ALPHA-BAND DYNAMICS IN HEARING AID WEARERS PERFORMING THE REPEAT-RECALL TEST (RRT)

Christopher Slugocki[1], Francis Kuk[1], & Petri Korhonen[1]

[1]Office of Research in Clinical Amplification (ORCA-USA, WS Audiology)

ORCA USA WSAudiology

INTRODUCTION

- Alpha-band (8–13 Hz) power in the electroencephalogram (EEG) may be a useful proxy for measuring exerted listening effort in real-time (Dimitrijevic et al., 2017, 2019; Strauß et al., 2014).
  - Increased neural activity in alpha-band is thought to reflect functional inhibition of task irrelevant brain areas (Weisz et al., 2011). Alpha-band activity over occipito-parietal lobes has been observed to increase with the difficulty of speech-in-noise tests (McMahon et al., 2016).
  - Alpha-band activity over frontal lobes has been observed to reflect maintenance of memory contents during working memory tasks (Manza et al, 2014).
- The Repeat-Recall Test (RRT; Slugocki et al., 2018) is a clinically friendly tool that provides an integrative assessment of listeners' speech-in-noise abilities.
  - Different RRT configurations are differentially demanding of listeners' hearing and cognitive abilities.
    - E.g., different signal-to-noise ratios (SNRs), memory for sentence content, availability of semantic context.
- The RRT presents an opportunity to study alpha-band dynamics in hearing aid wearers as they engage with processing speech across a range of difficult conditions.
  - Alpha-band activity may also offer insight into the demands of different listening conditions and validate or disambiguate ratings of listening effort as surveyed after each RRT trial.

PARTICIPANTS

- 16 native English speakers:
  - Mean age = 71 years, SD = 13, Range = 38–85 years, 11 female.
  - Symmetrical sensorineural hearing loss (Fig. 1).
  - Normal cognitive function (MoCA > 23).
  - 3 were not current hearing aid wearers.

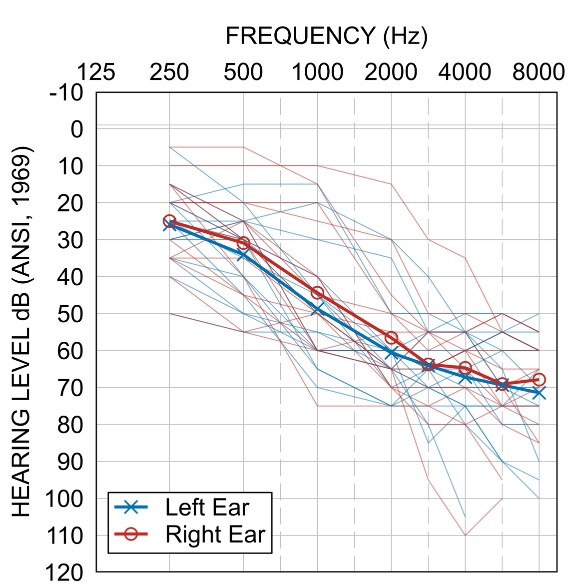


Fig. 1. Individual (thin lines) and average (bold lines) audiograms for the left (blue; X's) and right (red; O's) ears of the participant sample.

HEARING AIDS

- Listeners were tested in the aided mode with Signia AX Receiver-In-Canal (RIC) hearing aids:
  - Fit according to the NAL-NL2 at 100% prescription gain.
  - Standard omnidirectional microphone (OMNI) mode.
  - Features other than noise reduction and feedback cancellation were disabled.
  - Coupled using fully-occluding double-dome instant-fit ear-tips.

