An Adaptive Clinical Test of Temporal Resolution

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Purpose: It has been recommended that diagnostic and screening test batteries for auditory processing disorder (APD) include a measure of temporal gap detection using broadband noise stimuli. Although psychophysical laboratory procedures exist for the measurement of temporal resolution, none are clinically feasible. This study was designed to obtain preliminary data on a new clinical measure of gap detection, the Adaptive Test of Temporal Resolution (ATTR).
Method: The ATTR, a currently available clinical test (Random Gap Detection Test), and a standard psychophysical laboratory procedure were used to measure gap detection thresholds (GDTs) from a group of 30 young adults with normal hearing.
Results: Mean ATTR GDTs were 2.2 ms, consistent with GDTs measured using the psychophysical laboratory procedure (3.2 ms) and significantly smaller than those measured using the Random Gap Detection Test (7.0 ms).
Conclusions: Because it incorporates standard adaptive psychophysical methodology in a computer application that can be used on any desktop computer but does not depend on specialized hardware for application, the ATTR promises to be a clinically feasible addition to the APD test battery.

Key Words: auditory processing, test materials

Auditory processing disorder (APD) has been defined as a deficit in one or more of a number of auditory behaviors, including temporal processing (American Speech-Language-Hearing Association [ASHA], 2005; ASHA Task Force on Central Auditory Processing Consensus Development, 1996). APD may be exacerbated in unfavorable acoustic environments and may be associated with difficulties in listening, speech understanding, language development, and learning. The recommended diagnostic and screening test batteries for APD include a temporal gap detection test (ASHA Task Force, 1996; Jerger & Musiek, 2000).

One aspect of temporal processing, temporal resolution, may be defined as the ability to follow and resolve rapid fluctuations in intensity and frequency over time. Numerous studies link tasks of temporal resolution to the understanding of acoustically degraded speech (Gordon-Salant & Fitzgibbons, 1999; Irwin & McAuley, 1987; Snell, Mapes, Hickman, & Frisina, 2002; Tyler, Summerfield, Wood, & Fernandes, 1982). In particular, temporal resolution appears to be important for resolving brief dips in the intensity of background noise, an ability critical for understanding speech in noise (Dubno, Horwitz, & Ahlstrom, 2003; Oxenham, 2002; Peters, Moore, & Baer, 1998). Temporal resolution tasks include modulation detection, gap discrimination, and gap detection. Gap detection, in particular, is a common and well-studied behavioral measure of temporal resolution (e.g., Lister, Besing, & Koehnke, 2002; Lister & Tarver, 2004; Trehub, Schneider, & Henderson, 1995).

In a traditional psychophysical gap detection task, the listener is presented with two or more paired bursts of sound, one containing a silent pause, or gap. The listener's task is to determine which sound contains the gap, and the shortest detectable gap is termed the gap detection threshold (GDT; Phillips, 1999; Phillips, Taylor, Hall, Carr, & Mossop, 1997; Roberts & Lister, 2004). GDTs are influenced by the characteristics of the stimuli that define the gap, including bandwidth (e.g., Eddins, Hall, & Grose, 1992; Snell, Ison,

& Frisina, 1994), frequency (e.g., Lister et al., 2002; Lister & Roberts, 2005), and duration (e.g., He, Horwitz, Dubno, & Mills, 1999; Lister & Tarver, 2004). The experimental stimuli used in gap detection studies have included bursts of broadband noise, narrowband noise, and pure tones. Jerger and Musiek (2000) suggest that gap detection tests should utilize broadband noise stimuli. Although some disadvantages exist (e.g., equalization of overall loudness across intervals, lack of frequency specificity, influence of sloping hearing loss on effective bandwidth), broadband noise has an advantage over other stimuli in that it masks the spectral splatter that results from abruptly interrupting a signal (Trehub et al., 1995). Therefore, there is a need for a clinically feasible test of broadband noise gap detection.

Currently, one clinical test of broadband noise gap detection is commercially available, the Random Gap Detection Test (RGDT; Keith, 2000). The RGDT includes several subtests in which tone burst or noise burst pairs are presented in a nine-item, single-interval, fixed (nonadaptive) procedure with randomly presented gap durations. The listener is required to report hearing one or two tone bursts or noise bursts. Specific norms are not provided for the subtests of the RGDT that use broadband noise bursts, although a normal range of 2–20 ms is suggested (Keith, 2000).

An adaptive psychophysical laboratory procedure (PLP) may be considered a "gold standard" of GDT measurement. In the Psychoacoustics Laboratory at the University of South Florida in Tampa, as well as in other labs, GDTs are obtained using customized software incorporating a two-interval, two-alternative forced-choice (2I/2AFC) adaptive procedure with Tucker-Davis Technologies (TDT) hardware. Using such a system, stimulus parameters may be tightly controlled. GDTs obtained using a multiple-interval, multiple-alternative, forced-choice procedure are both reliable and valid, as demonstrated by numerous studies (Lister et al., 2002; Lister, Koehnke, & Besing, 2000; Roberts & Lister, 2004). However, because PLPs rely on complex digital signal-processing hardware and customized software for stimulus generation, recording subject responses, and estimating thresholds, they are not clinically feasible.

