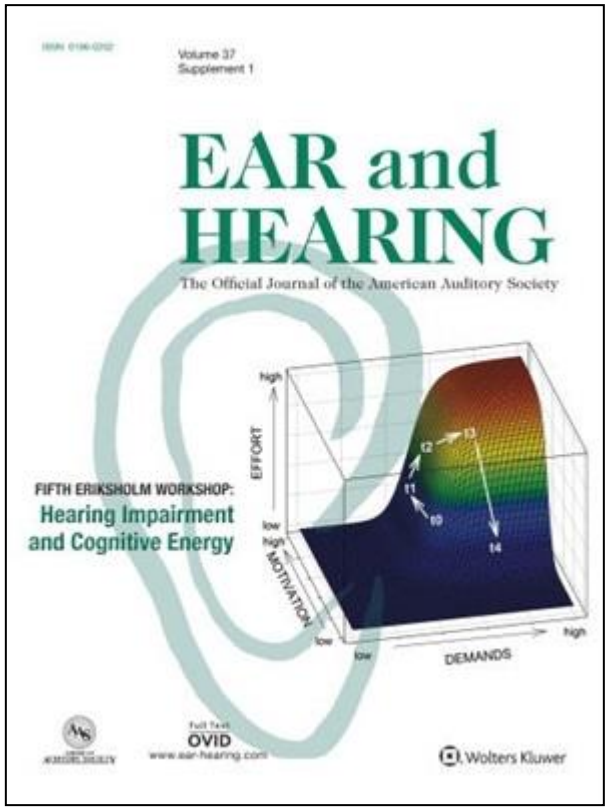
ENRICH workshop April 2017, Jana Besser

# Assessment of Cognitive Load During Listening

# Hearing Impairment and Cognitive Energy

## Ear and Hearing, Vol. 37, Suppl. 1




Pichora-Fuller et al. (2016). Hearing Impairment and Cognitive Energy: The Framework for Understanding Effortful Listening (FUEL). *Ear and Hearing, 37,* 5S – 27S.

# Cognitive Load and Listening Effort

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## Listening effort

"The deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a listening task"

Pichora-Fuller et al. (2016). Hearing Impairment and Cognitive Energy: The Framework for Understanding Effortful Listening (FUEL). *Ear and Hearing, 37,* 5S – 27S.

# Cognitive Load and Listening Effort

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Types of assessments

Physiological

Behavioral

Self report

Cognitive load

allocation of mental resources

Listening effort

"The deliberate

to overcome obstacles in goal pursuit
when carrying out a listening task"

McGarrigle et al. (2014). Listening effort and fatigue: What exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'white paper'. *International Journal of Audiology, 53,* 433 – 445.

# Mental Resources in Speech Understanding

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## Listening effort

"The deliberate allocation of **mental resources**
to overcome obstacles in goal pursuit
when carrying out a listening task"

## Examples

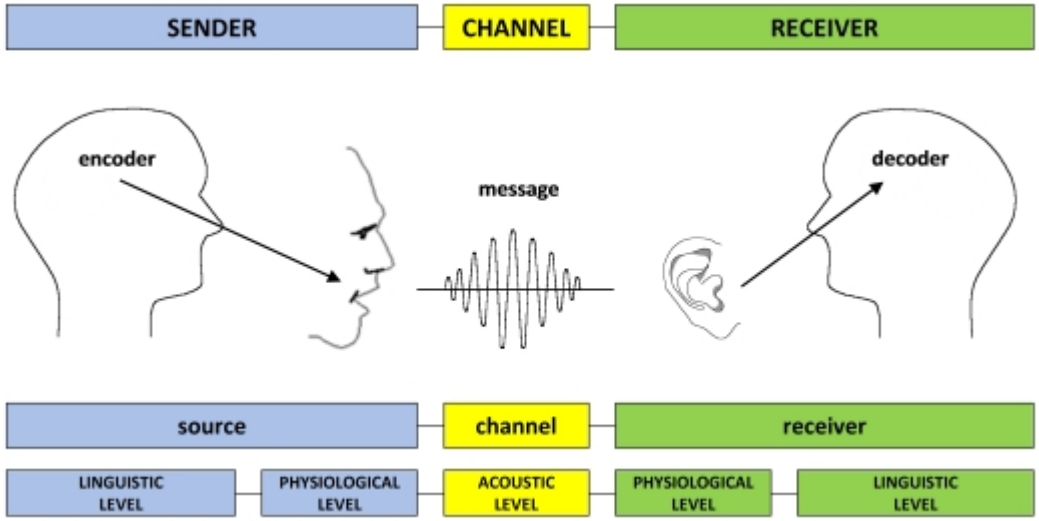
- Memory (semantic, episodic, working memory)
- Attentional control and other executive functions (e.g., inhibitory and interference control)
- Speed of processing
- Linguistic knowledge

Lemke and Besser (2016). Cognitive Load and Listening Effort: Concepts and Age-Related Considerations. *Ear and Hearing, 37,* 77S – 84S.

# Source – Channel – Receiver

## Listening effort

"The deliberate allocation of mental resources
to overcome obstacles in goal pursuit
when carrying out a listening task"




Hearing aid?

