Systems Neuroscience & Neurotechnology Unit

Neurocenter, Saarland University Hospital

UNIVERSITÄT DES SAARLANDES

Hochschule für Technik und Wirtschaft des Saarlandes

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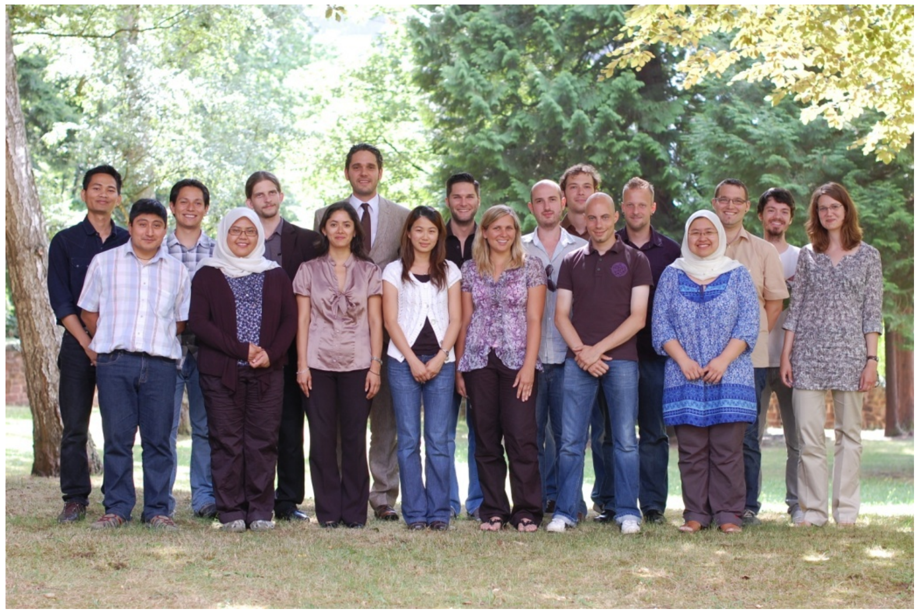

Objective Listening Effort Estimation by Electroencephalographic Methods

Listening Effort – Hearing Impaired Persons

- **Listening**
  - is the process of hearing with intention and attention for purposeful activities demanding the expenditure of mental effort **(Kiessling et al., 2003)**
  - is effortless for normal hearing persons in ideal listening situations

- **Hearing Impaired Persons**
  - speech comprehension in noisy situations is usually an effortful process
  - cognitive processing demands are needed to obtain an acceptable level of audibility

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Listening Effort

Listening Effort and Fatigue in School-Age Children With and Without Hearing Loss

Use of a Dual-Task Paradigm to Measure Listening Effort

...ouble tâche pour

...ation d'un p... l'attenti...

Testing listening effort for speech comprehension using the individuals' cognitive spare capacity

N. Rönnberg,[1,3] S. Stenfelt,[1,3] M. Rudner[2,3]

Objective measures of listening effort: Effects of background noise and noise reduction

Anastasios Sarampalis[1], Sridhar Kalluri[2], Brent Edwards[2], Ervin Hafter[1]

Pupil Response as an Indicatio... of Effortful Listening: The Influence of Sentence Intelligibility

Adriana A. Zekveld, Sophia E. Kramer, and Joost M. Festen

Table 1
Literature Review

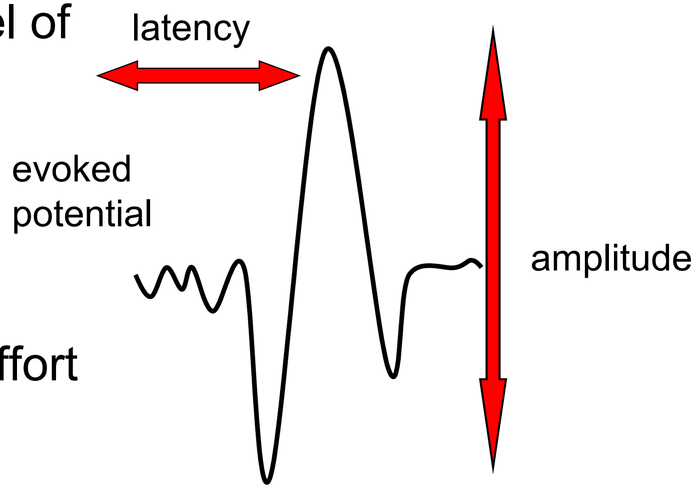
Author	Participants	Primary Task Description	Secondary Task Description	Significant Finding
Broadbent, 1958	8 NH adults	Word recognition using List 3 of the W-22 at 0, -200 Hz and -300 Hz downward transposed conditions each at 0 and 680 Hz high-pass filtering.	High speed visual tracking in which participants were required to keep a pointer on a line of contacts.	Under various conditions of distorted speech: 1) speech intelligibility scores were maintained for the primary task, and, 2) visual tracking accuracy performance decreased (especially with frequency transposition).
Rabbitt, 1966	Exp 1: 29 NH adults (19-53, M=39) Exp 2: 14 NH adults (17-25, M=23)	Word recognition in quiet and noise (i.e., +10 dB SNR)	Memory for primary task words	When noise was added, intelligibility remained high for the primary task but errors on the memory task increased.
Downs & Crum, 1978	49 NH adults (18-25)	Word recognition at 20, 35, 50 dB SL reference to each participant's PTA in quiet and at +6 dB SNR	Reaction time to respond to light probe	Reaction times to the light probe were significantly longer in the noise condition compared to the quiet condition irrespective of the sensation level.
Downs, 1982	23 adults with hearing loss (29-68, M=51) – with and without hearing aids	Speech recognition at 45 dB HL and 0 dB SNR, with and without hearing aids	Reaction time to respond to light probe	When adults with hearing loss wore their hearing aids, speech recognition was better and response time for the secondary task was significantly shorter, compared to the unaided condition.
...rstein,	48 NH young adults (M=19) who simulated a hearing loss with an earplug	Speech recognition at 65 dB SPL and +5 SNR	Reaction time to respond to light probe	Binaural listening produced better word recognition and better ease of listening ratings. Response times to the light probe were shorter with binaural listening compared to monaural indirect listening (when noise was directed to the ear that was not plugged). Binaural and direct listening (when noise was directed to the ear with the earplug) were equivalent.
		...ise listening task for ... and	Visually presented serial digit recall	Participants with hearing loss had more difficulty with digit memorization than NH listeners. More digits were forgotten when the memory retention interval was filled with speech compared to noise for those with NH and with hearing loss ... with hearing loss had more
Bourland-Hicks &	1...		... response ... to tactile pattern recognition task	improv... decreased. Exp 2: When 10 dB mo... added to the AV condition relative... condition, tactile response times slowed.
		... mean square (RMS) and +8 dB SNR	Visually presented serial digit recall	Regardless of instruction for which task should receive priority, significant dual-task decrements were seen for serial recall but not for word recognition. 7-8 year old children showed the greatest improvement in word recognition with the greatest decrease in serial recall.

Overview (I)

Main objective:

Development of a neurodiagnostic system, which reduces listening effort in hearing aid weares.

- development of a quantitative neurophysical model of brain structure interaction
  - simulation of attention effects on auditory late responses (ALRs)



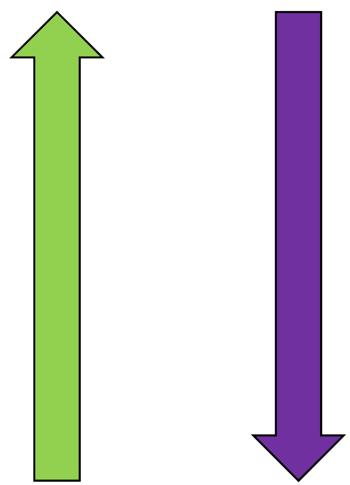
- analysis of a new approach to estimate listening effort
  - extraction of the instantaneous phase of ALR sequences
- validation of the new measure by experimental data (gained from different studies)

Listening - processing of auditory information

1. analytical stage: decomposition into discrete sensory elements
2. synthetical stage: recombination into a perceptual stream

bidirectional, complementary mechanism

bottom-up
exogenous,
purely data-driven,
effortless



top-down
endogenous,
subconsciously/
consciously driven,
effortful

Bregman, A. S. (1990). MIT Press, Cambridge

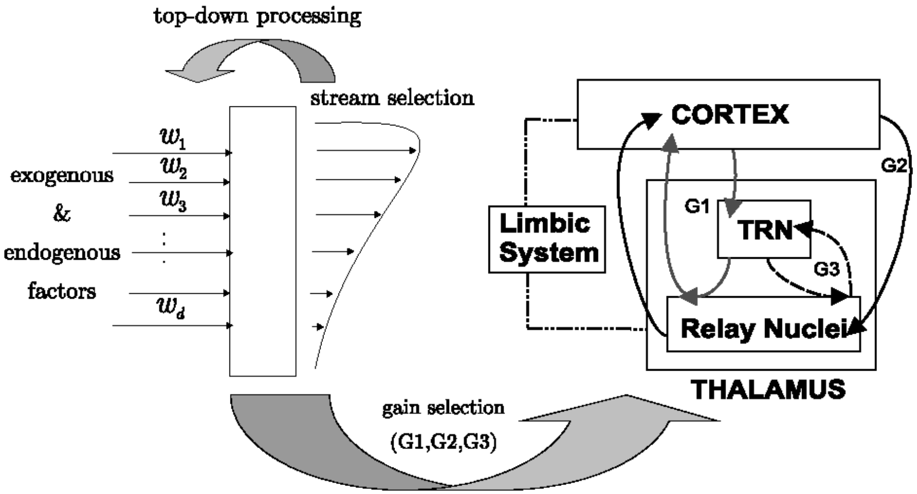
Kahneman, D. (1973).
Prentice Hall, EnglewoodCliffs

Model: endogenous augmentation - ASA

endogenous, effortful modulation:
perceptual filling
phonemic restoration
serial stream scanning
....

degraded automatic stream formation:
missing fine structure
suppressed frequencies
missing modulations
....

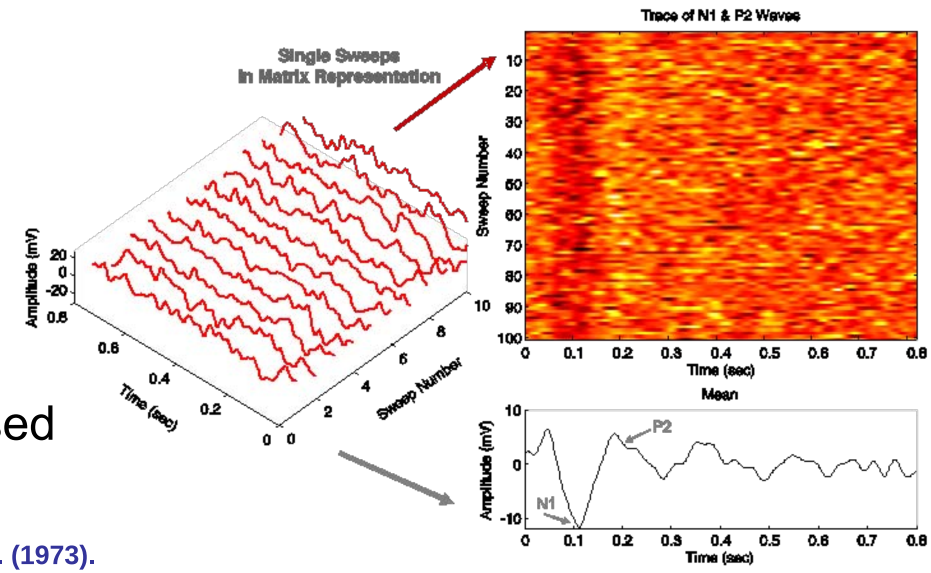
Shinn-Cunningham, B. G., & Best, V. (2008). *Trends in Amplification, 12*(4), 283-299



C Trenado, L Haab, DJ Strauss.
IEEE Trans Neural Syst Rehabil Eng. pp. 17:46-52, 2009

Attention Correlates in ALRs

Attention Effects on ALRs



- N1 wave
  - influenced by exogenous and endogenous factors
  - reflects selective attention
  - amplitude is enhanced by increased attention to the stimulus

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). *Science, 182*(4108), 177-180.
Näätänen, R., & Michie, P. T. (1979). *Biological Psychology, 8*(2), 81-136

- Model of corticothalamic feedback dynamics
  - predicts endogenous and effortful corticofugal modulations of ALR single sweeps using large-scale ALR simulations
  - predicts larger (instantaneous) phase synchronization stability for an increased endogenous modulation of the bottom-up data in the range of the N1 wave

D. J. Strauss, F. Corona-Strauss, C. Trenado, C. Bernarding, W. Reith, M. Latzel and M. Froehlich. Cogn Neurodyn (2010); 4(2):119-31.