STIMULI — REPEAT-RECALL TEST (RRT)

- The RRT includes speech materials from 5 sets of thematically related sentences (Fig. 2):
  - Sentences constructed for a fourth-grade Flesch-Kincaid reading level.
  - Each theme comprises 7 lists of 6 sentences.
  - Each sentence contains 3–4 target words (mostly nouns, adjectives, and verbs).
  - Each list scores 20 target words.
- RRT sentences are designed with complementary *high* and *low* context versions:
  - High context sentences are semantically meaningful. Listeners can draw on within- and between-sentence cues to word identity.
  - Low context sentences randomize target words among the high context sentences in each list. Sentences are syntactically valid but semantically meaningless.
- RRT speech materials were pre-recorded by a male native talker of English with a Midwestern accent.
  - Talker spoke with a normal vocal effort (monitored).

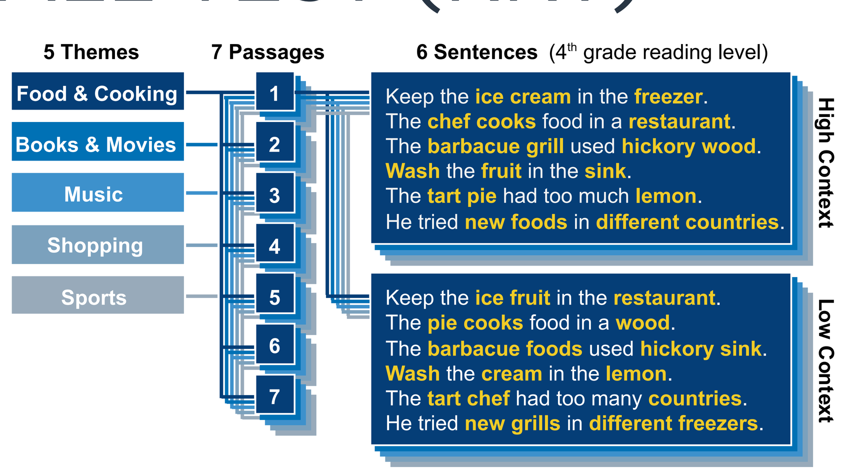
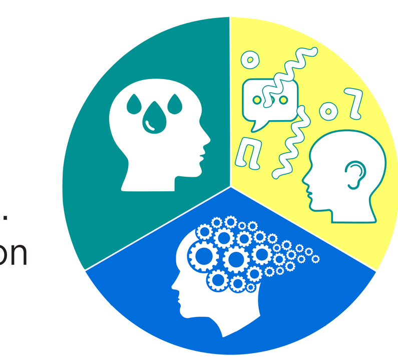


Fig. 2. Organization and sample of RRT speech materials. Target words are identified by bolded yellow text.

PROCEDURE

- Four stages of the RRT (Fig 3):
  - **REPEAT** each of 6 sentences (from a single RRT list) exactly as heard.
  - **RECALL** as much of the sentence content as possible, verbatim.
  - **LISTENING EFFORT**: rate how effortful the listening situation felt (11-point scale).
  - **TOLERABLE TIME**: estimate duration of willingness to engage in communication under current test conditions.



- RRT configuration:
  - Speech presented at 65 dB SPL from loudspeaker in front (0°).
  - Continuous noise presented from two loudspeakers in back (135° and 225° azimuth).
  - Listeners tested at 4 fixed SNRs: -5, 0, 5, and 10 dB.
  - Performance measured for both High and Low Context sentences.
  - RRT sequence administered using two versions: No Recall and With Recall.
- Listener EEG recorded at 19.2 kHz using 19 passive Ag/AgCl electrodes (Fig. 4).
  - Electrodes referenced to linked bilateral earlobes with high forehead ground.

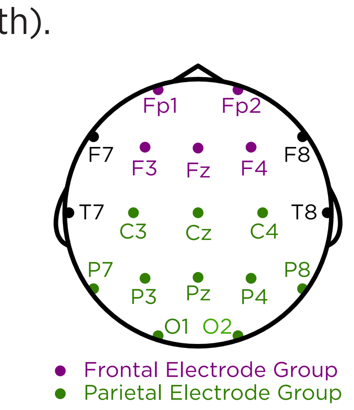


Fig. 4. Channel map of the 19 EEG electrodes used to record alpha activity. Channels are color-coded according to groupings used in later analysis (purple = frontal, green = parietal).