Figure source: http://www.sltinfo.com/the-encode-decode-model-of-communication/

# Sources of Degradation

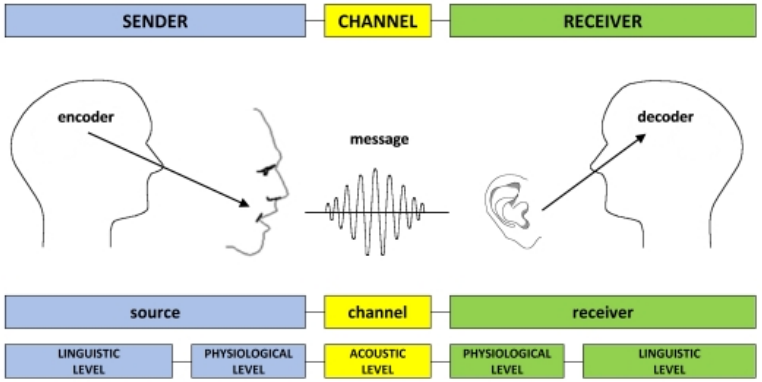



Figure source: http://www.sltinfo.com/the-encode-decode-model-of-communication/

## Source
- Accented speech
- Conversational speech
- Disfluencies
- Speech and language disorders

## Channel
- Energetic masking
- Other interferers
- Reverberation
- Frequency filtering

## Receiver
- Sensory impairment
- Linguistic abilities
- Cognitive resources, cognitive load

Mattys et al. (2012). Speech Recognition in Adverse conditions: A Review. *Language and Cognitive Processes, 27 (7/8)*, 953 – 978.

# Adverse listening conditions

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## Listening effort

"The deliberate allocation of mental resources to overcome **obstacles** in goal pursuit when carrying out a listening task"

- Speech understanding in adverse conditions

## Adversity

The mismatch between the external demands and the internal resources to meet these demands.

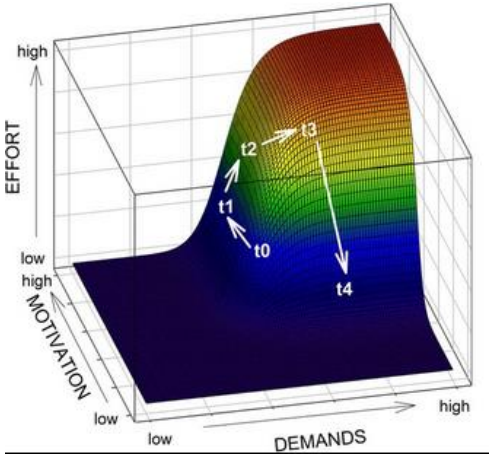
Lemke and Besser (2016). Cognitive Load and Listening Effort: Concepts and Age-Related Considerations. *Ear and Hearing, 37*, 77S – 84S.

## Listening effort

"The **deliberate** allocation of mental resources

to overcome obstacles in **goal pursuit**

when carrying out a listening task"




Pichora-Fuller et al. (2016). Hearing Impairment and Cognitive Energy: The Framework for Understanding Effortful Listening (FUEL). *Ear and Hearing, 37,* 5S – 27S.

# The «factor space» of Listening Effort

Listening effort

Cognitive functions, cognitive capacity

"The deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a listening task"

Adverse conditions

Factors related to source/channel/receiver

Motivation

# Assessment of cognitive load during listening

# Physiological Assessment of Cognitive Load

## Brain activity

Electroencephalography (EEG) / event related potentials (ERP)

Functional magnetic resonance imaging (fMRI)

Functional near-infrared spectroscopy (fNIRS)

## Peripheral physiological activity

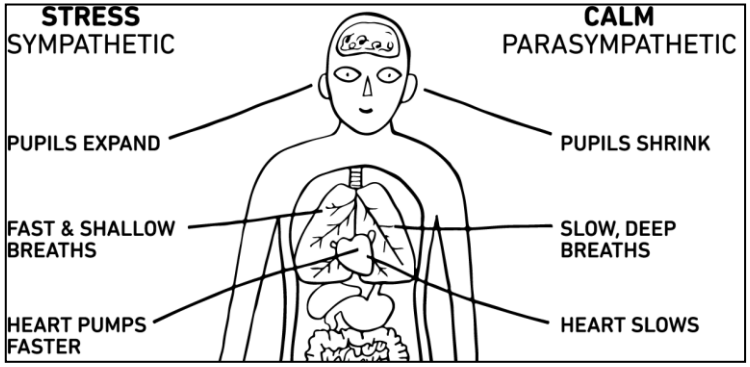
Pupillometry, Eye-tracking

Skin conductance / electrodermal actvity (EDA)

Electrocardiography (ECG) -> Heart-rate (variability)

Electromyography

Cortisol levels



# EEG Study on Binaural Voice Streaming

Winneke et al. (2016). Quantifying the effect of DuoPhone on listening effort: an EEG study. White paper.