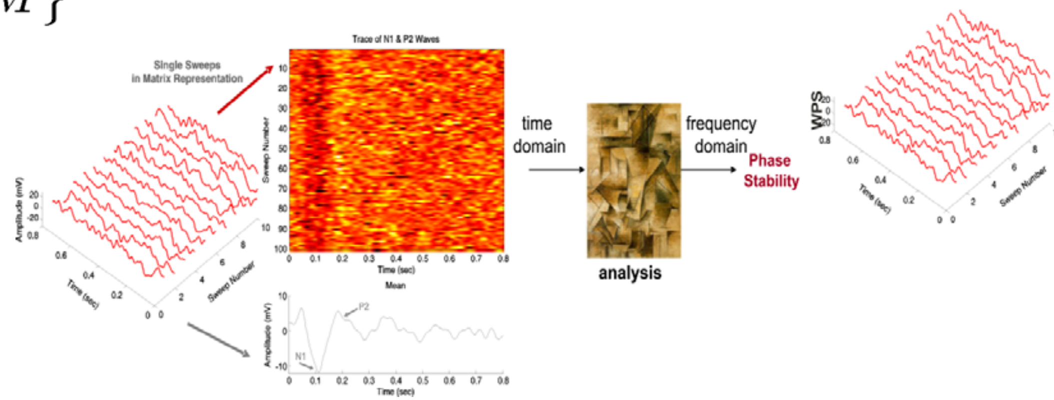
D. J. Strauss, F. I. Corona-Strauss and M. Froehlich. Conf Proc IEEE Eng Med Biol Soc, pp. 1777-1780, 2008

Extraction of Neural Correlates (I)

Calculation of the Synchronization Stability

- set of *M* ALR sweeps

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



- complex wavelet transform

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

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

- we define the wavelet phase synchronization stability (WPSS) by

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

- the WPSS was calculated for *M* = 100 target stimuli using a scale of *a* = 40

Extraction of Neural Correlates (II)

Synchronization Stability and Listening Effort

- we define the wavelet phase synchronization stability (WPSS) by

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

- we suggest for a fixed *a* and *b* and a suitable experimental paradigm

$$\text{Listening Effort} \propto \Gamma_{a,b}(\mathcal{X})$$

- we define the measure Listening Effort (LE) as the mean of the WPSS in the range of the N1-wave

- the larger the WPSS, the larger the cognitive effort to solve an auditory paradigm

D. J. Strauss, F. Corona-Strauss, C. Trenado, C. Bernarding, W. Reith, M. Latzel and M. Froehlich.Cogn Neurodyn (2010); 4(2):119-31.

Bernarding C, Corona-Strauss FI, Latzel M, Strauss DJ. Conf Proc IEEE Eng Med Biol Soc. 2010;1:6817-20

Overview: Studies

Comparison: Experiment vs. Model (Feasibility Study)*

D. J. Strauss, F. I. Corona-Strauss, C. Trenado, C. Bernarding, W. Reith, M. Latzel and M. Froehlich. Cogn Neurodyn (2010); 4(2):119-31.
D. J. Strauss, F. I. Corona-Strauss , and M. Froehlich. Conf Proc IEEE Eng Med Biol Soc., 2008, 1777-1780.

Stimulus effects (different noise types, noise onsets)

F.I. Corona-Strauss, C. Bernarding, M. Latzel, and D.J. Strauss. In Proceedings of the 5th International IEEE EMBS Conference on Neural Engineering, pp. 140-143, 2011.

Investigation of later ALR components (P300 component) and extraauditive factors

C. Bernarding, D.J. Strauss , M. Latzel, F. I. Corona-Strauss. Conf Proc IEEE Eng Med Biol Soc. 2010;1:6682-5

Extraction of the WPSS in a more realistic listening environment*

C. Bernarding, F. I. Corona-Strauss, M. Latzel , D. J. Strauss . Conf Proc IEEE Eng Med Biol Soc. 2010;1:6817-20

Extraction of the WPSS in different age groups and hearing impaired persons*

C. Bernarding, D.J. Strauss, R. Hannemann, M. Latzel, H. Seidler, U. Jobst, A. Bellagnech, M. Landwehr , and F.I. Corona-Strauss
Conf Proc IEEE Eng Med Biol Soc. 2011, 2323-2326.
C. Bernarding, D.J. Strauss, R. Hannemann et al., 2013. Brain Research Bulletin

Comparison:
Experiment vs. Model
(Feasibility Study)

Experimental Paradigm and Subjects

Experimental Paradigm

- auditory stimuli: pure tones (duration:40ms)
- set of paradigms
  - „**Difficult Paradigm (DP)**“: three tones (1kHz, target:1.3kHz, 1.6kHz)
  - „**Easy Paradigm (EP)**“: three tones (0.5kHz, target:1.3kHz, 2.1kHz)
- enhancement of the entropy of the paradigms
  - tones had randomized order and randomized interstimulus intervall of 1-2 s
  - maximum effort is required to detect the target tone (response button)
- presentation at 70 dB SPL to the right ear
  (calibration, EN 60645-3: 2007, Test signals of short duration)

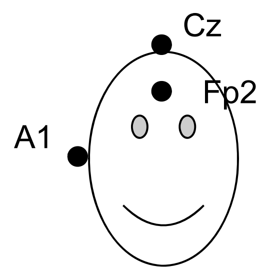
Subjects

- 20 subjects (27 ± 4.1 years,11 male, 9 female)
- student volunteers, no history of hearing problems
- normal hearing thresholds (< 15 dB HL)

Data Acquisition and Inclusion Criteria

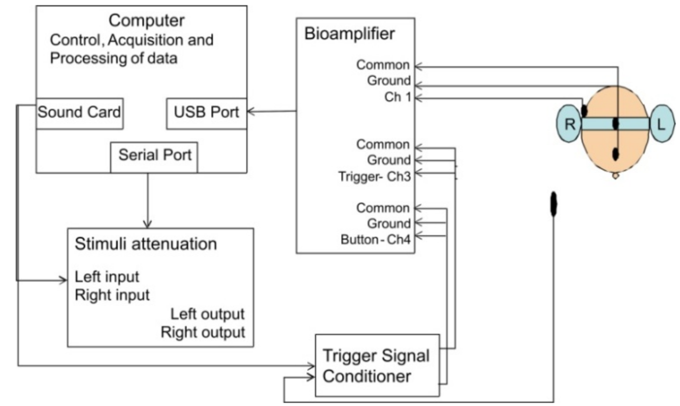
Data Acquisition

- biosignal amplifier
- sampling frequency: 512 Hz
- artifacts: rejected by an amplitude threshold of 50 µV
- bandpassfilter: 1 to 30 Hz



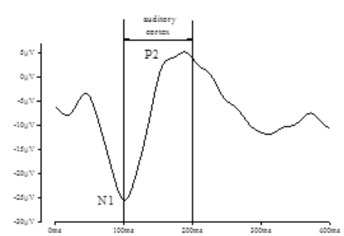
- Ag/AgCl-electrodes
  - right mastoid (ipsilateral to the stimulus), vertex (common reference), upper forehead (ground)
  - electrodes impedances < 5kΩ

Experimental Setup



Inclusion Criteria

- identifiable waveform of the N1-P2-complex



20 included subjects

Results (I): Comparison Experiment vs. Model

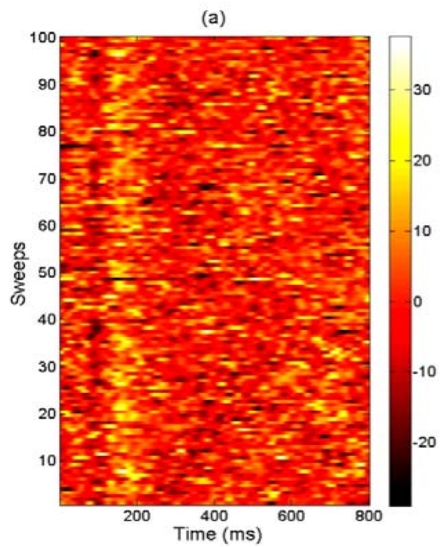
Single-Sweep-Matrices

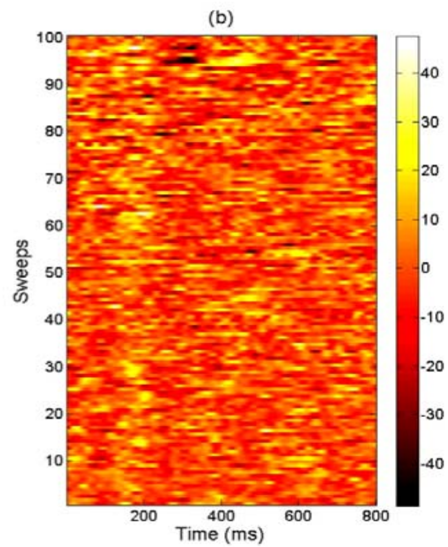
Grand Average of the WPSS

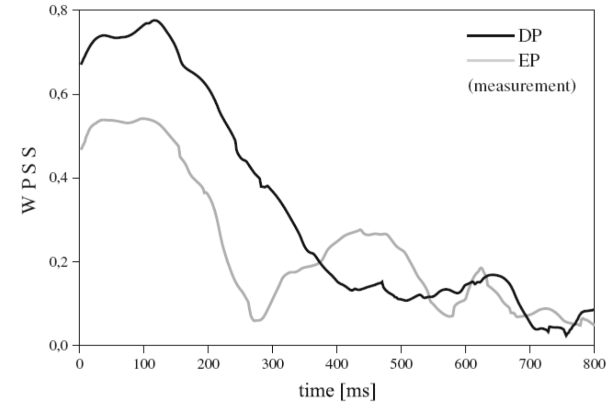
DP

EP

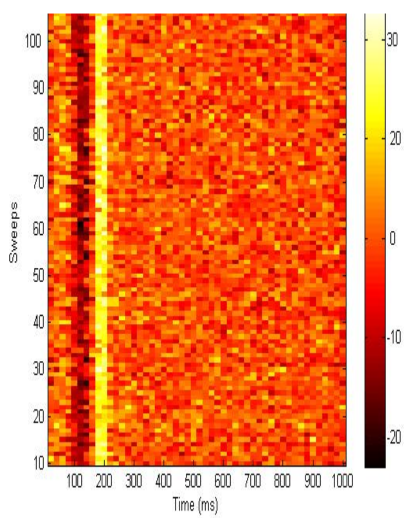
experimental data

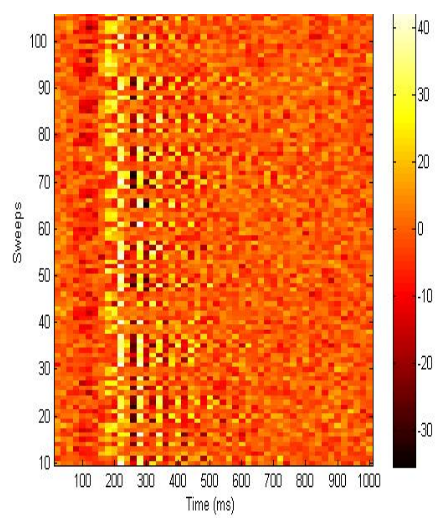


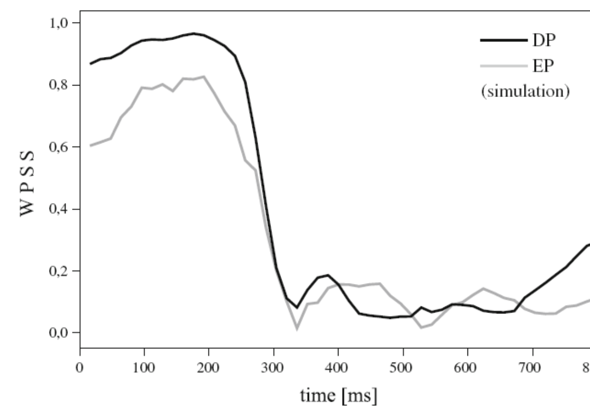




simulated data





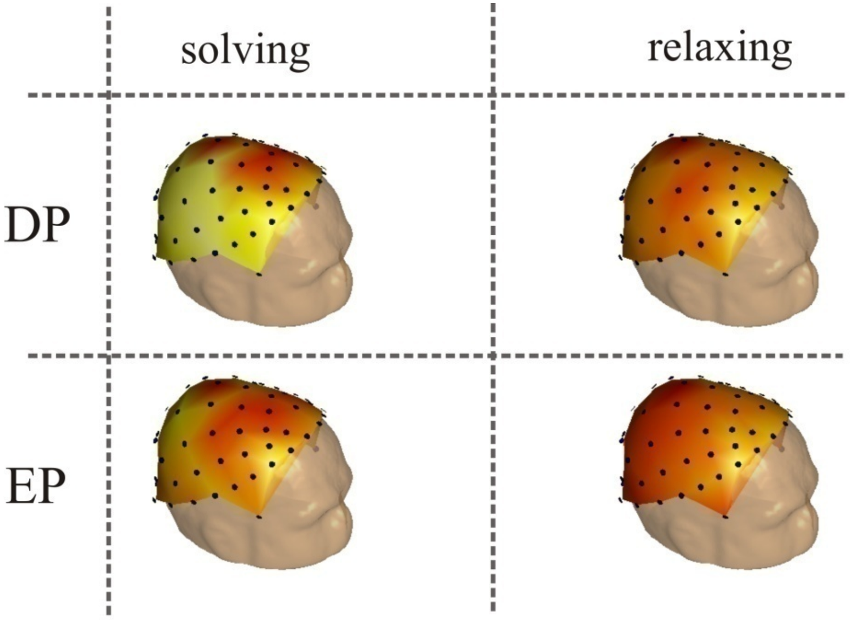


D. J. Strauss, F. Corona-Strauss, C. Trenado, C. Bernarding, W. Reith, M. Latzel and M. Froehlich. Cogn Neurodyn (2010); 4(2):119-31.

