

# What is listening effort and how do we measure it?

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HEARING WELL AND BEING WELL – A STRONG SCIENTIFIC CONNECTION

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# Disclosures

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## Employed by Vanderbilt University Medical Center

### Associations

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

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# What is listening effort?

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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

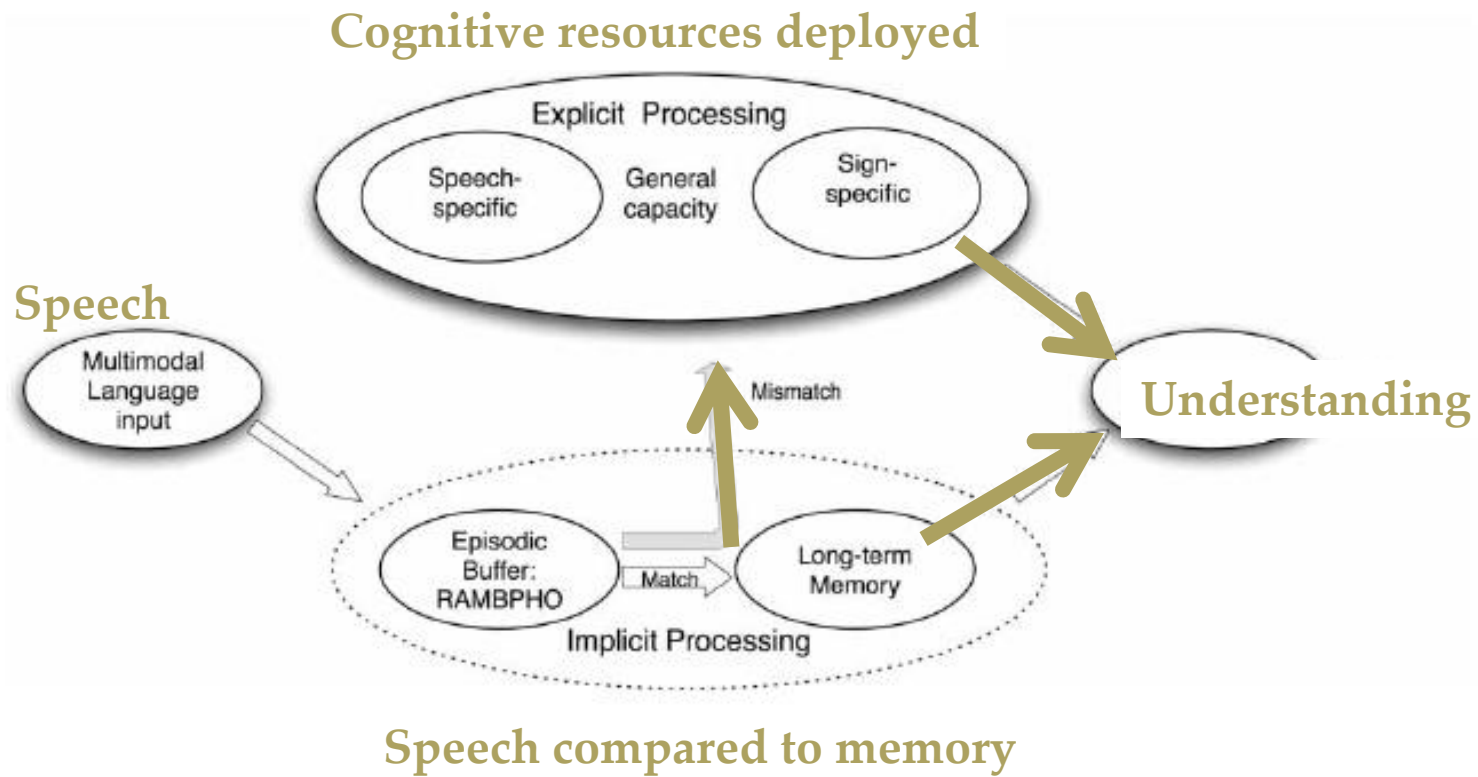
*McGarrigle et al (2014) Int J Audiol, 53, 433-445*

Deliberate allocation of cognitive resources to overcome obstacles when carrying out a task

