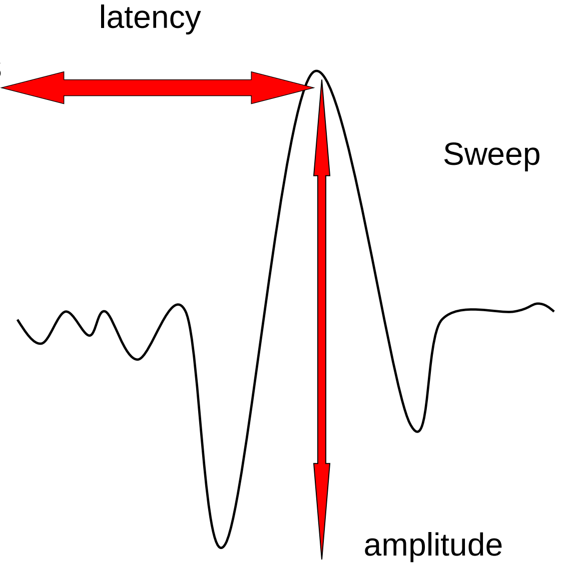
- EP signal is directly related to neural activity and this electrical activity is conducted instantaneously to the scalp
- Therefore, EPs have an excellent *temporal resolution*
- The EP signal is derived from different sources in the brain and it is not possible to infer exactly where these sources are from the scalp
- Therefore, EPs have a poor *spatial resolution*
- The small size of the EPs compare to the other physiological events make it difficult to discern. Thus, averaging techniques are commonly used to remove unrelated events.

Evoked Potentials (EPs)*

- Classification:
  - Latency: early, middle, late
  - Nature of stimulus: visual, acustic, somatosensory, ...

Characteristics

Evoked Potentials



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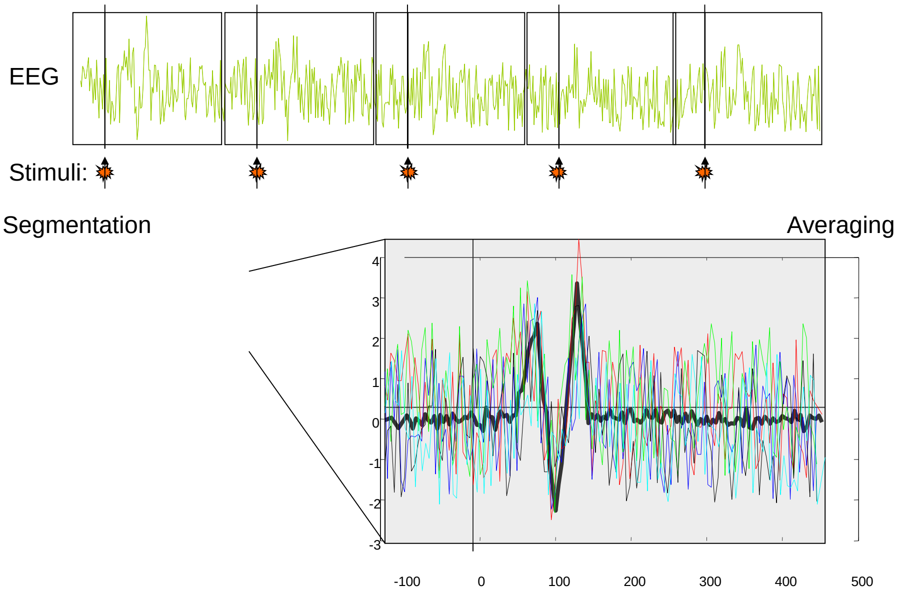
Evoked Potentials



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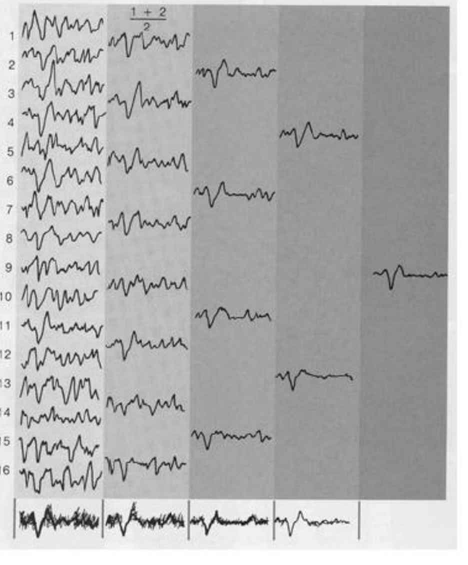
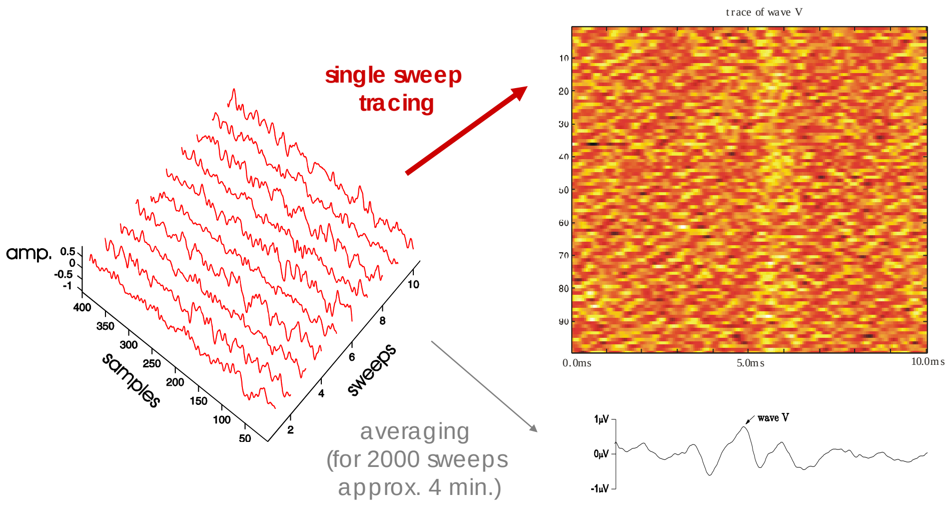
Evoked Potentials

✓ Evozierte Potentiale



Entstehen durch Mittelung der ereignisbezogenen Segmente

Single Sweep Processing



Left: Single sweeps (individual responses); Right (bottom): the averaged signal commonly used in the ABR analysis; Right (top): Single sweeps in matrix view.

Auditory Evoked Potentials

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Definition

- An auditory Evoked Potential (AER) or Auditory Evoked Response, is activity within the auditory system (ear, auditory nerve, or auditory regions of the brain) that is produce or stimulated („evoked“) by sounds („auditory“ or acoustic stimulus).

Hall J., Handbook of auditory evoked responses. Ally and Bacon, 1st ed., 1992.p.871.

