Spectral-temporally modulated ripple test Lite for computeRless Measurement (SLRM): A Nonlinguistic Test for Audiology Clinics

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Objectives: Many clinics are faced with the difficulty of evaluating performance in patients who speak a language for which there are no validated tests. It would be desirable to have a nonlinguistic method of evaluating these patients. Spectral ripple tests are nonlinguistic and highly correlated with speech identification performance. However, they are generally not amenable to clinical environments as they typically require the use of computers which are often not found in clinic sound booths. In this study, we evaluate the Spectral-temporally Modulated Ripple Test (SMRT) Lite for computeRless Measurement (SLRM), which is a new variant of the adaptive SMRT that can be implemented via a CD player.

Design: SMRT and SLRM were measured for 10 normal hearing and 10 cochlear implant participants.

Results: Performance on the two tests was highly correlated ($r = 0.97$).

Conclusions: The results suggest that SLRM can be used interchangeably with SMRT but can be implemented without a computer.

Key Words: Clinical test, SMRT, Spectral resolution.

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INTRODUCTION

Spectral resolution is important for speech understanding. Tasks designed to measure spectral resolution correlate with speech understanding tasks (e.g., Won et al. 2007; Holden et al. 2016, Lawler et al. 2017; Gifford et al. 2018). While speech understanding is one of the primary measures used to evaluate hearing in listeners with hearing loss, its usefulness as a measure is limited not only by the listener's auditory ability, but also by their knowledge of the language being evaluated. This is problematic when the person being evaluated does not speak the language used for evaluation. It is also problematic when testing listeners whose second language is that being evaluated, even if they are fluent in that language. For example, native speakers of English are better able to understand speech in noise than people who are fluent in English as a second language (Padilla & Shannon 2000). Therefore, a nonlinguistic test that is predictive of speech recognition is desirable as it allows fair evaluation of, and comparison across, listeners with various linguistic backgrounds and abilities.

One such test is the Spectral-temporally Modulated Ripple Test (SMRT; Aronoff & Landsberger 2013). In the SMRT, listeners discriminate a spectrally rippled stimulus with 20 ripples per octave (RPO) from a spectrally rippled stimulus with a lower ripple frequency. The phase drifts at 5 Hz to avoid the listener being able to use the amplitude of the signal at any given frequency as a cue. Using an adaptive method, the SMRT measures the highest spectral ripple frequency that the listener can discriminate from 20 RPO. Performance on the SMRT is highly correlated with speech understanding for cochlear implant (CI) users tested in their native language (e.g., Holden et al. 2016, Lawler et al. 2017). Based on the data from Holden et al. (2016), the current SMRT software (version 1.1.3) optionally reports the predicted performance on the AzBio in noise (+8 dB signal to noise ratio) and the hearing in noise test (HINT) speech reception threshold.

Although the SMRT has been used in many studies (e.g., Kirby et al. 2015; Aronoff et al. 2016; Vickers et al. 2016; de Jong et al. 2017; Zhou 2017; DiNino & Arenberg 2018; Landsberger et al. 2018), the adaptive nature of the test makes it difficult to implement in many clinics. The issue is that computers, which are necessary to run an adaptive task, are often not available in the testing booth. To address this issue, a new test called the SMRT Lite for computeRless Measurement (SLRM) has been developed. SLRM is a modification of the SMRT such that the test can be run using the method of constant stimuli. The specific advantage to this modification is that it can be implemented on an audio CD and therefore can be used to evaluate patients in a booth when there is no access to a computer. Although the scoring for SLRM and SMRT is different, it was hoped that measurements with the two tests would be sufficiently correlated such that usage of the two tests would be interchangeable. The goal of the present study is to determine if that is the case.

MATERIALS AND METHODS

Participants

Participants consisted of 10 normal-hearing listeners (thresholds of 20 dB HL or better at 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz) and 10 CI users. CI users were tested with both ears simultaneously, regardless of bilateral (n = 4), unilateral (n = 1), or bimodal (n = 5) status. One CI user (I04) was evaluated at the University of Illinois. The remaining 19 participants were evaluated at New York University. A description of the CI participants is given in Table 1.

