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Understanding Emotional Responses in Hearing Loss: From Facial Expressions to Clinical Applications, in partnership with Seminars in Hearing

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Soumya Venkitakrishnan completed her Bachelors and Master degrees in Audiology and Speech-Language Pathology from India. After working as an Audiologist and SLP for 2 years in India, she went to the University of Iowa for her combined Doctoral of Audiology and PhD degrees, graduating in 2022. Soumya's PhD dissertation was titled, "Facial expressions as a measure of emotional responses and listening difficulty". She is currently an assistant professor at CSUS working as a researcher and didactic and clinical instructor. Her research areas include improving hearing aid outcomes in older adults; investigating the role of emotional responses, stigma, and bias in audiology; and investigating auditory skills in individuals with long COVID.

Disclosures

- **Presenter Disclosure**: Financial: Soumya Venkitakrishnan is employed by CSUS. She received an honorarium for this presentation. Non-financial: Soumya Venkitakrishnan has no relevant non-financial relationships to disclose.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
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Learning Outcomes

After this course, participants will be able to:

- Describe how hearing loss affects recognition and expression of emotions.
- Explain how facial expressions can serve as indices of emotional responses and listening difficulty.
- List two potential clinical applications of using facial expressions in audiology.

Emotions and communication

- Emotions are essential for social survival: connect us to each other: help form social relationships.
- Positive emotions: help promote engagement with the world around us.
- Negative emotions: functionally, have evolved to help us deal with a problem. E.g., fear and anxiety, sadness.
- Negative emotions such as confusion or frustration help increase attention towards the task, facilitate problem-solving and learning.

Lench, H. C., & Carpenter, Z. K. (2018). What Do Emotions Do for Us? In H. C. Lench (Eds.), *The Function of Emotions* (pp. 1-8). Cham, Switzerland: Springer.
Lewis, M., Haviland-Jones, J. M., & Barrett, L. F. (2008). Handbook of emotions (3rd ed.). Guilford Press.
D'Mello, S. K., Lehman, B., & Person, N. (2010). Monitoring affect states during effortful problem solving activities. *International Journal of Artificial Intelligence in Education*, *20*(4), 361-389.

Affective audiology: Connections between emotion and hearing

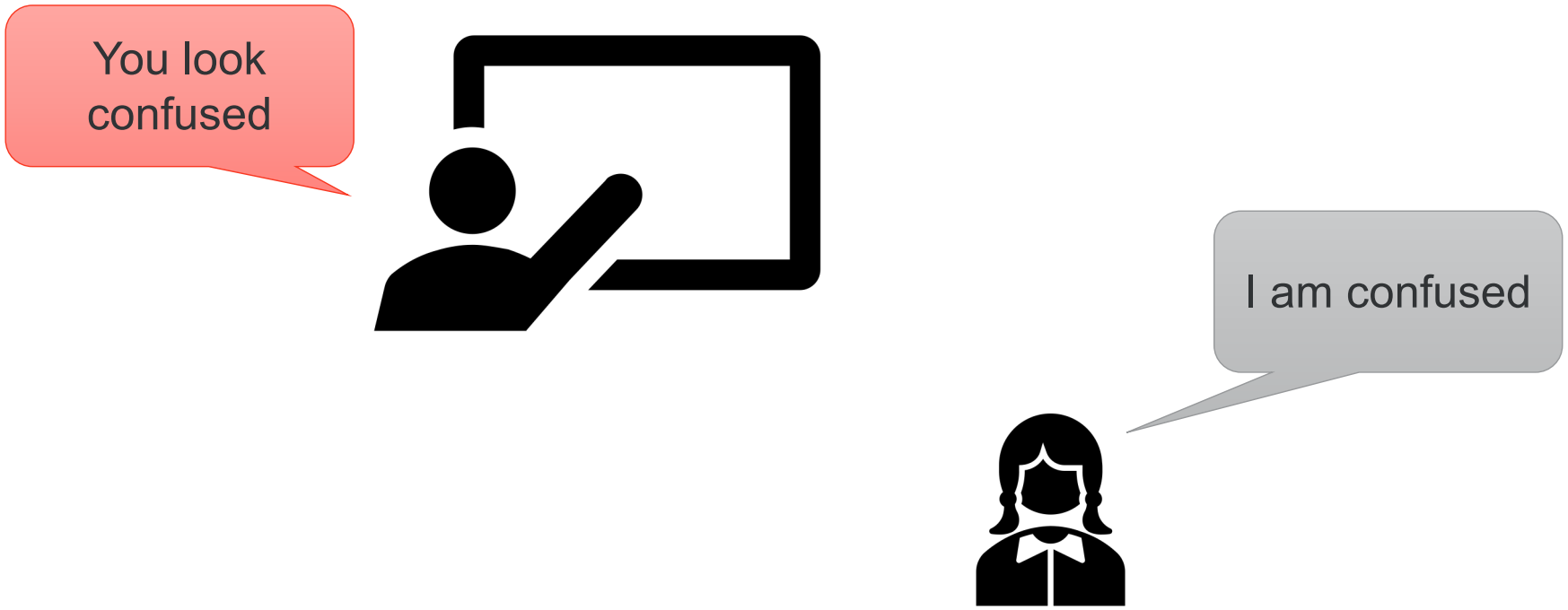
(Zhang & Siegle, 2023)

- Amygdala – central in emotional information processing → connected to the medial geniculate nucleus of the thalamus and the auditory cortex (LeDoux et al., 1984).
- Stronger activity seen in the auditory cortex when stimulated by affective (pleasant/ unpleasant sounds) than neutral sounds (Plichta et al., 2011).
- Complex relationship between a related concept of affect, i.e., motivation and listening effort: inverse U-shaped curve.

Hearing loss exacerbates negative emotions and quality of life

- Hearing loss is related to feelings of depression, anxiety, social isolation (Nachtegaal et al., 2009).
- Individuals with lower affect scores (lower moods) were related to greater hearing handicap scores - greater effects of hearing loss in their daily life (Preminger & Meeks, 2010).
- Individuals who noted negative affective states (anxiety, anger, pessimism) during the COVID-19 pandemic → reported increase in self-perceived tinnitus (Aydoğan et al., 2022).

Emotion Recognition and Emotional Response



Inability to understand emotions or issues with expressing emotions could both lead to issues with social interaction or problems with conveying information.

Images: Microsoft 365

Emotion can be recognized through vocal and visual stimuli

- Vocal emotion recognition stimuli may include:
  - Emotional speech
  - Emotional non-verbal vocalizations: crying, laughing
- Visual emotion recognition:
  - Facial expressions
  - Body language

- Investigated in children and adult populations.
- And with individuals with normal hearing (NH), hearing aid (HA) and cochlear implant (CI) users.

Use of HA/CI results in poorer emotion recognition in children

- Compared to children with normal hearing
  - Vocal emotion recognition is poorer (happy, scared, neutral, sad, and angry) in children with CI (Lin et al., 2022).
  - Facial expression recognition (happiness, sadness, anger, fear, neutral expression) is poorer in children with CI and/or HA (Wang et al., 2011).
- Compared to age/gender matched peers: Children with HAs and Cis – developmentally delayed in identification of color images of happy, sad, angry and fearful faces (Wang et al., 2016).
- Aural rehabilitation should include emotion recognition training.

Older adults have poorer emotion recognition

- For vocal emotion stimuli (angry, happy, sad, neutral, and scared) (Christensen et al., 2019; Goy et al., 2016; Ruiz et al., 2020).
- For visual emotion identification and discrimination compared to ONH and YNH adults (Saatci et al., 2022).
- Individuals with hearing loss have evidence of neuronal reorganization in the emotion-related areas in the brain (Husain et al., 2014).

HA/ CI don't help improve emotion recognition

- Hearing aids do not help with vocal emotion recognition compared to unaided recognition (Goy et al., 2016; Ruiz et al., 2020).
- CI users had poorer vocal emotion perception of fearful/angry word stimuli (von Eiff et al., 2022).
- CI users were less accurate than individuals with NH at recognizing happy, sad and fearful faces, fear, happiness, sadness) from dynamic faces. Pre-CI patients were less accurate for sad faces only (Ambert-Dahan et al., 2017).

Better emotion recognition in individuals with HL?

- For negative emotions.
- Individuals with profound hearing loss are better than NH in recognizing the emotions of fear and disgust from body language – and also intense genuine negative emotions (Ferrari et al., 2019).
- CI users and pre-CI users did as well as NH for the emotion of anger (Ambert-Dahan et al., 2017).

Emotion recognition is related to quality of life

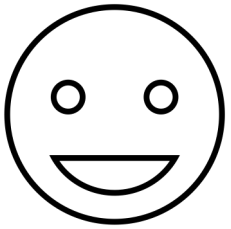
- Vocal emotion recognition (angry, happy, neutral, sad, and anxious sentences) performance was correlated with subjectively reported quality of life in adult CI users (Luo et al., 2018).
- More investigation is necessary to determine if rehabilitation to improve emotion recognition results in improvement in overall QOL (causality).

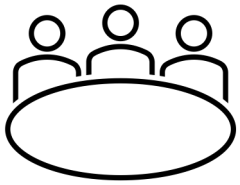
Emotion recognition is affected due to age, HL, and does not improve with HA/ CI

- Emotion recognition of vocal, visual emotional stimuli are better in children with normal hearing as compared to children using CI and/or hearing aids.
- Older adults with hearing loss have poorer emotion recognition (visual and vocal) as compared to ONH, OHL.
- HAs/CI do not help with improving emotion recognition.

Emotional responses impact daily life in different ways

- Emotional response: response of an individual to emotional stimuli.
- Attention and memory (Anderson, 2005; Cherry, 1953; McGaugh, 2004).
- Quality of life (Frijda, 2003).
- Negative emotions help with vital decision making, learning and critical enquiry (Parsafar & Davis, 2018; D'Mello & Graesser, 2012).
- Likelihood of participation in communication situations.