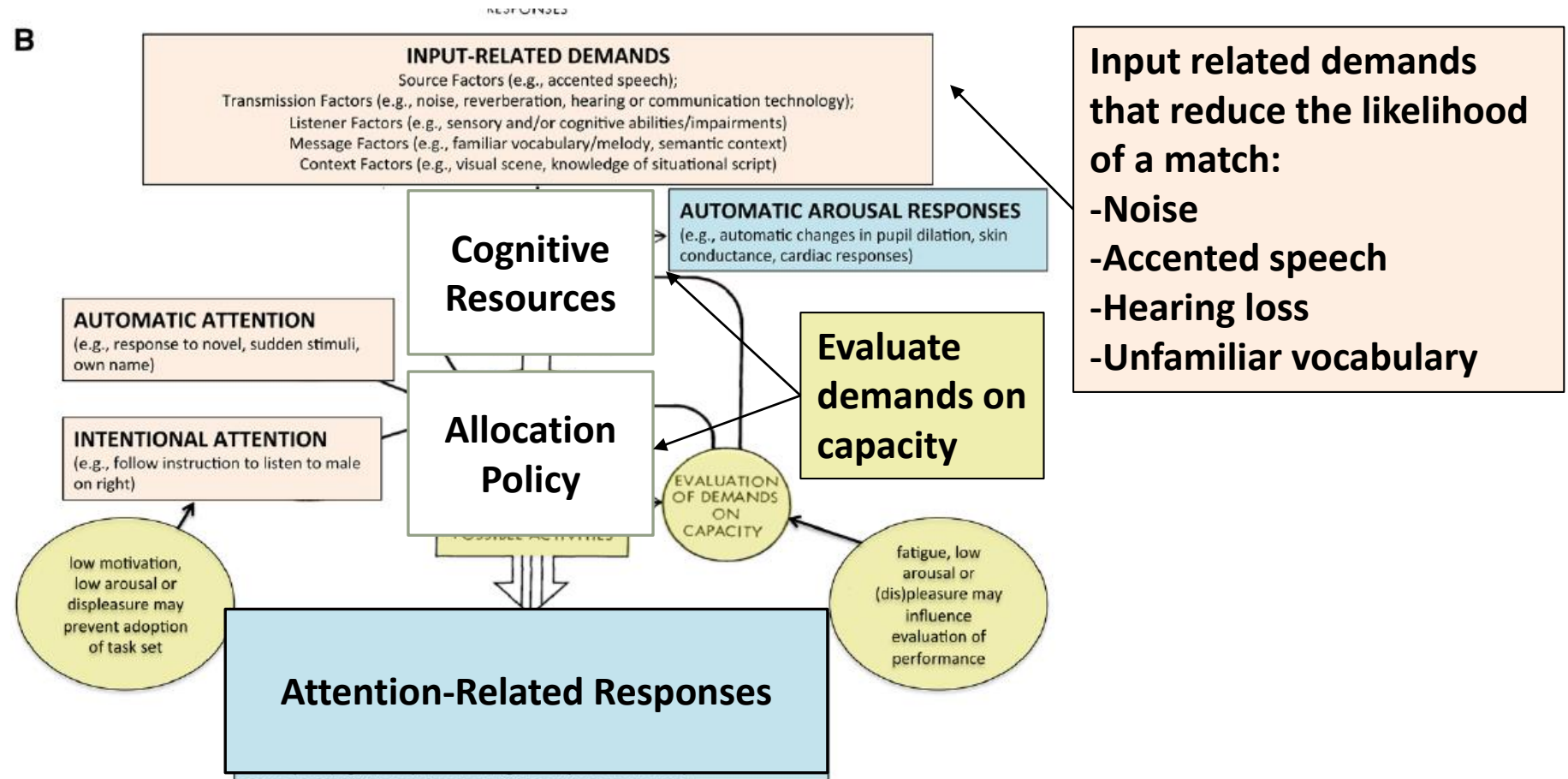
*Pichora-Fuller et al (2016) Ear Hear, 37, 5S-27S*



# Ease of Language Understanding (ELU)



# Framework for Understanding Effortful Listening (FUEL)



# How do we measure “cognitive resources”?



# Today's Focus

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## **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

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## Subjective measures

- Ask the patient

## Physiologic indicators

- Measure changes in body

## Electroencephalography

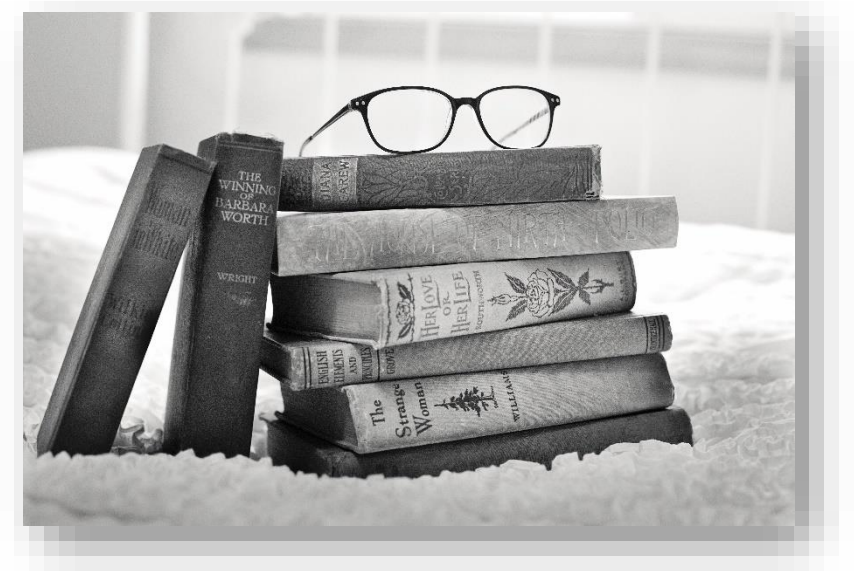
- Measure brain activity

## Recall paradigms

- Test patient's memory

## Response-time measures

- Time how quickly patient responds





# Rationale: Subjective Measures

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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

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## Ask the patient

- Anecdotal
- Standardized questionnaires
- Research questionnaires



# Anecdotal

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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

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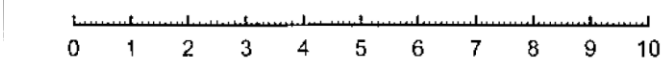
## National Aeronautics and Space Administration Task Load Index (NASA-TLX)

- 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?

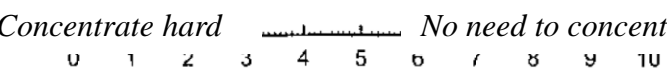
# Standardized Questionnaires

## 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?

<i>Lot of effort</i>	<i>No effort</i>	tick if not applicable
		<input type="checkbox"/>
		or wouldn't hear it

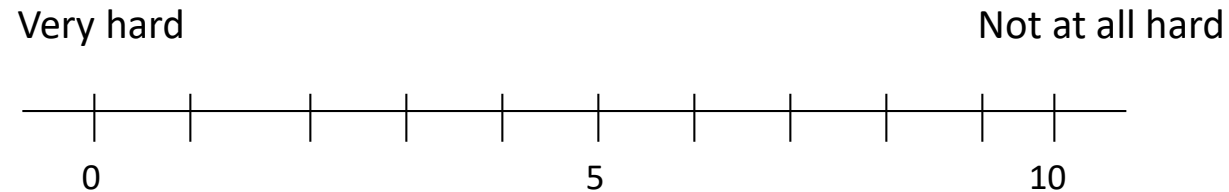
- Do you have to concentrate very much when listening to someone or something?

