Portable Automated Rapid Testing (PART) Measures for Auditory Research

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Introduction

- The current state of consumer-grade electronics means that researchers across the globe can do auditory research using tablet computers, built-in sound hardware, and calibrated consumer-grade headphones. Our laboratories have created a free application that supports this work: **PART (Portable Automated Rapid Testing)**. PART has implemented a range of psychoacoustical tasks including: spatial release from speech-on-speech masking, binaural sensitivity, gap discrimination, temporal modulation, spectral modulation, and spectrotemporal modulation.
- Data collected with this application are compared across testing sites and with data from the published literature. The similarity of the obtained data to expected values and the consistency across sites confirms the potential of this relatively inexpensive and easily disseminated approach to psychoacoustical data collection.
- The extent to which valid performance can be obtained is a metric of the possibility that in the future such test methods could be used by researchers without access to a full laboratory, clinicians interested in evaluating auditory function beyond the audiogram, and students as part of their training, as well as many other uses not yet imagined.

Acoustical Validation

Consumer Electronics Can Produce Laboratory-Grade Acoustical Outputs:

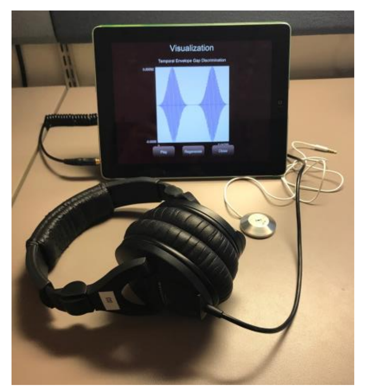


Figure 1. PART System

Tablet-based system shown in Figure 1: iPad Pro running custom PART app written in Unity, connected to Sennheiser HD 280 Pro headphones. Acoustical validation performed with Brüel & Kjær Head and Torso Simulator with Artificial Ears in VA RR&D NCRAR anechoic chamber.

Evaluation stimuli: 50 ms Gaussian-enveloped 2000-Hz tone pulses increasing in level from 60 to 105 dB and analyzing in the time and frequency domains, as a function of pressure and power.

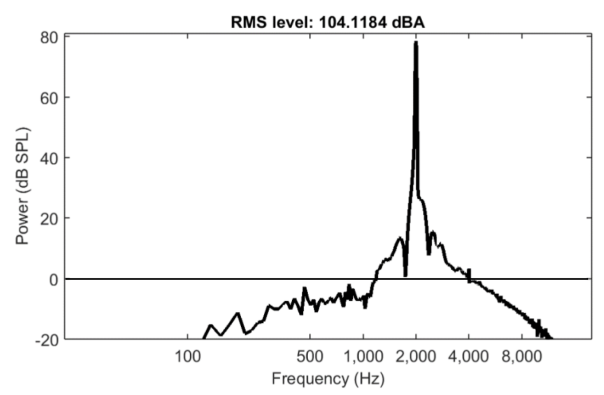


Figure 2. Single pulse from PART system (power vs frequency)

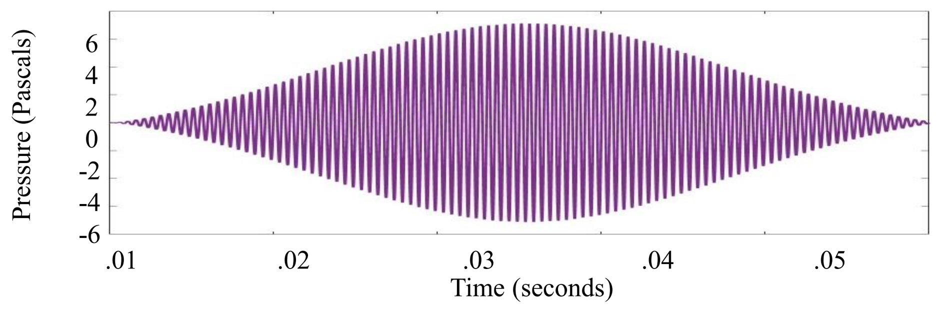
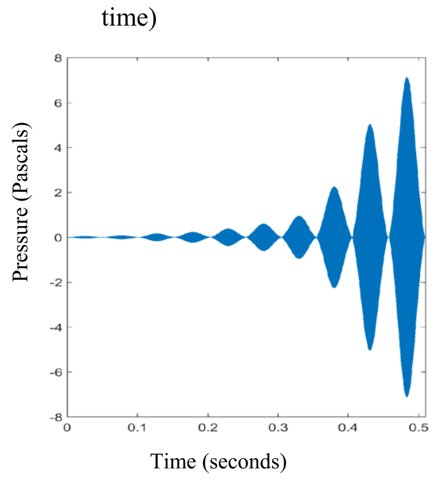