Results (II): Topological Mapping of the WPSS

Individual Result

- 64 channel recording
- WPSS for the target tone is much larger in temporal and parietal areas
  - for the difficult compared to the easy condition
  - for solving the paradigm compared to the relaxation phase



D. J. Strauss, F. Corona-Strauss, C. Trenado, C. Bernarding, W. Reith, M. Latzel and M. Froehlich. Cogn Neurodyn (2010); 4(2):119-31.

Extraction of the WPSS in a more realistic listening environment

Experimental Paradigm

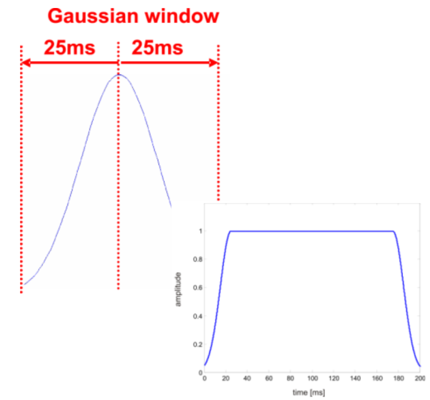
- auditory stimuli: consonant-vowel syllables (female voice, adapted, calibrated (EN 60645-3: 2007))

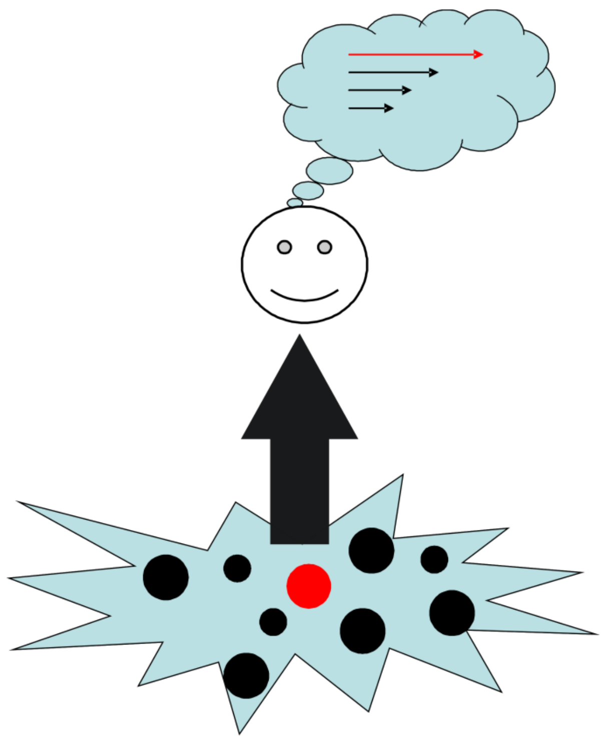
- set of paradigms
  - „**Difficult Syllable Paradigm (DSP)**“: different plosives, same vowel
  - „**Easy Syllable Paradigm (ESP)**“: different plosives and different vowels

- maximum entropy paradigms
  - randomized order of the syllables and the interstimulus interval (1-2s)

- the paradigms were embedded in female multi-talker babble noise (SNR +5dB)

- intensity level: 65 dB SPL





Subjects and Inclusion Criteria

Subjects

- 21 subjects (25 ± 3.52 years, 12 male, 9 female)
- student volunteers
- no history of hearing problems
- normal hearing thresholds (< 15 dB HL)

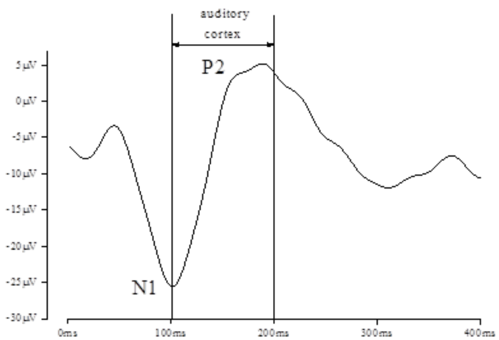
Inclusion Criteria

- identifiable waveform of the N1-P2-complex
- 80% correctly detected target syllables

→ 18 included subjects

Subject‘s instruction

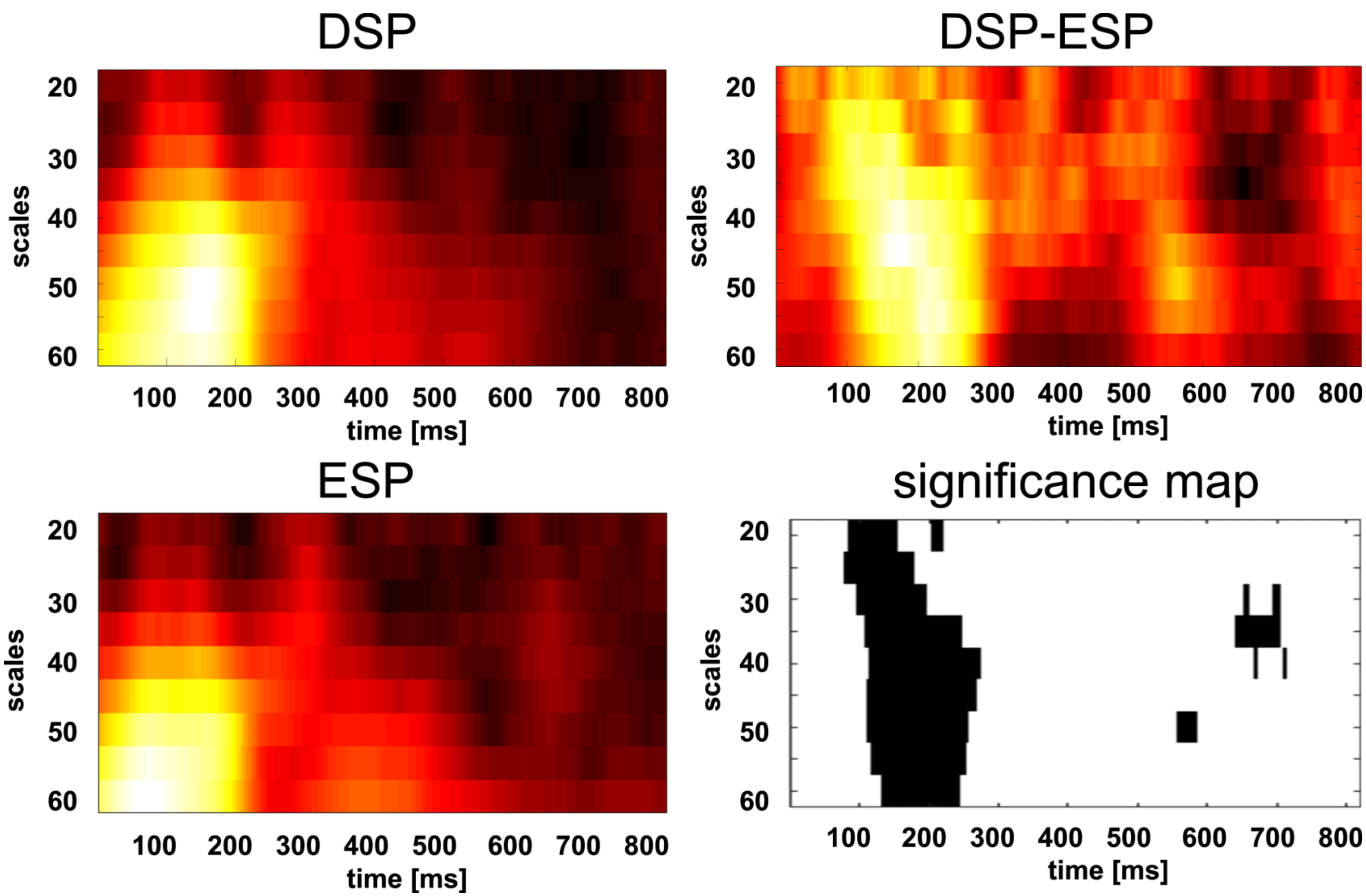
- detection of the target stimuli (response button)
- ignoring the background noise



Results (I): Grand Average of the WPSS

Grand Average of the WPSS (different scales)

scales a	frequency
60	4.27 Hz
50	5.12 Hz
40	6.40 Hz
30	8.53 Hz
20	12.80 Hz



black areas: significant difference ($p<0.05$)

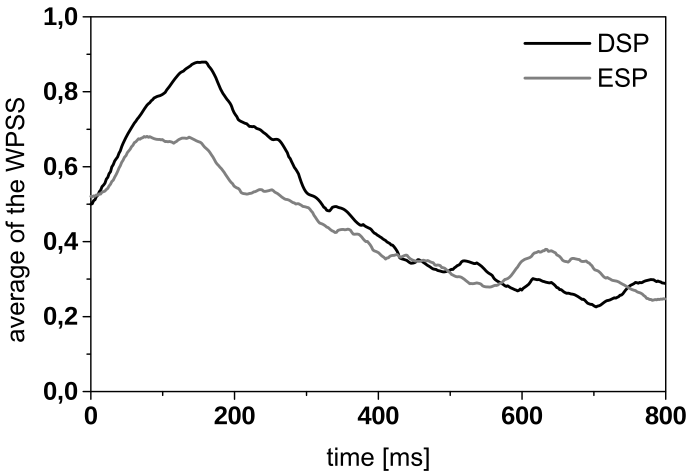
Bernarding C, Corona-Strauss FI, Latzel M, Strauss DJ.
Conf Proc IEEE Eng Med Biol Soc. 2010;1:6817-20

Results (II): Grand Average of the WPSS

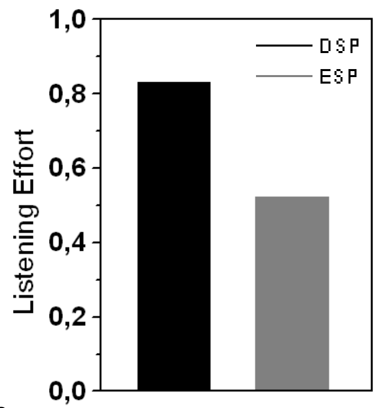
Grand Average of the WPSS

(over all the 18 subjects, M=70 sweeps, scale a=40)