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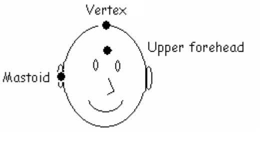
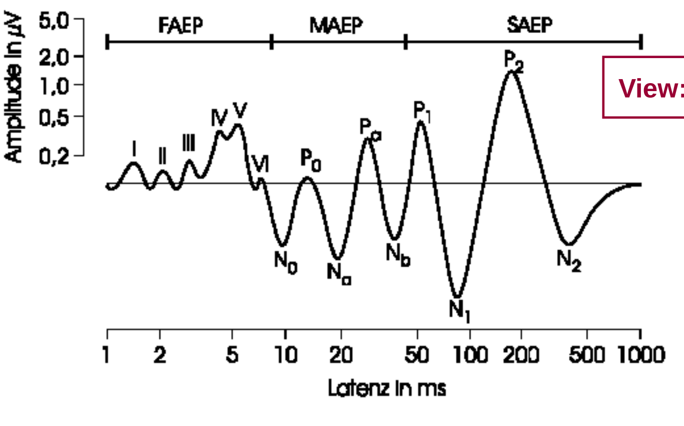
Auditory Evoked Potentials

•Elicited by tones, clicks, syllables, words....
•Early, middle and late latency EPs





View: Vertex (+)

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Early Auditory Evoked Potentials (AEP)

Early AEPs comprise:

a) The electrocochleogram (ECohG), which reflects responses in the first 2.5ms from the cochlea & the auditory nerve.

b) ABR, BERA or BAEP, first 12ms poststimulus & are recorded from the vertex.

- Mainly used clinically to study the integrity of the auditory pathway.
- Hearing impairments detection.
- The presence may be a sign of recovery from coma.
- Averages of 1000 ind. responses are used for diagnostics.

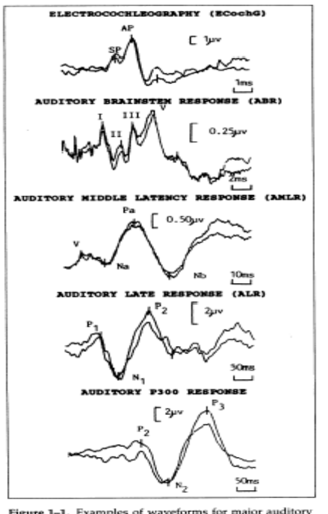

Figure 1–1. Examples of waveforms for major auditory evoked responses (AERs). Latency and amplitude scales for each AER are noted in the right portion of figure. (AP = action potential; SP = summating potential; µv = microvolts; I, II, III, and V = waves, numbered sequentially; N and P are negative and positive voltage indicators, respectively.)

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Auditory Brainstem Responses (ABRs)

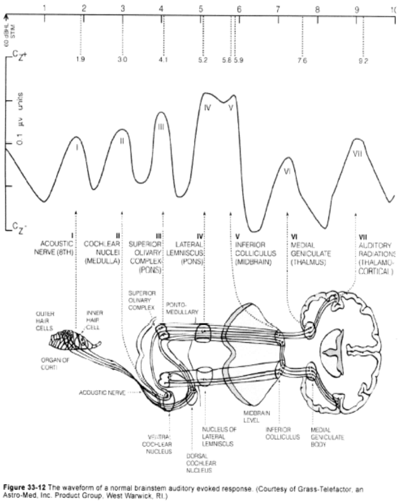
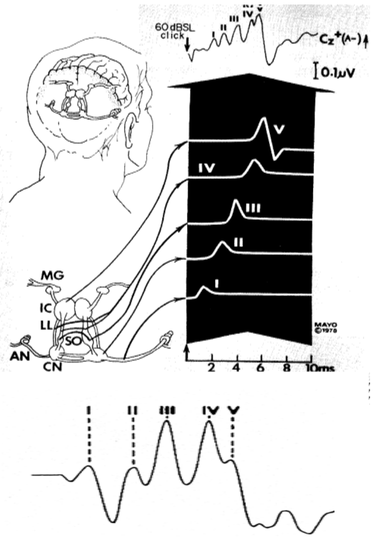


Figure 33-12 The waveform of a normal brainstem auditory evoked response. (Courtesy of Grass-Telefactor, an Astro-Med, Inc. Product Group, West Warwick, RI.)



Acquisition of ABRs, Stimuli

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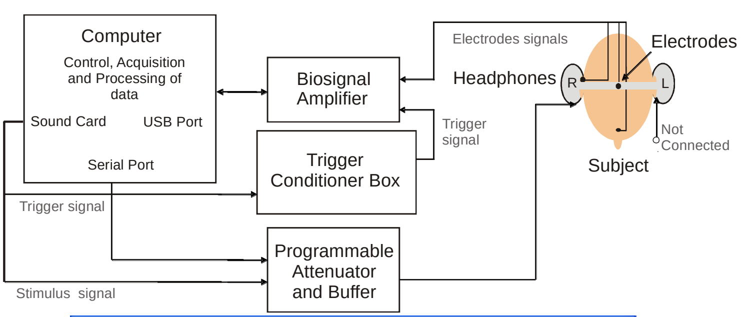
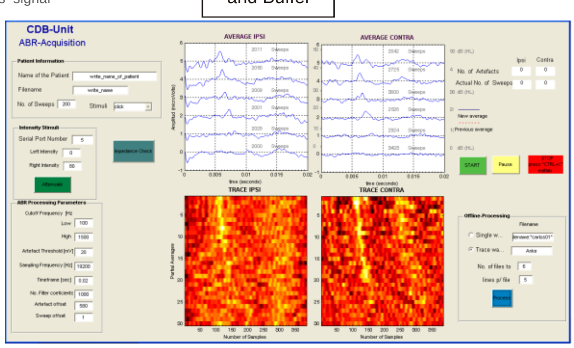
Experimental Setup



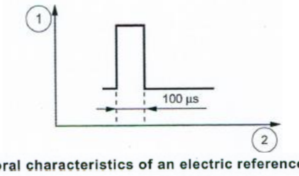


Click

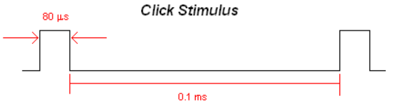
EN 60645-3:2007

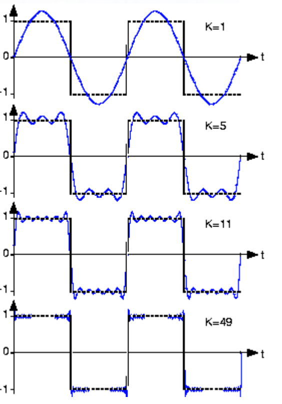
3.1
short-duration signal
signal having a duration of less than 200 ms

3.2
click
transient acoustic or vibratory signal whose frequency spectrum covers a broad frequency range, produced by applying a single rectangular electrical pulse to the terminals of the transducer