Figure 3. Single pulse recorded from PART system at maximum pressure (pressure vs time)



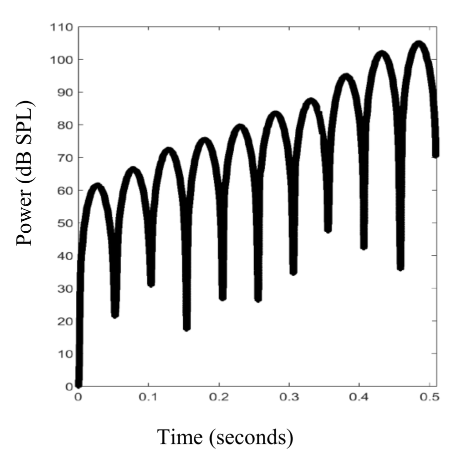


Figure 4. 10 pulses (pressure vs time)

Figure 5. 10 pulses (power vs time)

Data shown in Figures 2-5 demonstrate that the linearity, temporal precision, harmonic distortion, and dynamic range allow for the presentation of high-quality signals. All measures are within the range of performance of many much more expensive systems currently in use in psychophysical laboratories around the world.

Speech in Quiet

Participants: n=28; mean age: 47.6 yrs

Procedure: all testing completed at OHSU

- standard speech reception threshold (SRT) task administered by an audiologist at OHSU using a calibrated audiometer and ER3A earphones
- closed-set automated speech identification task on the PART system in which sentences spoken by a single talker from the Coordinate Response Measure (CRM, Bolia et al., 2000)

Discussion: These results confirm that performance on the iPad is a strong predictor of performance with an audiometer.

Results:

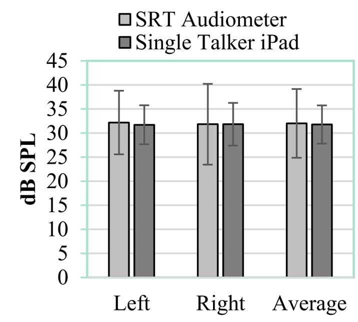


Figure 6. Left ear, right ear, and average speech identification thresholds in dB SPL for the SRT and for single-talker closed-set keyword identification in quiet on the iPad.

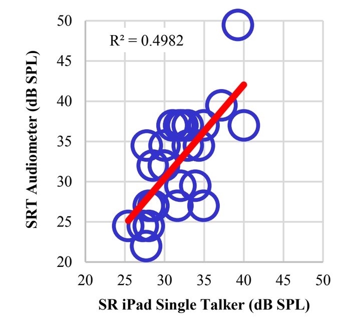


Figure 7. Correlations between average of left and right ear SRTs and average of left and right ear Single Talker thresholds collected on the iPad.