- Older HI adults, experienced hearing-aid users, N = 7
- 2-back task with digits
- Decreased alpha power with binaural voice streaming

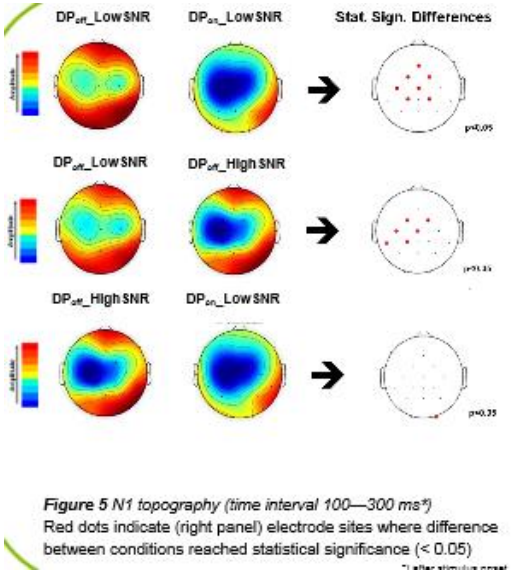



*Figure 5 N1 topography (time interval 100—300 ms*)*
Red dots indicate (right panel) electrode sites where difference between conditions reached statistical significance (< 0.05)

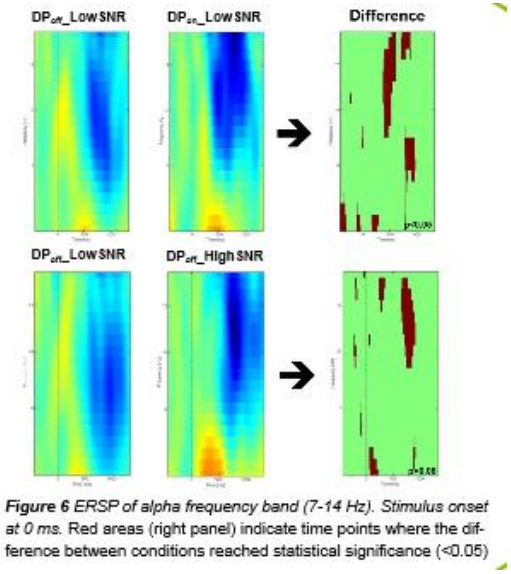


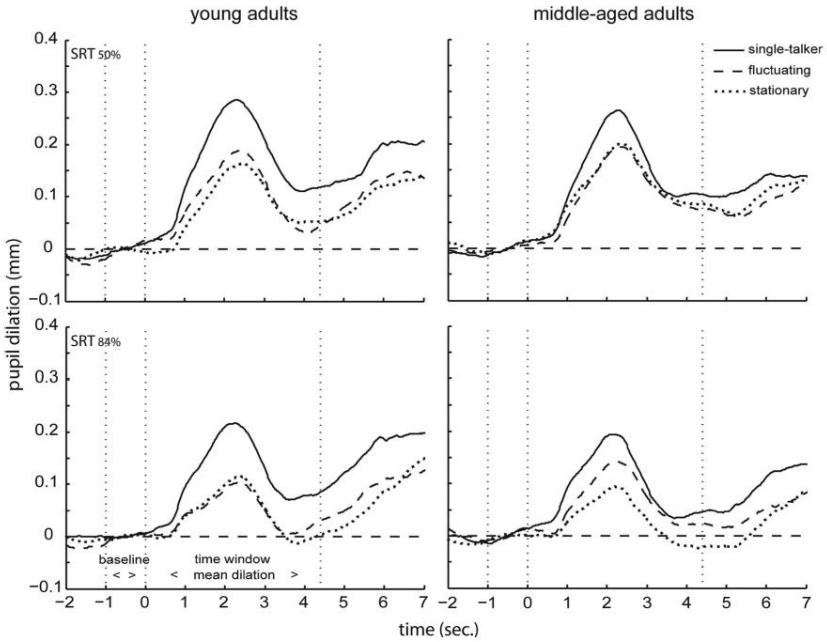

*Figure 6 ERSP of alpha frequency band (7-14 Hz). Stimulus onset at 0 ms.* Red areas (right panel) indicate time points where the difference between conditions reached statistical significance (<0.05)

# Pupillometry

Evidence for sensitivity to

- SNR
- Intelligibility level
- Masker type
- Native / non-native speech
- Divided vs selective attention

- No results on amplification / signal processing
- Most testing at negative SNRs