Temporal characteristics of an electric reference pulse





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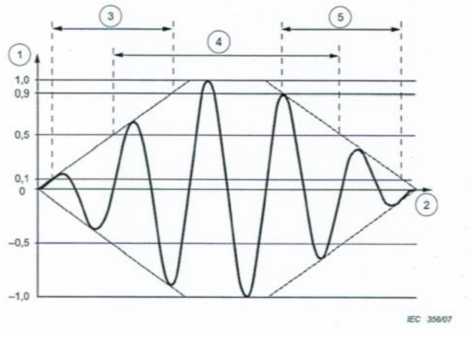
Tone-Burst

EN 60645-3:2007

3.3
tone-burst
sinusoidal signal having a duration of less than 200 ms

3.10
rise and fall times of a tone-burst
time intervals between the 10 % and 90 % amplitude points of the rising portion and the 90 % and 10 % amplitude points on the falling portion of the envelope of the tone-burst

- Tone burst: A brief (usually less than 1 s) tone stimulus with no specific duration characteristics (by norm<200ms).
- Tone pip: A brief tone stimulus sometimes defined as one complete cycle of the tone in rise, plateau, and fall portions of the stimulus. A 1KHz tone pip would have rise, duration and fall times of 1 ms each.



Key

1 Level

2 Time

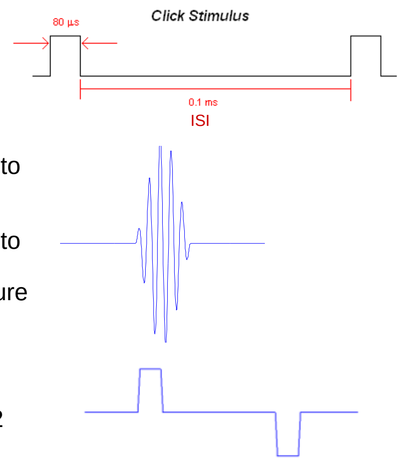
3 Rise time

4 Duration

5 Fall time

Stimulus related terminology

- **Polarity**: The initial direction of the pressure wavefront in the stimulus waveform, measured at the face of the transducer.
- **Condensation**: A stimulus polarity that initially causes the pressure wavefront of a transducer to move toward the eardrum.
- **Rarefaction**: A stimulus polarity that initially causes the pressure wavefront of a transducer to move away from the eardrum.
- **Alternating**: The polarity of the stimulus pressure wavefront is alternated on sucessive trials (between rarefaction and condensation).
- **Repetition rate**: The number of stimuli per unit time.
- **Interstimulus Interval**: time interval between 2 successive stimuli.
- **Rise/Fall time**: the time interval for a waveform to go from zero amplitude to maximum amplitude (rise time) or from maximum to zero (fall time).



Hall III J. W. Handbook of Auditory Evoked Potentials.Ally and Bacon.1st. ed. 1992.

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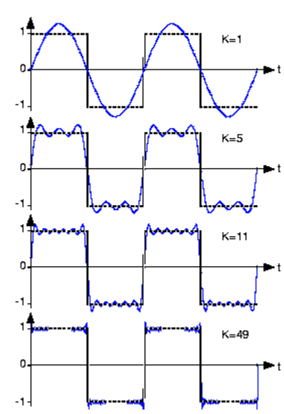
Stimuli- Chirps

- It was commonly believed that ABRs were elicited by the onset or offset of a stimulus, hence clicks were preferred because of its abrupt onset and wide spectral content.
- Recently [dau et. al., 2000] showed that ABRs are enhanced by an appropriate temporal organization of the stimulus (rising chirps) related to the properties of the basilar membrane (BM).
- In [Wegner, et. al. 2002] was reported that all chirps tested, evoked a larger wave V than the ones evoked by clicks, specially for low stimulation levels.



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Stimuli Generation: de Boer Chirp

The equation for the BM group delay: $\tau_{\mathrm{BM}}(f) = k(f+a)^{-d}$ $k = 4.78$, $a = 165.4$ Hz $d = 1.1$

the inverse function of was calculated: $\tau_{\mathrm{BM}}{}^{-1}(f) = f_a(t')$

where $t' \rightarrow t_0 - t$. and $t_o = \tau_{\mathrm{BM}}$ (100 Hz),

Instantenous Phase:

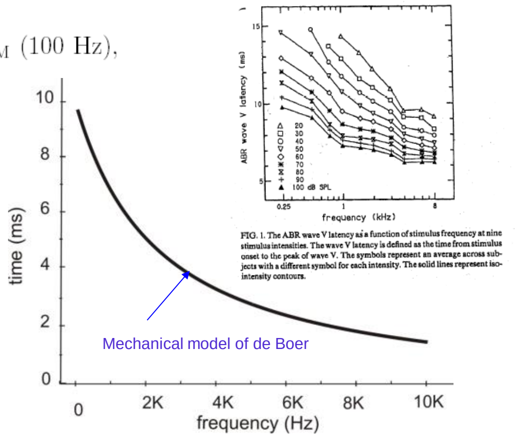
$$\phi(i,t) = 2\pi \int_0^t f_a(t)dt$$

Amplitude function:

$$A(i,t) = \sqrt{\frac{df_a(t)}{dt}}$$

Chirp equation:

$$S(i,t) = A(i,t)\sin(\phi(i,t) - \phi_o),$$



T. Dau, O. Wegner, V. Mellert, and B. Kollmeier, “Auditory brainstem responses (ABR) with optimized chirp signals compensating basilarmembrane dispersion,” J. Acoustical Soc. Am., vol. 107, pp. 1530– 1540, 2000.

E. de Boer, “Auditory physics. physical principles in hearing theory I,” Phys. Rep., vol. 62, pp. 87–174, 1980.

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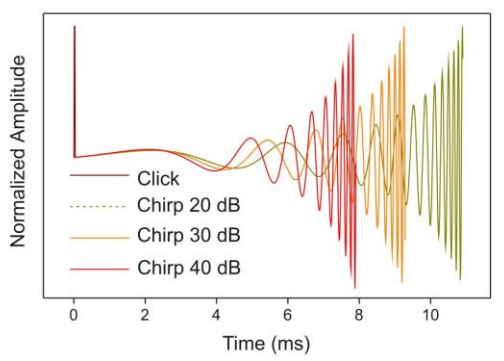
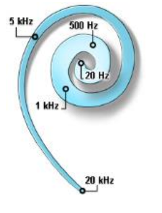
Study 1: Stimuli ABR-Chirps