Not at all	Perfectly	tick if not applicable
<i>Concentrate hard</i>	<i>No need to concentrate</i>	<input type="checkbox"/>
		or wouldn't hear it

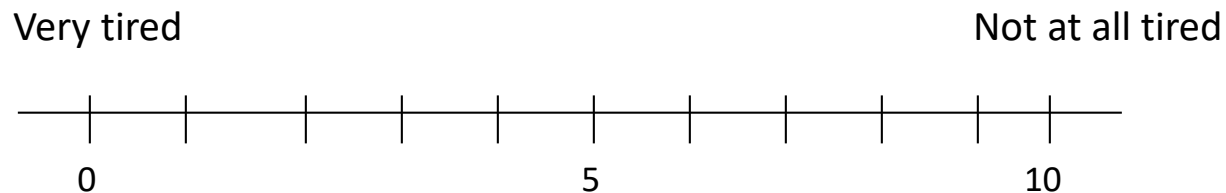
# Research Questionnaires

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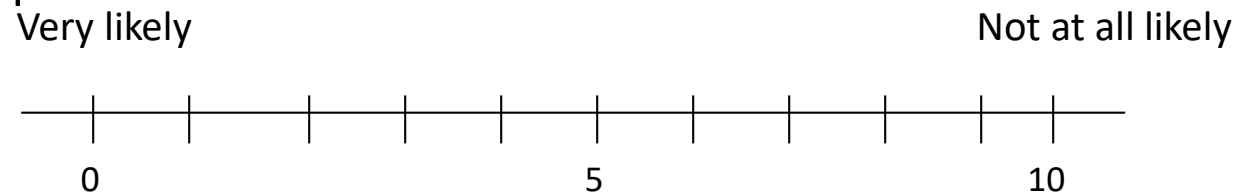
How hard did you have to work? Remember, this is different than how many words you got right.



How tired of listening do you feel?



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?



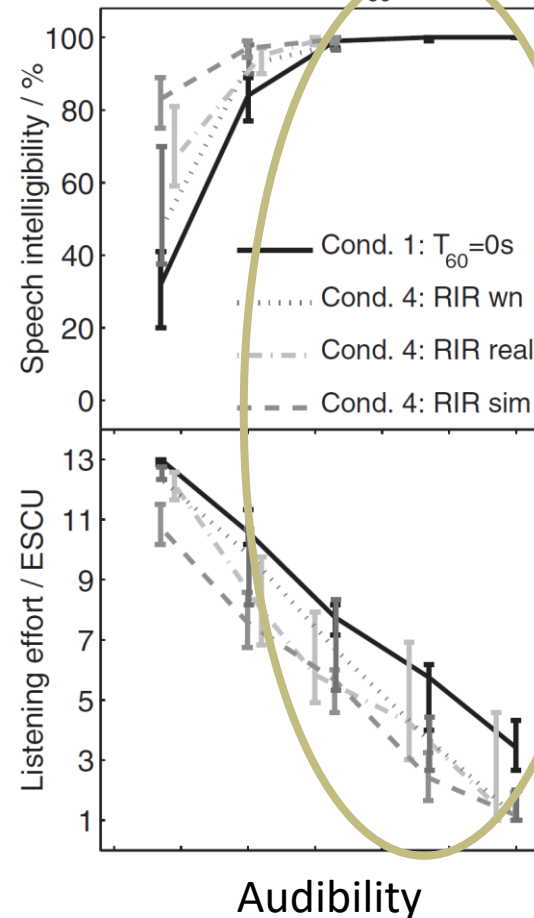
# Example: Subjective Reports in Research

Speech recognition

Better

Listening effort  
(subjective rating)

Better



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

# Appraisal: Subjective Reports

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## 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

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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

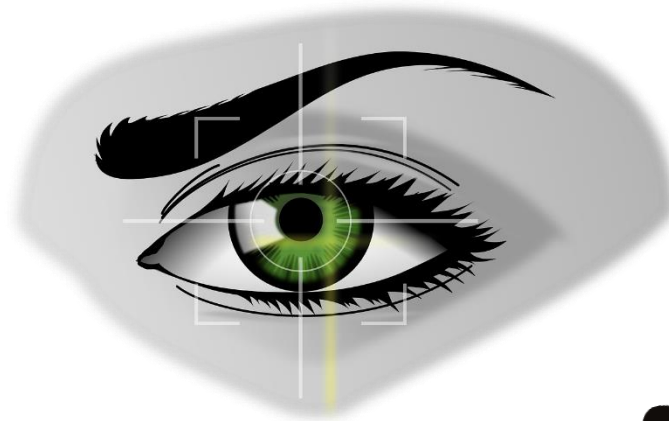
Larger changes in heart rate, skin conductance, or pupil dilation mean more listening effort