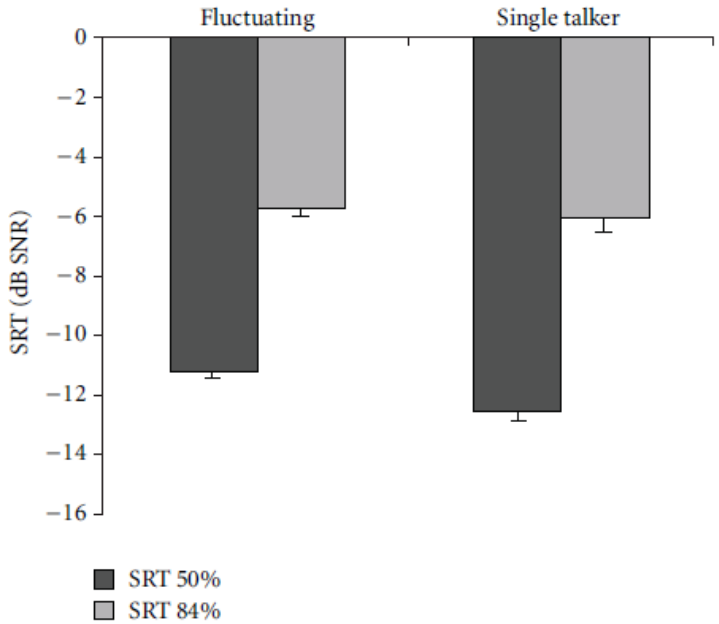

Koelewijn, T., Zekveld, A. A., Festen, J. M., & Kramer, S. E. (2012). Pupil dilation uncovers extra listening effort in the presence of a single talker masker. *Ear and Hearing*, *33*, 291–300.

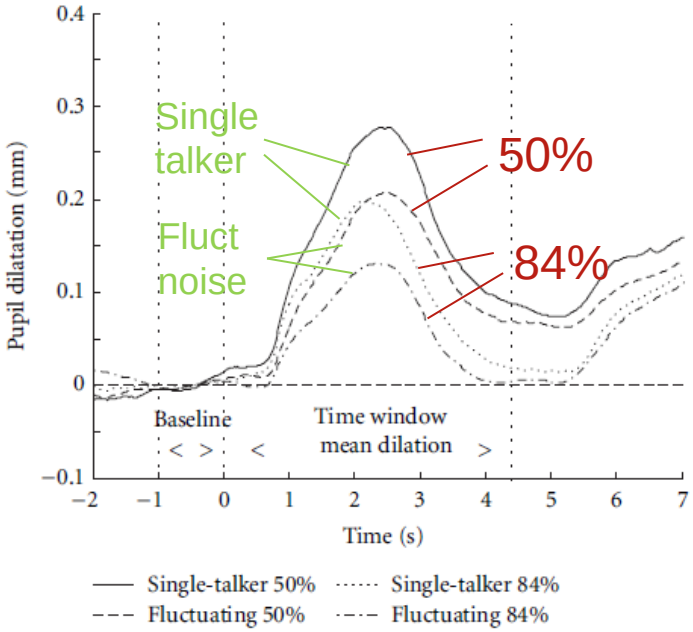
# Example of a Pupillometry Study

## Speech understanding in young listeners with normal hearing

Sentence-recognition in two background maskers

At two levels of performance: 50% and 84% correct sentences




Koelewijn, T., Zekveld, A. A., Festen, J. M., Rönnberg, J. & Kramer, S. E. (2012). Processing Load Induced by Informational Masking Is Related to Linguistic Abilities. *International Journal of Otolaryngology,* Volume 2012, Article ID 865731.

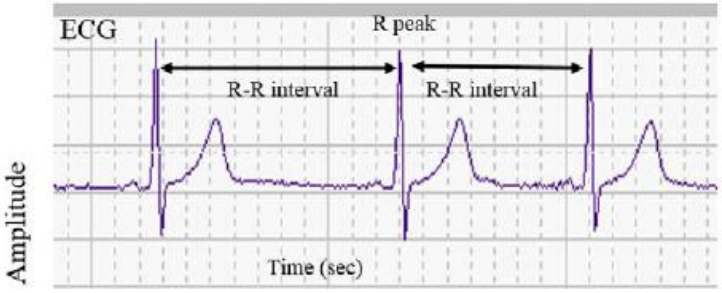
# Skin Conductance and HRV

## Skin Conductance (SC)

- Electrodermal activity (EDA)
- Amount of moisture on the surface of the skin
- Reflects sympathetic nervous system arousal
- Increases with increasing task demand
- Not measurable in X% of people

## Electrocardiography (EKG/ ECG)

- electric activity of the heart
- Heart rate increases with increasing task demand
- Heart rate variability (HRV) decreases with increasing effort
  - High HRV considered a positive health marker
- Time-domain: SD of R-to-R interburst intervals (SDRR)
- Frequency domain
  - Low frequencies (0.04 – 0.15 Hz), activity of sympathetic and parasympathetic nervous system
  - High frequencies (**HF-HRV**; 0.15 – 0.4 Hz), mainly parasympathetic activity
  - Decreased power in HF-HRV band indicates suppressed parasympathetic activity, thus increased effort