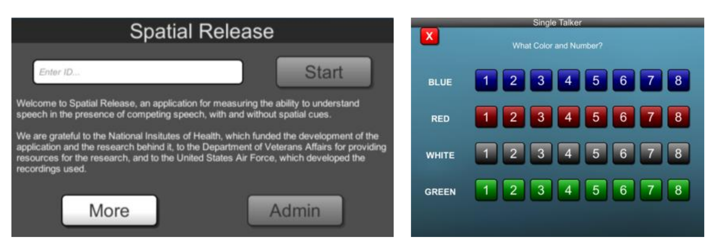
Spatial Release from Masking

Participants:

- OHSU: same 28 participants describe above
- Case Western Reserve University (CWRU): n=47; young normal-hearing college students

Procedure:

- Speech in Quiet: single talker task described above
- Spatial Release from Masking: measured with an iPad app that uses the same CRM sentences as in the Single Talker iPad test
  - Three male talkers speak sentences each with a different call sign, color, and number
  - The three sentences are either colocated (target and maskers at 0 degrees) or spatially separated (target at 0 degrees, maskers at +- 45 degrees).
  - The participant responds by choosing the color-number combination spoken by a given callsign on a screen that displays all color and number options.
  - A progressive tracking procedure presents an 18 dB range of TMR values in 20 trials and threshold is estimated based on the number of correct responses across all 20 trials (see Jakien et al., 2017 for details).
  - SRM is determined as the difference in TMR between the colocated and spatially separated thresholds.



Results:

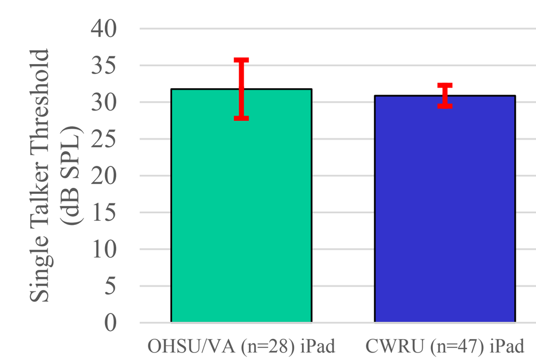


Figure 8. Single Talker thresholds for 75 listeners tested at two different sites with iPad systems.

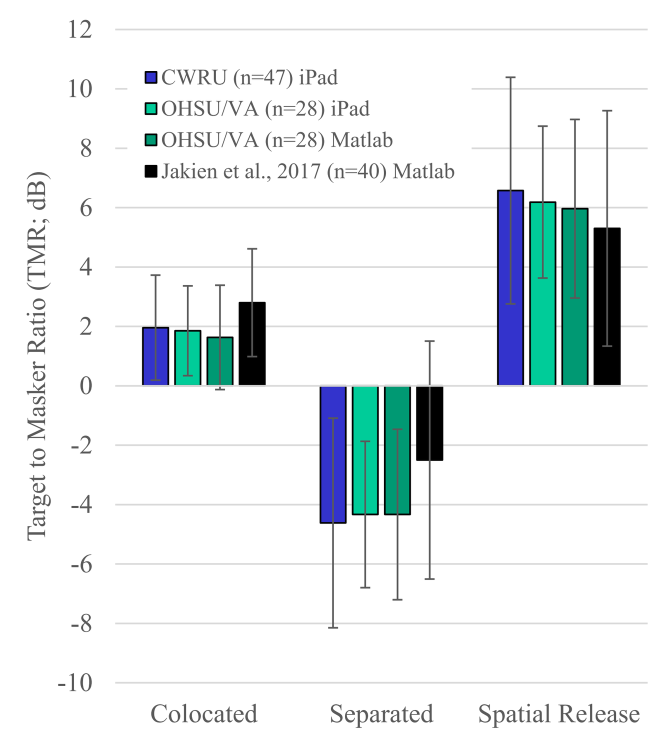


Figure 9. Speech on speech masking and spatial release measures for 75 listeners tested at two different sites with iPad systems, compared with results for the traditional Matlab-based testing, both on the same OHSU listeners on the same test visit and as compared with published data.

Discussion:

- Single talker speech in quiet thresholds were very similar across the two sites, despite the larger range of ages at OHSU (Table 1, Figure 8)
- Speech on speech masking and spatial release was very similar across sites and across methods (Table 1, Figure 9). Results were similar to published data. The slightly worse thresholds in Jakien et al. (2017) were likely due to the greater range of hearing loss in that sample.