# Physiologic Indicators

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Measure changes in body

- Heart rate variability
- Pupillometry
- Skin conductance

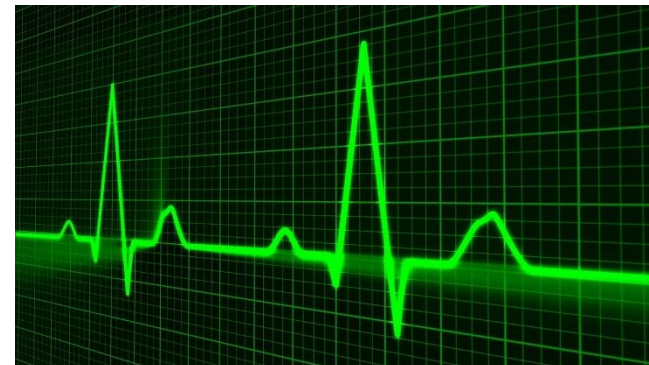
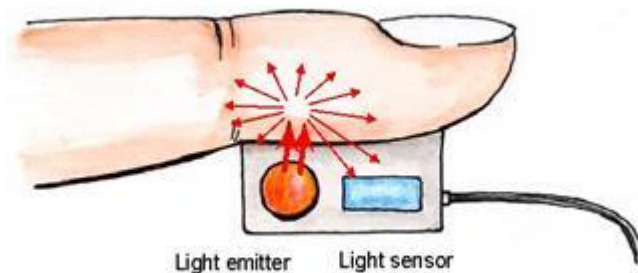


# Heart Rate Variability

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

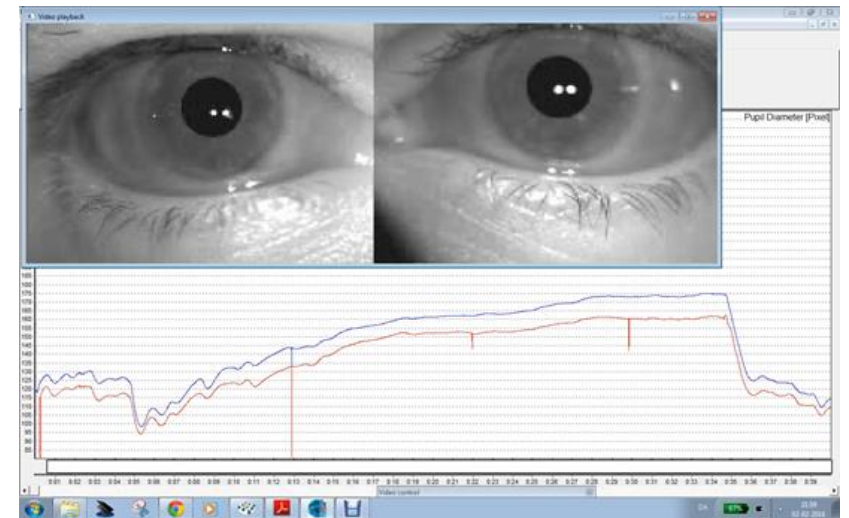


# Pupillometry

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

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Increased mental demand → 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

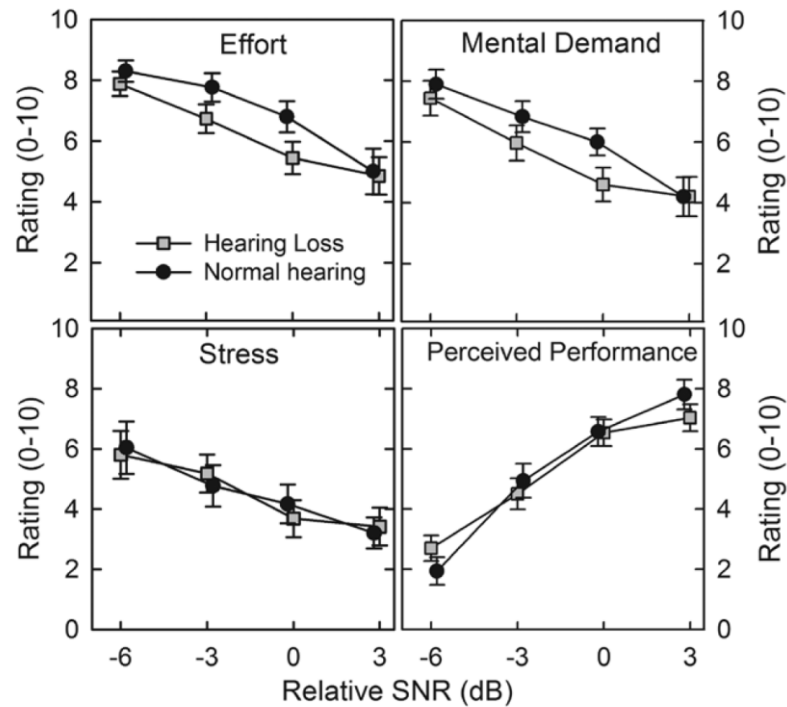


Fig. 5. Mean ratings of effort, mental demand, stress, and perceived performance for each relative signal-to-noise ratio (SNR). Error bars indicate ±1 SE.

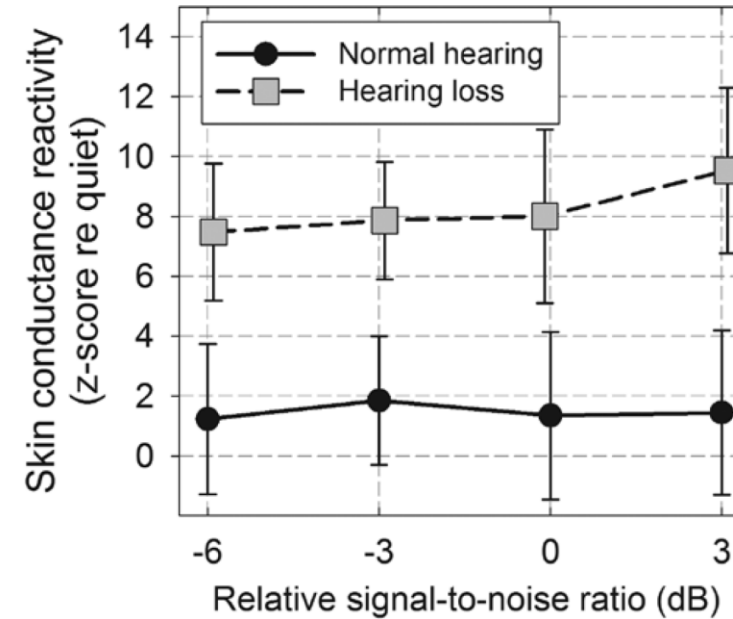


Fig. 3. Mean skin conductance reactivity indexes (re quiet) for each relative signal-to-noise ratio. Error bars indicate ±1 SE.

