Assessment of Cognitive Load During Listening
Hearing Impairment and Cognitive Energy

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Listening effort

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

Cognitive Load and Listening Effort

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”

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

Listening effort

“The deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a listening task”
Sources of Degradation

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


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

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.

Listening effort

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The «factor space» of Listening Effort

Listening effort

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Cognitive functions, cognitive capacity

Motivation

Factors related to source/channel/receiver

Adverse conditions
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 activity (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 (p<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 (p<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

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

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


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

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

No effect of group

Group difference

Group x reISNR 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

**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:
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)

No effect of NR on speech recognition
NR eliminates effect of primary-task demand

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

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 –

![Visual analog scale diagram]

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

Categorical scale

http://tgm.jade-hs.de/web/files/2014_DGA_M%C3%BCller_Skalierung%20H%C3%B6ranstrengung.pdf

NASA TLX (Task load index)

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

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Question</th>
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<tbody>
<tr>
<td>Mental Demand</td>
<td>How mentally demanding was the task?</td>
</tr>
<tr>
<td></td>
<td>Very Low</td>
</tr>
<tr>
<td></td>
<td>Very High</td>
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<tr>
<td>Physical Demand</td>
<td>How physically demanding was the task?</td>
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<tr>
<td></td>
<td>Very Low</td>
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<tr>
<td></td>
<td>Very High</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>How hurried or rushed was the pace of the task?</td>
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<tr>
<td></td>
<td>Very Low</td>
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<tr>
<td></td>
<td>Very High</td>
</tr>
<tr>
<td>Performance</td>
<td>How successful were you in accomplishing what you were asked to do?</td>
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<tr>
<td></td>
<td>Perfect</td>
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<tr>
<td></td>
<td>Failure</td>
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<tr>
<td>Effort</td>
<td>How hard did you have to work to accomplish your level of performance?</td>
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<tr>
<td></td>
<td>Very Low</td>
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<td></td>
<td>Very High</td>
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<tr>
<td>Frustration</td>
<td>How insecure, discouraged, irritated, stressed, and annoyed were you?</td>
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<tr>
<td></td>
<td>Very Low</td>
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<td></td>
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Koelewijn et al., 2012, IJO: Better inhibitory control <-> larger pupil response and better performance

Cross-assessment-method studies needed
Associations Between Different Assessment Types

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

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.
Thank you very much