Stimuli

The SLRM and SMRT stimuli are identical. Each stimulus is 500 msec with 100 msec onset and offset linear ramps with a 44.1 kHz sampling rate. The stimuli are generated using a nonharmonic tone complex with 201 equal amplitude pure-tone frequency components, spaced every 1/33.333 of an octave from 100 to 6400 Hz. The amplitude of each of the pure tones is modulated by a 5 Hz sine wave, with each modulating sine wave having a different starting phase, resulting in a spectral ripple

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TABLE 1. Demographics of participants with cochlear implants

Subject Code	Age at Testing	Gender	Onset of HL	Etiology	Years Implant Experience	Implant Brand	Modality	RE	LE
C101	72	M	Progressive	Unknown	6	Advanced Bionics	Bimodal	CI	HA
C105	56	F	Progressive	Unknown	RE: 13/LE: 13	Advanced Bionics	Bilateral	CI	CI
C106	40	M	Progressive	Unknown	8	Advanced Bionics	Bimodal	CI	HA
C107	46	F	Progressive	Unknown	16	Advanced Bionics	Bimodal	CI	HA
C114	72	F	Progressive	Meniere's/ Autoimmune	4	Advanced Bionics	Bimodal	CI	HA
M104	57	F	Progressive	Genetic	RE: 5/LE: 6	MED EL	Bilateral	CI	CI
M108	83	F	Sudden	Ototoxicity	10	MED EL	Unilateral	CI	N/A
N102	65	F	Progressive	LE: Unknown; RE: Lyme Disease and head trauma	5	Cochlear Corp.	Bimodal	CI	HA
N105	72	M	Progressive	Unknown	RE: 3/LE: 7	Cochlear Corp.	Bilateral	CI	CI
I04	61	F	Progressive	Autoimmune	RE: 5/LE: 4	Advanced Bionics	Bilateral	CI	CI

CI, cochlear implant; HA, hearing aid; HL, hearing loss; LE, left ear; RE, right ear.

that drifts over time (Fig. 1; see Aronoff & Landsberger 2013 for complete details on the stimuli). The density of the ripples is defined in terms of RPO.

Procedures

Spectral-temporally Modulated Ripple Test • SMRT is a three-interval forced choice adaptive test. For each trial, two of the intervals contain a reference stimulus and a third interval contains a target stimulus. Reference stimuli are at 20 RPO. The target is 0.5 RPO initially and is varied adaptively in 0.2 RPO steps using a 1-up/1-down adaptive procedure. The participants' task is to indicate which of the stimuli is the target. The test is completed after 10 reversals. Thresholds are calculated based on the average of the last six reversals. The stimuli are presented at 60 dB(A) from a speaker located in front of the listener at ear level at a distance of 1 m from the head. Software to conduct the SMRT is available free of charge at http://www.ear-lab.org/smrt.html.

SMRT Lite for computeRless Measurement • As with SMRT, SLRM consists of a three-interval, forced choice task.

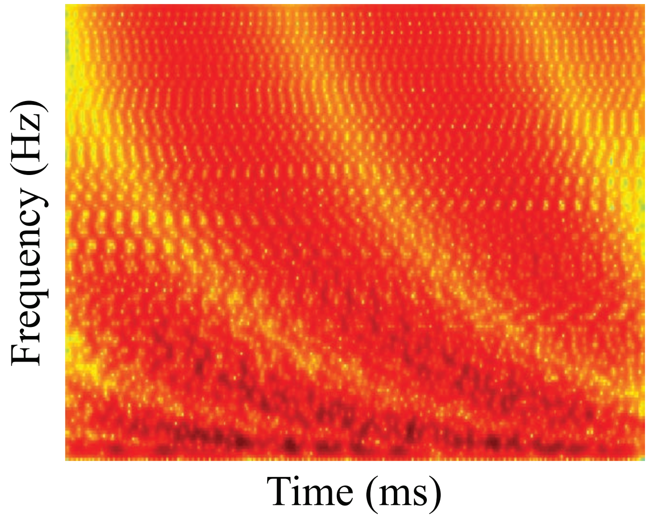

Fig. 1. An example for Spectral-temporally Modulated Ripple Test (SMRT)/SMRT Lite for computeRless Measurement (SLRM) target stimulus.

For each trial, two intervals contain a reference stimulus with 20 RPO and one interval contains a target stimulus. Unlike SMRT, the target RPO is not changed adaptively. Instead, SLRM is composed of 20 lists. Each list consists of targets ranging from 0.5 to 10 RPO, spaced every 0.5 RPO, with every target RPO occurring three times, resulting in 60 trials per list. The order of SLRM trials is randomized across a given list. Scoring is based on the total number of trials where the target was correctly identified. The stimuli are presented at 60 dB(A) from a speaker located in front of the listener at ear level at a distance of 1 m from the head. Materials required to conduct the SLRM are available free of charge at http://www.ear-lab.org/slrm.html, including the stimulus audio tracks for the CD, a calibration tone track, a calibration noise track, data sheets, and instructions.