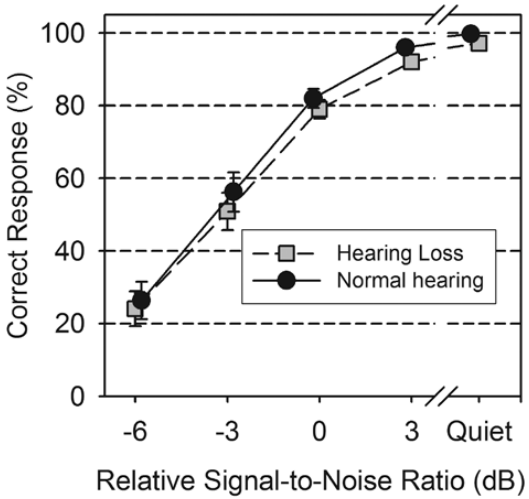


# Mackersie et al. 2015

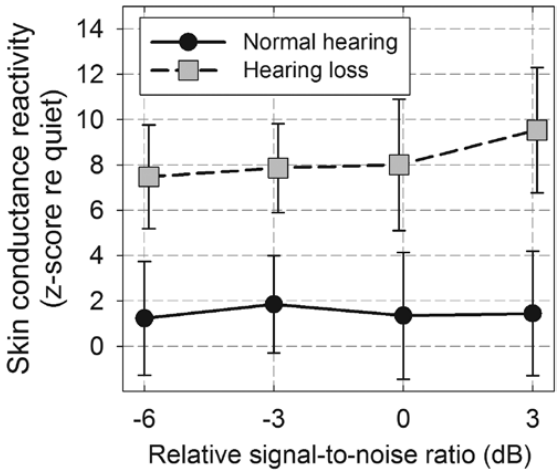
Mackersie, C.L., MacPhee, I.X., Heldt, E.W. (2015). Effects of Hearing Loss on Heart Rate Variability and Skin Conductance Measured During Sentence Recognition in Noise. *Ear and Hearing*, *36*, 145–154.

## SC and HRV at different relative SNRs for people w/o a hearing loss

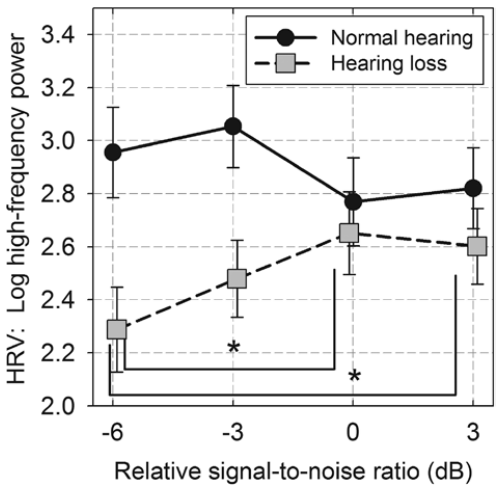
- Multitalker-babble masker
- 0 dB relSNR: SNR for 80% sentence-word recognition




No effect of group




Group difference




Group x relSNR interaction

## No associations with self-report task load (NASA-TLX)

# Physiological measures

- Direct measure of resource allocation/activation
- Sensitive
- Effect on performance unknown
- Unknown to which extent available capacity is being used up

# Behavioral assessment of cognitive load

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## Theoretical assumptions

Processing resources are limited in capacity and speed.
Resources are allocated on an as-needed basis.

## Dual task

Two tasks, two outcomes – one primary one secondary
Assessment: primary-task baseline, secondary-task baseline, dual task

## Single task

One task, two outcomes – one primary, one secondary

## Experimental design and results

Ideally, primary outcome constant across conditions
(Proportional) change in secondary outcome interpreted as difference in processing effort

Literature review of studies using dual-task assessments of listening effort:
Gagné, J-P., Besser, J., Lemke. U. (2017) Behavioral Assessment of Listening Effort Using a Dual-Task Paradigm: A Review. *Trends in Hearing*, *21,* 1–25.