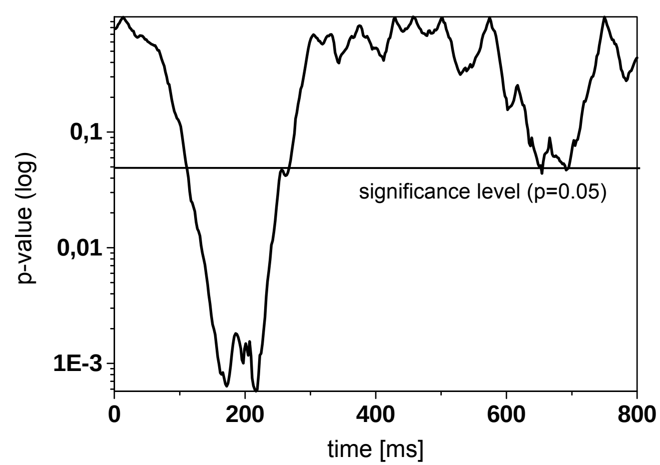
grand normalized average of the WPSS



Listening Effort-Levels

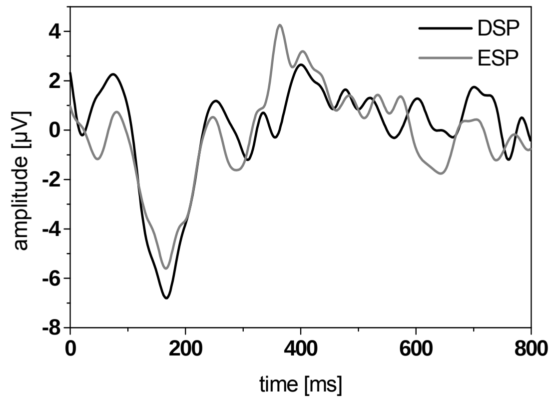
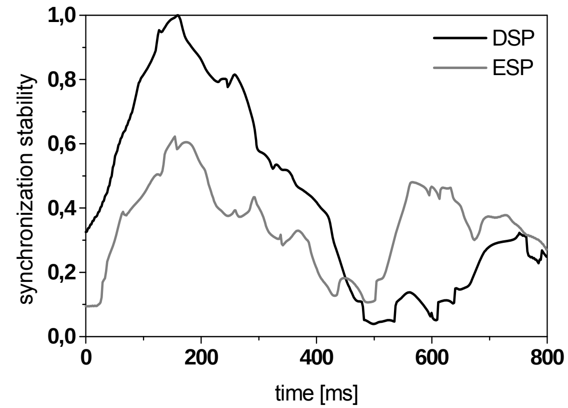
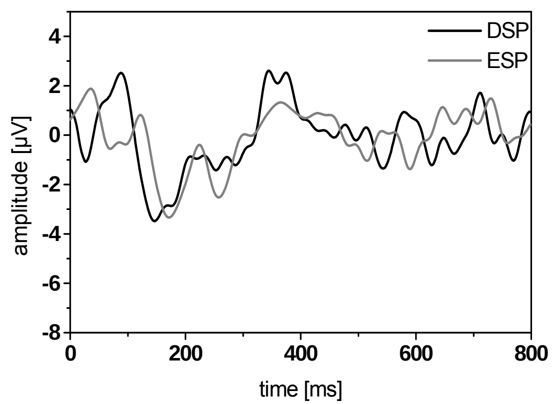
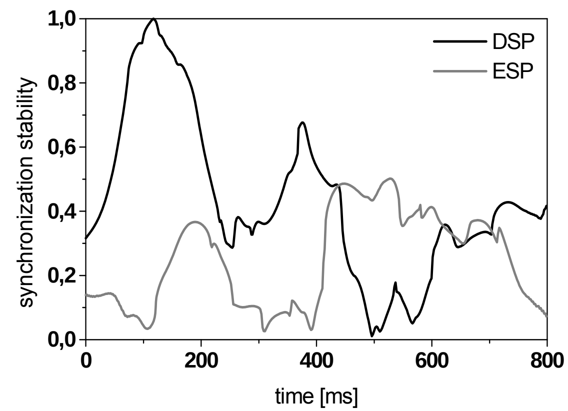


time-resolved one way ANOVA



Bernarding C, Corona-Strauss FI, Latzel M, Strauss DJ.
Conf Proc IEEE Eng Med Biol Soc. 2010;1:6817-20

Results (III): Individual Results

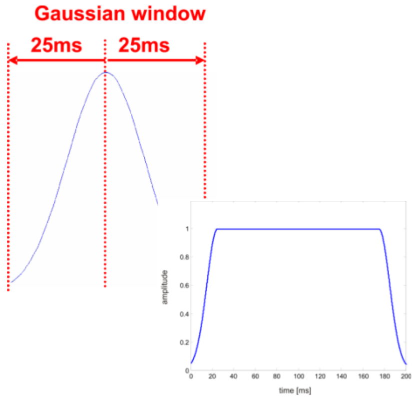
	Auditory Late Responses	Synchronization Stability
„good" ALR example		
„bad" ALR example		

Bernarding C, Corona-Strauss FI, Latzel M, Strauss DJ.
Conf Proc IEEE Eng Med Biol Soc. 2010;1:6817-20

Extraction of the WPSS in different age groups and hearing impaired persons

Experimental Paradigm

- auditory stimuli: consonant-vowel syllables (female voice, adapted, calibrated (EN 60645-3: 2007))

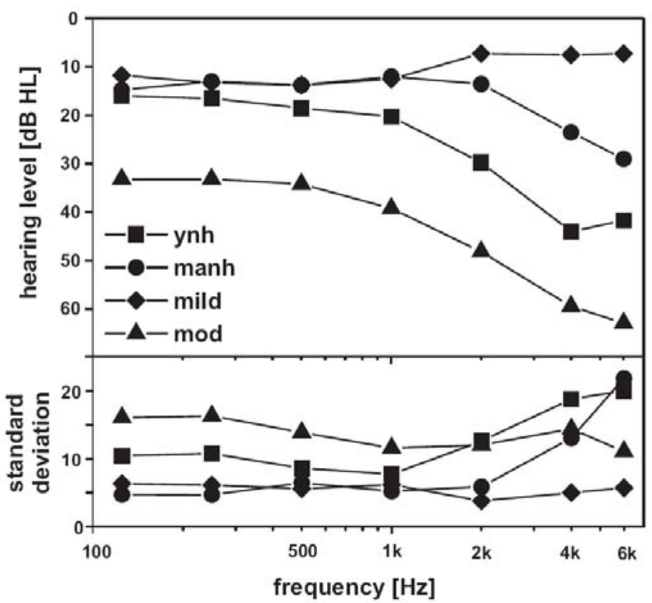


- set of paradigms
  - „**Difficult Syllable Paradigm (DSP)**“: different plosives, same vowel
  - „**Easy Syllable Paradigm (ESP)**“: different plosives and different vowels
- maximum entropy paradigms
  - randomized order of the syllables and the interstimulus interval (1-2s)
- intensity level
  - 65 dB SPL (normal hearing, mild hearing impaired subjects)
  - adjusted intensity (moderate hearing impaired subjects)

Subjects

A total of 94 subjects participated in the study

- 24 young subjects (13 m/11 f),
  normal hearing levels
  (ynh; aged 21 to 35 years, mean age: 25.25 ± 4.01 years)
- 21 middle-aged subjects (9 m/13 f)
  normal hearing levels
  (manh; 40 to 60 years, mean age: 51.15 ± 5.64 years)
- 25 middle-aged subjects (15 m/10 f)
  with mild hearing loss
  (mild; 45 to 63 years, mean age: 51.87± 5.82 years) ,
- 24 middle-aged subjects (9 m/15 f)
  moderate hearing loss
  (mod; 43 to 57 years, mean age: 51.12 ± 5.53 years)



C. Bernarding, D.J. Strauss, R. Hannemann et al., 2013

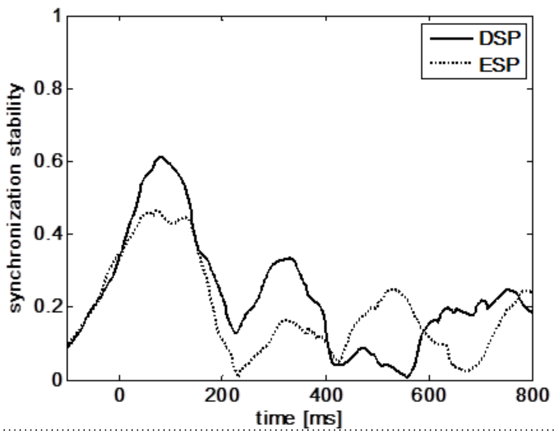
Individual Results

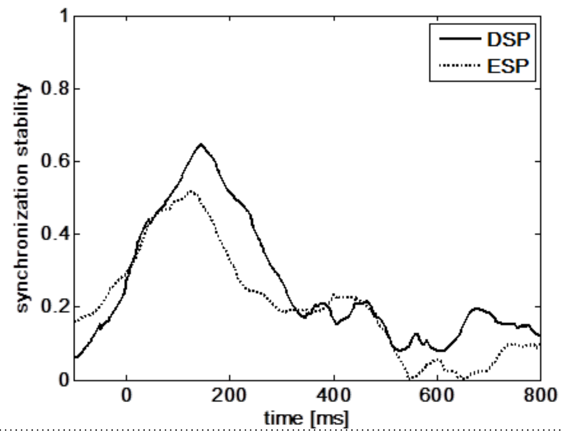
Normal hearing subject
(PTA: 18.75±24.28, 57 years)

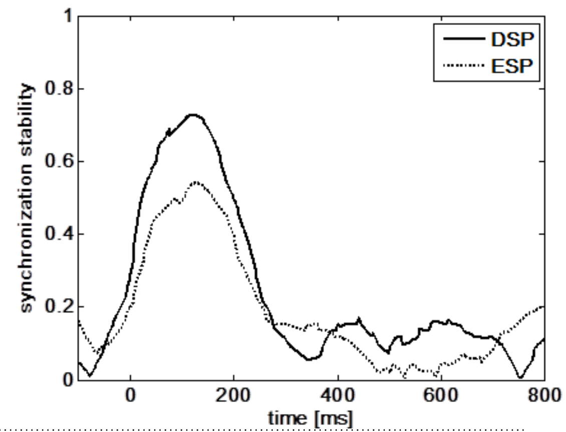
Mild hearing impaired subject
(PTA: 33.75±9.31, 55 years)

Moderate hearing impaired subject
(PTA:45±21.98, 50 years)

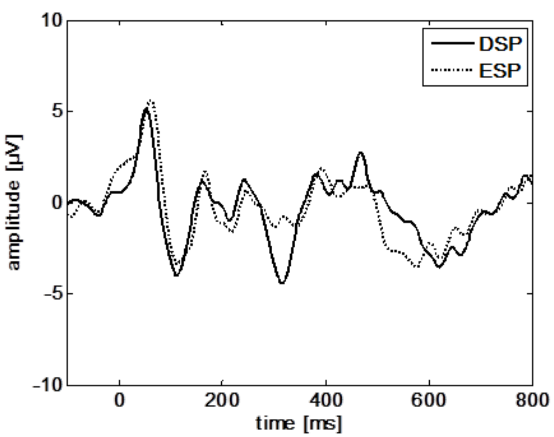
WPSS

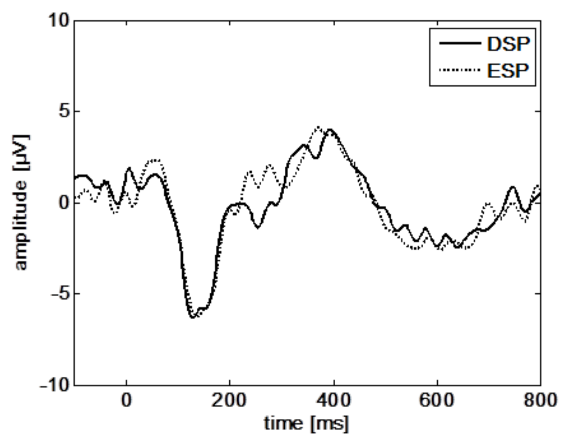


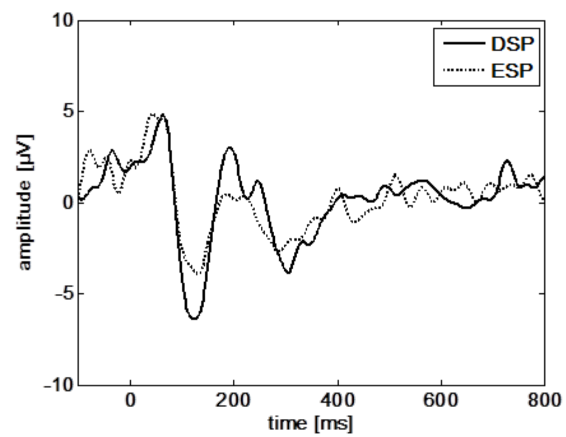




ALRs







Summary and Conclusions

- listening effort correlates can be assessed by the instantaneous phase synchronization stability of auditory late responses in
    - different listening conditions
    - different age groups
    - normal hearing persons
    - hearing impaired persons

WPSS was extracted in a total of **160** subjects

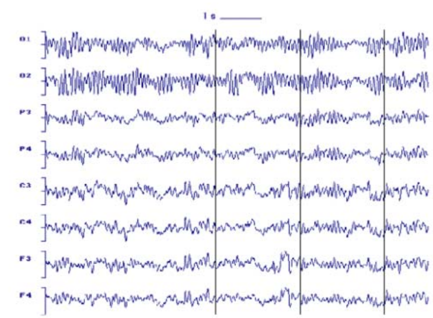
- strong theroretical basis for the experimental results
    - development and validation of a new neuroscientific/ corticothalamic model of selective attention/ listening effort

- WPSS is a solid measure (compared to the fragile amplitude information)

Overview (II)

Main objective:

Development of a neurodiagnostic system, which reduces listening effort in hearing aid weares.