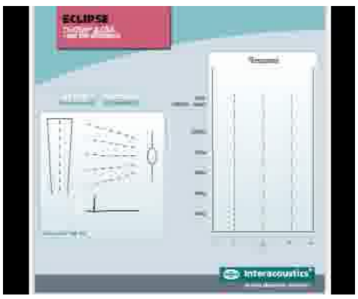
- Intensity levels:
  40 dB SPL (7.84 ms)
  30 dB SPL (9.21 ms)
  20 dB SPL (10.81 ms)
- Frequency range:
  0.100-10k Hz
- Clicks:
  80µsec duration.
- Repetition rate:
  20 Hz
- Polarity:
  Bipolar
- Frequency of:
  44.1kHz
- Calibration:
  peak equivalent signal level. pe-SPL
  (IEC 60645-3 2007, ISO 389-6: 2007)

Stimuli: Click and Chirps 0.1 to 10KHz

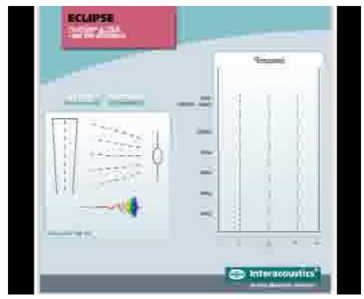




Clicks



Chirps



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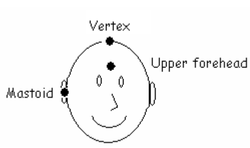
Study 1: Materials & Experiments

MATERIALS

- Two different types of Ag/AgCl electrodes were used:
  - Active: Easycap GmbH, Germany
  - Passive: Schwarzer,Germany
- Position of electrodes:
  - Right mastoid
  - Forehead
  - Vertex
- Impedances maintained <5kΩ
- EEG signals:
  - Biosignal Amplifier (g.Tec) Fs: 19.2k Hz
  - filtered: Bandpass 0.1-1.5 kHz.



EXPERIMENTAL PROCEDURE

- Duration:
  - approx. 1.5 hr.
- Healthy Subjects :
  - inside acoustically insulated room, instructed to relaxed and sleep.
- ABRs:
  - Active electrodes were attached
  - ABRs were obtained using:
    - clicks for 40, 30 and 20 dB pe SPL
    - chirps at the same intensity levels and same order.
    - spontaneous activity (no stimulation condition)
  - the Passive electrodes were placed and the same stimulation procedure was applied as for the active electrodes.
  - 2000 sweeps, i.e., individual responses, for each conditions, free from artifacts were recorded (>15 μV).

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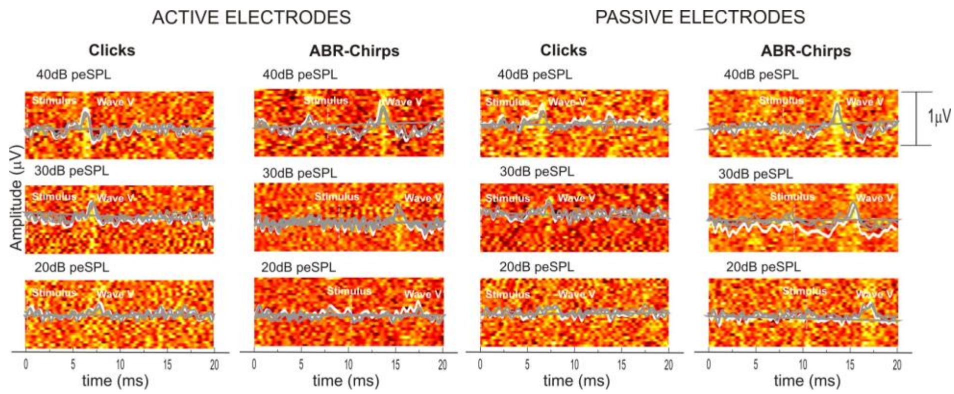
Results Study 1: ABRs

20 Subjects
(24.45±3.8 years, 13f/7m)

demonstration purpose:

-White and gray lines are averages of 1000.
-Colormap each line is the average of 75 sweeps

Intensity (dB HL)	Interval (ms)
Click 40	[5, 11]
Click 30	[5,11]
Click 20	[5,11]
Chirp 40	[10.84, 17.84]
Chirp 30	[12.21, 19.21]
Chirp 20	[13.81, 20.81]



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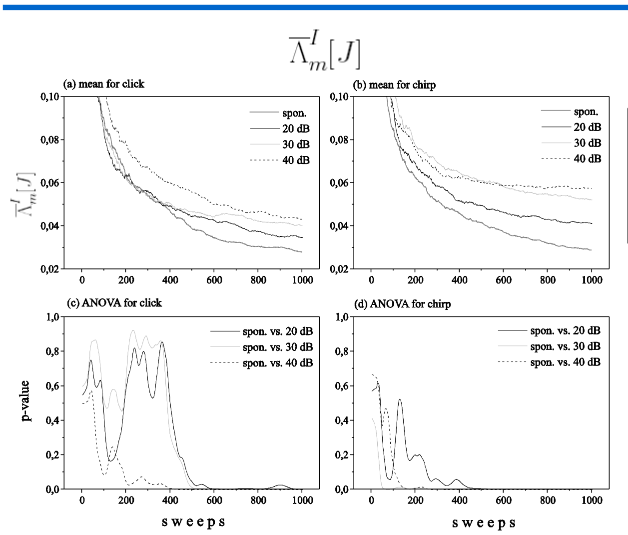
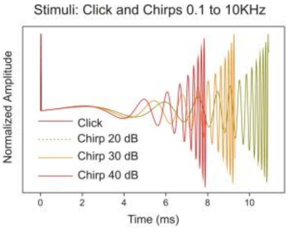
Results: Moving Average GFPS



Analyzed intervals for the different stimulations according to the intensity.

Intensity (dB(HL))	Interval $[b_l, b_u]$ (ms)
Clicks 40	[5, 9]
Clicks 30	[6, 10]
Clicks 20	[6, 10]
Chirp 40	[12, 16]
Chirp 30	[14, 18]
Chirp 20	[16, 20]

Stimuli: Click and Chirps 0.1 to 10KHz



-moving average of the mean of ABR GFPS for m=1
-significance test

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Study 1: Conclusions

- We introduced for the first time Gabor frame operators (GFO) as analysis tool for ABRs.
- GFPS provides a fast and reliable discrimination of the spontaneous activity from stimulations above the hearing threshold with a minimum number of sweeps as compared to conventional schemes in which thousands of sweeps are averaged.
- More clinically oriented studies should include hearing impaired patients and newborns as the key group for objective therapies.

