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Evaluation of Psychoacoustical Testing with A Portable Device for Individuals with Hearing Impairment

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Honors Capstone Project

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Abstract

Portable Automated Rapid Testing (PART) allows researchers to conduct psychoacoustical testing on consumer tablets. Previously, Lelo de Larrea-Mancera and colleagues (2020) had established a large dataset from normal-hearing listeners with PART. Here, we evaluated the feasibility of PART to screen clinical populations' auditory processing ability. Two groups of participants were recruited: nine young normal-hearing individuals (NH) and eight mild-to-moderate sensorineural hearing-impaired (HI) individuals. Each participant completed a battery of psychoacoustic tests assessed using PART on an Apple® iPad® in a quiet room. Data were recorded and analyzed to evaluate group differences. Results showed significant differences for the 2 kHz Notch Noise (Mask 400), Dichotic Frequency Modulation (FM), and Co-located Spatial Release from Masking (SRM) tests. These findings suggest that it is feasible to conduct psychoacoustical tests using PART on a population with mild-to-moderate hearing impairment, and that the portability of PART has potential value for future clinical audiology practice and research.

Keywords: psychoacoustic testing, audiology, auditory processing, portable device, hearing-impaired population

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Portable Automated Rapid Testing (PART) was developed at the University of California, Riverside Brain Game Center. It is an application with a flexible system that allows researchers to administer different tests batteries. PART features an unconventional testing method by administering psychoacoustic tests on a portable device, in this case, an iPad. In comparison to traditional testing which typically consists of large, bulky, and expensive hardware to create and amplify auditory test stimuli, an advantage of PART is the portability of the device. With PART, tests may be conducted in small research laboratories or clinical audiology settings saving time and money on equipment. Further, psychoacoustic tests of spectral and temporal processing are currently not feasible to administer in clinical practice due to the limited time audiologists have during a diagnostic appointment. Thus, testing conducted via portable devices, such as PART, may allow audiologists to incorporate additional auditory processing tests for their patients in a typical audiology clinic setting.

A recent study conducted by Lelo de Larrea-Mancera and colleagues (2020) established PART normative data from 150 undergraduate students at the University of California Riverside. Here, we replicated their study by using the same psychoacoustic test battery and methodology to evaluate a small group of young normal-hearing individuals at Western Washington University. In addition, we evaluated the feasibility of conducting PART in a population with mild-to-moderate hearing-impairment.

Research into using PART to evaluate the hearing-impaired population's auditory processing ability is valuable. If such testing protocols can be administered on a portable device for the hearing-impaired population, future clinical audiology practice may be reshaped.

Specifically, we hypothesize that additional tests of spectral and temporal processing will make more information available to the audiologists on their patients' hearing loss profile, which may enhance the diagnosing, counseling, and hearing aid fitting processes. In addition, the portability of the device would allow patient's auditory processing data to be collected in the lobby or a quiet room while the patient waits to see their audiologist, which in turn saves both patient's and audiologist's time at the clinic.

Methods

Data collection took place at Western Washington University's Department of Communication Sciences and Disorders. All procedures, including recruitment, consenting, and testing of human participants, were in compliance with Western Washington University's policies for Human Subjects testing and were approved by the Institutional Review Board.

A. Participants

Normal hearing (NH) participants were recruited via word-of-mouth at Western Washington University (WWU). Hearing impaired (HI) participants with bilateral symmetrical mild-to-moderate sensorineural hearing loss were recruited from the WWU Speech-Language-Hearing Clinic. Specifically, recruitment letters were sent out to patients who met eligibility criteria.

At the initial visit, each participant was given a hearing screening to ensure they met the research criteria. Otoscopy was performed to examine outer ear status, showing no signs of occlusion or infection. Next, tympanometry testing was conducted to confirm the health of the middle ear system. Finally, a test of pure tone audiometry was completed. Criterion for the NH participants' hearing thresholds was less than or equal to 20 dB HL for octave frequencies 250

Hz – 8 kHz. For the HI participants', hearing thresholds ranged from 20 – 55 dB HL for octave frequencies 250 Hz – 8 kHz, indicating a mild-to-moderate sensorineural hearing loss. Both groups had thresholds within 10 dB difference across ears to ensure symmetrical hearing.

