What is listening effort and how do we measure it?

ERIN M. PICOU, AUD, PHD

HEARING WELL AND BEING WELL – A STRONF SCIENTIFIC CONNECTION

FRANKFURT, GERMANY

15 NOV 2019
Disclosures

Employed by Vanderbilt University Medical Center

Associations

◦ Editorial Board of the *American Journal of Audiology*
◦ Section Editor for *Ear and Hearing*

Collaborators

◦ Todd Ricketts, Travis Moore, Ben Hornsby, Gina Angley
◦ Gabrielle Buono, Samantha Gustafson, Maddox Myers, Elizabeth Agboola, Javier Santos, Claire Umeda, Nia Potier, Anna Allen, Alaina Abadie, Katie Berg

Received funding for research from

◦ Sivantos
◦ Oticon
◦ Phonak / Sonova
◦ Resound
◦ Starkey
◦ National Institutes of Health
◦ National Science Foundation
◦ American Speech-Language Hearing Association
What is listening effort?

Mental energy needed to listen

Cognitive resources necessary for speech recognition  
*Hicks & Tharpe (2002) J Speech Lang Hear Res, 45, 573-584*

Mental exertion required to attend to, and understand, an auditory message  

Deliberate allocation of cognitive resources to overcome obstacles when carrying out a task  
Ease of Language Understanding (ELU)

Framework for Understanding Effortful Listening (FUEL)

Input related demands that reduce the likelihood of a match:
- Noise
- Accented speech
- Hearing loss
- Unfamiliar vocabulary

How do we measure “cognitive resources”? 
Today’s Focus

Review 5 major categories of methodologies
- Explain the general principles underlying the measurement category
- Describe several types of the measure
- Provide an example of the measure in use in audiology
- Evaluate the strengths and limitations of the measurement
Measurement Categories

Subjective measures
  ◦ Ask the patient

Physiologic indicators
  ◦ Measure changes in body

Electroencephalography
  ◦ Measure brain activity

Recall paradigms
  ◦ Test patient’s memory

Response-time measures
  ◦ Time how quickly patient responds
Rationale: Subjective Measures

People report their perception of mental effort
Patient experiences drive their behavior
Larger reports of effort mean more listening effort
Assumes that people are accurate reporters of their experiences
Subjective Measures

Ask the patient

◦ Anecdotal
◦ Standardized questionnaires
◦ Research questionnaires
Anecdotal

Patients come to the clinic and may volunteer descriptions like
◦ It’s exhausting
◦ I’m so tired from listening
◦ I have to work really hard to hear

Patients can be prompted to tell their story
◦ How do you feel when many people are talking?
◦ Is it difficult for you to understand in noise?
◦ What does it feel like at the end of the day?
Standardized Questionnaires

National Aeronautics and Space Administration Task Load Index (NASA-TLX)

- How mentally demanding was that task?
- How physically demanding was the task?
- How hurried or rushed was the pace of the task?
- How successful were you in accomplishing what you were asked to do?
- How hard did you have to work to accomplish your level of performance?
- How insecure, stressed, and annoyed were you?

Hart & Staveland (1988) Advances in Psychology, 52, 139-183
Standardized Questionnaires

Speech, Spatial, and Qualities of Hearing Scale (SSQ)

- Do you have to put in a lot of effort to hear what is being said in conversation with others?

- Do you have to concentrate very much when listening to someone or something?
Research Questionnaires

How hard did you have to work? Remember, this is different than how many words you got right.

Very hard                                  Not at all hard

0                                          5                                          10

How tired of listening do you feel?

Very tired                                  Not at all tired

0                                          5                                          10

How likely are you to do something to improve the situation? For example, as the talker to speak up or move to a quiet room?

Very likely                                  Not at all likely

0                                          5                                          10

Picou, Moore, & Ricketts (2017) J Speech Lang Hear Res, 60, 199 - 211
Example: Subjective Reports in Research

Speech recognition

Listening effort (subjective rating)

Speech recognition is nearly perfect, but listening effort continues to improve.

Appraisal: Subjective Reports

Advantages:
- Easy to administer
- Affordable
- Represent the patient’s perception

Disadvantages:
- Relationship to other methods not well understood
- Rely on assumption that patients can articulate their experiences
Rationale: Physiology Measures

Increased demands during mental activity are associated with increased activation of the autonomic nervous system (ANS)

Activation of autonomic nervous system leads to:

- Increased activation in **sympathetic** branch of ANS
  - “Flight or fight” response
  - Heart rate, respiration, skin conductance, pupil dilation, muscle tension
- Decreased activation in **parasympathetic** branch of ANS
  - “Rest and digest” response

Larger changes in heart rate, skin conductance, or pupil dilation mean more listening effort
Physiologic Indicators

Measure changes in body
- Heart rate variability
- Pupillometry
- Skin conductance
Heart Rate Variability

Increased mental demand → in a change to the balance of sympathetic and parasympathetic activity → increased heart rate variability

Measured by blood volume pulse via infrared light through a sensor attached to a finger; records amount of infrared light reflected from the skin surface

- Blood volume pulse peak occurs with each heartbeat
- Variability is change in moment to moment heart rate
Pupillometry

Increased mental demand → increased pupil dilation

Measured by evaluating changes in pupil size with changes in task or condition; measured in millimeters

Requires pupilometer, dark room, and open eyes
Skin Conductance

Increased mental demand $\rightarrow$ increased skin conductance (sweating)

Measured from electrodes which record activation of eccrine sweat glands; indicates moisture on the skin surface

Requires physiological recording device, access to recording place on body (often fingers); measured in micro-Siemens
Example: Physiology Measures in Research

No group differences in subjective ratings

Significant group differences in physiology

Fig. 3. Mean skin conductance reactivity indexes (re quiet) for each relative signal-to-noise ratio. Error bars indicate ±1 SE.