Participants completed three runs of SMRT and three SLRM lists. The first test evaluated was randomized across participants. Before testing with SMRT, participants completed a practice run that was identical to a regular SMRT run. Similarly, before testing with SLRM, participants completed a practice list. The practice list consisted of six trials where the target had either 0.5 or 1 RPO so that the listener was most likely able to perceive the different stimulus in each trial. Because the order of SLRM trials is randomized across a given list, using a regular list might have resulted in starting with multiple practice trials with a high RPO.

RESULTS

Robust statistical techniques were used to analyze the data (see the Appendix in the Supplemental Digital Content in Aronoff et al. 2016). A bootstrap Pearson correlation with outlier correction based on the minimum generalized variance outlier detection method was calculated. There was a significant correlation between the SMRT and SLRM scores (r = 0.97; 95% confidence interval, 0.91 to 0.99, where a confidence interval that does not contain 0 indicates a significant effect; see Fig. 2).

Least trimmed squares regressions are similar to least squares regressions, except that they minimize a subset of the errors to reduce the effects of outliers. A least trimmed squares regression was used to characterize the relationship between SMRT and SLRM scores. This indicated that an increase of

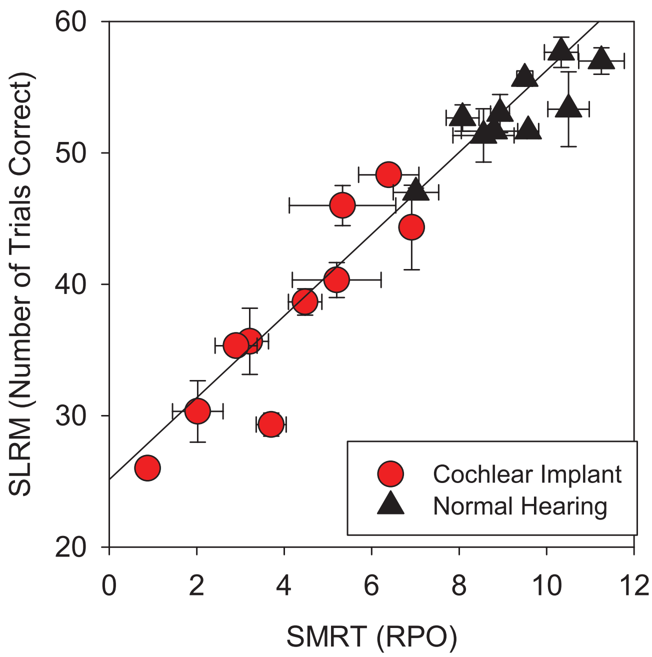

Fig. 2. Spectral-temporally Modulated Ripple Test (SMRT) Lite for computeRless Measurement (SLRM) scores (number of trials correct) plotted as a function of SMRT scores (ripples per octave [RPO]) for both cochlear implant users (circles) and normal-hearing listeners (triangles). Error bars indicate ±1 SE of the mean for each test. The best fitting line as calculated via a least trimmed squares regression is also plotted. Note that chance on SLRM is 20.

one correct response on SLRM corresponds with an increase of 0.32 RPO on SMRT (slope = 0.32, intercept = −8.08). In other words, it estimated that an SMRT Score (RPO) = 0.32 × SLRM Score (Total Correct) − 8.08.

The testing duration for SLRM was not recorded, but is expected to be about 7:30 which is the duration of each list. The duration of the SMRT varies based on performance during the adaptive track. The average test duration for CI users was 2:37 (range, 1:08–3:54), while the average duration for NH listeners was 4:16 (range, 3:01–5:09).

DISCUSSION

SMRT and SLRM scores are highly correlated, indicating that the two tests are largely interchangeable. It should be noted that, as shown in Lawler et al. (2017), SMRT stimuli are altered by the CI processor. As such, it is not clear if the relationship between speech and SMRT scores, and by extension, SLRM scores, differs when very high RPO stimuli are presented to a CI user. Given the strong relationship between SMRT and SLRM scores, data collected with SLRM can be directly compared with data collected with SMRT.

Because SLRM and SMRT are largely interchangeable, it is expected (but not formally verified) that the correlation between speech identification and SLRM will be similar to the correlation between speech identification and SMRT. Furthermore, as a strong linear relationship was found between SLRM and SMRT for CI and NH listeners, it is assumed that this relationship will be maintained for all listeners. However, comparing SLRM and SMRT in different populations may be warranted.

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