## Significant group differences in physiology

# Appraisal: Physiology Measures

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## 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

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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

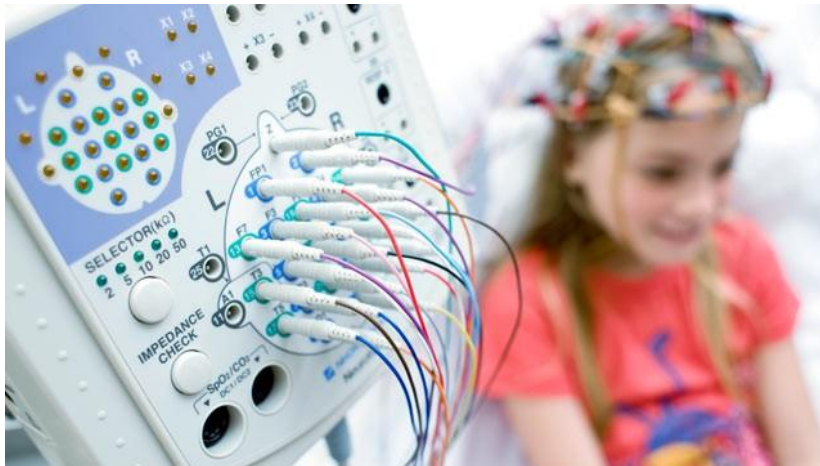




# Electroencephalography

Measure brain activity

- Alpha power change
- N1 evoked response potential



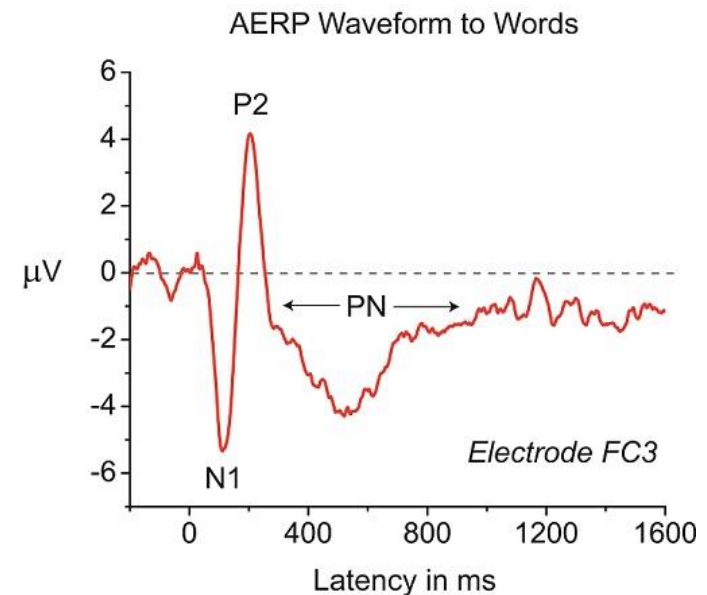
# N1 Evoked Response

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



# Alpha Oscillations

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Oscillatory alpha network reflects cognitive energy

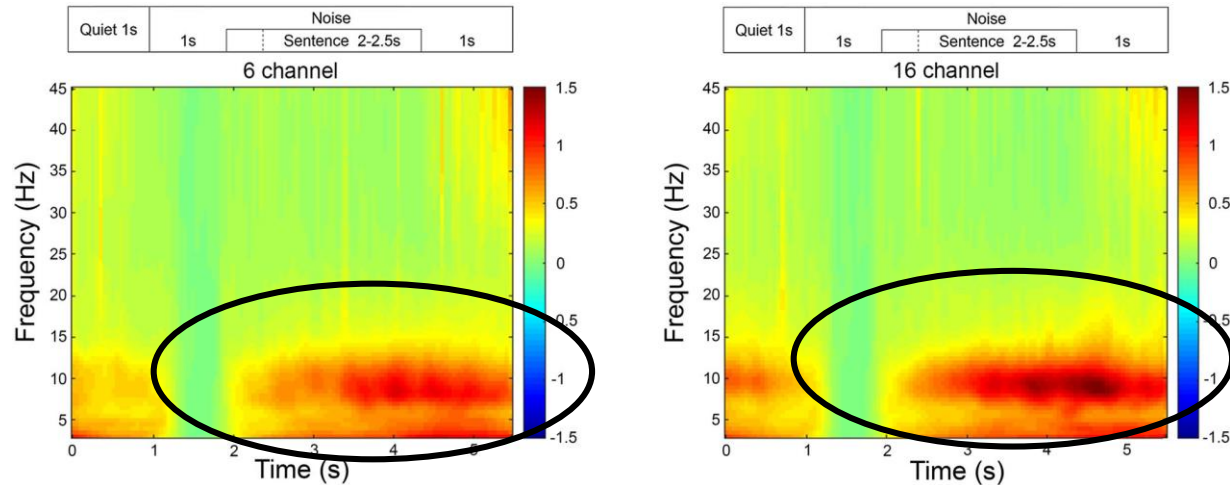
Measure alpha oscillations during stimulus-free period