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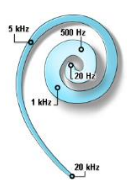
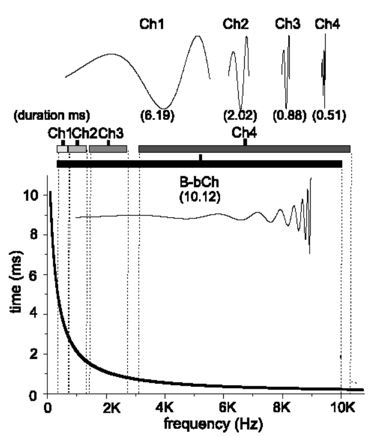
Study 2: Chirps Generation

Chirp number	Bandwidth (Hz)	Fc (Hz)	Interval (Hz)	Fc' (Hz)	Interval' (Hz)	duration (ms)
1	Range/2^5 = 309	250	[95, 405]	302	[108, 490]	6.1946
2	Range/2^4 = 619	750	[441, 1059]	813	[495, 1135]	2.0185
3	Range/2^3 = 1238	2000	[1381, 2619]	1915	[1230, 2600]	0.87806
4	Range/2^2 = 2475	4000	[2763, 5238]	6725	[2950, 10500]	0.5091
5	Range/2^1 = 4950	8000	[5525, 10475]	–	–	–
Broadband	Range/2^0 = 9900	5050	[100, 10000]	5050	[100, 10000]	10.12

- Frequency range:
  (range=0.1-10kHz)
- Sampling frequency of:
  44.1kHz
- Polarity:
  Bipolar
- Repetition rate:
  20 Hz
- Calibration:
  peak equivalent signal level. (pe-SPL)

(IEC 60645-3 2007, ISO 389-6: 2007)





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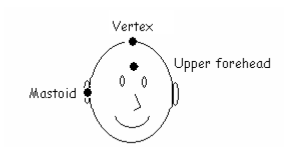
Study 2: Materials & Experiments

MATERIALS

- Ag/AgCl electrodes (Scwarzer, Germany):
  - Right mastoid
  - Forehead
  - Vertex
- Impedances maintained <5kΩ
- EEG signals:
  - Biosignal Amplifier (g.Tec) Fs: 19.2k Hz
  - filtered: Bandpass 0.1-1.5 kHz.

EXPERIMENTAL PROCEDURE

- Duration:
  - approx. 2 hr.
- Healthy Subjects :
  - inside acoustically insulated room, instructed to relaxed and sleep.
- ABRs:
  - Broadband chirp and the Band-limited chirps, for the intensiy level of 50, 40 and 30 dB peSPL.
  - 3000 sweeps, i.e., individual responses, for each conditions, free from artifacts were recorded (>15 μV).



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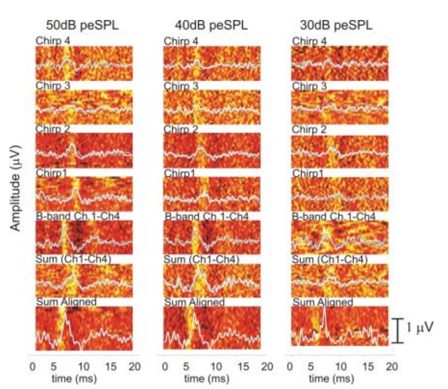
Results Study 2: ABRs

demonstration purpose:

10 Subjects:

- 25.1±2.96 years
- 4 female / 6 male
- Normal Hearing Thresholds (>15 dB HL)

each line represents the average of 1500 sweeps.



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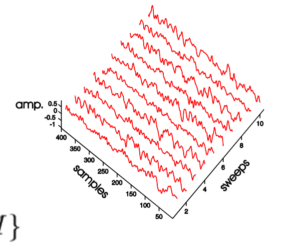
Wavelet Phase Synchronization Stability

Time-Scale Phase Synchronization

complex wavelet transform

$$\mathcal{W}_\psi : L^2(\mathbb{R}) \longrightarrow L^2(\mathbb{R}^2, \frac{\mathrm{d}a\mathrm{d}b}{a^2})$$

$$(\mathcal{W}_\psi x)(a,b) = \langle x, \psi_{a,b} \rangle_{L^2}$$



set of *M* ABRs

$$\mathcal{X} = \{x_m \in L^2(\mathbb{R}) : m = 1, \ldots, M\}$$

we define wavelet phase synchronization stability (WPSS) by

$$\Gamma_{a,b}(\mathcal{X}) := \frac{1}{M} \left| \sum_{m=1}^{M} e^{\imath \arg((\mathcal{W}_\psi x_m)(a,b))} \right|$$

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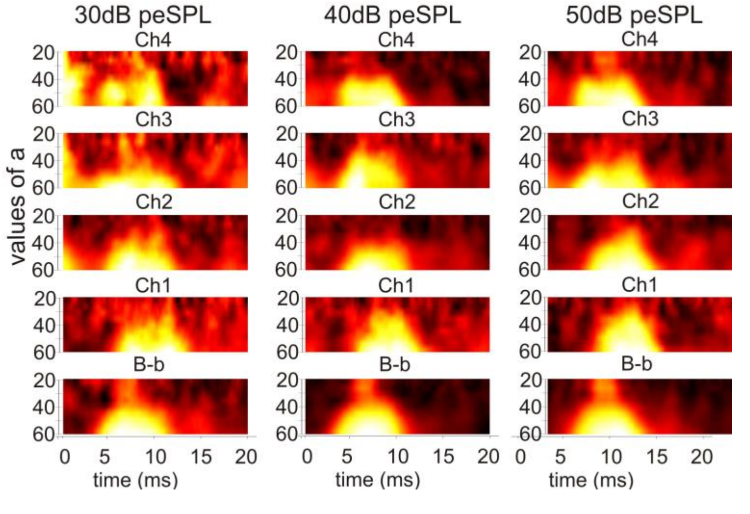
Results: WPSS

$$\Gamma_{a,b}(\mathcal{X}) := \frac{1}{M} \left| \sum_{m=1}^{M} e^{\imath \arg((\mathcal{W}_\psi x_m)(a,b))} \right|$$

M = 3000 sweeps

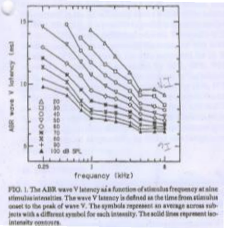
a ranged from 20 to 60 with increments of 5

Wavelet: 6th--derivative of Gaussian function



Conclusions & Future work

- A series of notched–noise embedded frequency specific chirps was developed, which allowed the acquisition of frequency specific ABRs, with an identifiable wave V for the different intensity levels.
- The WPSS of frequency specific chirp-evoked ABRs reflected the presence of the wave V for all stimulation intensities and was in line with previous findings.
- Future work:
  - evaluation the notched noise embedded chirps with patients with different types of hearing loss, and make a comparison against the currently used but slower methods.
  - further analysis can be done to make a faster recognition of frequency specific chirps evoked ABRs.
  - The model used to calculate the series of chirps is considered as first order approximation of the basilar membrane behavior. Further improvements related to the stimuli (making them intensity specific) can be done.
  - It can be further investigated which level of masking gives better results for low, medium and high frequency specific chirp stimulations.