The Adaptive Test of Temporal Resolution (ATTR) is a new gap detection test that has the potential for clinical feasibility. Like the PLP, the ATTR utilizes a 2I/2AFC adaptive procedure to measure GDTs. However, instead of creating and presenting stimuli through specialized hardware, the ATTR uses stimuli that are stored offline in wav format. The ATTR also includes software to control the presentation of stimuli and to record the responses. To minimize the number of offline files, gap durations were created in integer steps of 1 ms for the ATTR. While the stimuli and measurement paradigm mimic the PLP, the ATTR does not depend on specialized hardware for application and can be run on any desktop computer; therefore, the ATTR may be a clinically feasible part of the APD test battery.

The purpose of this study was to measure and compare GDTs using several available methods (ATTR, RGDT, PLP) in a control group of young adults with normal hearing sensitivity. It was hypothesized that the new adaptive procedure, the ATTR, would yield reliable results that were comparable to those of the PLP. GDTs measured using the RGDT were expected to be larger than those obtained using the ATTR or PLP because of the differences in measurement procedure.

Method

This investigation was conducted in four stages. First, binaural detection thresholds for the noise burst stimuli were measured using an adaptive procedure. During the final three stages, GDTs were obtained using the PLP, the ATTR, and the RGDT in random order.

Participants

Thirty adults (9 male and 21 female), ranging in age from 21 to 32 years (mean age = 25), participated in the study. All participants were monolingual American English speakers, and none reported history of middle ear pathology, ear surgery, attention disorder, learning disorder, language disorder, APD, or dyslexia. All participants presented with normal middle ear function and pure-tone thresholds less than or equal to 25 dB HL across the octave frequency range from 250 to 8000 Hz.

Stimuli and Instrumentation

For the binaural noise burst detection threshold measurements and the PLP, stimuli were 230-μs (rise–fall time = 0) and 4-ms (rise–fall time = 0) bursts of white noise, digitally generated (20-kHz sampling rate) online using TDT Model PDAC hardware and locally developed software. Stimuli were passed though attenuators (TDT Model PA4) to set the overall level and an anti-alias low-pass filter with a 10-kHz cutoff (TDT Model FT6-2) before being presented via circumaural earphones (Sennheiser Model HD265).

For the ATTR, 10 samples of 4-ms (rise–fall time = 0) white noise bursts were digitally generated (44.1-kHz sampling rate) using Sound Forge Version 4.5 (Sonic Foundry, 1998). This was done to control for frozen noise effects (i.e., listeners would not be able to "learn" the noise). For each of the 10 ATTR noise samples, 16 files were created, each with a different gap duration (0–15 ms in 1-ms steps). A total of 160 noise files were stored off-line in wav format. Representative time waveforms and magnitude spectra are shown in Figure 1. ATTR GDTs were obtained using locally developed software, which controlled presentation of the stimulus files and recording of the response. While the ATTR stimuli and measurement paradigm were very similar to that of the PLP, specialized hardware was not used to set levels and filter stimuli prior to presentation. Gap durations were also limited to integer values (in milliseconds) for the ATTR. This limit was imposed to minimize the number of stimulus files stored on the computer while maintaining the ability to measure valid GDTs and represents a compromise between the infinitely varying gap durations of the PLP and the nine gap durations represented in the RGDT. For the ATTR, stimuli were presented through a LynxOne (Lynx Studio Technology) sound card and circumaural earphones (Sennheiser Model HD265).

For the RGDT, noise burst markers had nominal burst durations of 230 μs with nominal gap durations of 0, 2, 5, 10, 15, 20, 25, 30, and 40 ms and were played in random order from a CD purchased from Auditec of St. Louis. Between each noise burst pair, 4.5 s of silence were inserted to allow time for the listener to respond. The output of the CD player was routed through an Interacoustics audiometer (Model AC40) and TDH-49 earphones. No normative data for noise burst GDTs are provided, but the author of the test suggests a normal GDT range of 2–20 ms (Keith, 2000).

For binaural noise burst detection, PLP and ATTR, sound pressure levels were calibrated by playing out a 400-ms noise

Figure 1. Time waveforms for the standard (A) and target (B) interval stimulus files, as stored on the computer. Magnitude spectra for the standard (dashed line) and target (solid line) stimuli (C). The *y*-axes in Panels A and B indicate amplitude relative to ±1, or the level above (or below) which the stimulus would have been peak clipped. The *y*-axis in Panel C indicates decibels, relative to a maximum range of about 90 dB possible for the 16-bit amplitude resolution of the files used. Standard and target spectral analyses used 356 samples (0.008 s) and 578 samples (0.013 s) respectively, resulting in frequency resolution of approximately 125 Hz for the standard spectrum and 77 Hz for the target spectrum. A fast Fourier transform using a rectangular analysis window was performed in each case; no window shaping was needed because the entire signal portion was saved to file and analyzed using one window in each case.