Pure tone audiometric testing results are shown in Figure 1 (NH group) and Figure 2 (HI group). All participants' pure tone thresholds were recorded, except for one (HI1908) due to an equipment issue. For that participant, a previous pure tone hearing test from the WWU clinic conducted within one year of the first research appointment was used as eligibility criterion. As indicated in Figure 2, the average thresholds of the HI individuals' right ear ranged from 17 dB HL (SD = 8.59) at 250 Hz to 51 dB HL (SD = 9.76) at 8 kHz. The average of their left ear pure tone audiometric thresholds presented a similar pattern, ranging from 17dB HL (SD = 6.99) at 250 Hz to 53 dB HL (SD = 9.51) at 8,000 Hz.

As part of the eligibility criteria, all participants completed the Montreal Cognitive Assessment (MoCA). A passing score of 26 or higher (maximum score is 30) was required. One HI participant failed the MoCA testing, and thus was excluded from further participation in the study and was compensated for contributing their time and effort.

In total, nine normal hearing (NH) individuals (n = 9, mean age = 21, SD = 2.5) and eight hearing impaired (HI) individuals (n = 8, mean age = 65, SD= 12.5) met the eligibility criteria of this study. Data were recorded and analyzed for each group.

Following the hearing and cognitive screenings, participants completed PART on an iPad® in a quiet room listening with Sennheiser® 280 Pro high ambient noise attenuation headphones. Breaks were encouraged as needed during testing. Two repetitions of the psychoacoustic test battery were completed over two appointments. Participants were paid at a rate of $15 an hour. The duration of each session was approximately two hours.

Participants HI1907, HI1908, NH1909, and NH1910 did not complete the second session of PART testing due to unspecified reasons, mostly pertaining to scheduling conflicts and experimental timeline limitations. One participant (HI1901) was unable to complete the 2 kHz Notch Noise testing due to audibility reasons which could be explained by that individual's pure tone audiometric threshold of 55dB HL at 2 kHz.

B. Equipment

Calibration was conducted at the National Center for Rehabilitative Auditory Research (NCRAR) in Portland, OR. iPad® and Sennheiser® 280 Pro headphones were calibrated on a Brüel & Kjær® Head and Torso Simulator with the iPad® volume set to maximum. Adjustments were made within the PART app accordingly.

Tympanometry testing was completed using a Grason-Stadler Inc. (GSI) TympStar™. Pure tone testing and QuickSIN™ (Etymotic Research, 2001) testing were completed in a sound resistant booth using a GSI 61 audiometer and Etymotic Research ER-3 insert headphones. All audiometric equipment was calibrated annually according to ANSI standards.

C. Procedure

The following experimental conditions were collected using the PART application: 2 kHz Notch Noise, Diotic Frequency Modulation, Dichotic Frequency Modulation, Spatial Release from Masking, Spectro, Temporal, and Spectrotemporal Modulation, and Temporal Gap Detection.

An adaptive two down/one-up procedure to modify the presented signals with respect to performance was used for all tests with the exception of the Spatial Release from Masking test which utilized a descending step method. For each trial, a “4-interval 2-alternative forced choice” (4I-2AFC) method was used to evaluate target selection. The experimental test protocol used was identical to that of Lelo de Larrea-Mancera et al. (2020) where further details of the test stimuli may be found.

The **2 kHz Notch Noise** stimuli selection resembled that of Patterson (1976) and Moore (1987). For **2 kHz Notch Noise (Mask 0),** the target signal was a 2 kHz center frequency accompanied by a bandwidth of 800 Hz noise, masking above and below the target frequency (1.6-2.4 kHz) in a tone-in-noise condition. The masker level ranged from 25 dB SPL to 90 dB SPL and started at 35 dB SPL. Similarly, **2 kHz Notch Noise (Mask 400)** adopted the same target frequency and masker level range. For this condition, the noise masker spanned from 1.2-1.6 kHz and 2.4-2.8 kHz leaving 2 kHz as the center frequency of the notched noise.