Auditory Evoked Potentials (AEP)

Middle AER – 12-50ms post stimulus

- Clinical applications are **"very limited"** – the location of their sources is still controversial.
- Suggest to give information of the auditory pathway above the level of the brainstem.
- Elements are named by polarity: Na, Pa, Nb, Pb.
- Most commonly type are MLR at high ISI : ASSRs

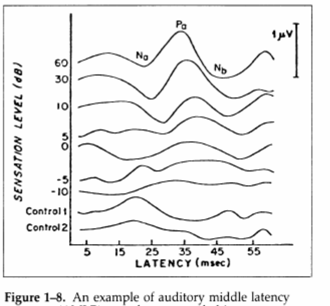


Figure 1–8. An example of auditory middle latency response (AMLR) waveforms recorded in numerous classic studies by Goldstein and colleagues (Goldstein & Rodman, 1967). Labels for major AMLR components, introduced by Goldstein, are shown. The smoothed waveform appearance is due to restricted filter settings. *Note.* From "Early Components of Averaged Evoked Responses to Rapidly Repeated Auditory Stimuli" by R. Goldstein and L.B. Rodman, 1967, *Journal of Speech and Hearing Research, 10*, pp. 697–705. Reprinted by permission.

Hall J., Handbook of auditory evoked responses. Ally and Bacon, 1st ed., 1992.p.25.

AMLR

Applications:

- Frequency specific estimation of auditory sensitivity in adults and old children.

Limitations:

- Not easily measurable in Newborns: the MLR components overlap with the early evoked components, which has a longer developmental timetable.
- Affected by sleep or sedation and other drugs.- Measure of Adecuate Anesthesia.

Middle Auditory Evoked Potentials : ASSRs

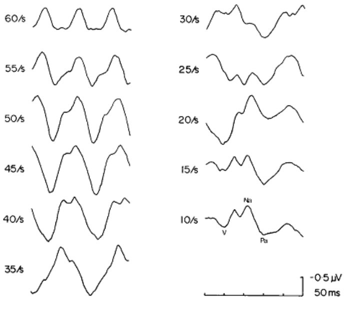
Auditory Steady–State Responses (ASSRs)

1. are periodic electrical responses of the brain to auditory stimuli presented at a rate fast enough to cause an overlap of sucessive responses.

2. oscillations with a constant amplitude and phase at the frequency of a periodic stimulus. The most prominent responses are obtained at 40Hz.

The 40 Hz auditory potential (Galambos et al, 1981)

- sequences of clicks, amplitude modulated tones or tone pulses at a frequency close to 40 Hz
- signal averaging in the time and the frequency domain
- latencies:
  - around 8 to 80ms,
  - increase with decreasing intensity
- amplitudes:
  - increase with an increasing stimulus intensity
  - maximal amplitudes with a 40Hz modulation rate



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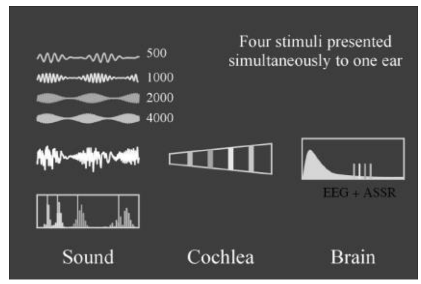
ASSRs

Application in the Audiometry

clinical advantages

- objective method for the prediction of the behavioral threshold (> 1 kHz)
- simultaneous presentation of multiple stimuli → analysis in the frequency domain
- complementation to ABRs and OAEs
- also, possible to test several carrier frequencies simultanously



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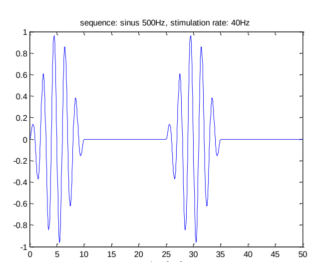
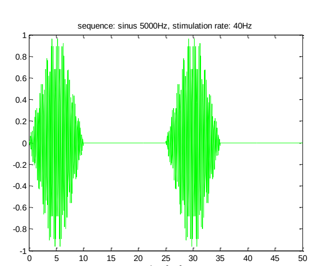
Materials & Methods

Stimulation

- sinus tones: 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz
- stimulus rate: 40 Hz
- duration: 10 ms
  - linear rise and fall time: 4 ms
  - plateau: 2 ms
- intensity level: 60 dB SPL
- stimulation: right ear





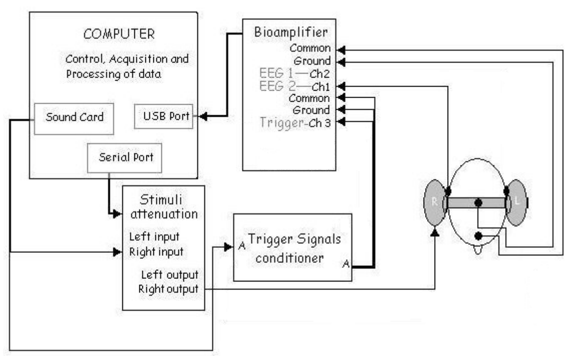
Materials & Methods

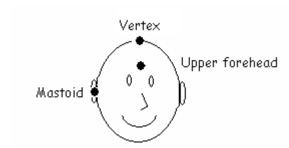
Acquisition parameters and set-up

- bandpass filter: 10 to 100 Hz
- sampling frequency: 19200 Hz
- artefacts > 50 µV were rejected
- offset was removed

electrodes:

- – right mastoid, vertex, forehead
- – impedances: < 5kΩ

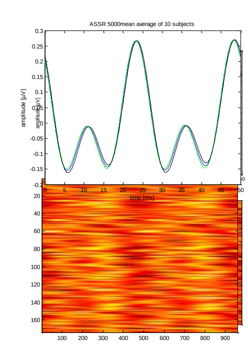




ASSRs Results

Averaging in the time domain

- averaging of 3500 sweeps



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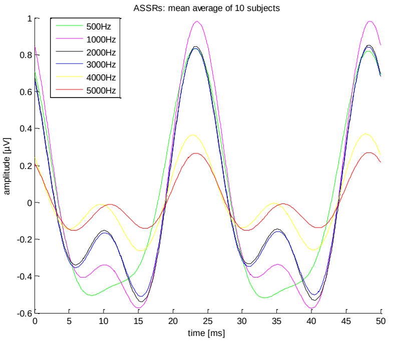
ASSRs Results

Comparison of the different carrier frequencies

- amplitudes
  decrease with increasing frequencies
  - 500 Hz: 0.5 µV
  - 1000 Hz: 0.4 µV
  - 2000 Hz: 0.33 µV
  - 3000 Hz: 0.35 µV
  - 4000 Hz: 0.14 µV
  - 5000 Hz: 0.15 µV
- latencies
  decrease with increasing frequencies
  - 500 Hz: 8.17 ms
  - 1000 Hz: 6.8 ms
  - 2000 Hz: 5.8 ms
  - 3000 Hz: 5.9 ms
  - 4000 Hz: 5.1 ms
  - 5000 Hz: 5.57 ms