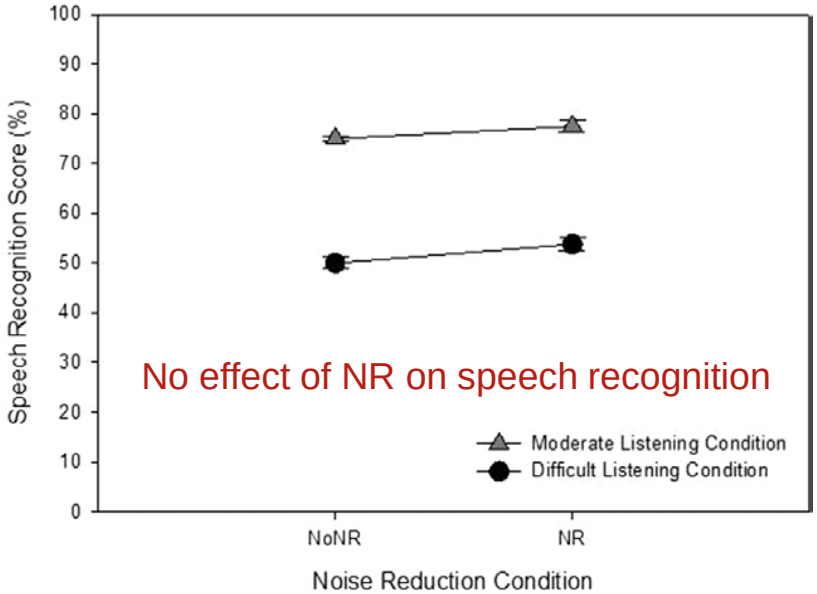
# A Dual-task Study on Noise Reduction

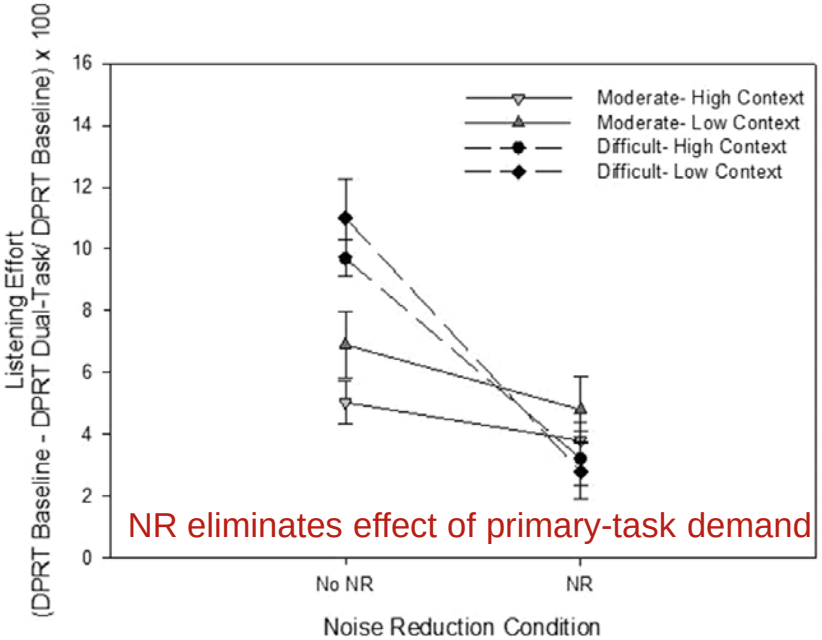
## Primary task

Target-word recognition in low- and high-context sentences
Two levels of performance: 50% and 75% correct at baseline

## Secondary task

Visual motor tracking (time on target)




**Desjardins and Doherty (2014)** The Effect of Hearing Aid Noise Reduction on Listening Effort in Hearing-Impaired Adults. *Ear & Hearing*, 35, 600–610.

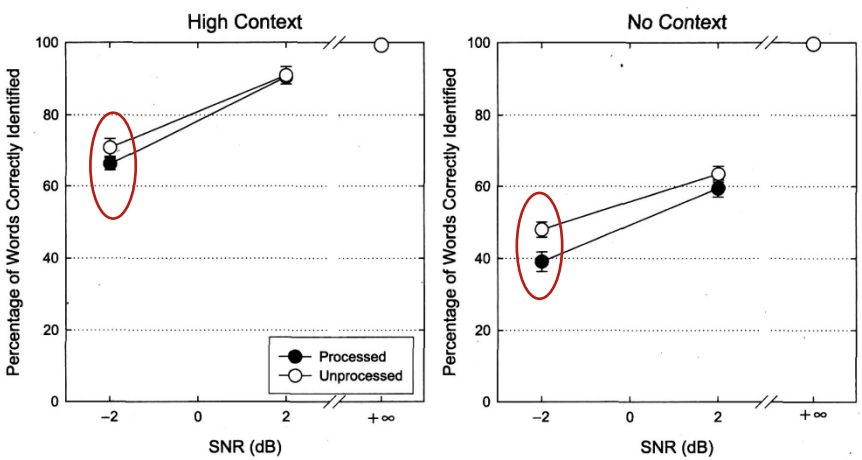
# Another Dual-task Study on Noise Reduction

## Primary task

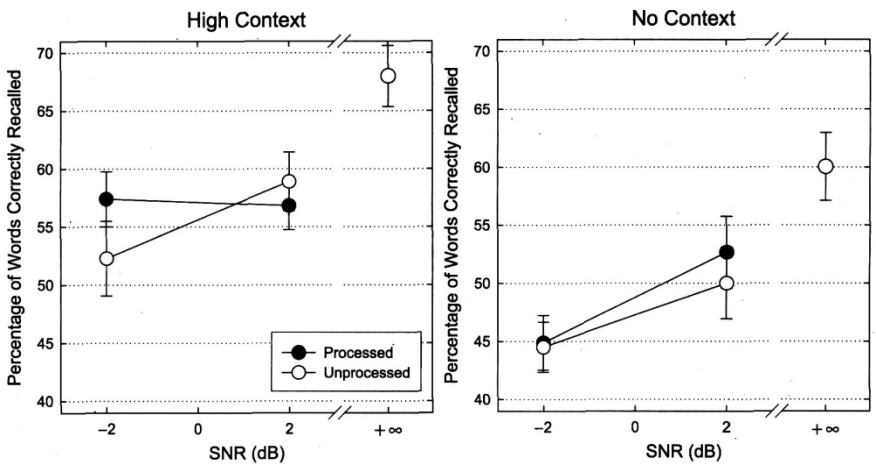
Target-word recognition in low- and high-context sentences
Two test SNRs (signal-to-noise ratios): -2 and +2 dB (and a baseline in quiet)