- analysis of a new approach to estimate listening effort
  - extraction of the instantaneous phase of the oscillatory EEG
  - calculation of the angular entropy

Angular Entropy (I): Wrapped Phase

Let $\psi_{a,b}(\cdot) = |a|^{-1/2}\psi((\cdot - b)/a))$ where $\psi \in L^2(\mathbb{R})$ is the wavelet with $0 < \int_{\mathbb{R}} |\Psi(\omega)|^2 |\omega|^{-1} \mathrm{d}\omega < \infty$ ($\Psi(\omega)$ is the Fourier transform of the wavelet), and $a, b \in \mathbb{R}$, $a \neq 0$. The wavelet transform $\mathcal{W}_\psi : L^2(\mathbb{R}) \longrightarrow L^2(\mathbb{R}^2, \frac{\mathrm{d}a\mathrm{d}b}{a^2})$ of a signal $x \in L^2(\mathbb{R})$ with respect to the wavelet ψ is given by the inner L^2–product $(\mathcal{W}_\psi x)(a,b) = \langle x, \psi_{a,b}\rangle_{L^2}$. The instantaneous phase of a signal $x \in L^2(\mathbb{R})$ can be achieved by taking the complex argument from the complex wavelet transform with the signal: $\phi_{a,b} = arg(\mathcal{W}_\psi x)(a,b))$. We divided the phase values into N bins and each bin has the probability $p_i, I = \{-\pi, -\pi + \frac{\pi}{10}, ..., +\pi\}$, with $\sum_i^N p_i = 1$. Then, the normalized angular entropy can be defined by

$$H = -\sum_{i \in I} \frac{p_i \cdot \ln p_i}{\ln N}.$$

First Study - Oscillatory Activity

Quantification of Listening Effort Correlates in the Oscillatory EEG Activity: A Feasibility Study

Corinna Bernarding, Daniel J. Strauss, Ronny Hannemann, and Farah I. Corona–Strauss

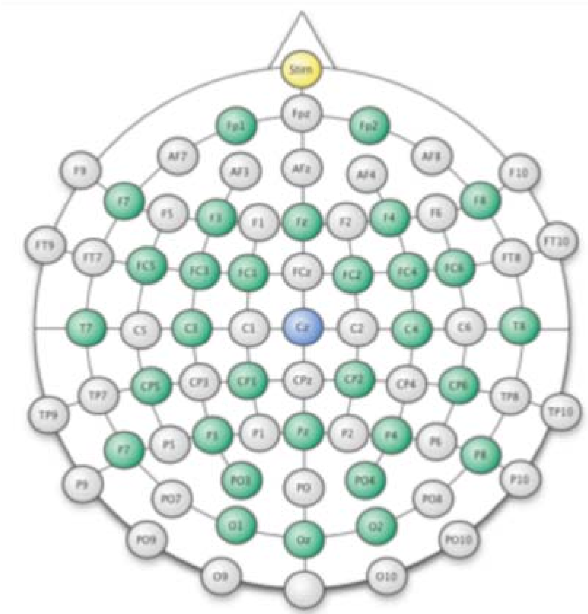
Focus: Angular Entropy as a possible new measure for the quantification of large-scale listening effort correlates.

- Assumption: Angular entropy reflects phase synchronization effects of the ongoing activities due to an increased attention on the relevant (speech) signal.
- We expect that smaller values of the angular entropy reflect a more ”ordered” process of the phase distribution.

First Study - Oscillatory Activity

Data acquisition

- EEG, 32 channels, fs=512Hz, Cz reference, forehead ground, impedances <5kOhm



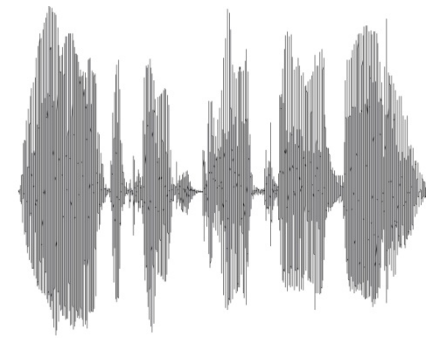
Data analysis

- Signals were filtered (0.5-40Hz)
- Extraction of the EEG data during the presentation of the sentence (trigger signal)
- Artifacts were rejected if either the maximum amplitude threshold exceeded ±70μV or the standard deviation exceeded ±40μV within a moving time window (window size: 50ms)

Study I

Paradigm 1 (PD1):
This paradigm consisted of the original sentences, presented without any background noise.

PD I

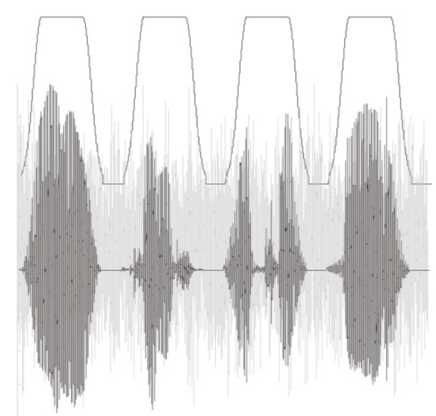


Paradigm 2 (PD2):
The second paradigm was built by the original Sentences, embedded in the speech simulating background noise (SNR of 0dB, cocktail-party environment).

PD II
(SNR 0dB)

Paradigm 3 (PD3):
25% of the information of each sentence was removed. The sentences were also embedded in the speech simulating background noise.

PD III
(SNR 10dB)



Study I

Stimulus presentation

- monaural (right side),intensity 65dB SPL
- duration of the complete experiment: approx. 40min

Subjects

- 13 normal hearing (<15dB HL) subjects (mean age 24.28±3.12 yrs, 7 F/ 6 M).
- 12 included subjects (too many EEG artifacts)

Instruction of the subjects

- **First part of the experiment (more active condition)**
  - pay attention to the sentence, not to the distracting background noise,
  - to follow each sentence/try to understand each sentence,
  - to repeat the last word of each sentence after the signal (response was noted by the experimenter).
  - After the presentation of each paradigm: subjective rating of the required listening effort.

- **Second part of the experiment (more passive condition)**
  - The subjects were instructed to relax, not to listen actively to the sentences, to repeat if the signal was presented (signals were randomly presented).

Listening Effort Scale

mühelos	sehr wenig anstrengend	wenig anstrengend	mittelgradig anstrengend	deutlich anstrengend	sehr anstrengend	extrem anstrengend

Study I

Power Spectrum Analysis

In order to compare the new proposed measure with traditional analysis methods, we analyzed also the power spectrum of the EEG data.

For the calculation of the power spectrum of each band, the Fourier transform was applied.

The following frequency bands were analyzed:

- Theta (4-8Hz)
- alpha (8-12Hz)
- beta (12-30Hz)

C. S. Herrmann, M. Grigutsch, and N. A. Busch, *Event-related potentials: A methods handbook. Cambridge, MA: MIT Press, 2005,* ch. EEG oscillations and wavelet analysis, pp. 229–259.

Study I: Results

Listening Effort Scale

- a number was added to each level of the scale (ranging from 1 (very little effort) to 7 (extreme effort)).
- For each paradigm, the following ratings were obtained (mean ± s.d.):
- PD1: 1.16±0.38 (no effort),
- PD2: 2.75±0.96 (very little effort - little effort),
- PD3: 3.33±1.15 (little effort – moderate effort).

Speech Intelligibility

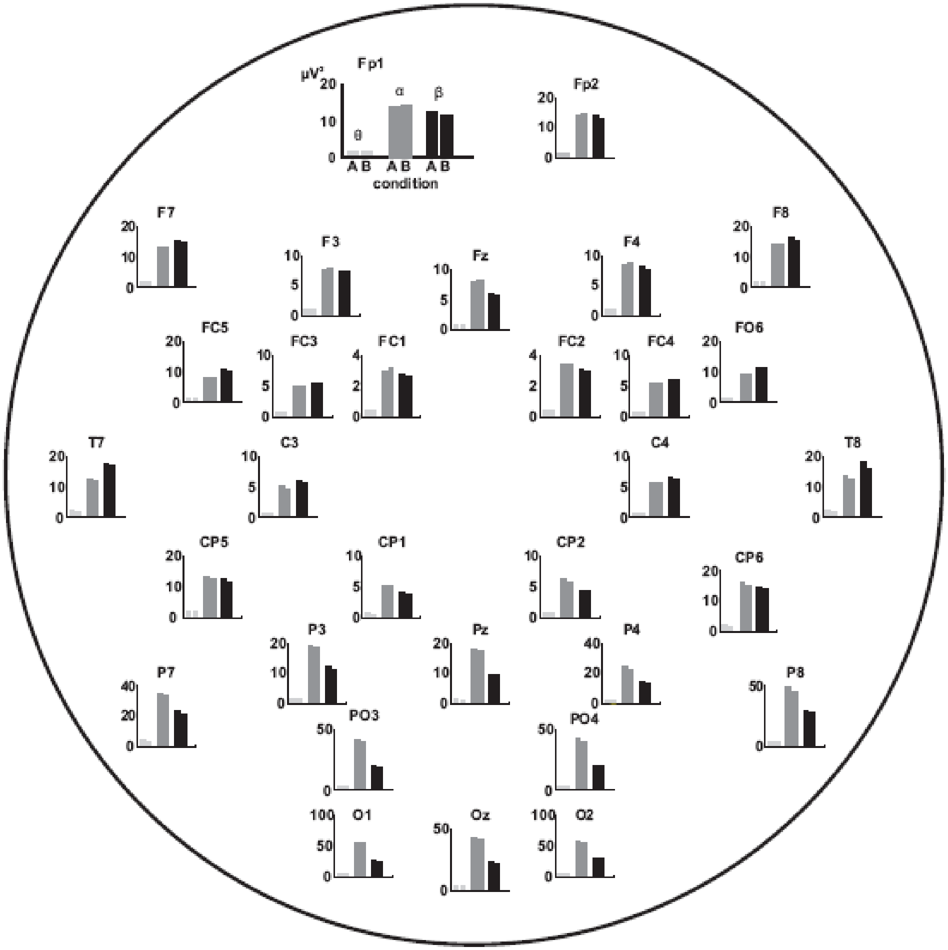
- All subjects could repeat correctly 100% of the last words of the first paradigm (PD1; original sentences).
- For the other paradigms, the performance was only slightly reduced:
- PD2 a mean of 97.91±1.62%
- PD3 a mean of 98.41±3.17%.

Study I: Results

EEG Power Spectrum

- The power for each frequency band and condition (A and B) is illustrated as a bar graph (from left to right (light grey to black): theta-, alpha- and beta band).

- None of the power spectra showed a statistical significance ((oneway) ANOVA, p>0.05) between the two conditions.



Results of the EEG power spectrum analysis for PD1 (representative for all paradigms;p>*0.05). The three main* blocks of the power spectrum correspond to one frequency band (left to right (light grey to black): theta-, alpha- and beta band). Each bar of one block corresponds to one condition (left: condition A, right: condition B).

Study I: Results

Angular Entropy

- Results of the ANOVA for the analysis of the angular entropy (cond. A vs. B) for each paradigm
- Only electrode positions are depicted, where the difference of the angular entropy between the conditions was significantly different($p<0.05$).
- The angular entropy was always significantly enhanced for condition B (relaxing part) compared to condition A (solving the paradigm) for the shown electrode positions.
- Most of the involved electrodes are located in the frontal areas (e.g. F3, F4, FC4) within the theta range.