	Single Talker	Colocated	Separated	Spatial Release
OHSU/VA (n=28) iPad	31.77	1.85	-4.33	6.19
CWRU (n=47) iPad	30.87	1.96	-4.62	6.57
Jakien et al., 2017 (n=40) Matlab	2.80	-2.50	5.30	
OHSU/VA (n=28) Matlab	1.63	-4.33	5.96	

Table 1. Average speech recognition performance across sites and conditions, and in comparison with the data in the literature.

Spectrotemporal Modulation Sensitivity

Spectrotemporal Modulation (STM; Chi et al., 1999) sensitivity has been shown to differ among listeners with different hearing sensitivities (Figure 10), and is correlated with speech understanding in noise among those with impaired hearing (Bernstein et al., 2013).

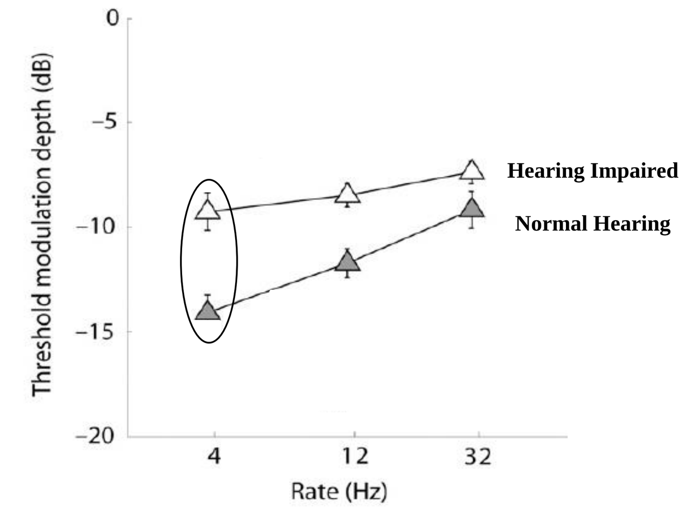
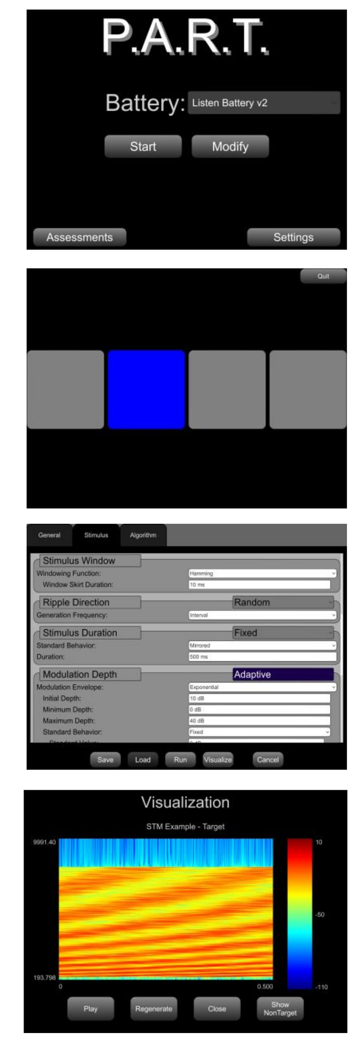


Figure 10. Data from Bernstein et al. (2013) showing the difference between those with normal and impaired hearing in modulation sensitivity for 2 cycle/octave spectral modulation as a function of temporal modulation rate (4, 12, and 32 Hz). The circled data are those to which the PART data should be compared.