## Secondary task

Target-word recall after each set of 8 sentences




Slight disadvantage in speech rec with NR in difficult cond



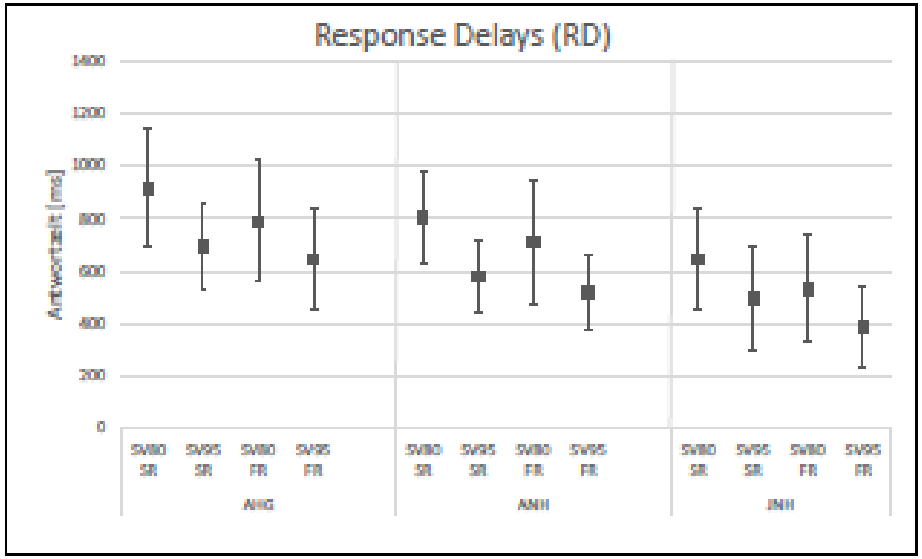

NR eliminates effect of SNR (task demand) for high-context sentences

Sarampalis et al. (2009) Objective measures of listening effort: Effects of background and noise reduction. *Journal of Speech, Language, and Hearing Research*, 52(5), 1230-1240.

# A Single-Task Study: Using Response Delays

Cooperation with Hartmut Meister and Sebastian Rählmann (Jean-Uhrmacher Institut, University of Cologne)

- Sentence understanding (OLSA)
  - At different fixed performance levels (80%, 95% correct)
  - In different noises
  - In three groups: YNH, ONH, OHI
- Assessment of response delays (RDs)




- No difference in RDs with/without amplification at 80% performance
- In contrast: Gatehouse and Gordon (1990) found shorter RDs with amplification at 5 dB SNR for different intensities

# Self-report assessment tools, examples

## Visual analog scale

Eriksholm – http://www.eriksholm.com/research-themes/outcome-measures-and-assessment-methods/listening-effort-test.aspx

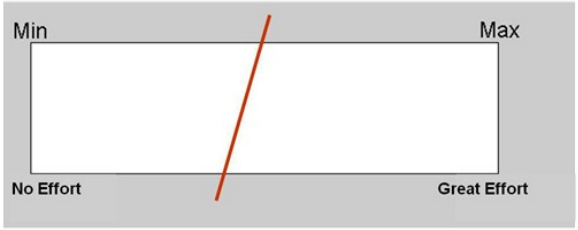



*Figure 1. In the figure, rate how much listening effort the last five sentences required.*

## Categorical scale

**Mueller, F., Scholl, A., Ehm, P. (2014)** Quantifizierung der erlebten Höranstrengung – ein Skalenvergleich, http://tgm.jade-hs.de/web/files/2014_DGA_M%C3%BCller_Skalierung%20H%C3%B6ranstrengung.pdf

Stufenskala

(nach Meis u. Gabriel, 2001)