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Emotional responses to non-speech sounds measured using subjective methods

- Stimuli = non-speech sounds
  - E.g., dog barking, laughing, crying, sneezing, etc. (pleasant, unpleasant, and neutral sounds)
- Measurement: Subjective Rating scale
  - Valence: (pleasant/unpleasant)
  - Arousal: (Exciting/calming)

Reduced emotional responses to non-speech sounds

- Compared to individuals with NH, individuals with HL/ simulated HL have reduced range of valence: report less extreme ratings for pleasant, and neutral sounds (Buono et al., 2021; Picou, 2016; Picou et al., 2021).
- Greater the hearing thresholds, less extreme – the valence ratings (Picou & Buono, 2018; Tawdrous et al., 2022).
- Experiencing a reduced range of emotions may have implications for overall psychosocial well-being.

Hearing aids/ cochlear implants don't improve emotional response ratings

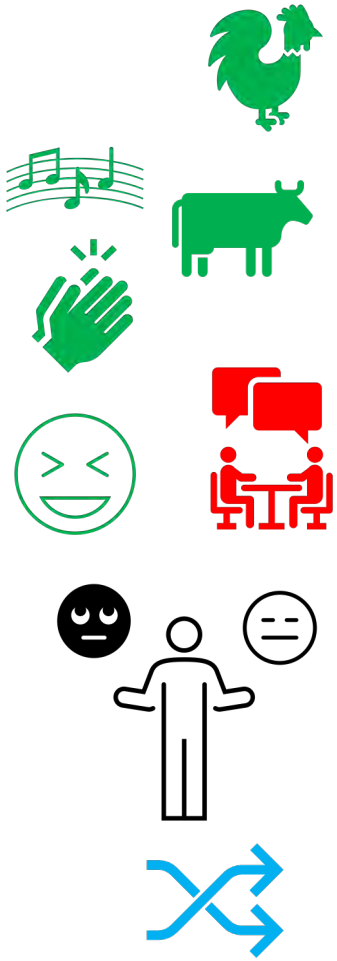
- Increasing overall level, using hearing aids, using hearing aids with nonlinear frequency compression do not improve emotional response ratings (Picou et al., 2021).
- ONH, HA, bimodal CI listeners: reduced emotional responses in HA and CI users: rated sounds as less pleasant and less unpleasant (Tawdrous et al., 2022).
- Need to investigate ways to restore emotional responses with devices.

Emotional responses- reduced range of valence/no benefit with devices

- Evaluation using non-speech stimuli shows reduced range of emotional valence in individuals with hearing loss.
- Management with hearing aids or cochlear implants does not cause improvement in range of emotional responses.

Important to determine emotional responses with speech stimuli and using objective measures

- Speech stimuli – meaningful in everyday life. Needs investigation in especially in adverse listening situations.
- Objective measures need supplemented explored because:
- Difficulty identifying their own emotions (Krosnick, 1988).
- Hesitate to give their honest emotional ratings (Berinsky, 2004).
- May provide ratings based on their evaluation of the stimuli (McDermott, 2007).
- Automatic facial expressions detection = objective method



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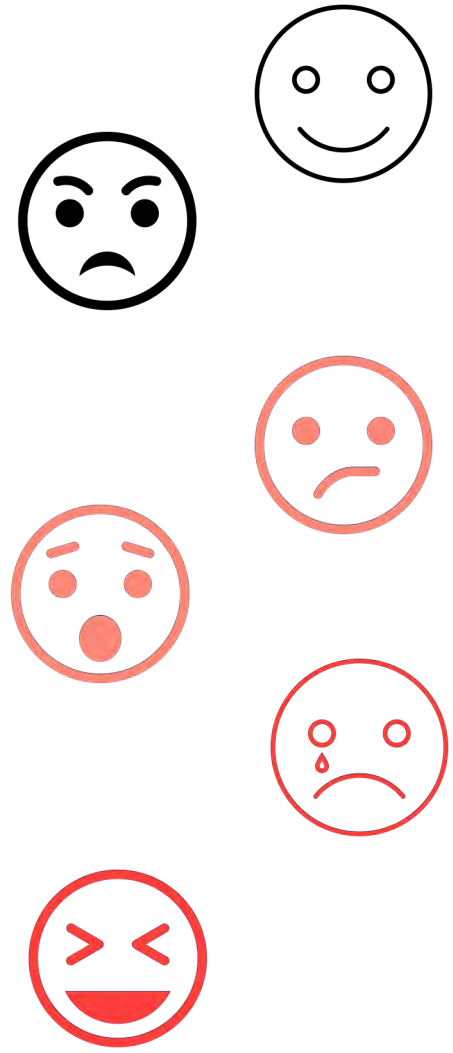
Facial expressions as a measure of emotional response and listening effort

Emotional responses are displayed by facial expressions

- Strong link between facial features and affective states (Ekman et al., 1980, Dimberg, 1990).
- Facial expressions of emotion also influence:
  - An individual's behavior (Baron, 1972).
  - Communication partner and affect communication (Marsh et al., 2005; Winkielman et al., 2005).
- Facial expressions of emotion can influence a communication situation in multiple ways.



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Facial recognition algorithms help detect emotional responses via facial expressions

- **Universality of facial expressions** (Darwin & Prodger, 1998): all people regardless of their race or cultural origins express emotions in the same manner. Basis of automatic facial expression detection algorithm.
- Universality has been debated (Gendron et al., 2018; Jack et al., 2012; Matsumoto, 1992).
- Automatic facial expression recognition algorithms train their machine learning algorithm with facial expressions from a variety of cultural groups during their training and validation phases.

Setting for the experiment: speech in noise

- Automatic facial expressions detection algorithm – objective way to measure emotional response.
- Setting = speech in noise
  - Challenging situation – common complaint with HL
  - Likely to express adverse emotional reactions
- Complex situations: problem-solving; Cognitive disequilibrium, encounter gaps in knowledge: **confusion, frustration, anger, anxiety** (D'Mello, Picard & Graesser, 2007; Craig, D'Mello, Lehman, D'Mello & Person, 2008; Di Leo, Muis, Singh & Psaradellis, 2019; Taub et al., 2019).

Understanding speech in noise is a complex process

- Complex process: Peripheral and higher-level processing
- Segregation of information
- Maintaining attention
- Decoding the message
- Committing to memory

Confusion

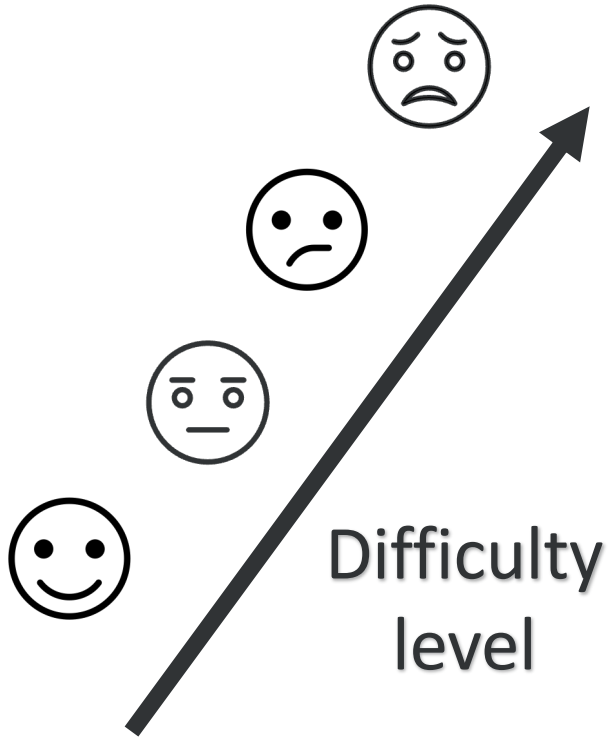
Frustration

Breakdown at any level could give rise to cognitive disequilibrium resulting in confusion and frustration

Images: Microsoft 365

Emotional responses may be present in difficult listening situations

- **Francis and Oliver (2018):**
  - Model showing interactions between effort, motivation, and affective systems.
  - Role of affect systems during speech perception in challenging listening situations.
  - Measure both these constructs to determine an individual's engagement in a social situation.

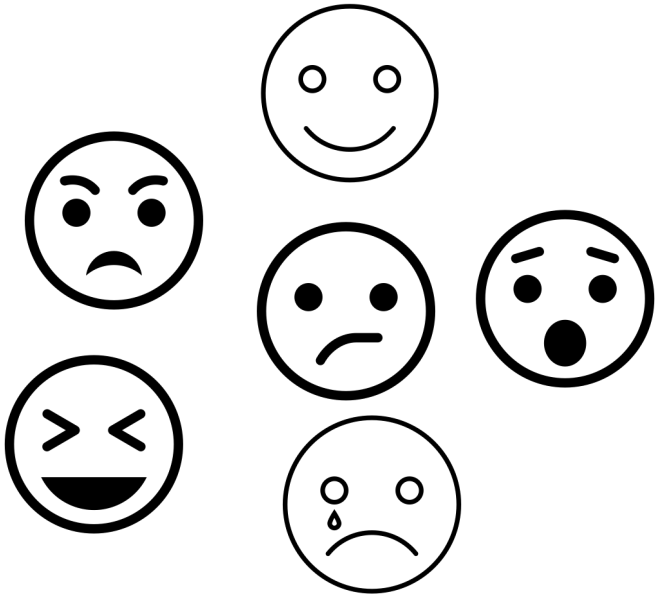


Images: Microsoft 365

Increased listening effort in adverse listening situations

- Studies show that listening effort increases as the signal-to-noise ratio (SNR) reduces; as the situation is more challenging (Zekveld, Kramer & Feston, 2010,2011; Zekveld & Kramer, 2014; Wu, Stangl, Zhang, Perkins & Eilers, 2016).
- Overlap between physiological systems associated with listening effort and affect (Francis & Love, 2020).
- Long-term consequences of exerting listening effort ~ an individual's affective state.
- Negative emotional state + increased listening effort = reinforce negative mood → social isolation/ reduced engagement

Measuring emotional responses (affect) and listening effort will provide a more complete picture of the speech perception process in challenging listening environment