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

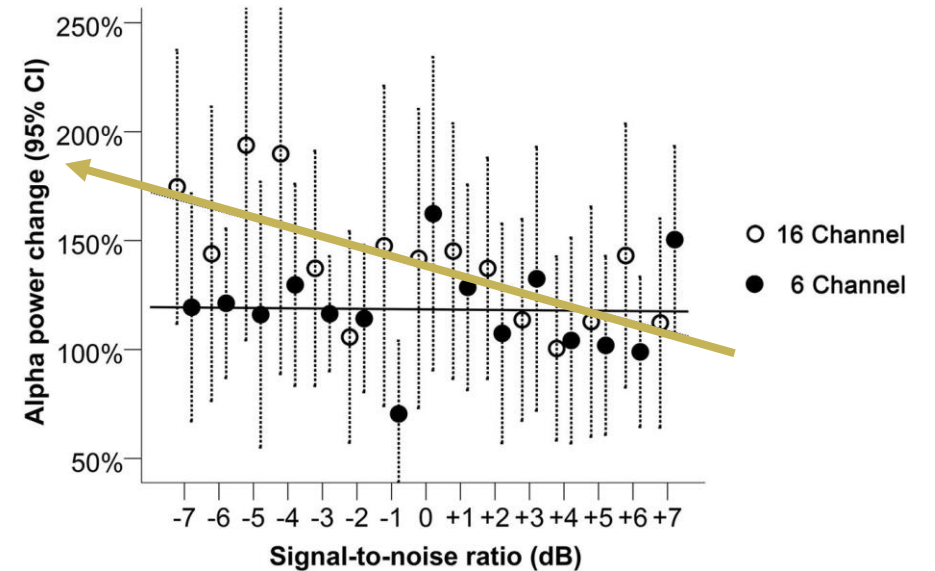


# Example: Electroencephalography



Change in alpha power relative to baseline indicates effort

Increased listening effort increases with increased noise



# 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

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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

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## Test patient's memory

- Free recall
- Paired-associates recall



# Free Recall

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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**



# Paired Associates Recall Task

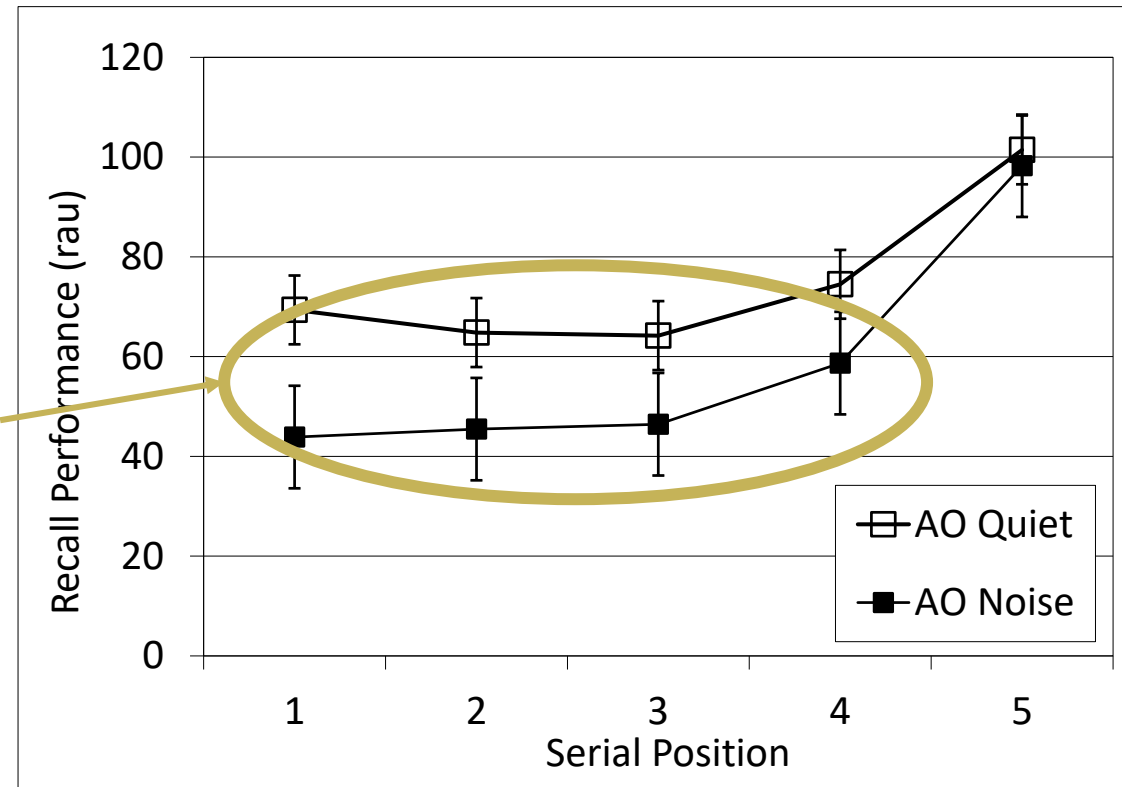
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Put Run