Fig. 5. Mean ratings of effort, mental demand, stress, and perceived performance for each relative signal-to-noise ratio (SNR). Error bars indicate ±1 SE.
Appraisal: Physiology Measures

Advantages:
- Insight into cognitive processes without relying on patient
- Based on solid understanding of body processes
- Might be more sensitive to changes than traditional measures

Disadvantages:
- Require technological expertise
- Age-related changes may present challenges
- Rely on assumptions about autonomic nervous system
- Emotion and stress reactions also affect sympathetic and parasympathetic systems
Rationale: Electroencephalography

Neural activity generates measurable electrical power
Can measure it with electrodes placed on the scalp
When the brain is working hard, the electrical signal will be bigger
  ◦ Recruitment of additional neurons to achieve a task
  ◦ Active suppression of adjacent brain areas to improve focus

Bigger changes in electrical activity associated with more listening effort
Electroencephalography

Measure brain activity
- Alpha power change
- N1 evoked response potential
N1 Evoked Response

N100 is a component in an auditory late response

Negative deflection in neural response occurring around 100 ms after stimulus

Reflects selective attention, initial selection for later pattern recognition, and intentional discrimination

Amplitude is enhanced by increased attention

Image from Jerger (2014, June) AudiologyOnline, Article 12731
Alpha Oscillations

Oscillatory alpha network reflects cognitive energy

Measure alpha oscillations during stimulus-free period

Cognitive resources are working towards storage of heard information or the inhibition of irrelevant information

Expect more alpha power in degraded conditions or when memory load is higher
Example: Electroencephalography

Increased listening effort increases with increased noise

Change in alpha power relative to baseline indicates effort

Appraisal: Electroencephalography

Advantages:
- Direct measure of brain activity
- Good temporal resolution
- Fair spatial resolution

Disadvantages:
- Require technological expertise
- Requires expensive equipment
- Limited stimulus delivery options
- Not clear how different frequency bands are related
- Patient cooperation is critical
Rationale: Recall Paradigms

Human cognitive capacity is fixed

If more cognitive resources are recruited to assist with speech recognition, fewer are available for other tasks

In this case, the “other task” is rehearsal and recall of presented information

Fewer items recalled means more listening effort
Recall Paradigms

Test patient’s memory

- Free recall
- Paired-associates recall
Free Recall

Listen to a series of words or sentences; repeat the words or sentences; recall as many of them as possible once the list is complete

Score based on the number of words correctly recalled

They heard I called about the PET

What were the 3 final words?

Pie  Ox  Pet

Pichora-Fuller, Schneider, & Daneman (1995) JASA, 97, 593-608
Paired Associates Recall Task

Example: Recall in Research

Background noise increases listening effort for listeners with normal hearing.

Data from Picou, Ricketts & Hornsby (2011) *J Speech Lang Hear Res*, 54, 1416 - 1430
Example: Recall Research

“Hearing loss can cause apparent memory failure”

Hearing loss increases listening effort

Appraisal: Recall Measures

Advantages:
- Direct evidence of available cognitive resources
- Relatively easy to implement

Disadvantages:
- Requires knowledge of cognitive tests
- Time consuming
- Some patients hate it
Rationale: Response Times

Human cognitive capacity is fixed

The “other resources” under study are reflected by the time it takes to respond to a stimulus

Longer response times mean more listening effort
Response Times

Time how quickly patient responds

- Verbal response time
- Dual-task paradigms
Verbal Response Time

Onset time for patient to vocalize response

Measure how long it takes someone to respond

Usually measured in milliseconds

Requires stimulus presentation method and way to record response
Dual-Task Paradigm

Measure how accurately and/or how quickly someone performs a secondary task

Example secondary tasks
- Press a button as soon as a light appears
- Press a button if you feel a long-short-long pattern with a bone oscillator
- Use a mouse to track a moving cursor on a circle
- Press a button if the word you heard is a noun (person / place / thing)
- Press a button if a blue circle or yellow triangle appears; DON’T press a button if a blue triangle or yellow circle appears
Example: Response Times in Research

Directional microphones reduce listening effort

Less effort

Appraisal: Response-Time Measures

Advantages:
- Reflective of cognitive capacity
- Relatively easy to implement

Disadvantages:
- Rely on assumptions about cognitive capacity
- Requires equipment with precise timing
- Participant instructions are important
- Data can be quite variable
- Age considerations
Summary

Diverse methods for measuring listening effort

All rely on some assumptions
- Subjective – participants are accurate reporters
- Physiology – bodily changes reflect increased cognitive load
- EEG – measured brain activity primarily reflects effort
- Recall paradigms – testing spare capacity
- Response times – speed reflects spare capacity

Combining information across measurements and laboratories will give us a comprehensive understanding of listening effort
Thank You!

Questions?