Emotional responses:
Facial expressions

Listening effort:
Subjective rating scale

Images: Microsoft 365

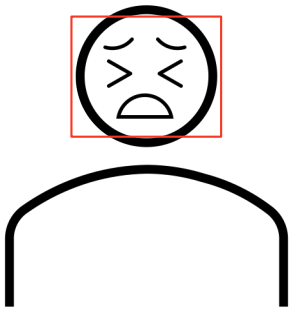
Research Question and Hypothesis

- To investigate the effect of the following on facial expressions of emotions:
  - Signal-to-noise ratio (SNR) – difficulty levels
  - Hearing loss
- We hypothesize that:
  - Confusion and frustration will increase with worsening SNR.
  - Compared to normal hearing (NH) condition, hearing loss (HL) will increase likelihood of emotions of confusion and frustration

Materials

Participants	IEEE sentences in noise	Conditions	Outcome measures
• 33 young adults (16M, 17F) with normal hearing • Age range: 18 to 34 years • Excluded participants at risk of depression/ anxiety per scores on Hospital Anxiety & Depression questionnaire (Snaith, 2003)	• SNRs: -1, +2, +5 dB with reference to individual SNR-50 and in quiet	• Normal hearing, simulated hearing loss • Nejime & Moore (1997)'s hearing loss simulator GUI with a mild to moderate simulated hearing loss	• Facial expressions of confusion and frustration • Speech recognition scores • Listening effort self-rating

Facial expression algorithm first detects the face: Face detection



Emotient FACET software (v8.0; iMotions)

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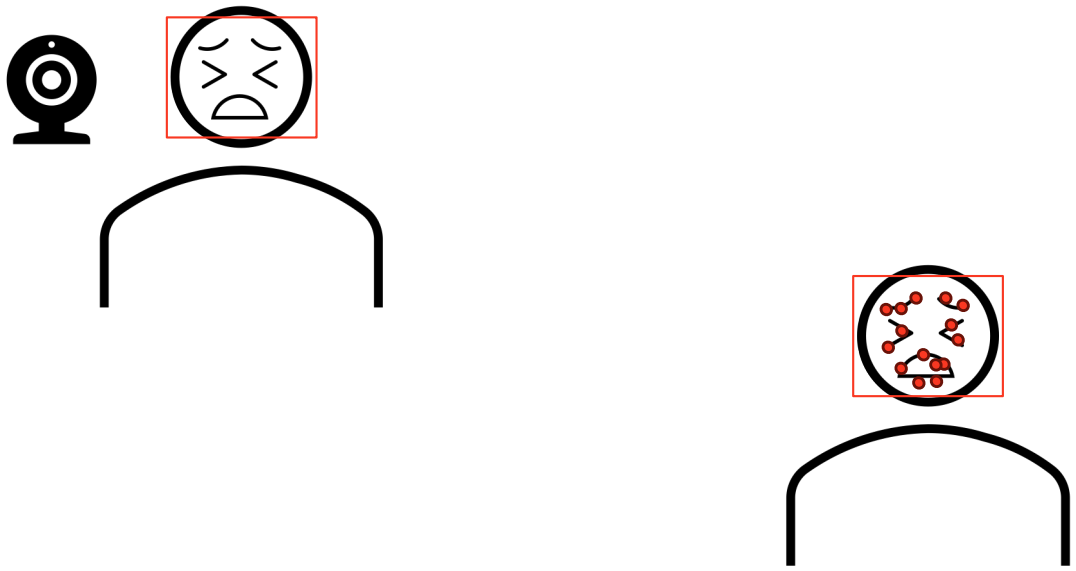
Facial expression detection algorithm then identifies features of the face.



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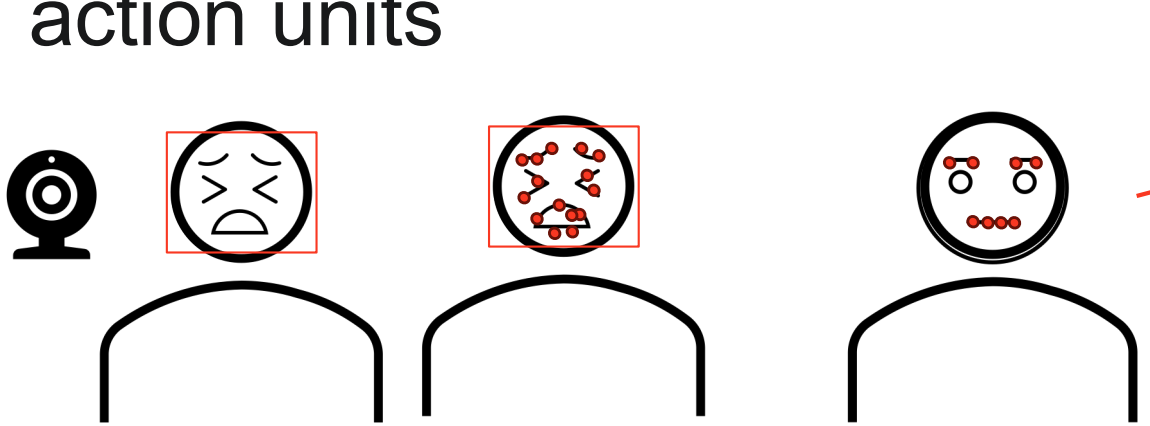
Movement of muscle groups are identified as action units



AU6: Inner brow raiser: frontalis, pars medialis muscle

AU12: Lip corner puller: Zygomatic major

Facial Action Coding System (FACS)
Developed by Ekman & Friesen (1976)

Action Units: Actions of muscles/muscle groups

Emotient FACET software (v8.0; iMotions)

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Co-occurring action units signify the presence of an emotion

JOY

AU6: CHEEK RAISER

AU12: LIP CORNER PULLER

CONFUSION

AU4: BROW LOWERER **AU7: LID TIGHTENER**

AU12: LIP CORNER PULLER

Universality of facial expressions makes their automatic detection possible

Emotient FACET software (v8.0; iMotions)

Images: Microsoft 365

Action units are monitored

- All action units of the face are monitored during the experiment.
- Combination of action units making facial expressions are also monitored at each instance in time.

Facial expressions/emotions are quantified in probability terms

Emotient FACET software (v8.0; iMotions)

- The **evidence value** for an expression channel represents the **odds, in logarithmic** (base 10) scale, of a target expression being present.
- For instance:
  - An evidence value of **1** for joy means that it is **10 times more likely** that the facial expression seen will be classified as joy by an expert human coder.
  - An evidence value of **2:100 times more likely.**
  - An evidence value of **0: equally likely.**

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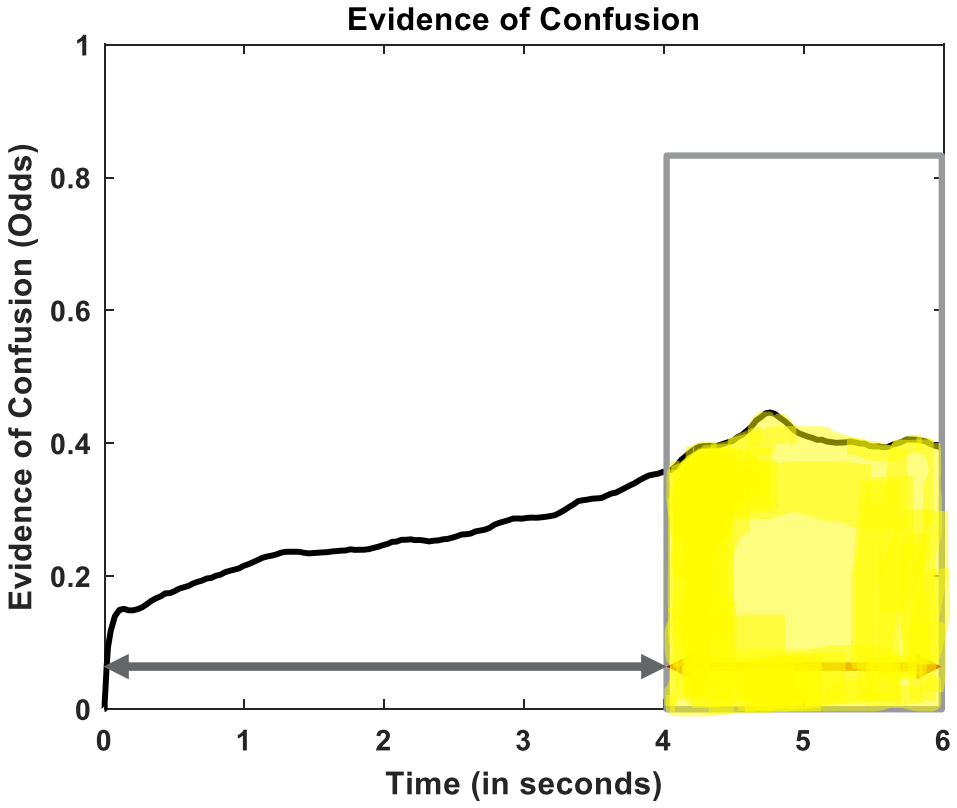
Time course of the emotion of confusion



The **evidence value** for an expression channel represents the **odds, in logarithmic** (base 10) scale, of a target expression being present.