**Wie anstrengend ist die Hörsituation?**

6 = extrem anstrengend

5 = sehr anstrengend

4 = deutlich anstrengend

3 = mittelgradig anstrengend

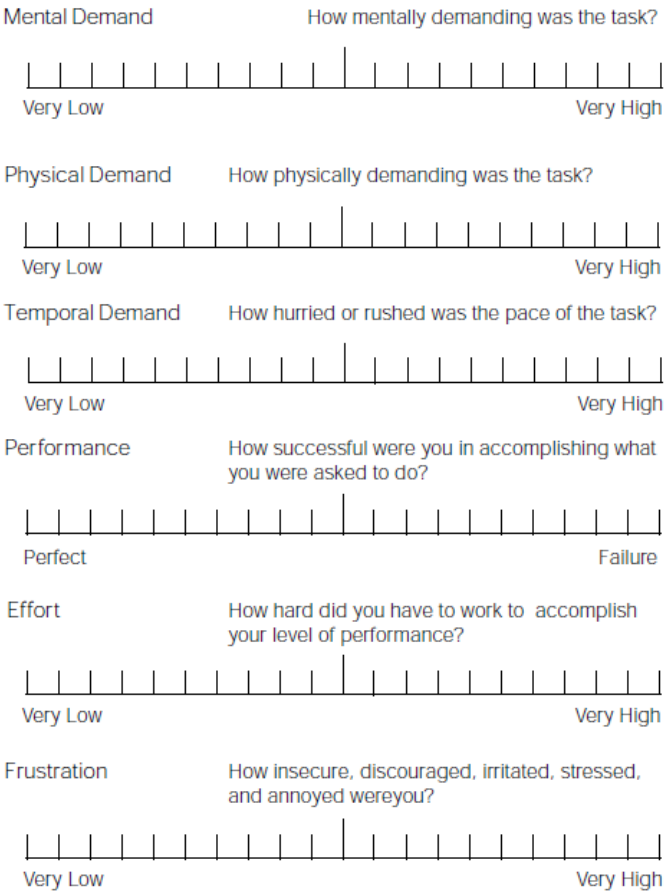
2 = wenig anstrengend

1 = sehr wenig

0 = nicht anstrengend

## NASA TLX (Task load index)

http://humansystems.arc.nasa.gov/groups/tlx/



# Cognitive Load and Listening Effort

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Types of assessments

Physiological

Behavioral

Self report

Cognitive load

allocation of mental resources

Listening effort

"The deliberate

to overcome obstacles in goal pursuit
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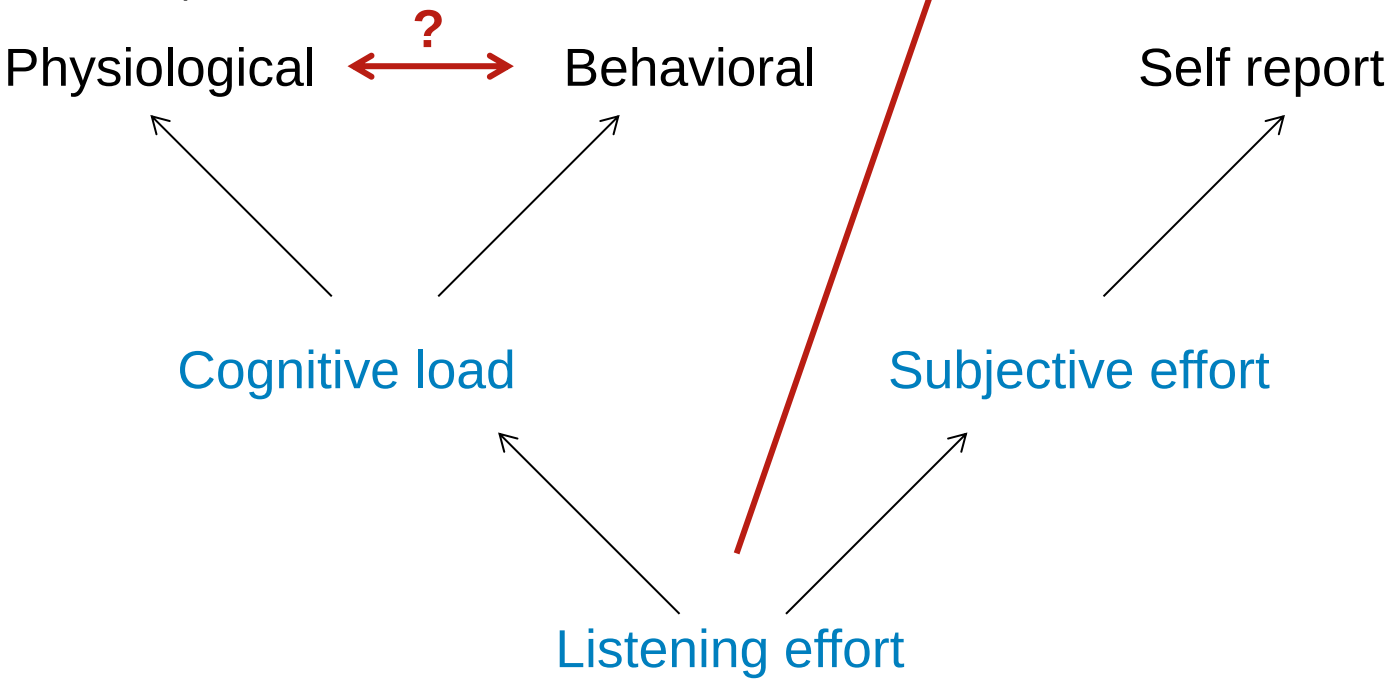
# Listening Effort

Koelewijn et al., 2012, IJO:
Better inhibitory control <-> larger pupil response and better performance




**Cross-assessment-method studies needed**

# Associations Between Different Assessment Types

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## Behavioral <-> Self-report

- Literature review of studies using dual-task assessments of listening effort (Gagné, Besser, Lemke (2017, TiH))
- In 13 of reviewed dual-task studies also self-report measurements
- Associations / corresponding patterns found in very few cases

## Physiological <-> Self-report

- Limited evidence
- No or maybe sporadic associations
  - Mackersie et al. (2015, EarHear), Tun et al. (1991): no associations between skin conductance or HRV and NASA-TLX
  - Mackersie and Cones (2011, JAAA): very limited associations
  - Zekveld and Kramer (2014, Psychophysiology): no association between pupil response and subjective ratings
  - But: Koelewijn et al. (2014, 2015, HearRes): associations between pupil response and subjective ratings

## Physiological <-> Behavioral

- Limited evidence
- Associations observed
  - Steel et al. (2015, PlosOne): Pupil responses and reaction times corresponded in binaural fusion task
  - Seeman and Sims (2015, JSLHR): Associations of skin conductance and heart-rate measures with dual-task outcomes (but not with subjective ratings)

**Overall, subjective outcomes are not associated with objective outcomes.**

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# Thank you very much