ELECTRODE POSITIONS, IN WHICH THE (ONE-WAY) ANOVA TEST FOR THE ANALYSIS OF THE ANGULAR ENTROPY REVEALED SIGNIFICANT DIFFERENCES (CONDITION A VS. CONDITION B).

frequency band	scale	PD1	PD2	PD3
β	10	FC4	F3,FP2	-
	14	O3, F4	FC4	-
	16	F4, FC4	-	-
	18	F4	-	-
	22	FP2	-	FC5
α	24	-	PO4	-
	26	-	-	FC3
	30	-	T7	F8, FO6
	32	-	F3	-
	34	T7	FP1	-
	36	-	P4, F3	CP2
	38	-	P8	-
θ	40	-	-	T7,P8
	44	F3	F3,FP1,F2	-
	46	-	FP2	-
	48	F7, FC4	F4	T7
	50	F7	FC2	FC4, P8
	52	F8	CP2	-
	54	P7	OZ	P4
	56	-	-	CP6
	58	-	CP2	-
	60	PO3, T7	PO4	-

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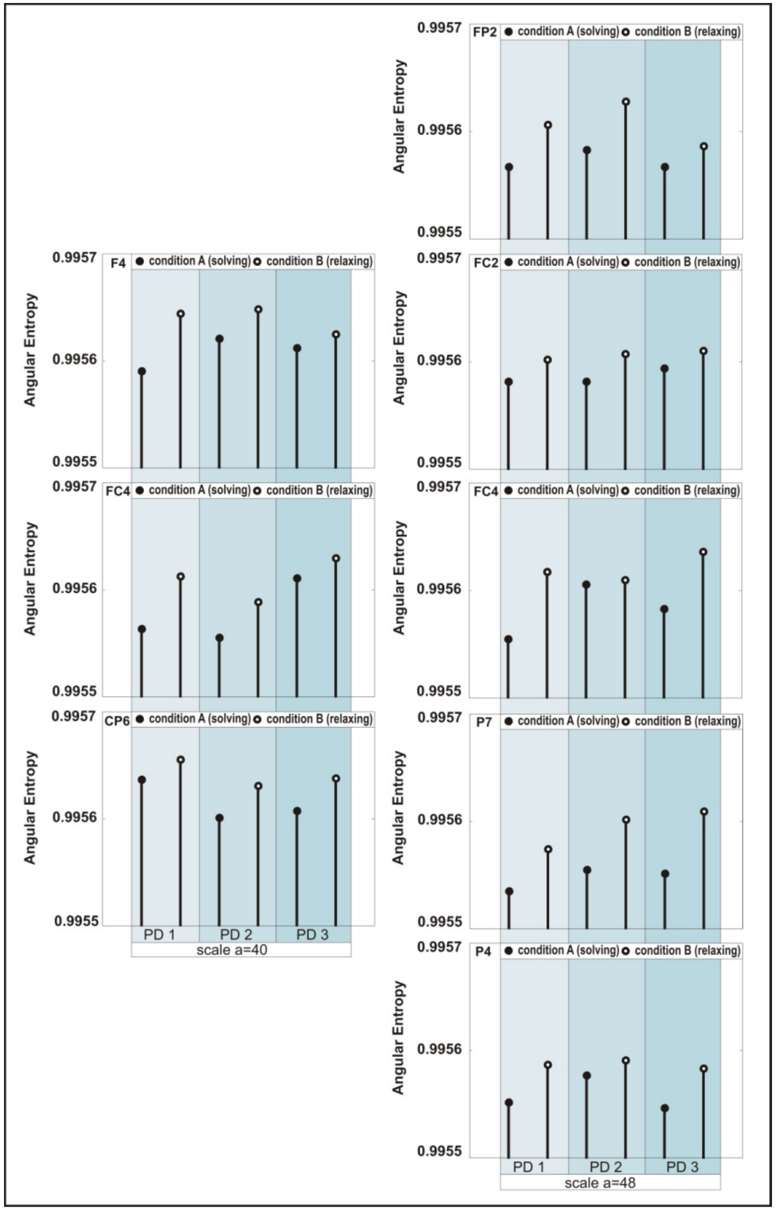
Hochschule für Technik und Wirtschaft des Saarlandes HTW

Study I: Results

Angular Entropy

- The grand averages of the angular entropy (over all the 12 included subjects) for two scales
  – a=40 (corresponds to the α/θ-border)
  – a=48 (corresponds to the center of the theta band)
- The angular entropy is enhanced for condition B (relaxing part) compared to condition A (solving the paradigm) .
- This means, that the angular phase for the effortful condition is not uniformly distributed, i.e. the phase is more ”ordered” and synchronized in these conditions



Study II

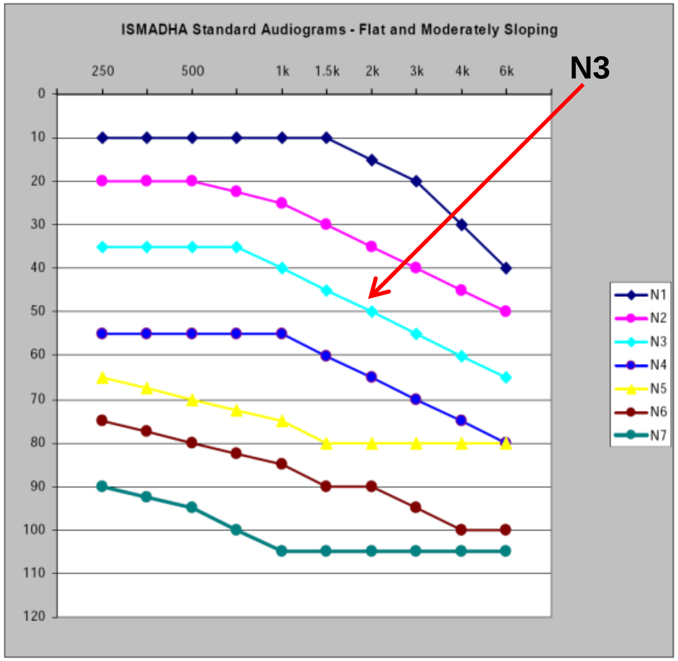
Objective

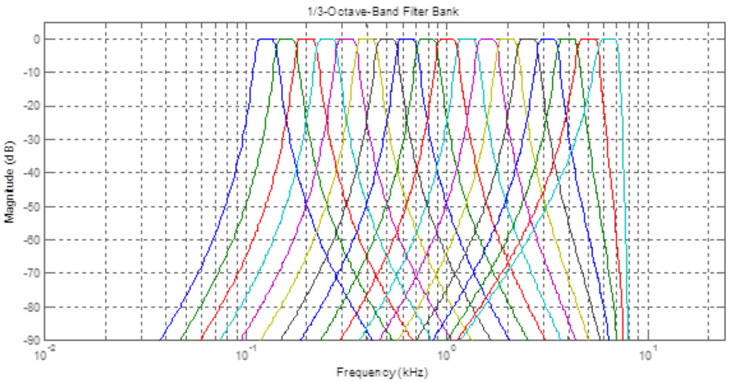
Estimating neural correlates of listening effort in realistic hearing aid settings by means of oscillatory EEG activity

Stimuli

- Speech material:
  - German sentence test (Oldenburger Sentence Test (OLSA) Each sentence has a five-words structure: subject - verb - numeral - adjective - object
  - filtered (1/3 octave band, 18channels, frequ. range 250-6kHz **(DIN EN 61260:1995)**)and attenuated speech material to simulate a moderate hearing loss (N3, IEC 60118-15:2008).

- Background noise:
  - „multitalker babble noise“
  - consists of 5 speech sequences (composed by 150 Sentences of the OLSA Test, male speaker). Each sequence was shifted in time by one sentence and finally, the sequences were added together.
  - the babble noise starts 5s before the presentation of the sentences **(Luts et al., 2010)**





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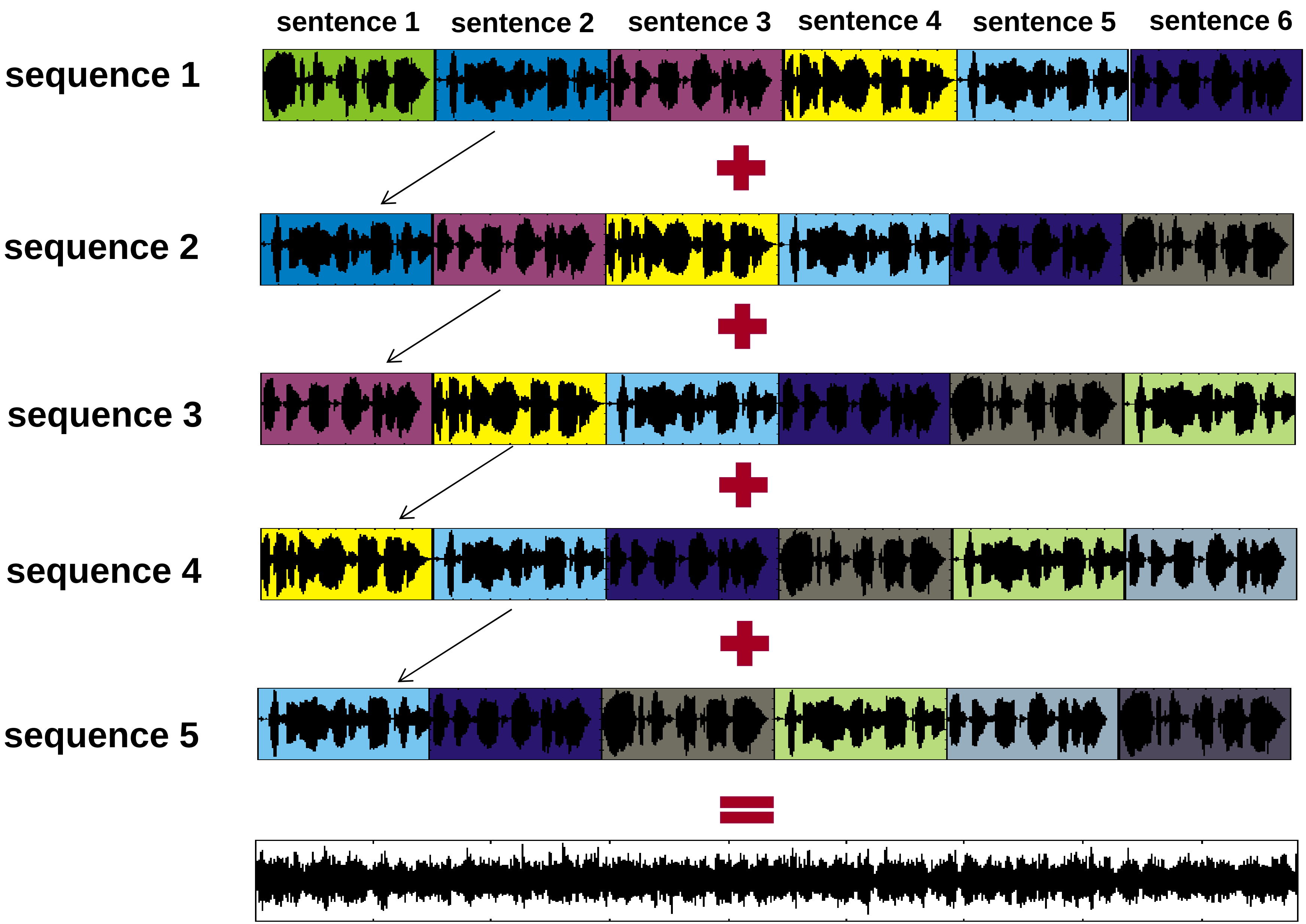
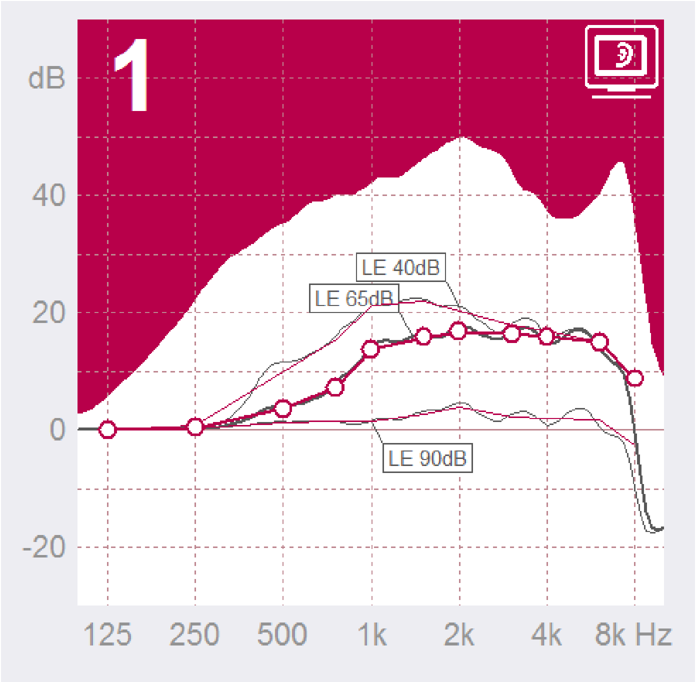
Design: Multitalker Babble noise