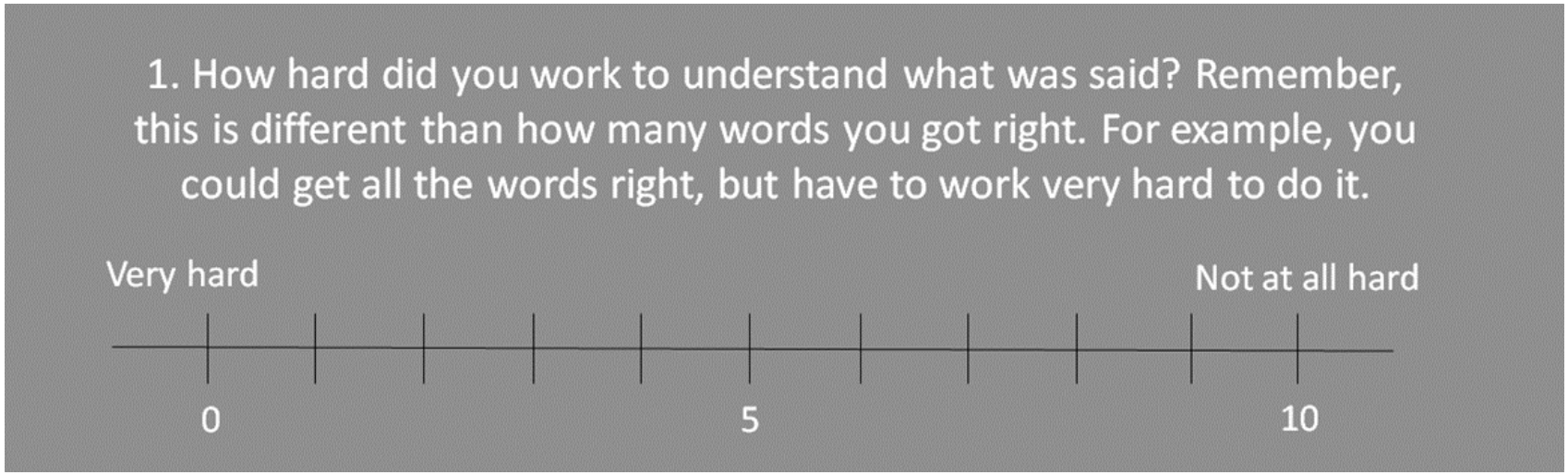
Used for AUC analyses

Noise + Speech

Retention period

Image: Soumya Venkitakrishnan

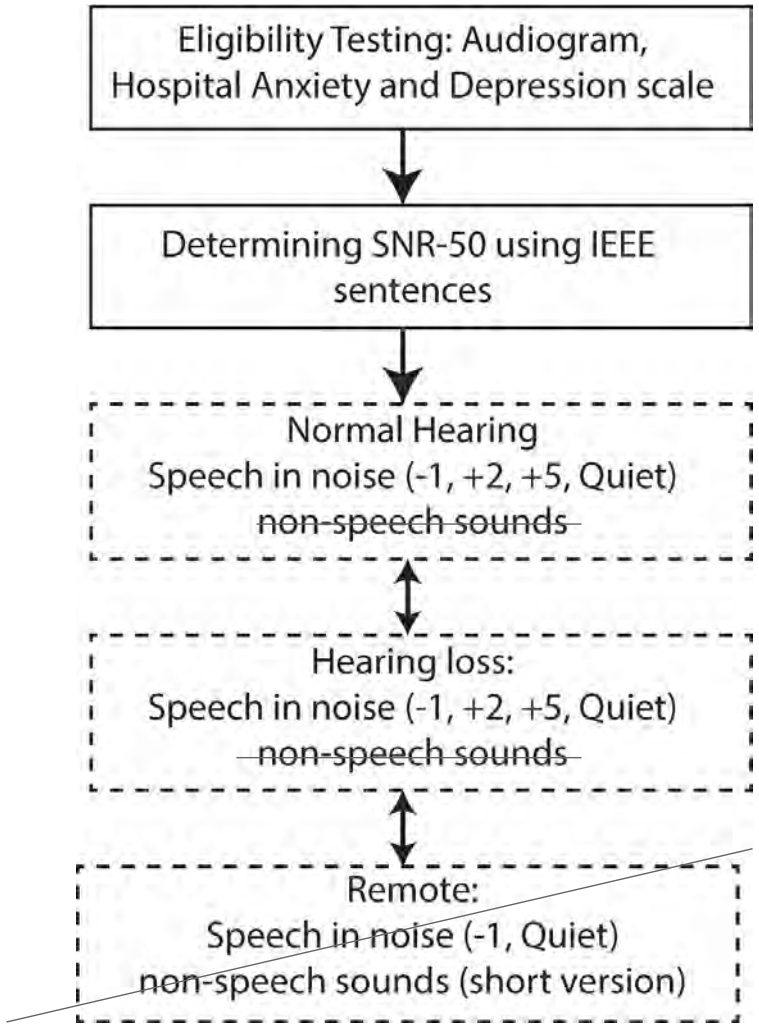
Subjective rating scale

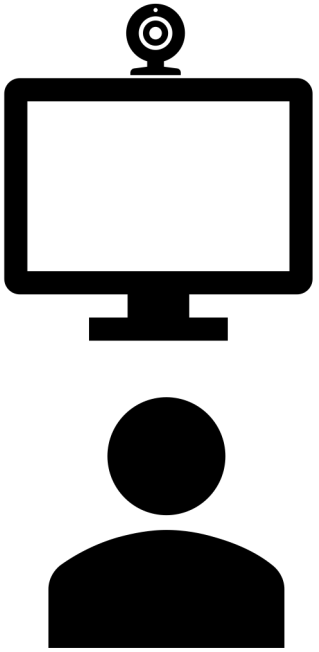


Picou, E. M., & Ricketts, T. A. (2014). Increasing motivation changes subjective reports of listening effort and choice of coping strategy. *Int J Audiol*, *53*(6), 418-426.

Image: Soumya Venkitakrishnan

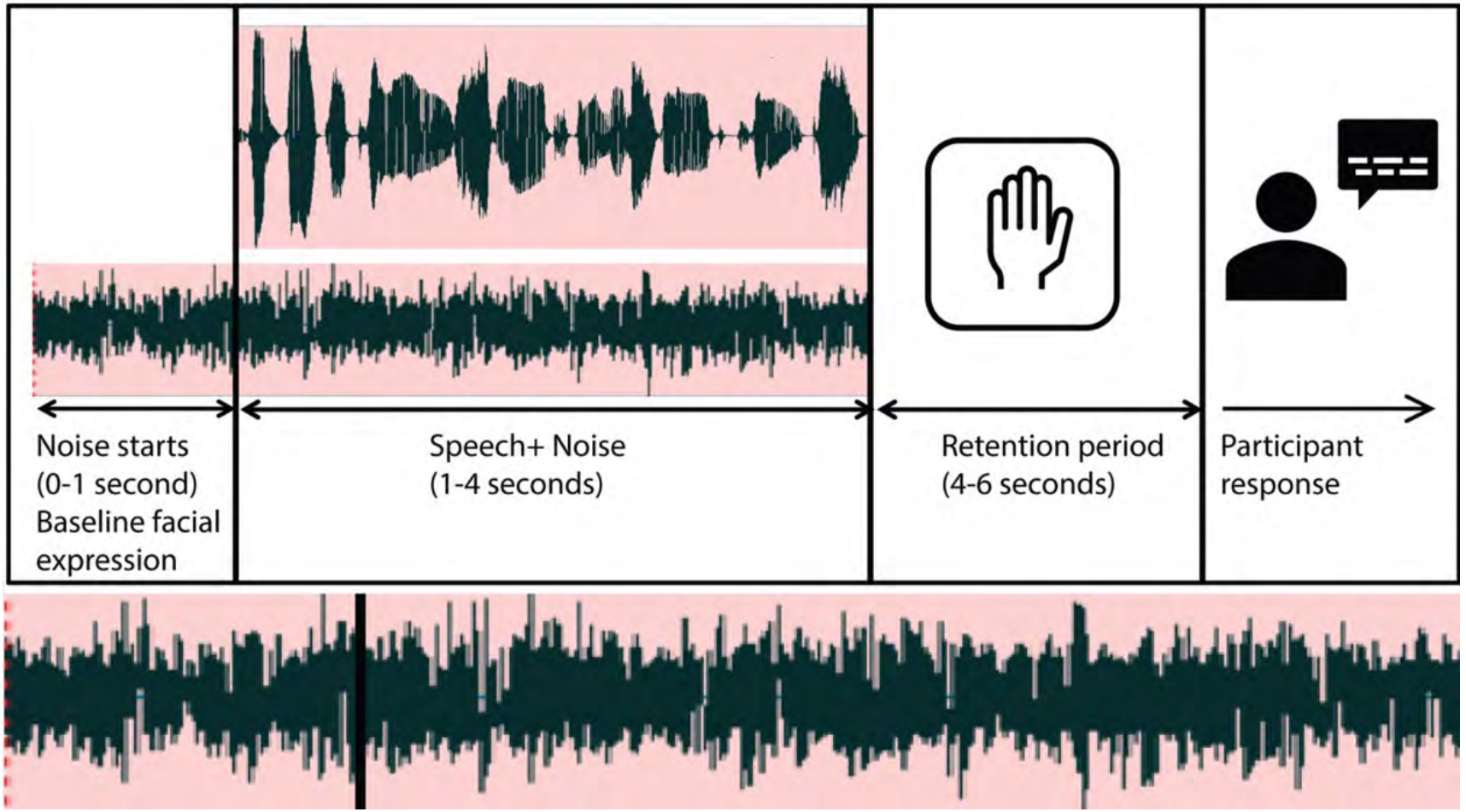
Procedure





Images: Microsoft 365

Time course of the first trial of a speech in noise sentence



Venkitakrishnan, S., & Wu, Y. H. (2023). Facial Expressions as an Index of Listening Difficulty and Emotional Response. *Seminars in hearing*, *44*(2), 166–187.

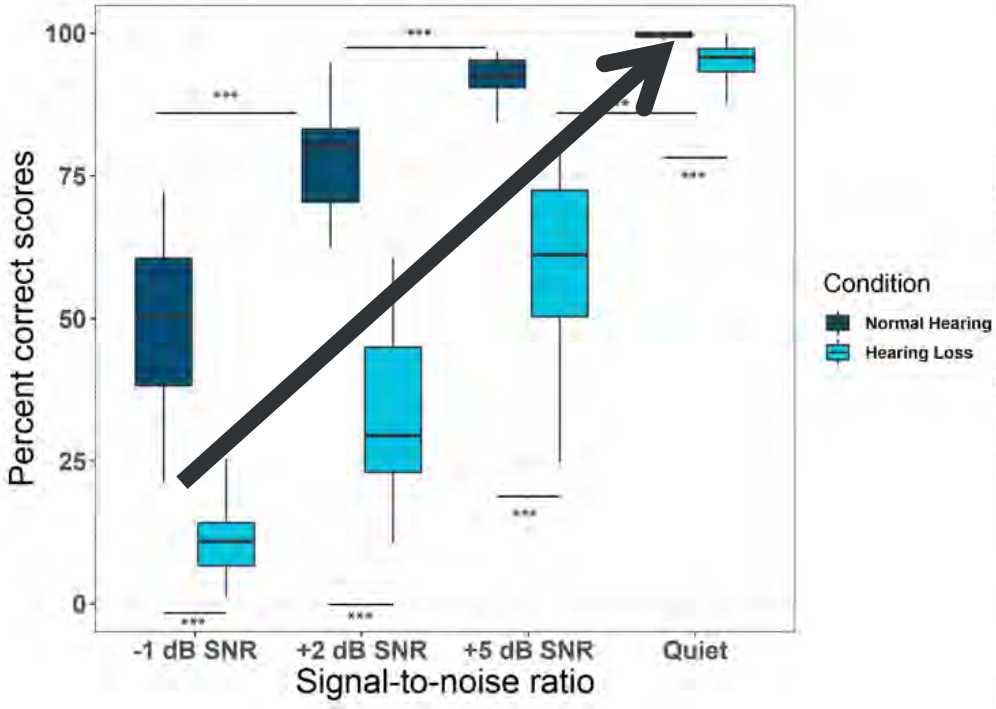
Statistical analyses

- Separate linear mixed effect analyses
- Dependent variable – speech scores, confusion and frustration emotional response, subjective ratings.
- Fixed effect: Condition (NH, HL); SNR (-1 dB SNR, +2 dB SNR, +5 dB SNR) and quiet.
- Random intercept: subject.