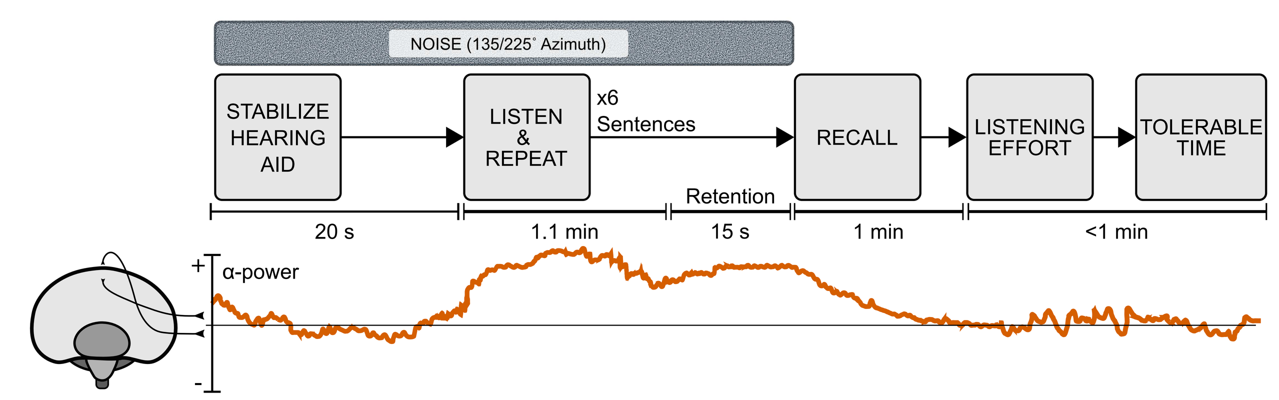


Fig. 3. A schematic representation of the task sequence involved in this version of the Repeat-Recall Test (RRT). Participant alpha power in the EEG was recorded throughout testing. The Recall task was omitted on half of all RRT trials.

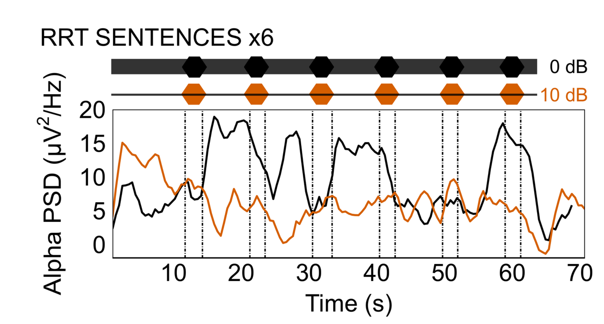


Fig. 5. Example of one participant's parietal alpha power traced across time for a single trial of six RRT sentences. Here, the No Recall RRT was administered using Low Context sentences at SNRs of 0 dB (black) and 10 dB (orange).

ANALYSIS

- EEG data processed offline in MATLAB:
  - Resampled at 250 Hz and filtered between 1–30 Hz.
  - Analyzed using Short-time Fourier Transforms (STFTs).
    - Alpha-band power defined by maximum power spectral density (PSD) between 8–13 Hz in each time window of the STFT.
  - Time traces of alpha-band power cut from beginning of each RRT sentence until start of next (see Fig. 5).
    - Alpha-band power averaged across sentences for each combination of test conditions.
- Linear Mixed Effects (LME) models assessed fixed effects of: *SNR* (-5, 0, 5, and 10 dB), *Context* (High and Low), and *RRT Version* (No Recall and With Recall), and their interactions; *participants* coded as random effects.
  - Separate LME for each outcome measure: Repeat, Recall (no *RRT Version*), Listening Effort, Tolerable Time, Parietal Alpha Power and Whole Head Alpha Power (with *Electrode Group* as fixed effect).
- Additional LME model assessed relationship between Parietal Alpha Power and RRT ratings of Listening Effort.