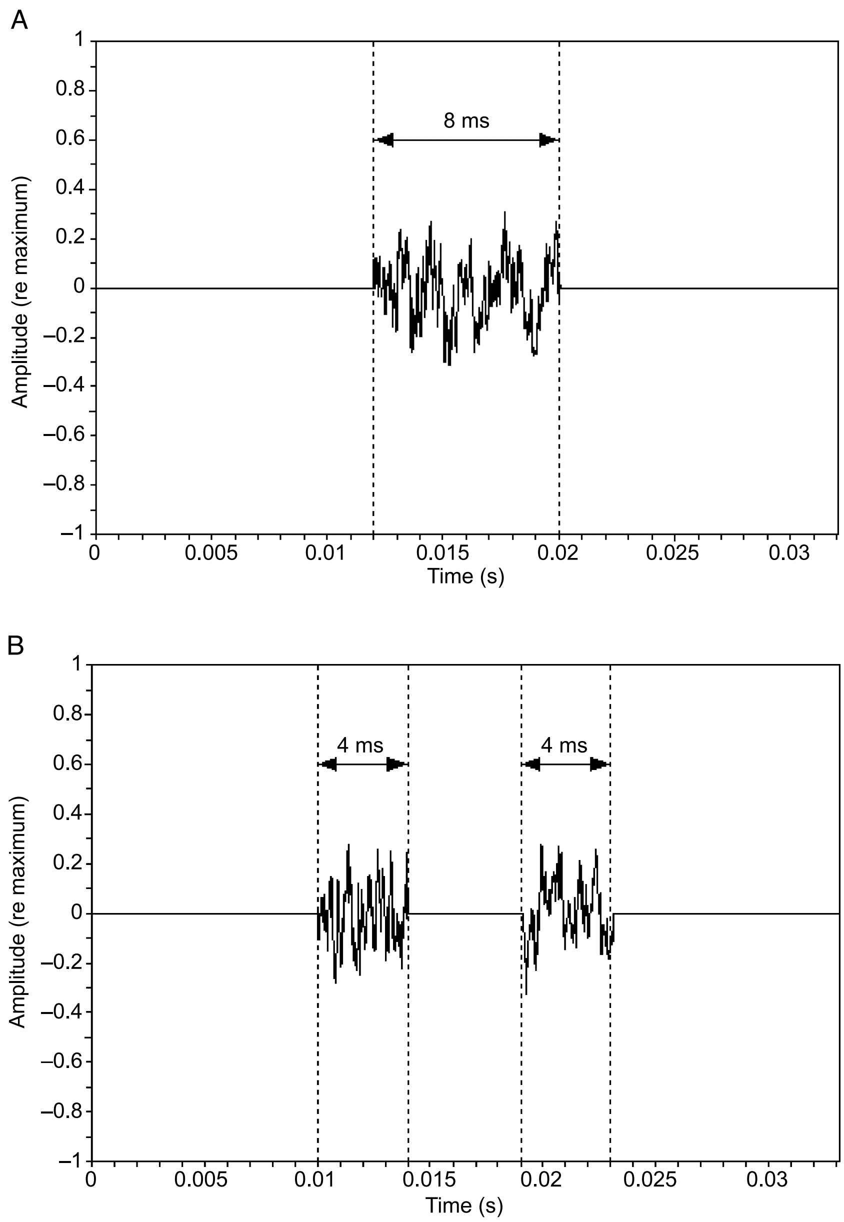

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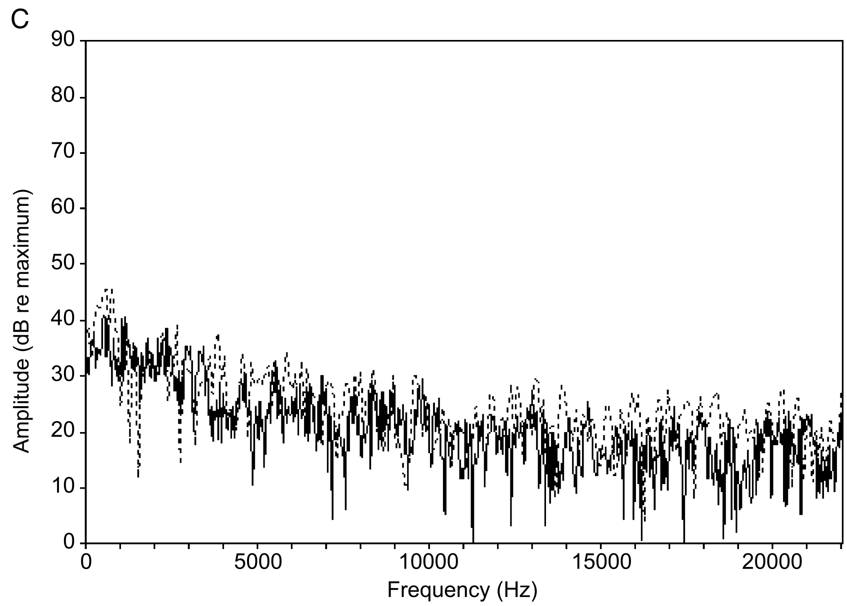
Figure 1 ***(continued)*.**



burst and recording the level using a Bruel & Kjaer Type I sound level meter (Model 2235, linear setting, fast mode) with a ½-in. condenser microphone (Model 4134), connected to a Bruel & Kjaer artificial ear (Model 4153) with a flat plate adapter for the circumaural earphones. For the PLP and ATTR, stimuli were presented at a level of 80 dB SPL. For the RGDT, the audiometer was set to a level of 55 dB HL as recommended by the test author (Keith, 2000). It should be noted that the Sennheiser HD 265 earphones (used for the PLP and ATTR) have a flat response over a broader frequency region than the TDH-49 earphones (used for the RGDT).