Experimental Paradigms

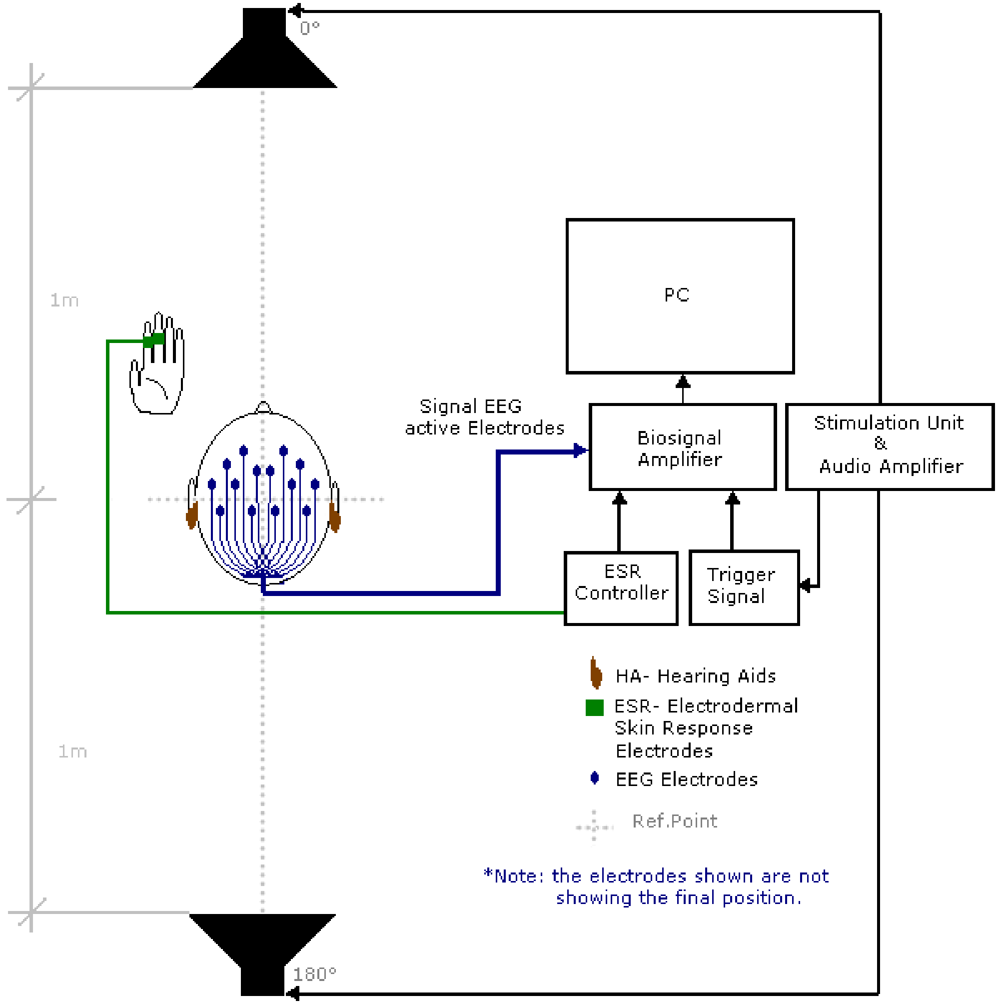
Auditory Paradigms (duration: 5min each)

- Test Ia: Presentation with hearing aid (Control Measurement, „First Fit") for acclimatization
  - Audiogram: moderate hearing loss **(N3, IEC 60118-15:2008).**
  - UCL 0.5,1,2,4kHz = 80dB HL
  - Mastergain: 18dB
  - Speech enhancement 8-15dB
- Test II: Gain reduction
  - Mastergain: 9dB
- Test III: Gain reduction in the speech area,
  - resulting in 11dB Mastergain
- Test IV: Reduction: Speech enhancement
  - to 4-5dB
- Test V: Increase: Speech enhancement
  - to maximum level 12-24dB
- Test VI: Omnidirectionale microphone
- Test VII: Automatic/ TruEar
- Test Ib: Presentation with hearing aid (Control Measurement, „First Fit", c.f.Test1a)



Study Design & Setup

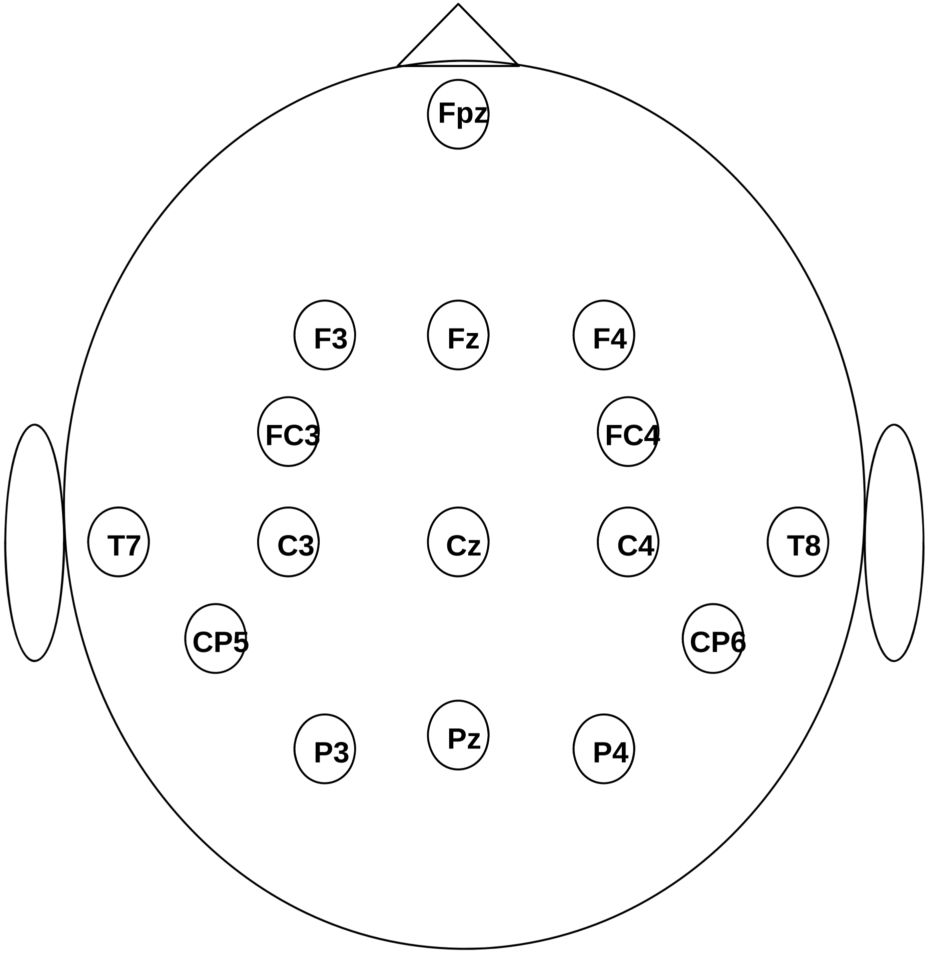
- Stimuli presentation:
  - –speech material: 60 dB SPL
  - –background noise: 60 dB SPL (SNR: 0 dB)
- Loudspeakers arrangement (S=Signal, N=Noise):
  - –Test Ia,b-IV.: S 0° N 0°
  - –Test VI-VII.: S 0° N 180°
- Auditory task
  - –Repetition of the last word (after tone- signalization (1kHz))
  - –Evaluation of listening effort by a subjective scale after each test



1 mühelos	2 sehr wenig anstrengend	3 wenig anstrengend	4 mittelgradig anstrengend	5 deutlich anstrengend	6 sehr anstrengend	7 extrem anstrengend

Data acquisition and Analysis

- Continuous EEG recording (Electrode positions according to 10/20 system, 16 channels)
- Extraction and analysis of the instantaneous angular phase entropy as possible objective measure of listening effort.



Subjects

Normal hearing subjects

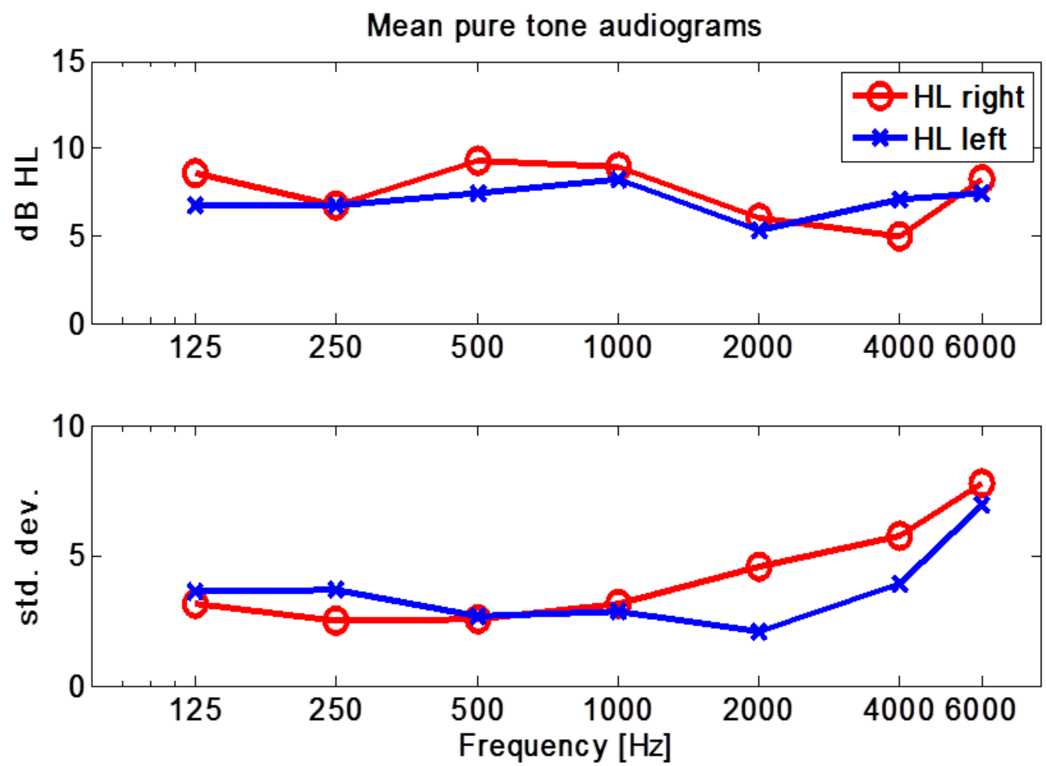
- 15 subjects (7m/8f)
- Mean age: 24.8±2.59 years

Inclusion criteria:

- 50 % of correctly recognized-repeated words in test 1b (control measurement)
- 85 % artefactfree EEG data

Included subjects:

- 14 subjects (7m/ 7f)
- Mean age: 24.78±2.69 years



Linear Fit: Different Approaches

Approach 1

- „pseudo“ frequency fa (wavelet transform) to fit the line
- Res. structure= unwrapped_phase - 2pi*t*fa;

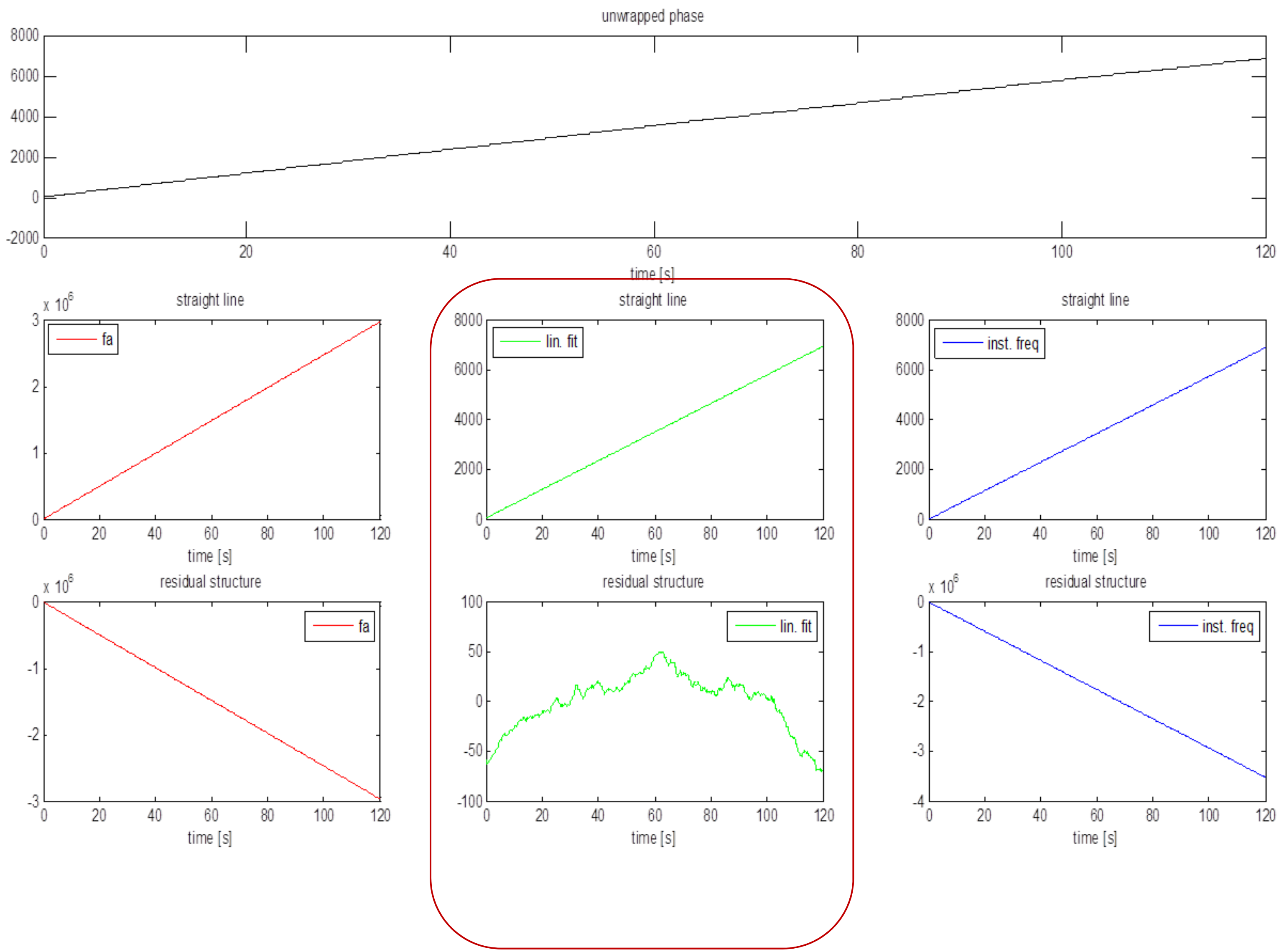
Approach 2

- Linear fit
- Res. structure = unwrapped_phase –linear fit
- c.f. phase modulated signals