Put

# Example: Recall in Research

Background noise increases listening effort for listeners with normal hearing

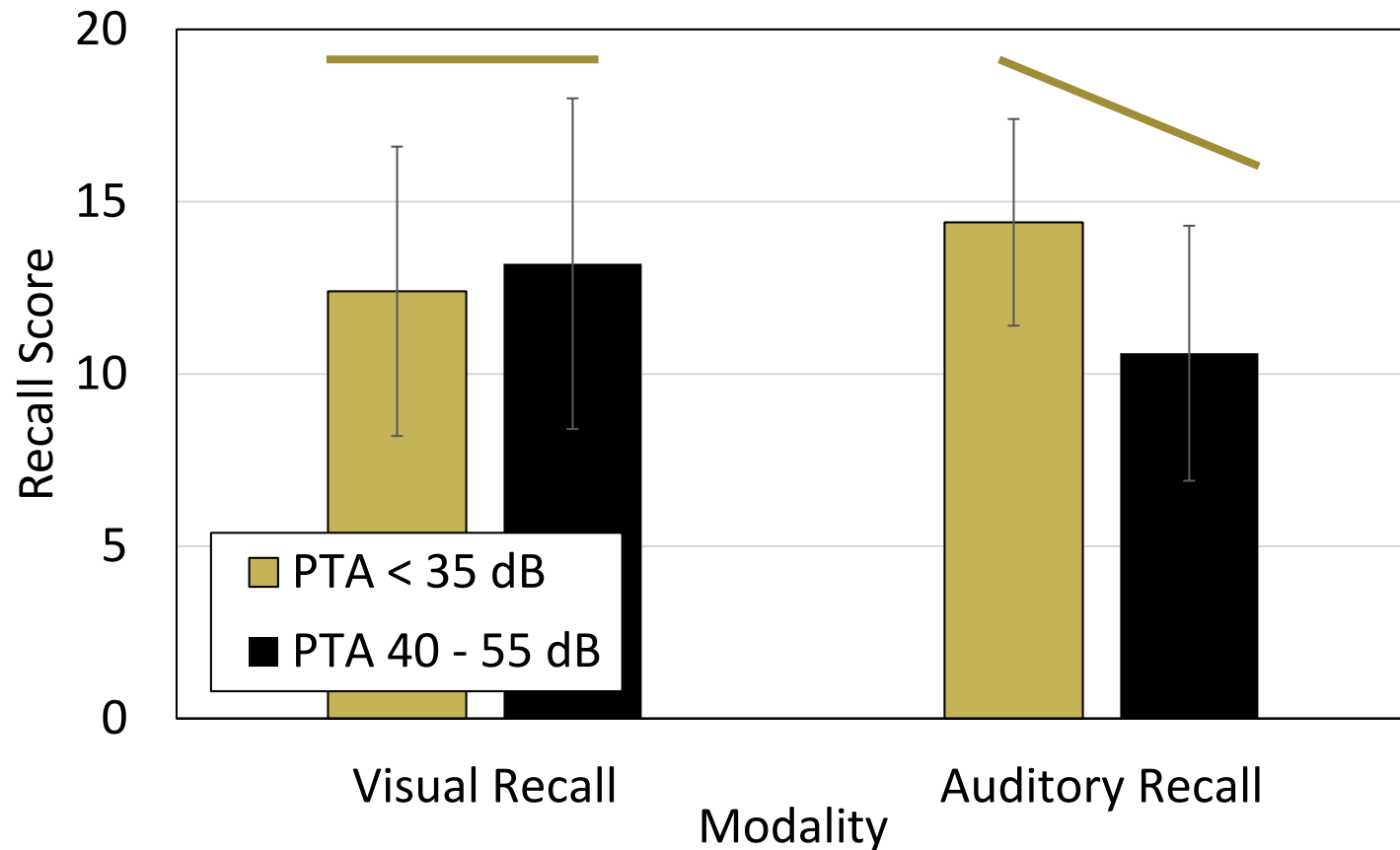


Less effort

# Example: Recall Research

“Hearing loss  
can cause  
apparent  
memory failure”

Hearing loss  
increases  
listening effort



# Appraisal: Recall Measures

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## Advantages:

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

## Disadvantages:

- Requires knowledge of cognitive tests
- Time consuming
- Some patients hate it



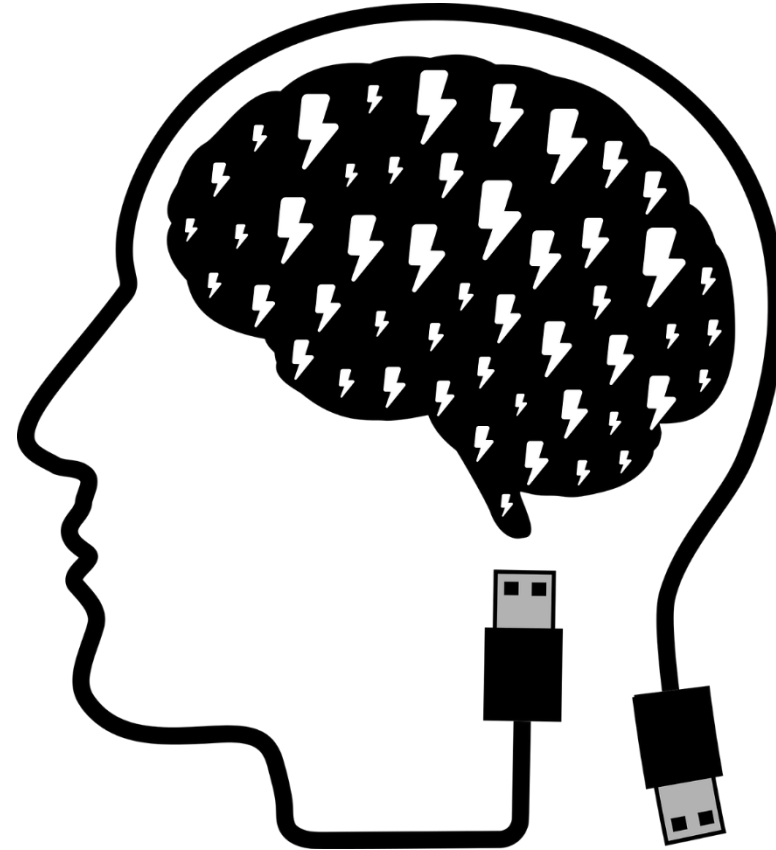
# Rationale: Response Times

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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