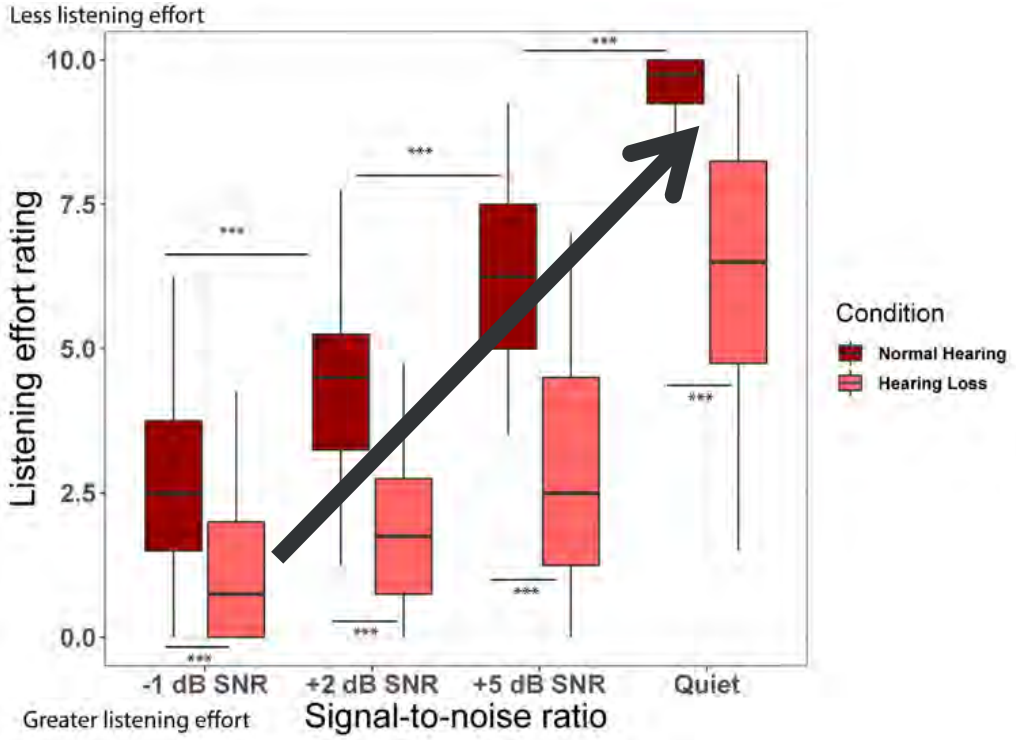
Aim 1: Effect of SNR on facial expressions of emotions:

Effect of SNR on facial expressions: worse speech scores and increased listening effort with increasing listening difficulty

Speech scores



Listening effort rating



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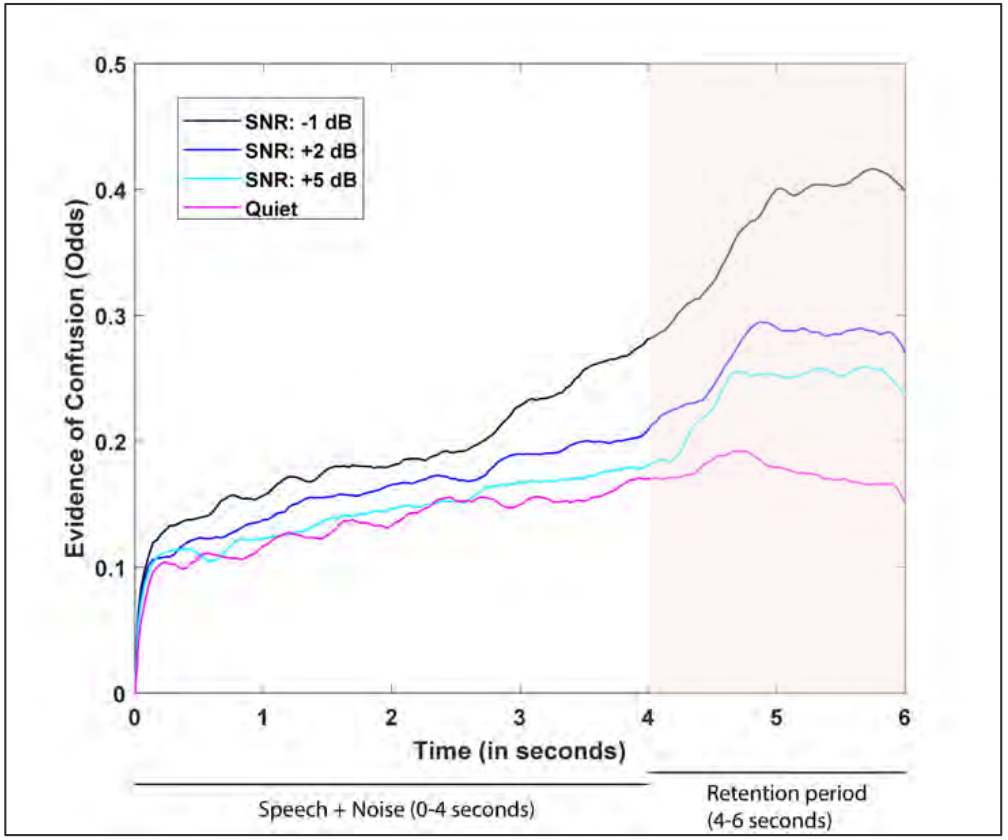
Confusion increases with difficulty level and is greatest during the retention period.



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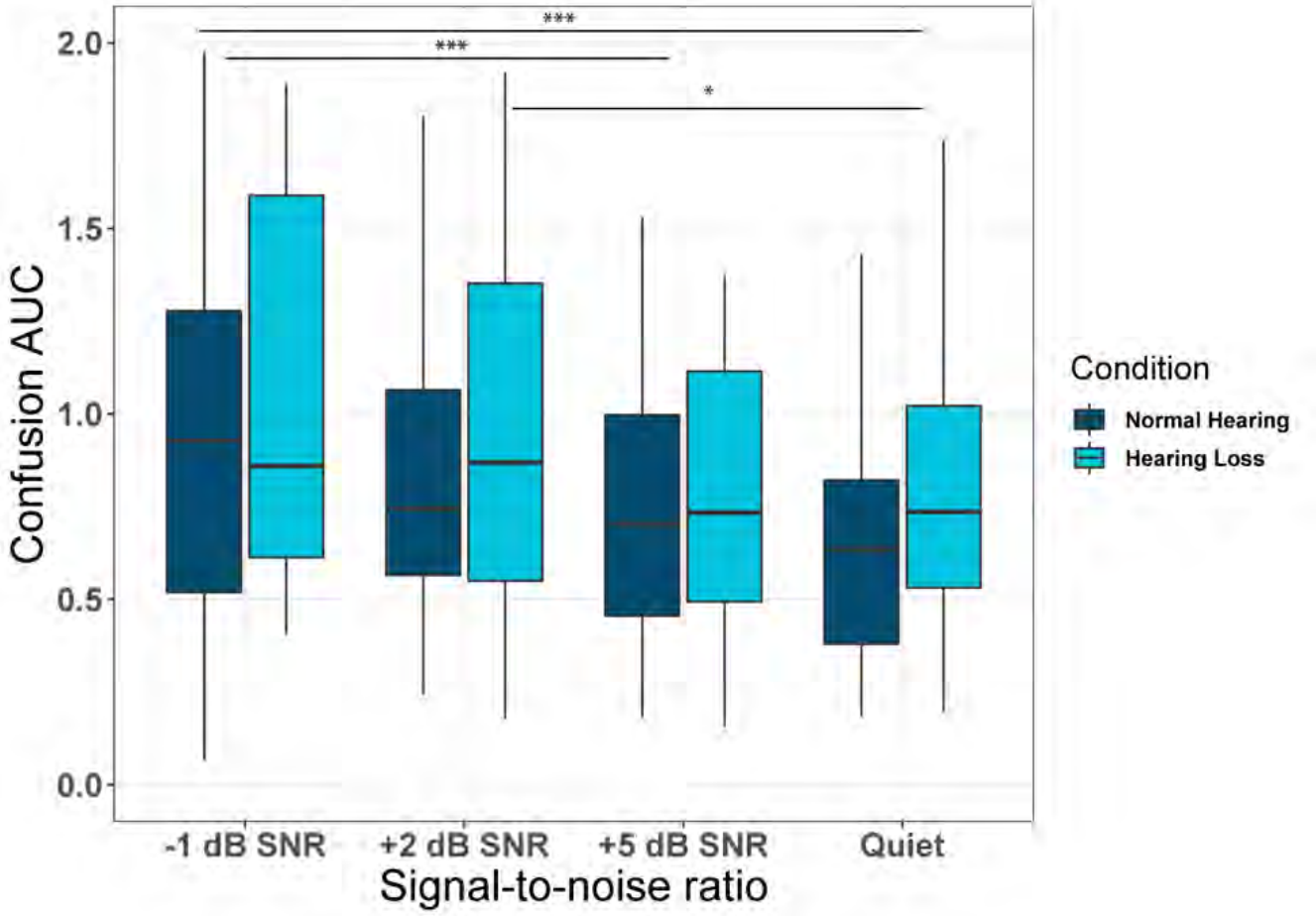
Effect of SNR on facial expressions: increased confusion with increasing listening difficulty