Approach 3

- Calculation of the instantaneous frequency
- Fit a line using the mean of the instantaneous frequency
- Res. structure = unwrapped_phase - 2*pi*mean(instfreq)*t

Examples Linear Fit: Different Approaches



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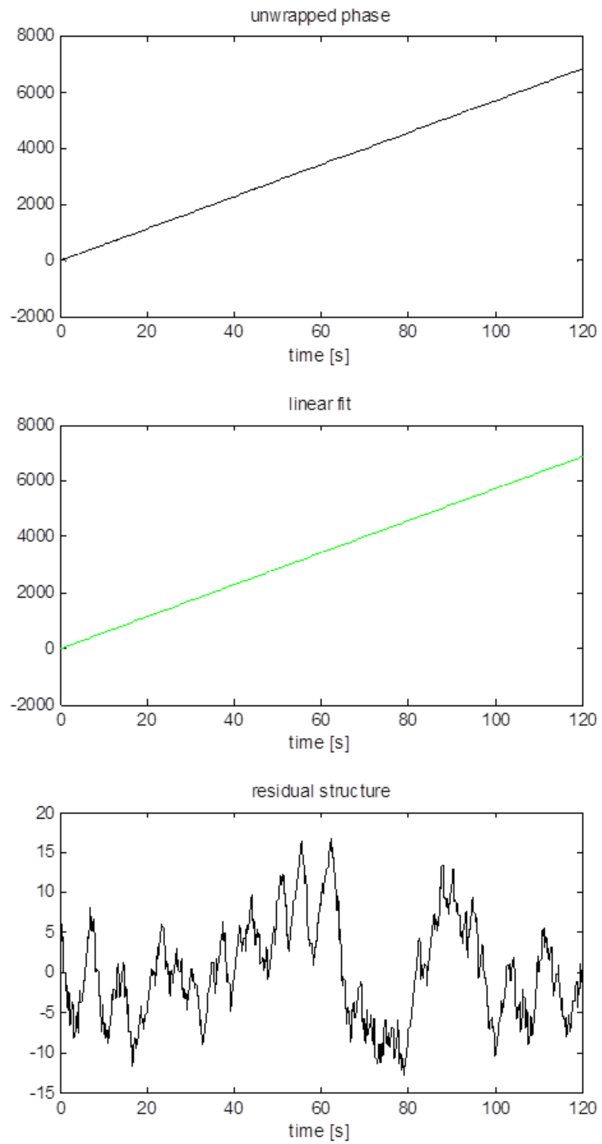
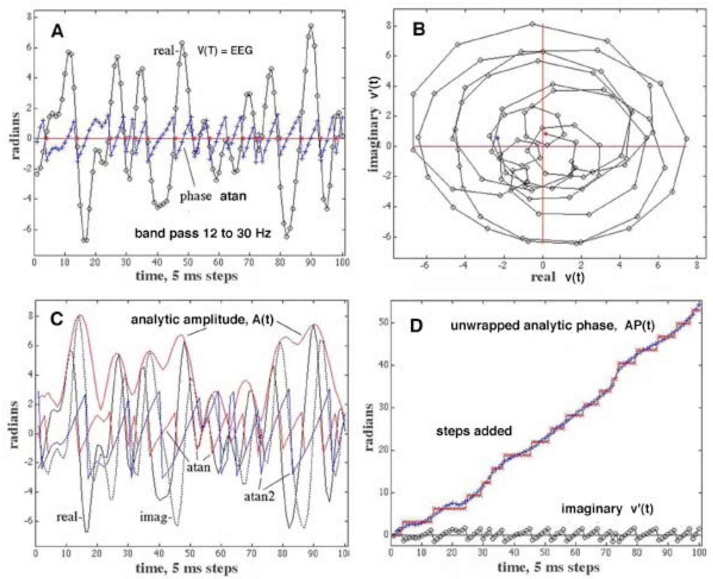
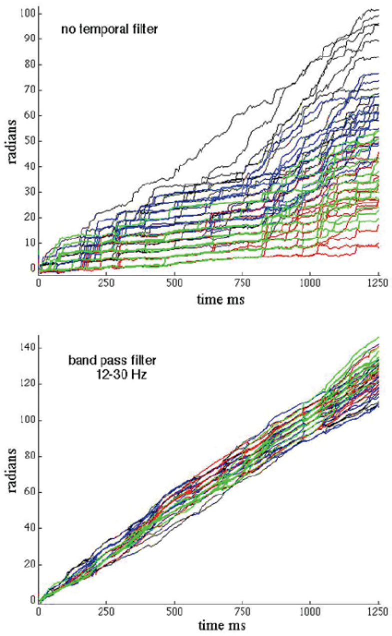
Instantaneous phase



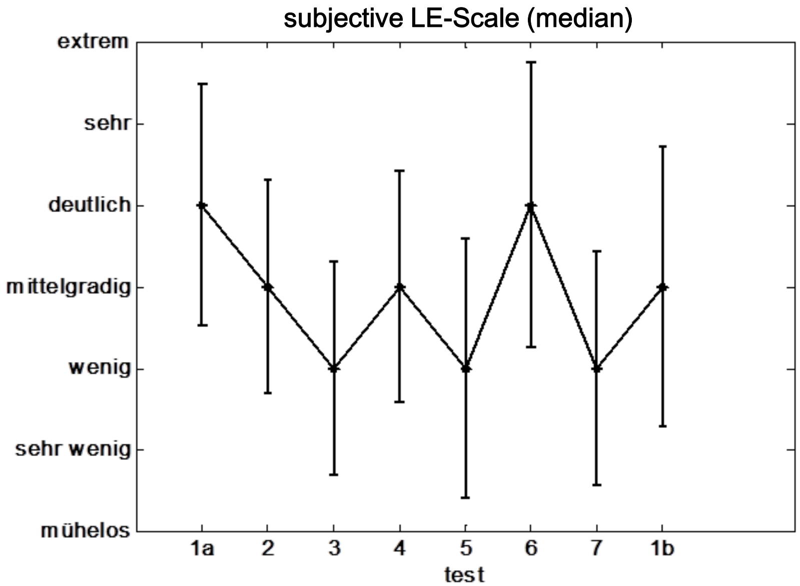


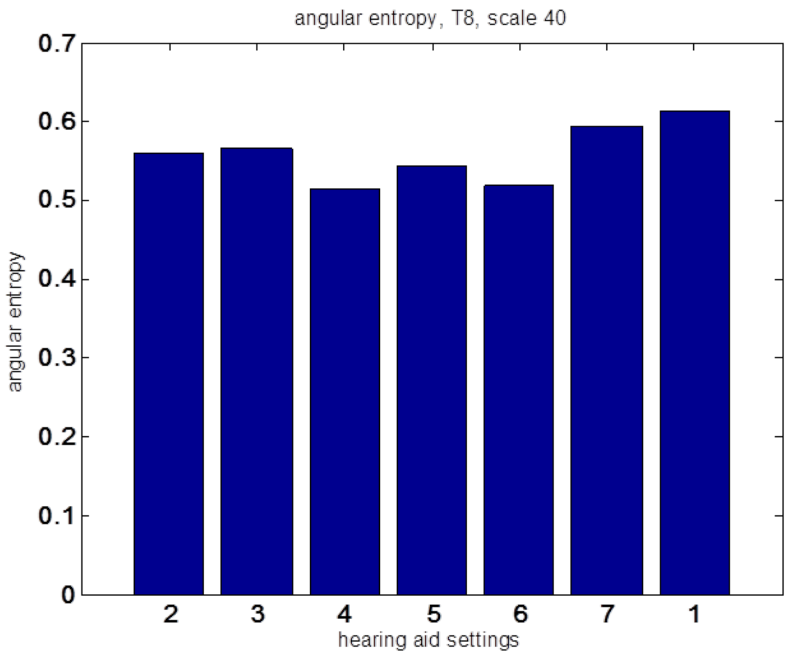


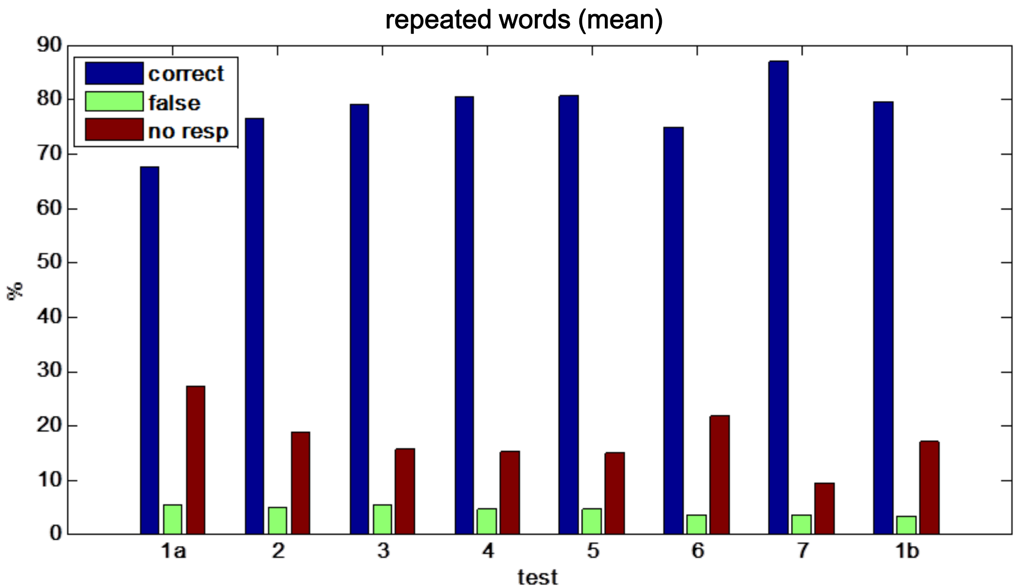
unwrapped phase-linear fit=residual structure

Freeman et. al (2003). Application of Hilbert transform to scalp EEG containing EMG. Human Brain Mapping 19(4):248-272

Results: Subjective LE scaling







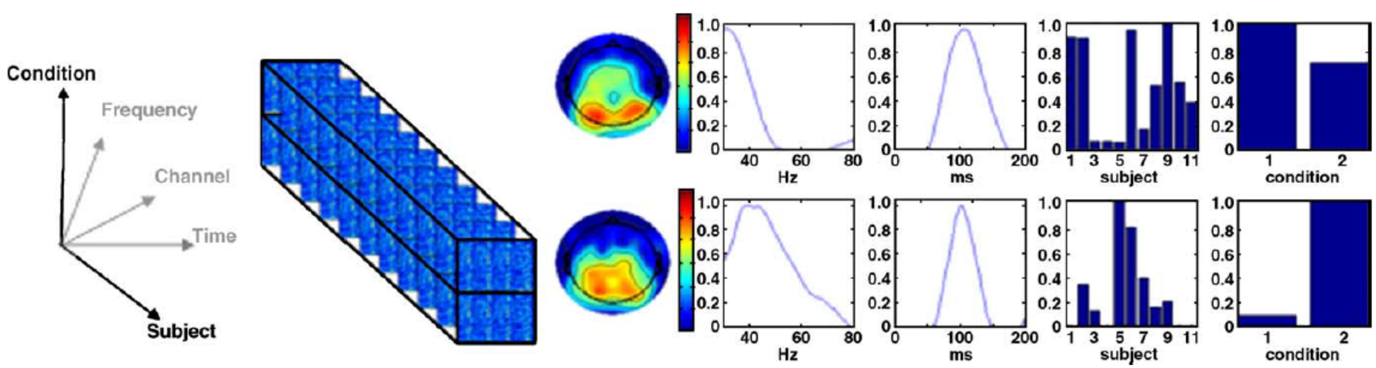
Future Work

Multidimensional data analysis (e.g. Parafac)

- decomposing EEG-data

  (Channel x Frequency x Subjects x Paradigm)

- extracting significant activities from EEG
  - region of interest (electrode channels)
  - scales/frequencies



Morten Mørup, Lars Kai Hansen, Christoph S. Herrmann, Josef Parnas, and Sidse M. Arnfred, **Parallel Factor Analysis as an exploratory tool for wavelet transformed event-related EEG**
2005

Thank you for your attention!