For **Diotic Frequency Modulation** and **Dichotic Frequency Modulation**, stimuli were adapted from past literature of similar laboratory research, such as Grose & Mamo (2010), Whiteford et al. (2017), and Hoover et al. (2019). Here, the target signal was a pure tone randomly selected within the range of 460 Hz and 550 Hz while being modulated between 0 Hz and 10 kHz. In contrast, the non-target signal was the same stimulus without any modulation. The stimuli were presented at 75 dB SPL for 400 ms. The difference between Diotic and Dichotic Frequency Modulation conditions was that the stimuli were identical across ears in the Diotic condition and inverted across ears for the Dichotic condition.

The **Spatial Release from Masking (SRM)** test in PART is similar to that of Gallun et al. (2013). Using the Coordinate Response Measure (CRM), stimuli consist of four color options (blue, red, white, and green) and eight numbers (1 to 8). Listeners were expected to identify the correct color and number (one out of 32 total options) from a target talker beginning with a call sign "Charlie". Simultaneously, two other talkers were presented as maskers using other call signs such as "Baron" or "Ringo". The masker utterances consisted of non-target colors and numbers that were intended to distract the listeners. Two conditions were evaluated: co-located and spatially separated. The **Co-located SRM** condition differs from the **Separated SRM** condition by presenting all three talkers (one target and two maskers) at 0 degrees azimuth. In the spatially separated condition, the target is at 0 degrees and the maskers are at +/- 45 degrees azimuth. Recordings of these materials were made in an anechoic chamber at NCRAR and were presented over headphones. See Gallun et al. (2013) for more detail.

For the **Spectral Modulation** test in PART, a broadband noise was used as the target signal. It was randomly selected between 400 Hz to 8 kHz and modulated at 2 cycles per octave, similar to the method presented in Bernstein et al. (2013). Testing began with a 6 dB of modulation depth ranging between 0.2 - 40 dB of modulation depth. For **Temporal Modulation**, the band noise carrier remained the same while being modulated at a rate of 4 Hz. For the **Spectrotemporal Modulation** condition, the target signal was the combination of the spectral and temporal modulations using the same modulation frequency range. For spectral, temporal, and spectrotemporal modulation subtests, the non-target signal was the same stimulus without any modulation added.

Finally, the last test we evaluated was **Temporal Gap Detection**. The target signal for **Temporal Gap Detection** was similar to the tone burst described in Gallun et al. (2014). Here, participants listened for an inter-click delay within the range of 0 ms to 100 ms, with the gap starting at 20 ms from the beginning of the test block. The non-target signal was two concurring clicks with no gap in between. Stimuli were presented diotically using 500 Hz clicks at a level of 80 dB SPL.

Results

After the completion of PART, the NH and the HI group average performances for each subtest conducted on PART are displayed in Table 1, along with the group's standard deviation and standard error of the mean. The group means and standard deviations from Lelo de Larrea-Mancera et al. (2020) were included as a comparison to the NH group results of this study.

Next, a two-sample t-test, assuming unequal variances, was conducted to analyze the group differences. Significant differences were found for the **2 kHz Notch Noise (Mask400) testing $t(6)=2.73$, ($p=0.034 < 0.05$)**, **Dichotic FM testing $t(8)=-3.70$, ($p=0.006 < 0.05$)**, **and Co-located SRM testing $t(15)=2.87$, ($p=0.012 < 0.05$)**. All t-test results are displayed in Table 2.

Both groups' mean scores were compared across subtests, indicating both groups were able to perform better in some subtests over others. Predictably, both NH and HI groups performed better on Mask 400 testing than on Mask 0 testing, better on Dichotic FM testing than on Diotic FM testing, better on Separated SRM testing in comparison to Collocated SRM testing.

For Diotic FM testing, the HI group showed a greater variety of performance span (mean of 11.86, SD of 10.43, SE of 3.69) compared to the NH group (mean of 8.90, SD of 5.51, SE of 1.84) (See Table 1). Likewise, the HI group's Separated SRM performance scores (mean of 71.81, SD of 3.25, SE of 1.15) were more scattered than those of the NH group (mean of 74.17, SD of 0.71, SE of 0.24). In addition, the t-test result of the Separated SRM testing $t(8) = 2.01$, (p

= 0.080, $p > 0.05$) was trending towards a significant difference. For **Spectral Modulation, Temporal Modulation,** and **Spectrotemporal Modulation** tests, both groups scored better in spectrotemporal modulation testing than in either spectral or temporal modulation tested in isolation. Temporal modulation revealed the worst performance. Though no significant difference across both groups was found in all three subtests mentioned above, the greatest group performance difference was seen in the spectrotemporal modulation testing $t(8) = -1.76$, ($p = 0.134$, $p > 0.05$).