Participants: 70 listeners; age and hearing status ranged between young normal hearing college students and older hearing impaired volunteers from 5 test sites:

- Students at Pavel Jozef Safarik University (PJSU) and Western Washington University (WWU) completed testing as part of a class, which demonstrates the utility of PART as a teaching tool.
- Students at University of California, Riverside (UCR) were tested as part of an auditory training experiment, which demonstrates the utility of PART for rapid evaluation of auditory function beyond the audiogram.
- Volunteers at Northwestern University (NU) and OHSU/VA were tested as part of a battery of tests designed to better understand the relationships among aging, hearing loss, and speech understanding.



Procedure:

- STM thresholds for 2 cycles/octave and 4 Hz averaged across two runs
- Following work done on spectral modulation detection (e.g., Summers & Leek, 1994; Eddins & Bero 2007), STM was implemented with sinusoidal modulation on a log scale (dB) in both temporal and spectral domains, rather than sinusoidal in linear amplitude in the spectral domain (Chi et al., 1999; Bernstein et al., 2013). The resulting excitation pattern is sinusoidal to a first approximation and is consistent with the use of dB in various models of across-frequency intensity discrimination including profile analysis (Green 1987) and the excitation pattern model (e.g., Zwicker 1970).
- Four stimuli were presented on every trial, with either the second or third containing modulation and the others having a flat spectrum.
- The modulation depth was adaptively varied to provide an estimate of threshold.
- Due to differences in experimental protocols, slight variations occurred across sites:
  - WWU, UCR, and OHSU/VA presented all stimuli diotically at a level of 70 dB SPL, with a 3 dB level rove on each presentation interval.
  - To account for potential variations in detection thresholds, NU and PJSU listeners first performed a noise burst detection task and levels were set 30 dB above detection threshold.
  - For the PJSU students, levels were between 55-60 dB SPL; for the OHI volunteers at NU, levels varied between 60 and 95 dB SPL.

Results:

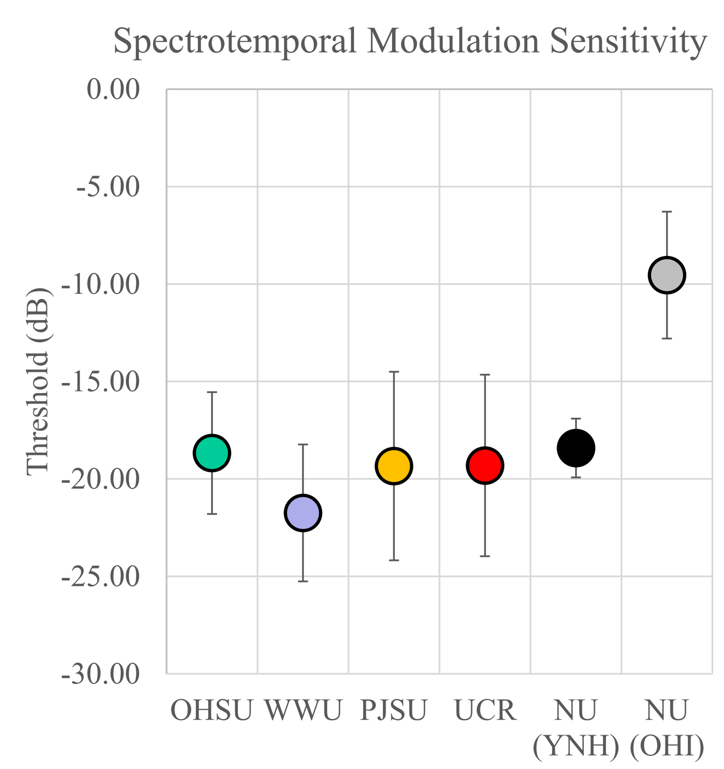


Figure 11. STM sensitivity for 70 listeners tested five different sites using the PART iPad system.

	n	mean	stdev
OHSU/VA	11	-18.67	3.12
Western Washington (WWU)	7	-21.74	3.51
Safarik (PJSU)	12	-19.34	4.84
Riverside (UCR)	22	-19.31	4.66
Northwestern (NU) (YNH)	4	-18.42	1.51
Bernstein et al. (2013): YNH	8	-14	
Chi et a. (1999); YNH	4	-22	
NU (OHI)	14	-9.54	3.26
Bernstein et al. (2013): OHI	12	-9	

Table 2. Average STM sensitivity across sites and in comparison with the data in the literature.