For all tasks (detection thresholds, RGDT, ATTR, and PLP), stimuli were presented diotically. Although monotic conditions have been included in other gap detection studies, GDTs measured monotically and diotically have not been shown to be significantly different (Oxenham, 2000; Roberts & Lister, 2004); therefore, no monotic condition was included in the present investigation. Future program options will include monotic and dichotic presentation so that ear asymmetries and across-channel (ear) processing may be explored.

Procedures

Participants were seated inside a sound-treated booth wearing earphones for all tasks, with the exception of the ATTR. The ATTR was administered via earphones from a computer located in a quiet room. The room was chosen to be representative of a quiet space in which a clinical audiologist might have a computer placed for hearing aid fittings, electrophysiology, vestibular evaluations, and so forth. For the binaural detection thresholds, the PLP, and the ATTR, response options and feedback were presented on a computer screen, and participants used a computer mouse to indicate their response.

Noise burst detection thresholds. Diotic detection thresholds for the 230-μs and 4-ms noise bursts were measured using an adaptive 2I/2AFC procedure targeting 70.7% correct (Levitt, 1971). The target interval contained the noise burst stimulus, and the remaining interval contained silence. The target interval was chosen randomly. The adaptive procedure continued until eight reversals were completed. A 4-dB step size was used for the first four reversals, after which a 2-dB step size was employed. Detection thresholds were calculated as the average sound level of the final four reversals and were measured as an average of at least two runs. If thresholds from the two runs differed by more than 4 dB, additional runs were completed until two thresholds were obtained within 4 dB.

GDTs. The administration order of the three gap detection test procedures was randomized to control for any potential order effects. A 2I/2AFC procedure was used to measure PLP and ATTR GDTs. For both tasks, the standard interval contained a single 8-ms noise burst and the target interval contained paired 4-ms noise bursts separated by a silent gap varying adaptively in duration by a factor of 1.2, targeting 70.7% correct detection (Levitt, 1971). Because the target interval increased predictably in duration with increases in gap duration, it is possible that listeners could make interval selections based on overall interval duration rather than gap duration. None of our listeners reported such a strategy, however.

GDTs for both 230-μs and 4-ms noise bursts were measured using the PLP method, while only 4-ms noise bursts were used for the ATTR due to concerns regarding the accuracy with which the software was able to create and the computer sound card was able to present the shorter (i.e., 230-μs) stimuli. The 4-ms PLP and ATTR conditions were included to facilitate comparison with the results of our previous investigation (Roberts & Lister, 2004), and the 230-μs PLP condition was included to facilitate comparison with the RGDT results.

For the ATTR, silent gap durations were limited by the integer (1-ms) step size used in file creation; therefore, all gap durations required by the adaptive algorithm were rounded to the nearest integer value (e.g., if a gap duration between 1.5 and 2.4 ms was calculated by the adaptive paradigm, a wav file with a 2-ms gap was played, and if a gap duration between 2.5 and 3.4 ms was calculated, a wav file with a 3-ms gap was played). The standard interval contained two continuous noise bursts with no silent gap. The target interval was presented randomly.

For the PLP and the ATTR, the participants were instructed to select the interval that sounded like two "clicks." Visual feedback of the correct interval was provided following each response. The adaptive procedure continued until eight reversals occurred, and GDTs were calculated as the average gap size for the final six reversals. If a target interval gap duration of 0 ms was selected by the adaptive procedure more than three times within a run, the run was immediately terminated by the program and had to be repeated. Participants completed three runs for each gap detection procedure, and the GDTs obtained for the three runs were used to calculate average GDTs for each procedure.

For the RGDT, a single-interval fixed paradigm was employed. Participants were instructed to respond verbally if they heard one or two clicks following each of the nine intervals. The examiner then recorded the response as a 1 or 2 on the response sheet provided. Responses were recorded from three runs. No response feedback was provided. As suggested by Keith (2000), the GDT was defined as the smallest gap duration for which the listener responded "two clicks." Given this measurement method, the limited range of gap durations (0–40 ms), and the varying step size (2–10 ms), a specific performance level cannot be determined for this task.

Each of the 30 participants completed the three repetitions of each of the three gap detection procedures (total of nine runs), along with the hearing evaluation and detection thresholds in one 2-hr session. A randomly selected subgroup of 5 listeners returned approximately 1 week later to repeat the nine runs as a measure of test–retest reliability.