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Time how quickly patient responds

- Verbal response time
- Dual-task paradigms



# Verbal Response Time

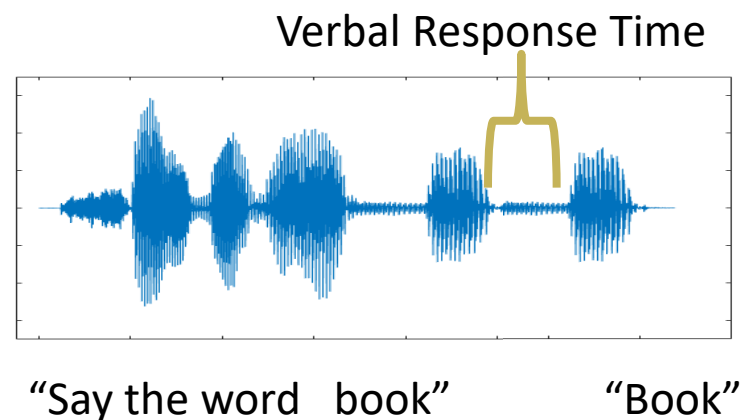
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Onset time for patient to vocalize response

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

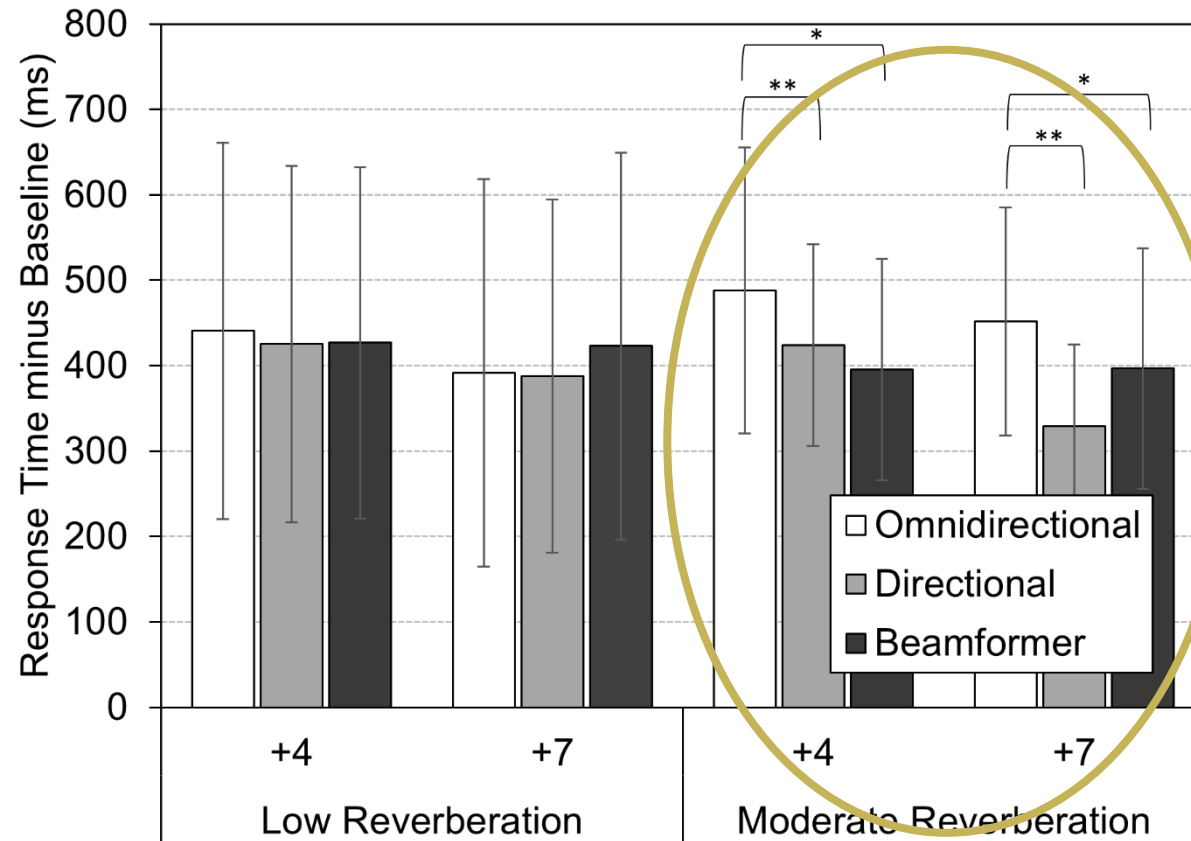
- Press a button as soon as a light appears
- Press a button if you feel a long-short-long pattern with a bone oscillator
- Use a mouse to track a moving cursor on a circle
- Press a button if the word you heard is a noun (person / place / thing)
- Press a button if a blue circle or yellow triangle appears; 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

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## 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

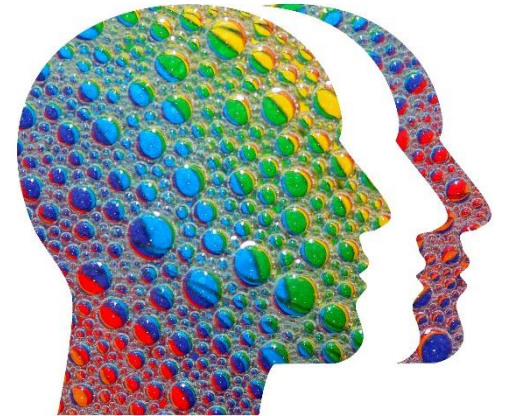
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Diverse methods for measuring listening effort

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?