RESULTS

- RRT performance-intensity (P-I) functions (Fig. 6) agree with previous data from aided older adults tested with speech-front/noise-back in OMNI mode (Kuk et al. 2020).
- RRT results suggest that test conditions influence experienced listening difficulty, as expected (Tbl. 1).
  - All outcomes improved with increasing *SNR*.
  - All outcomes improved with semantic *Context*.
  - Ratings of Listening Effort and Tolerable Time were better (i.e., easier and more tolerable) when *No Recall* was required.
  - *SNR* x *Context* interactions reflect stronger context effects at better SNRs (i.e., ≥ 5 dB).

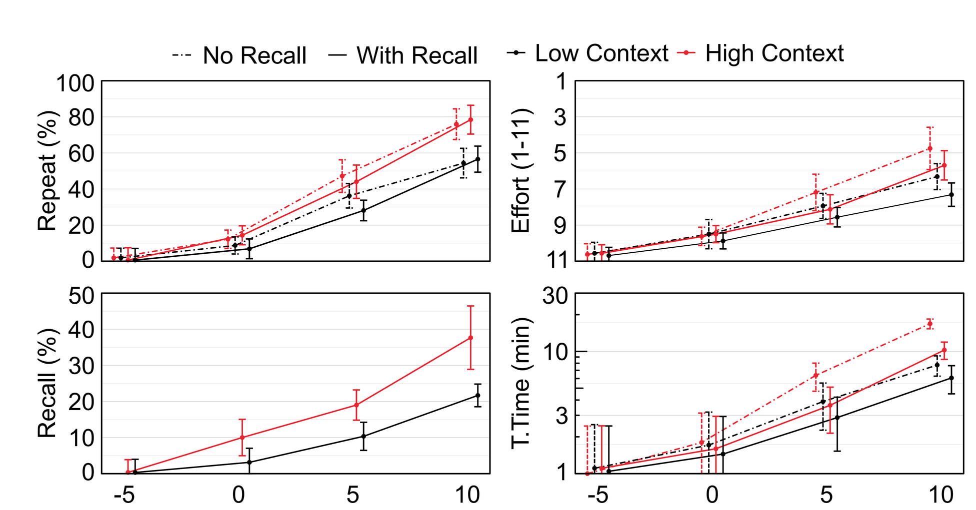


Fig. 6. RRT Performance-Intensity (P-I) functions. Points represent performance means and error bars represent within-subjects 95% confidence intervals of the means. Data are shown as measured for High (red) and Low (black) context sentences in No Recall (dash-dotted) and With Recall (solid) versions of the RRT.

RESULTS (Cont.)

- Alpha Power measured over the Parietal Electrode Group was significantly modulated by test *SNR* (Tbl. 2) in a manner that closely resembled RRT performance and subjective ratings data (Fig. 7).
  - Topography of alpha power shows SNR effects did not involve frontal regions (Fig. 7).
  - No other factors were found to significantly affect alpha power for the parietal electrode group alone.
- Analysis of whole head alpha power revealed additional significant interactions (Tbl. 2 and Fig. 7):
  - *RRT Version* x *Context* — High Context sentences evoked greater alpha power when listeners were tested With Recall compared to No Recall.
  - *RRT Version* x *Electrode Group* — Compared to No Recall, testing With Recall evoked greater alpha power specifically over the Frontal electrodes.
  - *SNR* x *Context* x *Electrode Group* — SNR effects were stronger for Parietal than Frontal Electrodes, except at SNR = 10 dB. High Context sentences evoked stronger alpha over frontal electrode sites at SNR = 10 dB but otherwise had no effect at any combination of SNR and Electrode Group.
- Across conditions, alpha-band power measured over the Parietal Electrode Group was significantly related to ratings of listening effort collected as part of the RRT (Fig. 8).

Tbl. 1. Summary of significant fixed effects and interactions on RRT outcome measures.