Results

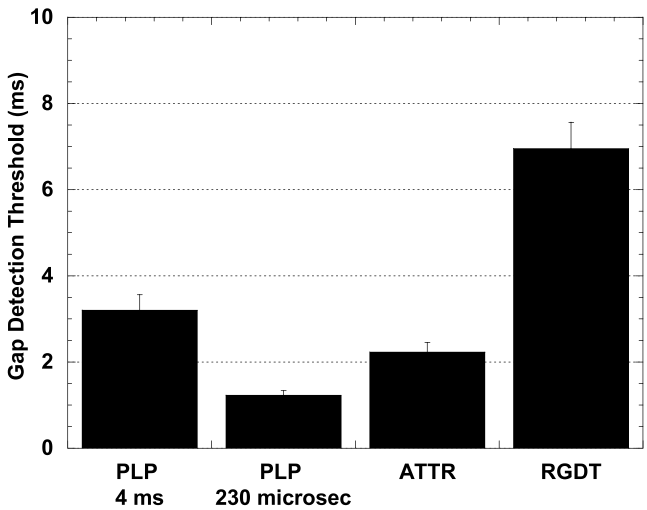
Noise Burst Detection Thresholds

Average noise burst detection thresholds are shown in Table 1 for both the 4-ms and 230-μs noise bursts. Average

Table 1. Mean noise burst detection thresholds (dB SPL) for the 4-ms and 230-μs experimental stimuli.

Stimulus duration	Threshold	*SE*
4 ms	17.1	1.0
230 μs	24.3	1.1

Figure 2. Mean gap detection thresholds (GDTs) and standard errors for each gap detection task for all 30 listeners. PLP = psychophysical laboratory procedure; ATTR = Adaptive Test of Temporal Resolution; RGDT = Random Gap Detection Test.



noise burst detection thresholds were 17.1 dB SPL and 24.3 dB SPL for the 4-ms and 230-μs noise bursts, respectively. Given the stimulus level for the PLP and ATTR (80 dB SPL) and the noise burst detection thresholds (see Table 1), presentation levels were over 50 dB SL for all of the participants. As indicated by Fitzgibbons and Gordon-Salant (1987), a sensation level of 25–30 dB is sufficient for optimal gap detection. A one-way analysis of variance (ANOVA) revealed that average noise burst detection thresholds for the two stimuli were significantly different, $F(1, 29) = 62.07$, $p < .0001$.

GDTs

The results of the initial session were examined to determine the effects of gap detection procedure on GDT. Individual runs within each procedure were also examined for an effect of run. As shown in Figure 2, GDTs are smaller for the adaptive procedures (PLP and ATTR) than for the nine-item procedure (RGDT). A two-way mixed ANOVA revealed that the effect of gap detection procedure was significant, $F(3, 117) = 10.95$, $p < .0001$, but the effect of run within each procedure was not significant, $F(2, 78) = 0.71$, $p = .50$. Further, there was not a significant interaction between gap detection procedure and run, $F(6, 234) = 0.61$, $p = .72$. A Tukey honestly significant difference post hoc analysis indicated that GDTs measured using the RGDT were significantly larger than those measured using the ATTR or either of the two PLP stimuli (4 ms and 230 μs; $p < .05$). Mean GDTs were 6.96 ms for the RGDT, 2.23 ms for the ATTR, and 3.20 and 1.24 ms for the 4-ms and 230-μs PLPs, respectively.

The GDT results of the return session were compared with the GDT results of the initial session for the random selection of 5 participants. Table 2 shows the initial and repeat

Table 2. Gap detection thresholds (GDTs) for each run of each gap detection task for 5 participants who repeated all GDT measures 1 week after the initial session.

		GDT Task											
		PLP (4 ms)			PLP (230 μs)			ATTR			RGDT		
Participant	Session	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
P01	Test	2.8	2.6	2.7	0.7	1.6	0.9	1.0	0.8	1.5	10	5	5
	Retest	2.0	1.9	1.9	0.9	0.7	0.5	1.3	1.2	1.2	10	10	10
P04	Test	1.9	3.0	1.9	1.3	0.7	0.9	1.7	1.3	1.7	10	10	10
	Retest	3.8	2.8	2.5	0.9	1.7	0.7	1.7	1.5	1.2	2	5	5
P12	Test	2.6	1.5	1.9	1.2	0.8	0.7	1.0	1.3	1.2	2	5	2
	Retest	2.3	3.4	3.0	1.0	1.0	0.9	2.8	1.4	1.3	5	2	2
P16	Test	2.0	2.2	3.3	1.1	1.3	0.8	2.5	2.1	2.5	10	5	2
	Retest	1.9	2.6	3.1	1.0	0.7	0.8	1.9	1.5	1.7	5	10	10
P25	Test	2.5	1.2	1.7	0.4	0.7	0.8	1.5	1.1	1.4	5	5	10
	Retest	1.5	1.3	1.4	3.0	2.1	2.1	1.5	1.3	2.0	5	2	5