Discussion and Conclusions

One goal of Lelo de Larrea-Mancera and colleagues (2020) paper was to evaluate a series of psychoacoustic test using PART for a group of young normal-hearing listeners, in quiet and noisy environments, to establish a normative dataset. As a continuation of their research, our study showed that it is also feasible to use the same psychoacoustic test battery, on a portable device using PART, to evaluate individuals with mild-to-moderate amounts of hearing loss. With the exception of one HI participant in our study, who could not complete the 2 kHz notch noise testing due to audibility issues at 2 kHz, the rest of the participants were able to complete all components of the testing protocol using PART. Additionally, participants provided positive feedback regarding the experiment. Some participants commented that using the PART application was a fun experience and several participants completed the testing much faster than anticipated. Overall, the psychoacoustic test protocol conducted on an iPad® was shown to be feasible for people with normal hearing and those with mild-to-moderate hearing loss.

Another finding of this study was the significant differences across test groups for the 2 kHz Notch Noise (Mask400), Dichotic FM, and Co-located SRM tests. These tests, along with tests showing similar trends in the data, are in line with the idea that hearing-impaired individuals should have some reduction in spectral processing but should perform similarly to the normal hearing group for tests of temporal processing. Reduced performance on tests of spectral processing is likely due to cochlear damage, evidenced by hearing-impaired individuals' elevated pure-tone hearing thresholds. In contrast, as suggested by our results, performance on tests of temporal processing should be less affected by cochlear damage.

Nevertheless, it is important to consider that only limited data were collected in this study due to its pilot-study design. The interpretation of significant results needs to be read with caution due to our small sample sizes. In addition, due to the COVID-19 pandemic, four participants were not able to complete the PART retest to further enhance test results' reliability. Future directions of this research would include larger, more complete, testing groups to strengthen the study's findings.

In the future, we hope to find psychoacoustic tests of auditory processing that may show a range of performance across hearing-impaired individuals. Particularly, we are interested in finding tests of auditory processing ability that may correlate with more "real world" audiological tests, such as tests of speech-in-noise. Currently, pure tone audiometry, the gold standard test for fitting hearing aids, does not predict speech-in-noise performance. We hypothesize that there may be other tests, such as those we conducted in this experiment, that may correlate to patients' performance on speech-in-noise tests, such as the Quick speech-in-noise (QuickSIN) test. The ability to evaluate individual differences would potentially guide clinicians on how to best fit hearing aids to a particular patient in a more systematic way than by using pure tone audiometry alone.

Ultimately, PART has great potential for contributing to the field of clinical audiology practice by providing a fast, easy, and affordable way to measure additional tests of auditory processing. Further, the potential of finding auditory processing tests that correlate to speech-in-noise performance may be useful for future research in hearing aid fittings where spectral and temporal processing ability is not currently considered.

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Appendix

Table 1

NH and HI Groups' Results From PART; Compared to Results of Lelo de Larrea-Mancera et al. (2020)

	2 kHz Notch Noise		Dichotic FM	Gap	Diotic FM	Spatial Release		Spectral Temporal Modulations		
	Mask 400	Mask 0				Separated	Co-located	Temporal	Spectral	Spectrotemporal
Lelo de Larrea-Mancera et al., 2020 NH **M** (n=150)	75.98	56.63	0.87	2.51	8.09	69.34	63.48	1.59	1.71	1.18
SD	7.88	2.57	1.25	2.9	7.96	3.49	2.83	1.08	1.12	1.03
NH **M** (n=9)	76.81	56.74	0.71	2.42	8.90	74.17	63.61	1.89	1.29	0.86
SD	1.97	1.57	0.59	1.68	5.51	0.71	1.08	1.13	0.48	0.34
SEM	0.66	0.52	0.20	0.56	1.84	0.24	0.36	0.38	0.16	0.11
HI **M** (n=8)	66.95[a]	53.71[a]	3.34	2.81	11.86	71.81	62.19	2.10	1.78	1.52
SD	9.41[a]	3.94[a]	1.93	2.33	10.43	3.25	0.96	1.23	0.89	1.08
SEM	3.56[a]	1.49[a]	0.68	0.82	3.69	1.15	0.34	0.44	0.32	0.38

Note. NH and HI groups' mean results, standard deviation, and standard error of the mean for each subtest were indicated subsequently.