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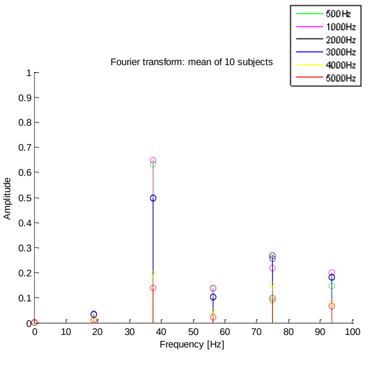
3. Results

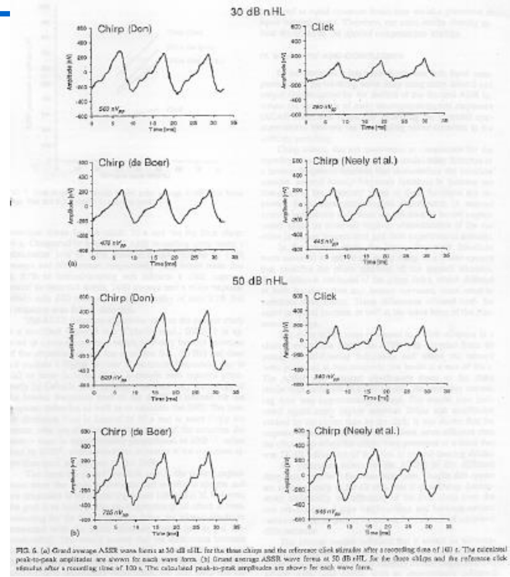
Averaging in the frequency domain

- clear peak at 37.5 Hz for all carrier tones
  → modulation rate of 40 Hz
- 2nd harmonic at ~75 Hz and
  a subharmonic at ~20 Hz
- decreasing amplitudes with increasing frequencies
- distances between the amplitudes in the frequency domain are in the same range as the amplitudes in the time domain



ASSRs evoked by chirps

- Used chirps to evoke ASSRs and compensate for the traveling wave delay.
- ASSRs collected in healthy subjects using clicks and different types of chirps.
- The chirps gave a shorter detection time and higher SNR than clicks.
- The chirps are more efficient than clicks for recording middle auditory evoked potentials in healthy subjects.



Elberling C. , et. al. Auditory Steady-state Responses to chirp stimuli based on cochlear traveling wave delay.J. Acoust. Soc. Am., 122:5, 2007

Auditory Evoked Potentials (AEP)

Late AER – 50ms-1s

- Consists of main peaks
  Named by latency – P50, N100, P150, & N200,P300
  Or by polarity (P1, N1, P2, N2, P3), MMN-(100-250ms), N400, P600,
- Cortical origin & have a max. amplitude at the vertex locations.

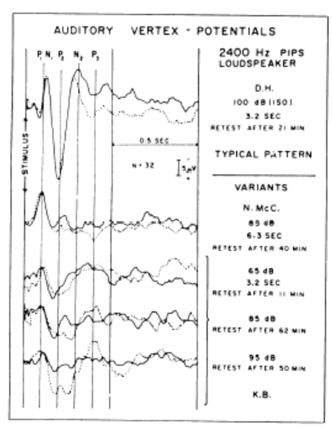


Figure 1–11. Auditory late response (ALR) waveform, as reported in one of the earliest papers on the topic by Hallowell Davis and colleagues (Davis, Mast, Yoshie, & Zerlin, 1966), shows positive voltage peaks plotted downward. The typical ALR waveform is illustrated in the top portion of the figure. Stimulus conditions are also indicated in this portion. *Note.* From "The Slow Response of the Human Cortex to Auditory Stimuli: Recovery Process" by H. Davis, T. Mast, N. Yoshie, and S. Zerlin, 1966, *Electroencephalography and Clinical Neurophysiology, 21*, pp. 105–113. Reprinted by permission.

Hall J., Handbook of auditory evoked responses. Ally and Bacon, 1st ed., 1992.p.32.

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Auditory Evoked Potentials (AEP)

- Exogenous EP - Elicited by the physical characteristics of the external stimulus, such as intensity, duration, frequency

- Endogenous ERP – Elicited by internal brain processes and respond to the significance of the stimulus. It can be used to study cognitive processes.

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P1 Component

- Not easily identified
- ~50ms (auditory stimulus), ~100ms (visual stimulus)
- Functionally – neurophysiological indicator of preferential attention to sensory inputs & reflection of the general level of arousal

P1 Component

- Larger amplitudes over frontal or central regions, Nagamoto, Adler, Waldo, Griffith & Freedman (1991) – peak was largest over the Cz electrode
- Distribution is symmetrical over the two hemispheres
- Peak amplitude & latency appear to decrease with age to the point where the peak disappears (Coch, Groissi, Coffey-Corina, Holcomb, & Nevilee, 2002)

N1 Component

- Assumed to reflect selective attention to basic stimulus characteristics, initial selection for later pattern recognition, and intentional discrimination processing (Vogel & Luck, 2000)
- Amplitude is enhanced by increased attention to the stimuli (Hillyard et al., 1973, etc) & by increasing the ISI (Hari, Kaila, Katila, Tuomisto, & Varpula, 1982)
- Latency & amplitude of the peak depend on the stimulus modality – auditory stimuli elicit a larger N1 with shorter latency than visual stimuli (Hugdahl, 1995)

P2 Component

- Has been identified in many different cognitive tasks, including selective attention (Hackley, Woldorff, & Hilyyard, 1990, etc), stimulus change (Naatanen, 1990), feature detection processes (Luck & Hillyard, 1994), and short-term memory (Golob & Starr, 2000;Starr & Barrett, 1987)
- Often occurs together with N1 (N1-P2 complex)

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Tinnitus:
Decompensation Correlates and Multiscale Modeling

it just sounds like that

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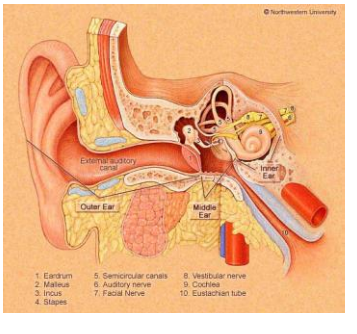