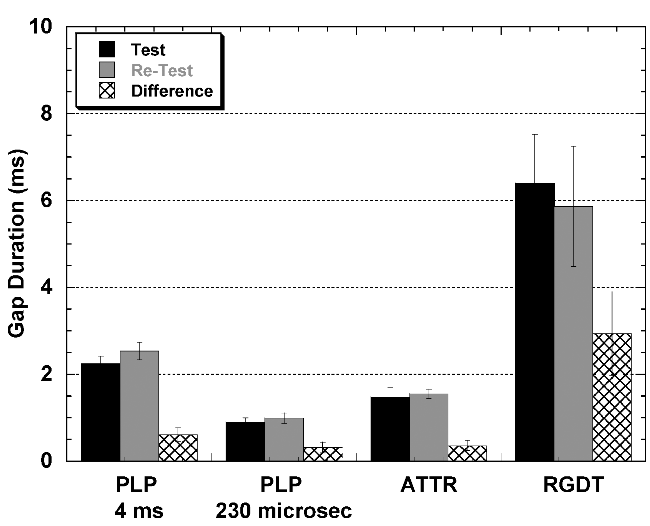
Note. PLP = psychophysical laboratory procedure; ATTR = Adaptive Test of Temporal Resolution; RGDT = Random Gap Detection Test.

session results for each participant. As shown in Figure 3, average thresholds differed by less than 1 ms for the PLP and ATTR tasks and by less than 10 ms for the RGDT.

Discussion

The purpose of this investigation was to compare GDTs obtained using three methods: a PLP, a currently available clinical test (RGDT), and a new adaptive clinical test (ATTR). It was hypothesized that the ATTR GDTs would be reliable across test session and that the ATTR would yield GDTs similar to the "gold standard" PLP, despite the fact that the ATTR stimuli were created and stored off-line and were not routed through specialized hardware prior to presentation.

Figure 3. Mean GDTs on test (solid bars) and retest (shaded bars) and the difference between test and retest GDTs (crosshatched bars) for each gap detection task for a subset of 5 listeners who repeated the test procedures 1 week after the initial session. Standard errors are shown.



It was further hypothesized that ATTR GDTs would be smaller than those measured using the RGDT for a number of reasons. First, the number and range of gap durations differ between the two clinical measures. Only 9 stimuli, each with a different gap duration, are presented for the RGDT. For the ATTR, 20 to 30 standard and target stimuli are typically presented. The RGDT gap durations are spread over a relatively wide range (0, 2, 5, 10, 15, 20, 25, 30, and 40 ms), whereas the ATTR uses 16 gap durations over a more limited range (0–15 ms in 1-ms steps). Therefore, the adaptive procedure (ATTR) allows for a greater number of measurements to be made closer to GDT. Second, the observation intervals for the ATTR are marked by a visual stimulus, and feedback is provided, whereas the intervals for the RGDT are unmarked, and no feedback is given. This may provide greater opportunity for uncertainty and less opportunity for learning during the RGDT. Third, the performance level for the RGDT is undefined, whereas the ATTR approximates 70.7% correct. Fourth, the ATTR is adaptive, whereas the RGDT uses a nine-item method of constant stimuli, a fixed procedure. It is established that adaptive methods provide greater control over response bias than fixed procedures. Fifth, the RGDT instructions require listeners to label the single observation interval as one click or two clicks, whereas ATTR instructions require listeners to compare two stimulus intervals and select the one with two clicks. This trial labeling, combined with observation interval uncertainty, may make judgments more difficult for the RGDT than for the ATTR (Marshall & Jesteadt, 1986).

The measurement paradigm selected for the ATTR, 2I/2AFC with a two-down/one-up stepping rule, is one that we have used many times (e.g., Lister et al., 2002; Roberts & Lister, 2004) with success. Other methods exist for psychophysical measurement, including three-interval, three-alternative forced-choice (3I/3AFC), method of constant stimuli, and maximum likelihood. We decided against a 3I/3AFC method and a method of constant stimuli in order to minimize test time for this initial version of the ATTR. Other methods may be considered in the future.

The GDTs measured using the PLP (M = 3.20 ms) and the ATTR (M = 2.23 ms) were comparable and were not significantly different. Although the average ATTR GDTs appear smaller than the average PLP GDTs for the 4-ms condition, both values fall within the range of GDTs measured previously in our lab for similar stimuli and listeners (Roberts & Lister, 2004). These results are similar to GDTs obtained by young listeners with normal hearing as noted in other studies of broadband noise gap detection (Phillips, 1999; Roberts & Lister, 2004). Average RGDT GDTs were close to 7 ms.

Comparable results for the ATTR and PLP suggest the ATTR may prove useful in studying the gap detection ability of clinical populations. Gap detection has been shown to be impaired in a number of special populations, including older adults (Roberts & Lister, 2004; Schneider & Hamstra, 1999), adults with hearing loss (Roberts & Lister, 2004), adults with auditory neuropathy (Michalewski, Starr, Nguyen, Kong, & Zeng, 2005; Zeng, Oba, Garde, Sininger, & Starr, 1999), children with dyslexia (Van Ingelghem, van Wieringen, Wouters, Vandenbussche, Onghena, & Ghesquiere, 2001), adults with multiple sclerosis (Hendler, Squires, & Emmerich, 1990; Rappaport et al., 1994), and adults with lesions of the central auditory nervous system (Musiek et al., 2005).