[a] Note that in the HI group, 2 kHz Notch Noise data were collected and averaged from seven individuals instead of eight individuals.

Table 2

Two-Sample Assuming Unequal Variances T-Test Results From PART

Tests	NH (n)	HI (n)	t Stat	df	*p*
2 kHz Notch Noise (Mask400)	9	7	2.73	6	**0.034 ***
2 kHz Notch Noise (Mask0)	9	7	1.92	7	0.097
Dichotic FM	9	8	-3.70	8	**0.006 ****
Diotic FM	9	8	-0.72	10	0.489
Spatial Release (Separated)	9	8	2.01	8	0.080
Spatial Release (Co-located)	9	8	2.87	15	**0.012 ***
Temporal Modulation	9	8	-0.37	14	0.716
Spectral Modulation	9	8	-1.39	10	0.195
Spectrotemporal Modulation	9	8	-1.67	8	0.134

Gap	9	8	-0.39	13	0.703

*$p < 0.05$ **$p < 0.01$

Note. Significant differences between the NH group and HI group were found in 2 kHz Notch Noise (Mask400), Dichotic FM, and Co-located SRM tests.

Figure 1

NH Participants' Pure-Tone Hearing Thresholds with A Dark Line Representing Group Mean Performances

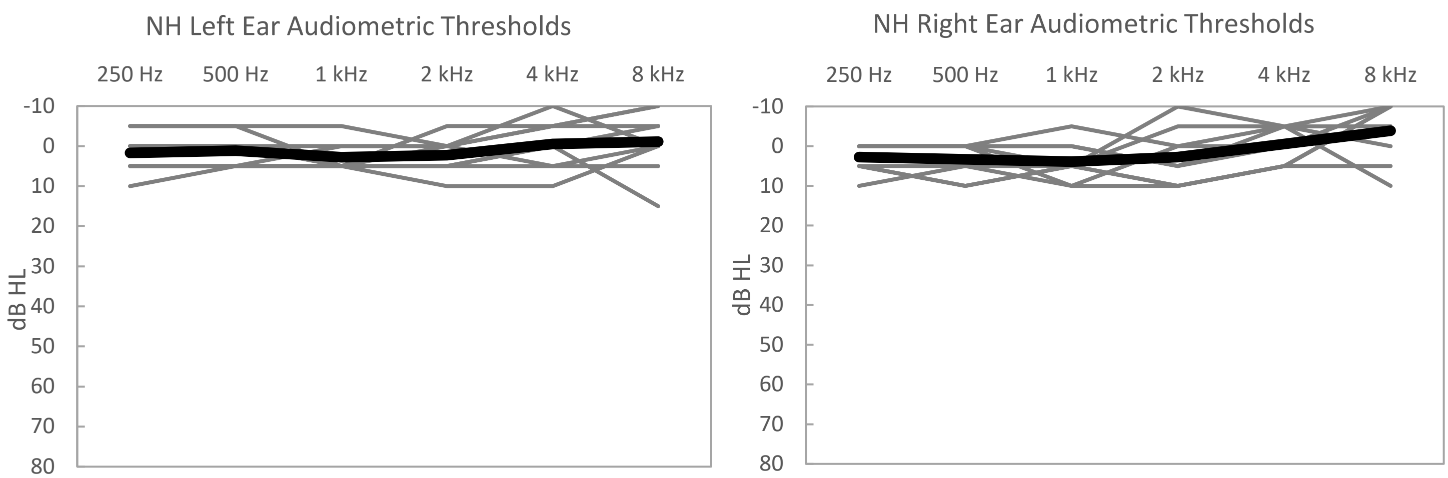

Figure 2

HI Participants' Pure-Tone Hearing Thresholds with A Dark Line Representing Group Mean Performances