Discussion:

- Figure 11 and Table 2 show the extremely consistent average thresholds across all five sites for YNH listeners. The slight increase at OHSU/VA is consistent with the larger age range and greater range of hearing thresholds compared with the students and other YNH listeners.
- It is also clear that the OHI listeners at NU performed worse than the YNH and similarly to the hearing impaired listeners in the literature. Interestingly, the YNH outperformed the thresholds in Bernstein et al. (2013), but were similar to those reported in Chi et al. (1999). Differences in stimulus generation methods as well as duration are most likely responsible.

Conclusions

These data from 75 listeners for Spatial Release and 70 listeners for PART show that a tablet-based method of auditory testing can produce thresholds similar to those in a laboratory setting, consistent across sites, and capable of being compared with the data in the literature. Specifically, these data reveal the following:

- Acoustical performance of the tablet-based system is comparable to that of considerably more expensive high-quality laboratory systems. High output levels can be obtained with high accuracy and acceptable levels of distortion. Low-level signals are also produced reliably, as revealed by the similarity of speech recognition thresholds on the tablet with the speech reception threshold (SRT) measured using gold-standard audiometry. Low-level signals result in similar speech thresholds in quiet across multiple sites using different calibration methods and different testing rooms.
- Speech on speech masking results show the same effects of spatial separation using simulated spatial locations over headphones and thresholds are as good or better than those obtained with standard laboratory methods. Jakien et al. (2017) also showed that those laboratory measures are good predictors of performance in an anechoic chamber with real loudspeakers. This shows that the iPad system is also capable of producing results comparable to the data obtained in an anechoic chamber.
- Spectrotemporal modulation thresholds were obtained rapidly and, for YNH listeners, were also as good or better than those in the literature. For OHI listeners, rapid testing resulted in similar thresholds to those reported previously (Bernstein et al., 2013).
- Listeners at five different testing sites produced very similar STM thresholds, despite a variety of testing conditions and calibration routines. This shows that the iPad system can be used to improve the reliability and replicability of the data obtained. This is very important if these tests are to some day be used clinically.
- Students used the PART system to learn about psychophysical testing, showing the utility of this tool for teaching as well as research.

References

Bernstein, J.G.W., Mehraei, G. Shamma, S., Gallun, F.J., Theodoroff, S. & Leek, M.R. (2013). Spectrotemporal modulation sensitivity as a predictor of speech intelligibility for hearing impaired listeners. *Journal of the American Academy of Audiology*, 24 (4), 293-306.

Bolia, R. S., Nelson, W. T., Ericson, M. A., & Simpson, B. D. (2000). A speech corpus for multitalker communications research. *The Journal of the Acoustical Society of America*, 107(2), 1065-1066.

Chi, T., Gao, Y., Guyton, M. C., Ru, P., & Shamma, S. (1999). Spectro-temporal modulation transfer functions and speech intelligibility. *Journal of the Acoustical Society of America*, 106(5), 2719-2732.

Eddins, D. A., & Bero, E. M. (2007). Spectral modulation detection as a function of modulation frequency, carrier bandwidth, and carrier frequency region. *Journal of the Acoustical Society of America*, *121*(1), 363-372.

Jakien, K.M, Kampel, S.D, Stansell, M.M., Gallun, F.J. (2017) Validationg a rapid, automated test of spatial release from masking. *American Journal of Audiology*. 26 (4), 507-518

Summers, V., and Leek, M. R. (1994). The internal representation of spectral contrast in hearing-impaired listeners. *Journal of the Acoustical Society of America*. 95, 3518–3528.

Download Spatial Release, PART, and Listen: An Auditory Training Experience for free at https://bgc.ucr.edu/games/ or use this QR Code:

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