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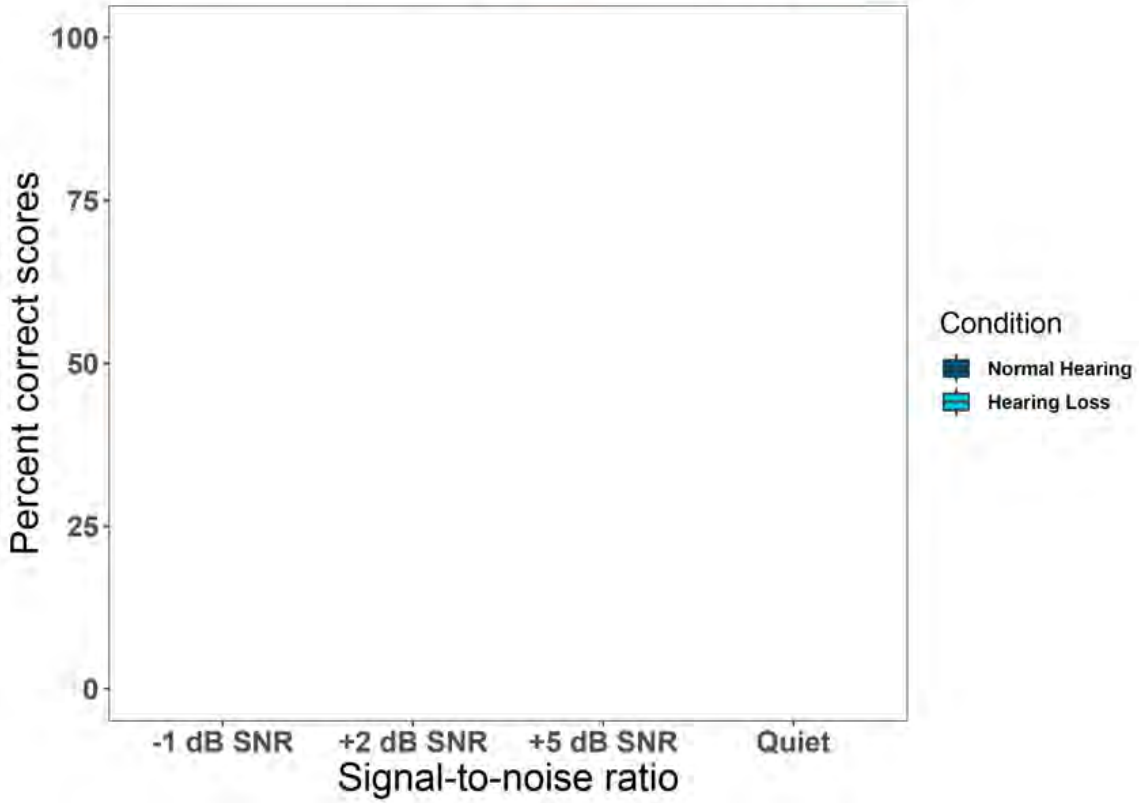
Aim 2: Effect of hearing loss on emotional responses

Effect of hearing loss: Speech recognition



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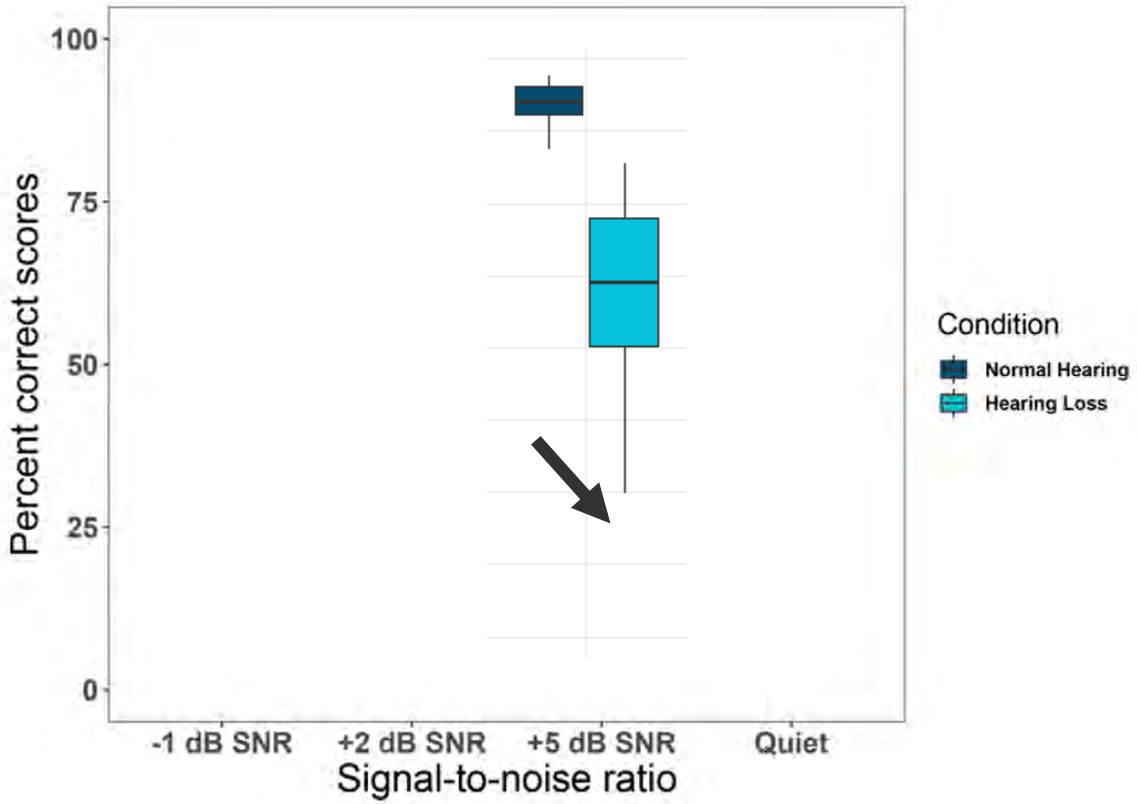
Effect of hearing loss: Speech recognition



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Speech recognition scores are worse in the HL condition

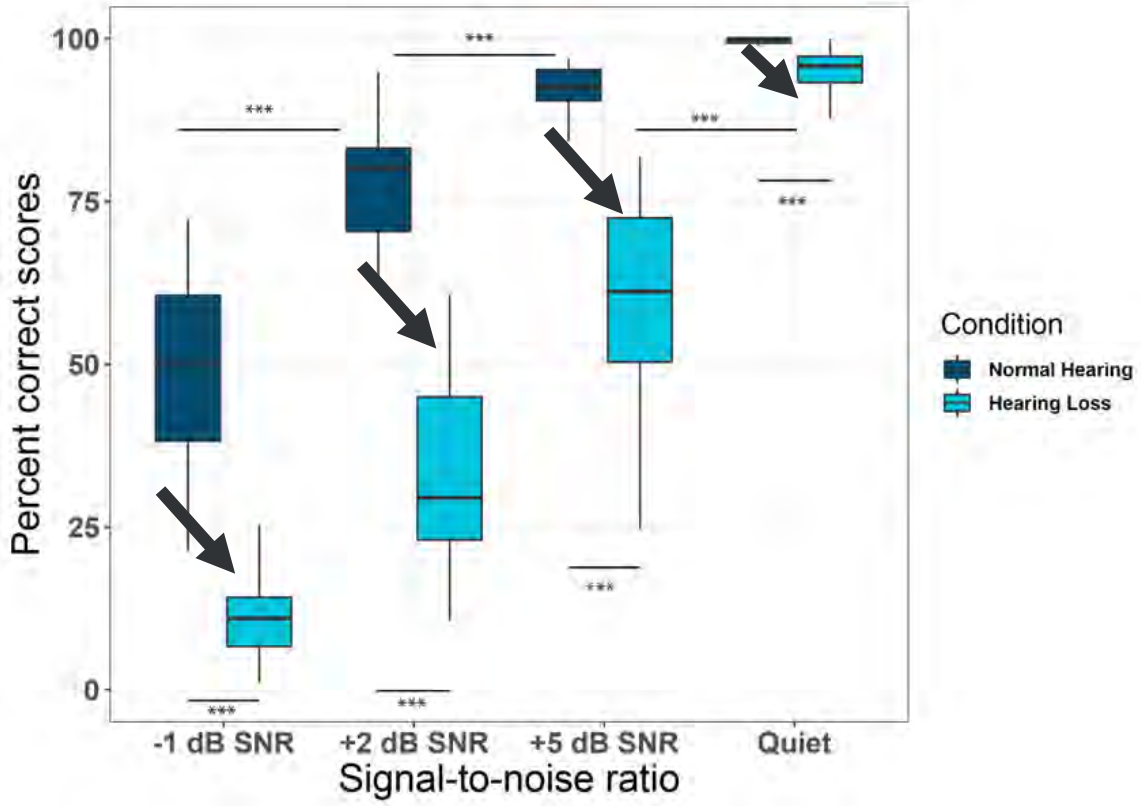
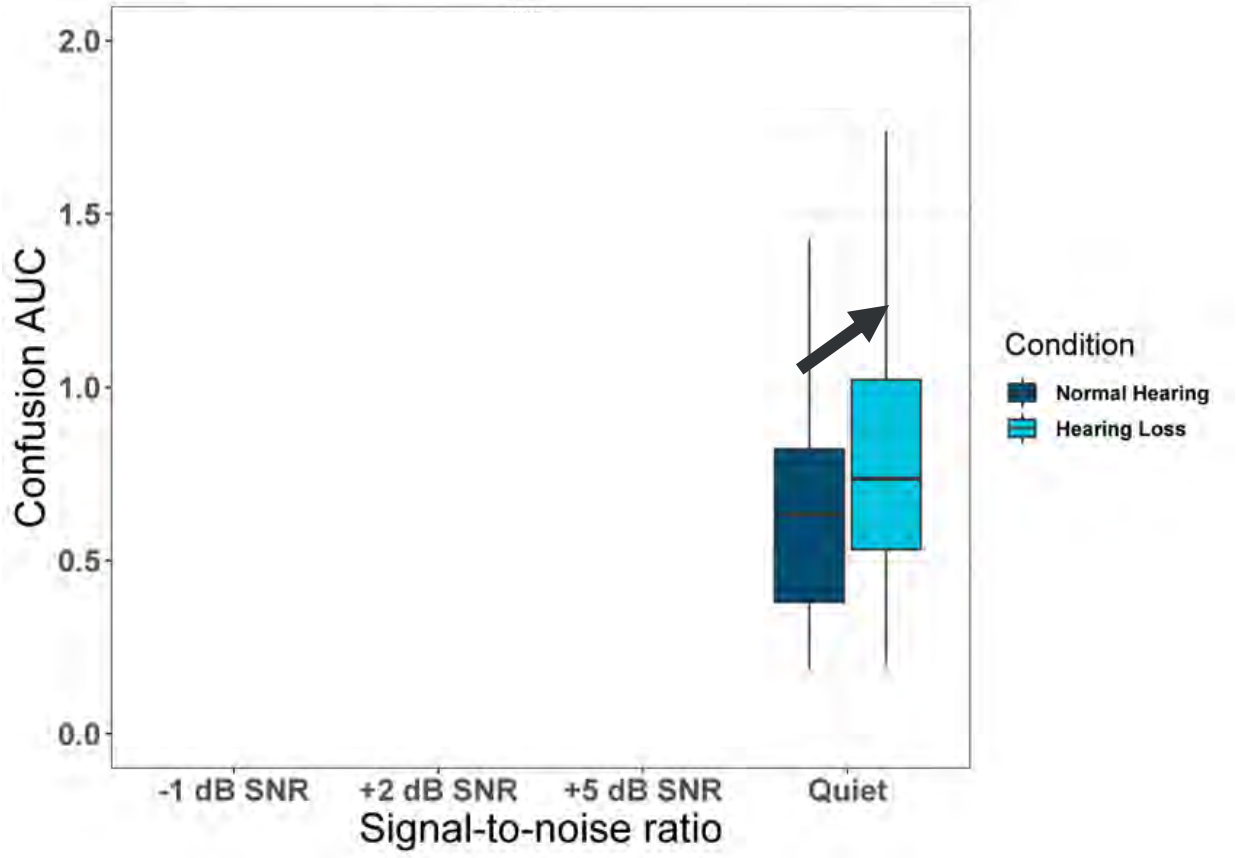