Roberts and Lister (2004) found that broadband GDTs of older adults with normal hearing fall into the range of 4–5 ms and are significantly different from those of young listeners (2–3 ms). Older adults with impaired hearing have GDTs of similar size (approximately 6–7 ms as found by Roberts & Lister, 2004). Michalewski et al. (2005) and Zeng et al. (1999) have shown that the GDTs of adults with auditory neuropathy range from 5 to 40 ms. Children with dyslexia have been shown to have GDTs that fall into the region of 3–4 ms, significantly larger than those of normal children (Van Ingelghem et al., 2001). Adults with multiple sclerosis may show impaired temporal resolution with GDTs falling into the range of 6–8 ms (Hendler et al., 1990; Rappaport et al., 1994). Adults with confirmed lesions of the central auditory nervous system have been shown to have GDTs of approximately 5–20 ms (Musiek et al., 2005). For all of these studies, gaps in the region of 4–8 ms appear important for discriminating groups of listeners with normal and impaired temporal processing. As this region is well within the normal range suggested for the RGDT (2–20 ms), it is clear that a more precise clinical test of temporal processing is needed.

Reliability of the gap detection procedures was examined across individual runs and test sessions. None of the procedures showed variability across run or session. Individual runs of the ATTR took no longer than 3 min, but this was somewhat dependent on the performance of the participant. Based on the reliability across runs and short administration time, the ATTR is efficient for testing gap detection, with only one run necessary for calculation of a GDT. Test time and efficiency are especially important considerations when selecting tests for an APD battery to be administered to both children and adults. For children, the ATTR could be easily adapted to include graphics designed to give the test a game-like feel. In the current version of the ATTR, simple gray boxes visually mark the intervals and a flashing green circle provides feedback.

Ease of test administration is also an important factor when selecting tests for an APD battery. The ATTR is easily administered using a desktop computer and sound card. Once the clinician enters patient data and selects "run," the ATTR presents stimuli and records the patient's responses. A GDT is shown at the end of the adaptive procedure. No recording of patient responses or calculations of GDTs are required of the clinician. It is believed that the test will be accessible to any audiology practice or clinic that currently utilizes a computer for such tasks as hearing instrument fittings, electrophysiology, or vestibular evaluations.

Future studies will focus on specific populations (e.g., children, older adults, individuals with hearing loss, individuals with lesions of the central auditory system) and specific stimulus parameters (e.g., duration, level, bandwidth, monotic/diotic/dichotic presentation). Additionally, the ATTR is designed to be a comprehensive test of temporal resolution, with gap detection being merely one component. It is planned that future versions of the ATTR will include other measures of temporal processing.

Summary

The purpose of this investigation was to evaluate a new adaptive clinical test of temporal resolution, the ATTR, using a group of young adults with normal hearing. Results of this investigation indicate that (a) GDTs are comparable across runs and sessions for each gap detection procedure evaluated; (b) ATTR GDTs are smaller than RGDT GDTs; and (c) ATTR GDTs are comparable to PLP GDTs. These results suggest that the ATTR has promise as a clinical tool useful for the assessment of temporal processing in general among clinical populations, especially during evaluation for APD.

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References

American Speech-Language-Hearing Association. (2005). *(Central) auditory processing disorders—The role of the audiologist* [Position statement]. Available from www.asha.org/policy.

American Speech-Language-Hearing Association Task Force on Central Auditory Processing Consensus Development. (1996). Central auditory processing: Current status of research and implications for clinical practice. *American Journal of Audiology, 5*(2), 41–54.

Dubno, J., Horwitz, A., & Ahlstrom, J. (2003). Recovery from prior stimulation: Masking of speech by interrupted noise for younger and older adults with normal hearing. *Journal of the Acoustical Society of America, 113,* 2083–2094.

Eddins, D., Hall, J., & Grose, J. (1992). The detection of temporal gaps as a function of frequency region and absolute noise bandwidth. *Journal of the Acoustical Society of America, 91,* 1069–1077.

Fitzgibbons, P., & Gordon-Salant, S. (1987). Minimum stimulus levels for temporal gap resolution in listeners with sensorineural hearing loss. *Journal of the Acoustical Society of America, 81,* 1542–1545.

Gordon-Salant, S., & Fitzgibbons, P. (1999). Profile of auditory temporal processing in older listeners. *Journal of Speech, Language, and Hearing Research, 42,* 300–311.

He, N., Horwitz, A., Dubno, J., & Mills, J. (1999). Psychometric functions for gap detection in noise measured from young and aged subjects. *Journal of the Acoustical Society of America, 106,* 966–978.

Hendler, T., Squires, N., & Emmerich, D. (1990). Psychophysical measures of central auditory dysfunction in multiple sclerosis: Neurophysiological and neuroanatomical correlates. *Ear and Hearing, 11,* 403–416.