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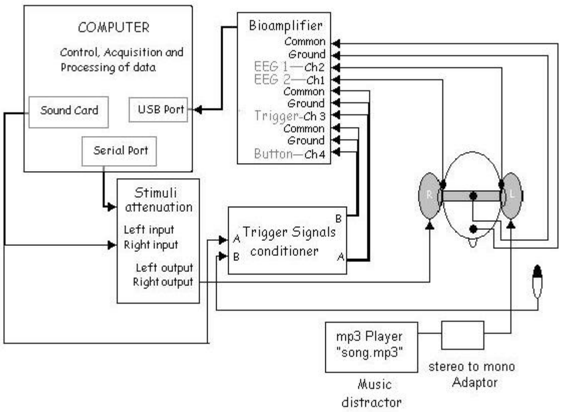
ALR Measurement setup



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ALR-Attention Methods

- Tone A, B, C, attention and no attention:

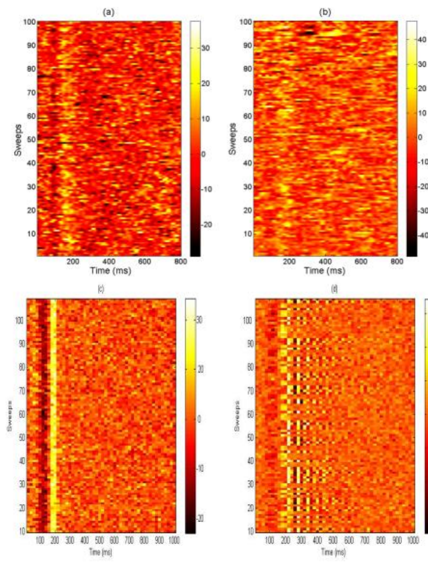
target tone

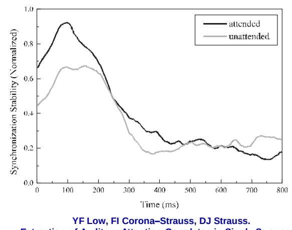
experiment difficult

Comparison Experiment vs. Model

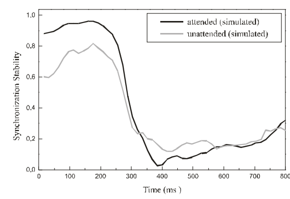
focal non-focal

$$\Gamma_{a,b}(\mathcal{X}) := \frac{1}{M}\left|\sum_{m=1}^{M} e^{i\arg((W_\psi x_m)(a,b))}\right|$$





YF Low, FI Corona–Strauss, DJ Strauss.
Extraction of Auditory Attention Correlates in Single Sweeps of Cortical Potentials.
IEEE NER pp.469-472, 2007



C Trenado, L Haab, W Reith, DJ Strauss.
Biocybernetics of Attention in the Tinnitus Decompensation: An Integrative Multiscale Modeling Approach.
J Neurosci. Meth. pp. 237-247, 2009

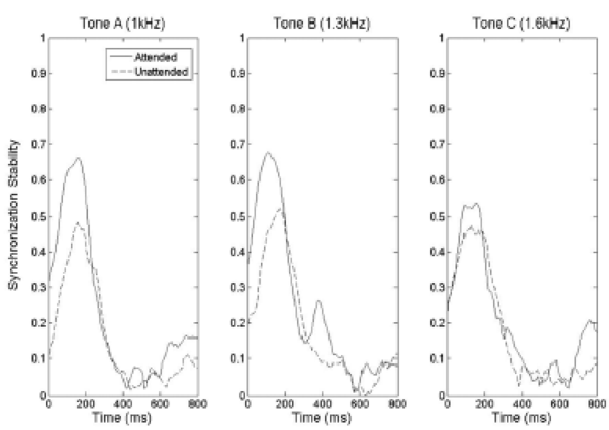


Fig. 2. The difference of the synchronization stability for a subject ($a = 40$ as example) for 3 different tones.

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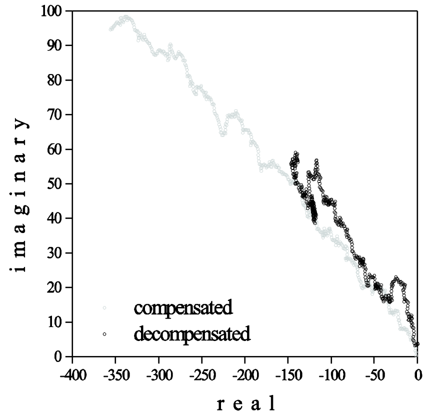
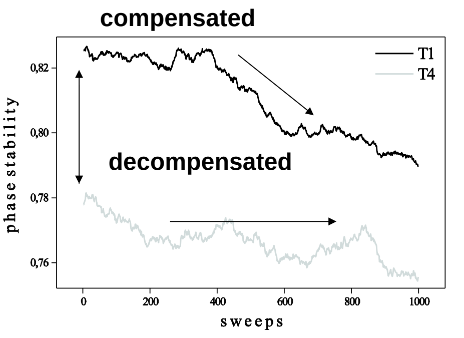
Study 1. Tinnitus Results





D. J. Strauss, W. Delb, R. D'Amelio, and P. Falkai. Adaptive Resonance and Attention in the Tinnitus Decompensation: Neural Correlates in Auditory Evoked Potentials, IEEE Trans. on Biomed. Eng.

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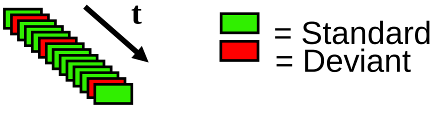
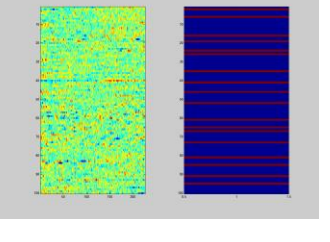
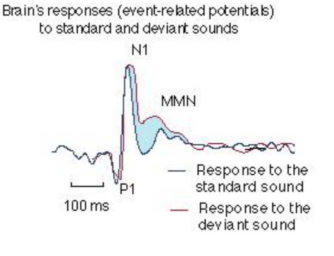
Mismatch Negativity (MMN)

Oddball paradigm



MMN und oddball paradigm, Näätänen, R. (1978)





MMN (Mismatch Negativity)

- MMN is a negative deflection that has a typical latency of 100ms to 250ms (Naatanen, Gaillard, & Mantysalo (1978))
- Elicited by oddball paradigm
- MMN paradigms typically do not require attention to the stimuli – development research & sleep studies

MMN (Mismatch Negativity)

- May also depend on number of trials – too many deviants trials may allow a participant to habituate to the particular stimulus
- McGee et al. (2001) – complex and simple stimuli – as number of exposure increased, the size of the MMN response decreased in a nonlinear fashion
- The exact time for habituation varied as a function of the complexity of the stimuli

Other important components

- P300 Component: present in auditory and visual tasks. Interpretation is diverse, some view it as an indication of memory updating, whereas others believe that it reflects a combination of processes that vary by task and situation.
- N400 Component: occurs aprox. 400 msec after stimulus. Associated with visual and auditory sentence comprehension tasks.

- P600 Component: associated memory processes and to language.