Image: Soumya Venkitakrishnan

More confusion with simulated HL



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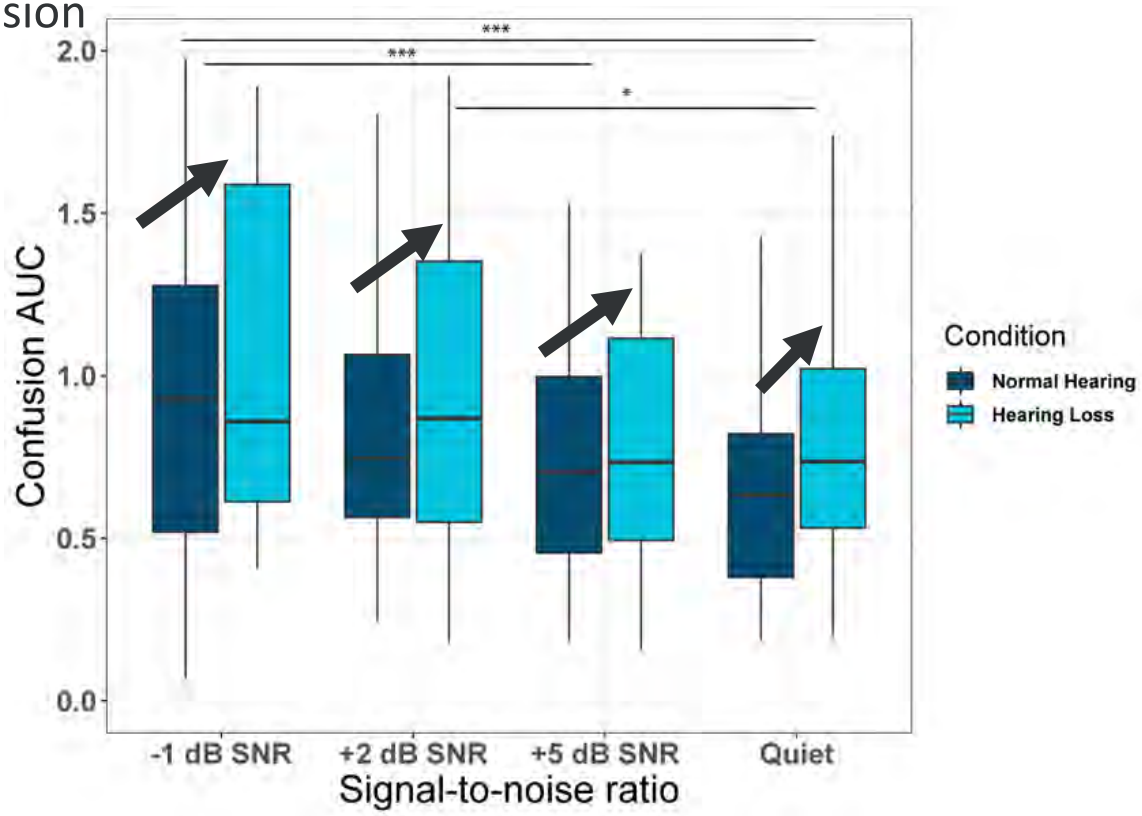
Confusion is greater in the HL condition

Greater confusion

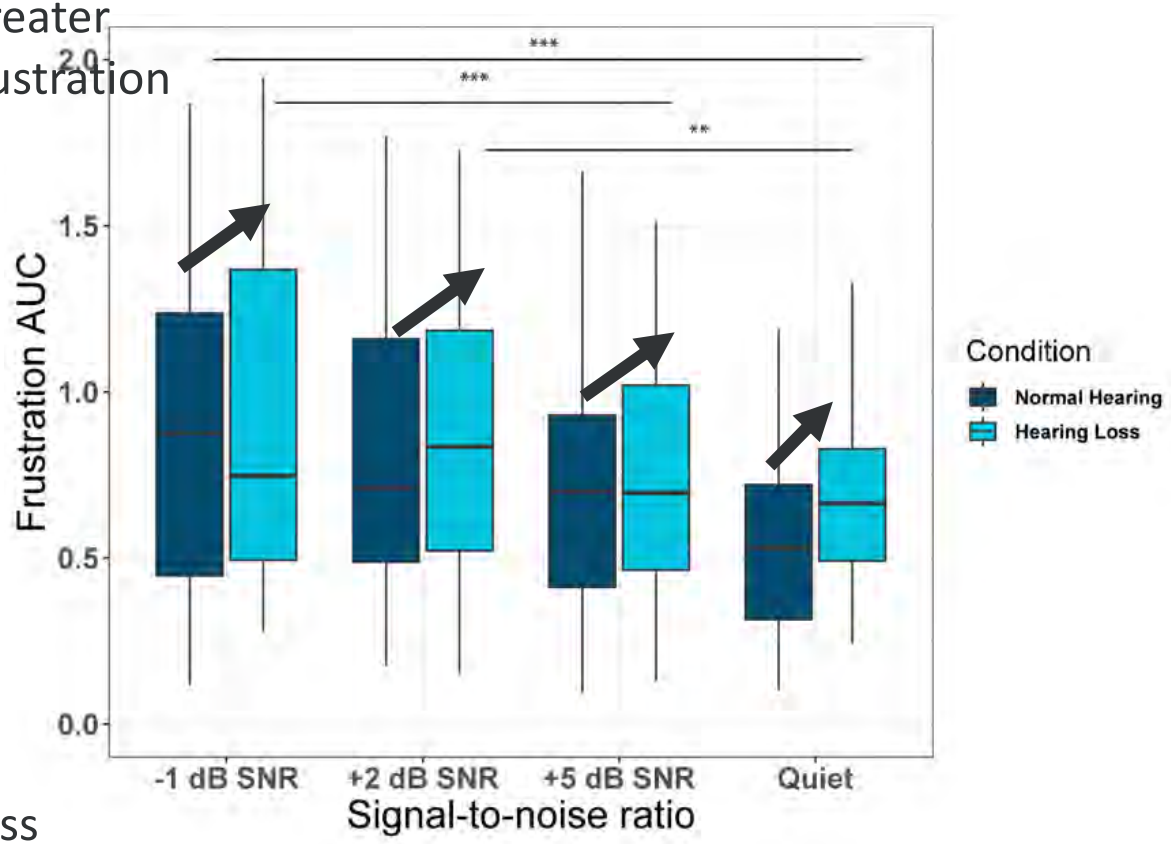


Less confusion

Image: Soumya Venkitakrishnan

Frustration also increases with difficulty level and is greater in the HL condition

Greater frustration



Less frustration

Image: Soumya Venkitakrishnan

Confusion and frustration responses are strongly positively correlated (r = 0.97, p < 0.001).