Irwin, R., & McAuley, S. (1987). Relations among temporal acuity, hearing loss, and the perception of speech distorted by noise and reverberation. *Journal of the Acoustical Society of America, 81,* 1557–1565.

Jerger, J., & Musiek, F. (2000). Report on the consensus conference on the diagnosis of auditory processing disorders in school-aged children. *Journal of the American Academy of Audiology, 11,* 467–474.

Keith, R. (2000). *Random Gap Detection Test* [Manual]. St. Louis, MO: Auditec of St. Louis.

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *Journal of the Acoustical Society of America, 49,* 467–477.

Lister, J., Besing, J., & Koehnke, J. (2002). Effects of age and frequency disparity on gap duration discrimination. *Journal of the Acoustical Society of America, 111,* 2793–2800.

Lister, J., Koehnke, J., & Besing, J. (2000). Binaural gap duration discrimination in listeners with impaired hearing and normal hearing. *Ear and Hearing, 21,* 141–150.

Lister, J., & Roberts, R. (2005). Effects of age and hearing loss on gap detection and the precedence effect: Narrow-band stimuli. *Journal of Speech, Language, and Hearing Research, 48,* 482–493.

Lister, J., & Tarver, K. (2004). Effect of age on silent gap discrimination in synthetic speech stimuli. *Journal of Speech, Language, and Hearing Research, 47,* 257–268.

Marshall, L., & Jesteadt, W. (1986). Comparison of pure-tone audibility thresholds obtained with audiological and 2-interval forced-choice procedures. *Journal of Speech and Hearing Research, 29,* 82–91.

Michalewski, H., Starr, A., Nguyen, T., Kong, Y., & Zeng, F. (2005). Auditory temporal processes in normal-hearing individuals and in patients with auditory neuropathy. *Clinical Neurophysiology, 116,* 669–680.

Musiek, F., Shinn, J., Jirsa, R., Bamiou, D., Baran, J., & Zaidan, E. (2005). GIN (gaps-in-noise) test peformance in subjects with confirmed central auditory nervous system involvement. *Ear and Hearing, 26,* 608–618.

Oxenham, A. (2000). Influence of spatial and temporal coding on auditory gap detection. *Journal of the Acoustical Society of America, 107,* 2215–2223.

Oxenham, A. (2002, April). *Behavioral measures and consequences of cochlear nonlinearity.* Presented at the meeting of the American Academy of Audiology, Philadephia.

Peters, R., Moore, B. C. J., & Baer, T. (1998). Speech reception thresholds in noise with and without spectral and temporal dips for hearing-impaired and normally hearing people. *Journal of the Acoustical Society of America, 103,* 577–587.

Phillips, D. (1999). Auditory gap detection, perceptual channels, and temporal resolution in speech perception. *Journal of the American Academy of Audiology, 10,* 343–354.

Phillips, D., Taylor, T., Hall, S., Carr, M., & Mossop, J. (1997). Detection of silent intervals between noises activating different perceptual channels: Some properties of central auditory gap detection. *Journal of the Acoustical Society of America, 101,* 3694–3705.

Rappaport, J., Gulliver, J., Phillips, D., van Dorpe, R., Maxner, C., & Bhan, V. (1994). Auditory temporal resolution in multiple sclerosis. *The Journal of Otolaryngology, 23,* 307–324.

Roberts, R., & Lister, J. (2004). Effects of age and hearing loss on gap detection and the precedence effect: Broad-band stimuli. *Journal of Speech, Language, and Hearing Research, 47,* 965–978.

Schneider, B., & Hamstra, S. (1999). Gap detection thresholds as a function of tonal duration for younger and older listeners. *Journal of the Acoustical Society of America, 106,* 371–380.

Snell, K., Ison, J., & Frisina, R. (1994). The effects of signal frequency and absolute bandwidth on gap detection in noise. *Journal of the Acoustical Society of America, 96,* 1458–1464.

Snell, K., Mapes, F., Hickman, E., & Frisina, D. (2002). Word recognition in competing babble and the effects of age, temporal processing, and absolute sensitivity. *Journal of the Acoustical Society of America, 112,* 720–727.

Sonic Foundry. (1998). Sound Forge 4.5 [Computer software]. Madison, WI: Author.

Trehub, S., Schneider, B., & Henderson, J. (1995). Gap detection in infants, children and adults. *Journal of the Acoustical Society of America, 98,* 2532–2541.

Tyler, R., Summerfield, Q., Wood, E., & Fernandes, M. (1982). Psychoacoustic and phonetic temporal processing in normal and hearing impaired listeners. *Journal of the Acoustical Society of America, 72,* 740–752.

Van Ingelghem, M., van Wieringen, A., Wouters, J., Vandenbussche, E., Onghena, P., & Ghesquiere, P. (2001). Psychophysical evidence for a general temporal processing deficit in children with dyslexia. *NeuroReport, 12,* 3603–3607.

Zeng, F., Oba, S., Garde, S., Sininger, Y., & Starr, A. (1999). Temporal and speech processing deficits in auditory neuropathy. *NeuroReport, 10,* 3429–3435.

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