RRT Measure	Fixed Effects	X^2	df	*p*	sig.
Repeat	SNR	1233.88	3	0.000	***
	Context	44.08	1	0.000	***
	SNR:Context	26.09	3	0.000	***
Recall	SNR	224.53	3	0.000	***
	Context	19.63	1	0.000	***
Listening Effort	SNR	74.54	3	0.000	***
	Context	39.83	1	0.000	***
	RRT Version	19.92	1	0.000	***
	SNR:Context	14.14	3	0.003	**
Tolerable Time	SNR	338.68	3	0.000	***
	Context	8.49	1	0.004	**
	RRT Version	6.36	1	0.012	*
	SNR:Context	8.26	3	0.041	*

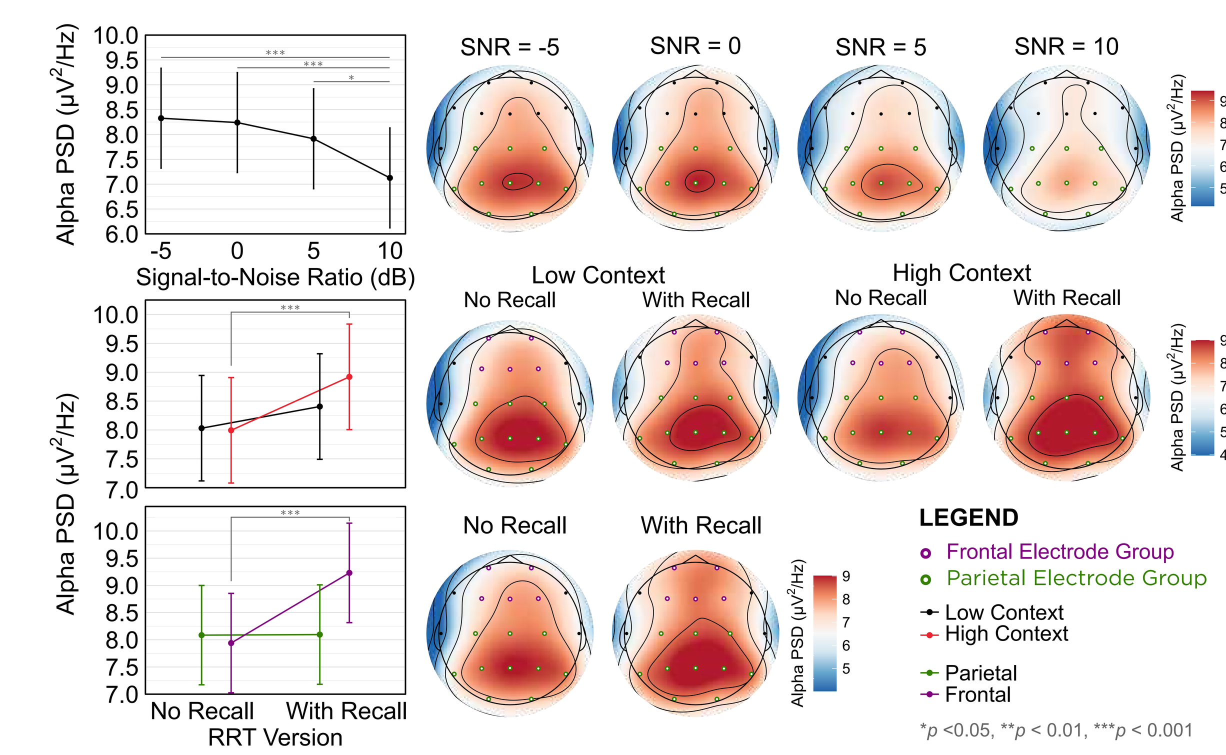


Fig. 7. Summary of results for alpha-band power during the RRT. LEFT: Estimated marginal means exploring significant fixed effects and higher-order interactions on alpha activity measured at the parietal electrode group (top row) and at both parietal and frontal electrode groups (middle/bottom rows). Post-hoc tests examining simple contrasts were Tukey adjusted for multiple comparisons. RIGHT: Topography of alpha power measured in different RRT conditions associated with significant model effects.