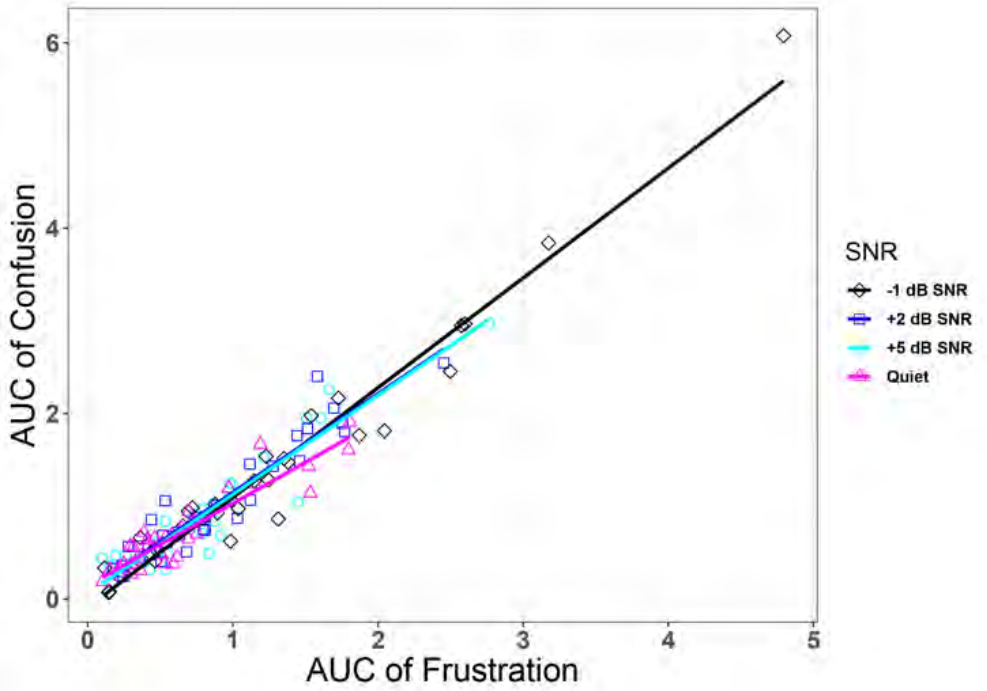


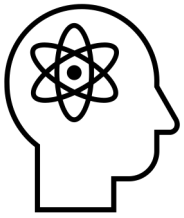
Image: Soumya Venkitakrishnan

Summary of results

Effect of SNR on emotional responses	Effect of hearing loss on emotional responses.
• Speech recognition scores were worse and listening effort was greater as difficulty level increased. • Facial expressions of confusion and frustration were more likely with increasing difficulty level.	• Speech recognition scores, confusion and frustration emotional responses were greater in the hearing loss condition. • Confusion & frustration measure the same underlying construct.

Hearing loss causes increased confusion and frustration.

- Individuals with hearing loss: risk for negative consequences.
- Emotional responses: related to social isolation/disconnectedness.
- Memory for emotional stimuli/ emotionally charged situations: greater.
- May remember negative emotions in adverse listening situations and avoid such situations.



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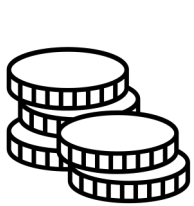
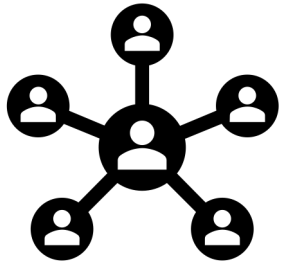
Research is necessary to determine if hearing devices can reduce these negative consequences

- Emotional responses to non-speech sounds – not affected by device fitting.

- Emotional responses to speech: not explored.
- Education: Unresolved confusion → frustration → giving up/disengagement.
- Improvement in audibility → reduction in confusion/ frustration → increase engagement!!





- CI users: analyze cost of listening effort to social connectedness benefit.
- Cost of increased effort → reduction in negative emotions: worth the cost.

Important to measure emotional responses in individuals with hearing loss and in hearing device users.

Hughes, S. E., Hutchings, H. A., Rapport, F. L., McMahon, C. M., & Boisvert, I. (2018). Social connectedness and perceived listening effort in adult cochlear implant users: A grounded theory to establish content validity for a new patient-reported outcome measure. *Ear and hearing*, *39*(5), 922-934.

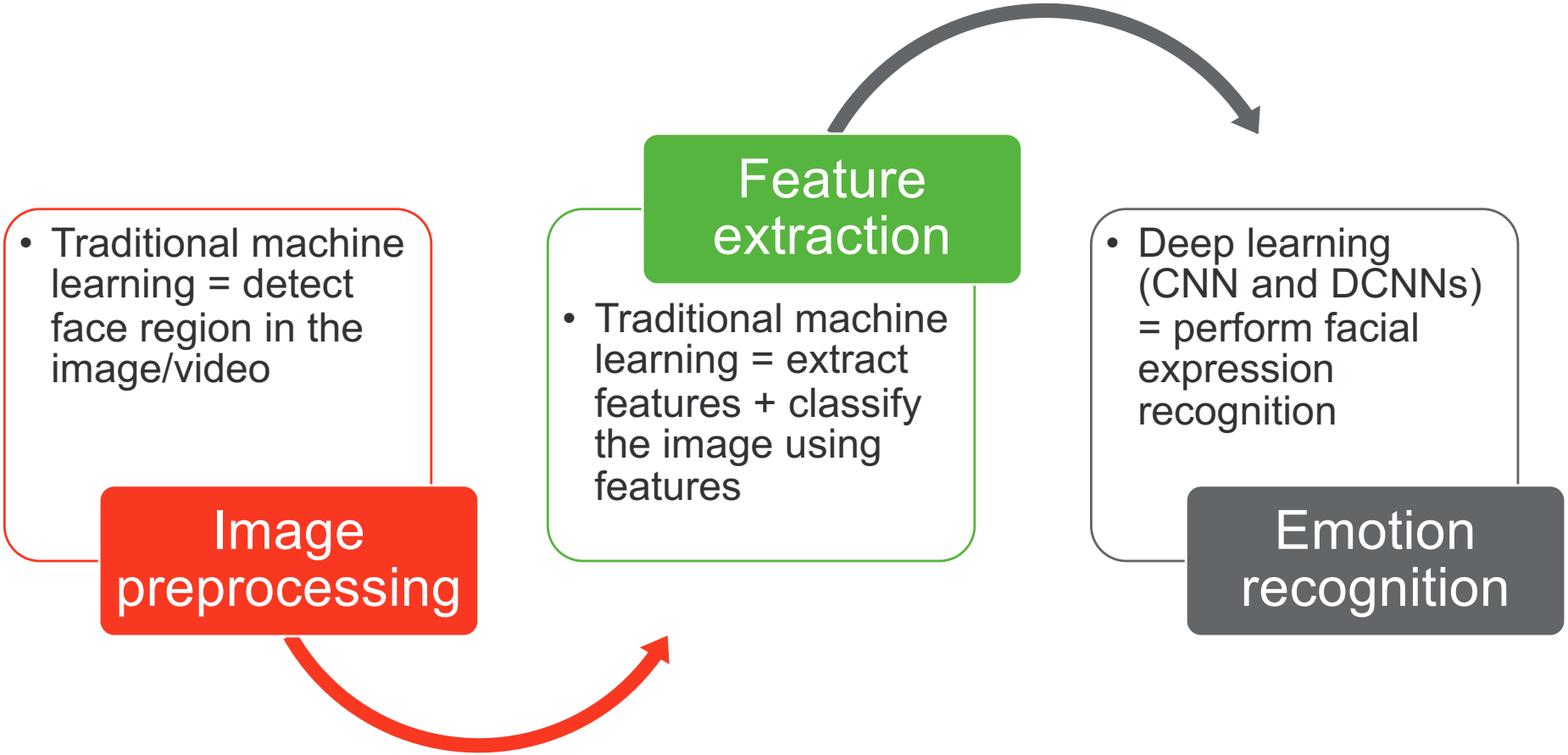
Images: Microsoft 365

Applications of facial expressions

Advantages of using facial expressions monitoring

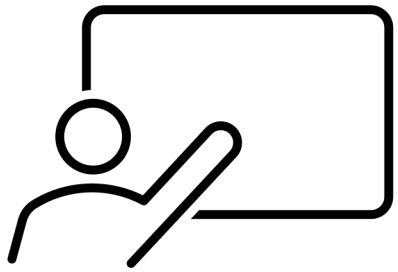
- Unobtrusive monitoring (compared to other physically worn monitors of emotion: galvanic skin response, heart rate monitor, etc.).
- Can be measured simultaneously with other responses used in audiology, e.g., pupillometry; with minimal additional equipment.
- Allow for continuous monitoring during speech perception.
- Limitations:
  - Physiological responses: prone to emotional contagion, emotional induction
  - Sensitivity needs to be investigated

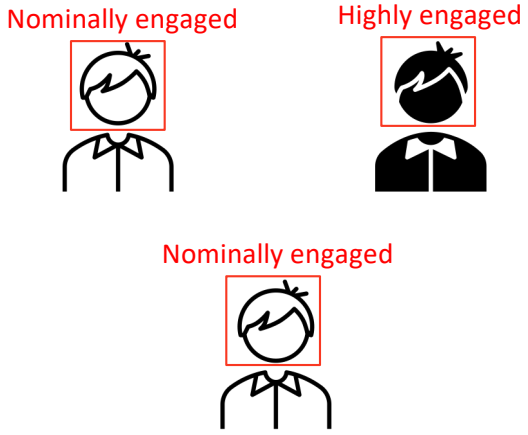
Engagement monitoring with facial expressions (Lasri et al., 2023)



Engagement detection of deaf & Hard of hearing students (Lasri et al., 2023)

- Detect the engagement level: ‘highly engaged,’ ‘nominally engaged,’ and ‘not engaged.’
- Deep convolutional neural network (DCNN) model and transfer learning technique.
- Other similar studies: (Ayouni et al., 2021)





Images: Microsoft 365

Engagement monitoring

- Determines level of engagement
- Understanding of material
- Can help adjust teaching methodology
- Signal the need for academic supports

- Utilized in in-person classrooms and for online learning

Hearing loss detection

- Facial expressions such as discomfort or fatigue can signal hearing difficulties during conversations, particularly in noisy environments, and these expressions can be analyzed to detect hearing loss.
- Advanced machine learning techniques, including self-supervised pre-training and adversarial representation learning, can be employed to model and identify hearing-related facial expression changes while mitigating age-related biases.
- Yin et al., 2024

Hearing loss detection

- By analyzing facial expressions in varying noise conditions (e.g., 75 dBA), these models have demonstrated superior performance in distinguishing individuals with hearing loss, providing a non-invasive and effective detection method (Yin et al., 2024).

Listening effort and facial expressions

- Francis and Oliver (2018): effort, motivation, and affect systems in challenging listening situations.
- Confusion and frustration increase with increasing difficulty (reducing SNRs).
- Adverse emotional responses/increased listening effort and memories of those experiences may have implications on social engagement.
- Studying emotional responses and their impact on quality of life is crucial to determine if hearing rehabilitation effectively reduces negative feelings in individuals with hearing loss.

Thank you!

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