Tbl. 2. Summary of significant fixed effects and interactions on listeners' alpha-band power.

Electrodes	Fixed Effects	X^2	df	*p*	sig.
Parietal Only	SNR	28.15	3	0.000	***
Whole Head	SNR	10.70	3	0.013	*
	Elec.Group	11.51	1	0.000	***
	RRT Version:Context	3.86	1	0.048	*
	SNR:Context	8.01	3	0.046	*
	RRT Version:Elec.Group	21.01	1	0.000	***
	SNR:Context:Elec.Group	15.57	3	0.004	**

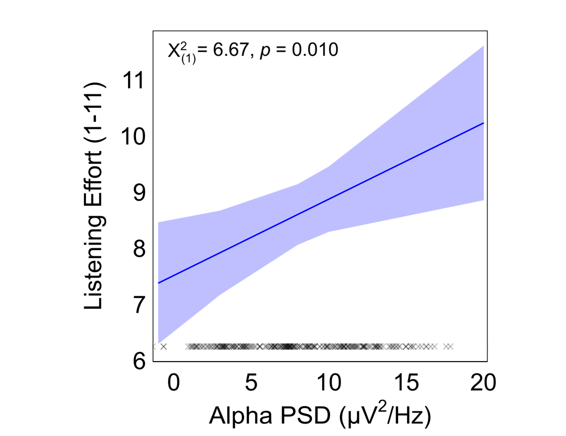


Fig. 8. Significant relationship between listeners' alpha-band power in the parietal electrode group and their ratings of listening effort collected as part of the RRT. Shaded blue region represents 95% confidence interval of the model fit. Black x's along the abscissa show the distribution of listeners' alpha-band power spectral density (PSD) measures.

CONCLUSION

- Alpha-band power in older hearing aid wearers is modulated by the difficulty and demands of different speech-in-noise test (i.e., RRT) configurations.
- Results support use of the RRT as a clinical tool for combined speech-in-noise and listening effort assessment across a variety of challenging conditions that involve auditory memory and inhibition of distracting noise.
- The RRT may be useful for better understanding how different sources of alpha are modulated during speech processing tasks. Future studies might use dense-array EEG to better localize sources of alpha power modulated by the RRT conditions.

REFERENCES

Dimitrijevic, A., Smith, M.L., Kadis, D.S., & Moore, D.R. (2017). Cortical alpha oscillations predict speech intelligibility. *Front Hum Neurosci*, *11*, 1–10.
Dimitrijevic, A., Smith, M. L., Kadis, D. S., & Moore, D. R. (2019). Neural indices of listening effort in noisy environments. *Sci Rep*, *9*(1), 1–10.
Kuk, F., Slugocki, C., Korhonen, P. (2020). An integrative evaluation of the efficacy of a directional microphone and noise-reduction algorithm under realistic signal-to-noise ratios. *J Am Acad Audiol*, *31*, 262–270.
Manza, P., Hau, C. L. V., & Leung, H. C. (2014). Alpha power gates relevant information during working memory updating. *J Neurosci*, *34*(17), 5998–6002.
McMahon, C. M., Boisvert, I., de Lissa, P., Granger, L., Ibrahim, R., Lo, C. Y., ... & Graham, P. L. (2016). Monitoring alpha oscillations and pupil dilation across a performance-intensity function. *Front Psychol*, *7*, 745.
Slugocki, C., Kuk, F., & Korhonen P. (2018). Development and clinical applications of the ORCA Repeat and Recall Test (RRT). *Hear Rev*, *25*(12), 22–26.
Strauß, A., Wöstmann, M, & Obleser, J. (2014). Cortical alpha oscillations as a tool for auditory selective inhibition. *Front Hum Neurosci*, *8*, 1–7.
Weisz, N., Hartmann, T., Müller, N., & Obleser, J. (2011). Alpha rhythms in audition: cognitive and clinical perspectives. *Front Psychol*, *2*, 73.