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Marking time: The precise measurement of auditory gap detection across the lifespan

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Deficits of temporal resolution are thought to contribute to speech understanding in noise difficulties and may be documented using auditory gap detection thresholds (GDTs). It is important to establish the appropriate methods to measure GDTs clinically. The USF Psychoaoustics Lab has established GDTs for a variety of stimuli, ages (7-90 years), equipment, degrees of hearing loss, psychophysical paradigms, neurophysiological paradigms, marker relationships (within-channel, across-channel), time points, and presentation ears (left, right, diotic). A number of important findings are discussed: 1. Best stimulus for measurement of GDTs is narrow-band noise. 2. GDTs improve from 7 to 9 years of age, stabilize between 9 and 40 years of age, and deteriorate with age thereafter. 3. GDTs may be measured reliably using a variety of equipment. 4. Hearing loss has a minor impact on GDTs. 5. A 2-interval psychophysical paradigm may be used to measure GDTs. 6. GDTs may be documented using the P1-N1-P2 auditory evoked potential. 7. Across-channel GDTs provide different information than within-channel GDTs. 8. GDTs are reliable within and across test sessions. 9. GDTs do not differ across ear conditions. A stable and sensitive measure of temporal resolution that may be used in a clinical setting to assess temporal resolution is recommended and discussed.

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Deficits in processing temporal information are thought to contribute to difficulties understanding speech in noise. To understand temporal processing difficulties reported in the clinic, reliable and flexible methods for measurement are needed. One effective method is to establish a gap detection threshold (GDT) or the smallest increment of silence that can be detected between two stimuli. Two GDT paradigms commonly used are within-channel (similar stimuli on either side of the silent gap) and across-channel (differing stimuli on either side of the silent gap). Clinically available gap detection measures are the Gaps in Noise Test (GIN: Musiek, Shinn, Jirsa, Bamiou, Baran et al., 2005) and the Random Gap Detection Test (RGDT: Keith, 2000). However, both of these tests use within-channel paradigms and fixed gap durations.

The Psychoacoustics Lab at the University of South Florida has completed numerous studies investigating procedures to effectively and easily establish GDTs using a variety of paradigms and adaptive gap durations. Studies have assessed using various stimuli on either side of the gap, gap detection across the lifespan (including children as young as 7 years of age up to 90 year old adults), various psychophysical paradigms, several neurological paradigms, and a few different marker relationships (such as within- and across-channel markers). This paper is a review of some of the work completed in an effort to develop a reliable, but flexible clinical method of measuring temporal resolution.

Stimuli: Broadband and Narrowband Noise

The stimuli preceding and following the gap can have an influence on GDTs. Broad band noise (BBN) was suggested by Jerger and Musiek in the Report of the Consensus Conference on the Diagnosis of Auditory Processing Disorders in School-Aged Children (Jerger and Musiek, 2000) as an effective stimulus for establishing GDTs. BBN stimuli provide smaller GDTs, as compared to narrow band noise (NBN) or pure tones. In addition, BBN can mask spectral splatter that occurs from interrupting a signal. Masking the splatter is useful, as it can be used as a cue during a GDT task. However, loudness of the BBN stimuli can be difficult to equalize across intervals when one interval contains a continuous noise burst and the other intervals contain BBN interrupted by a silent gap.

NBN stimuli may have advantages over BBN stimuli when working with a clinical population. Hearing loss (which can vary in degree and configuration from patient to patient) can act as a filter affecting the bandwidth of a BBN stimulus (Snell, Ison, and Frisina, 1994; Eddins, Hall, and Grose, 1992). That alone can reduce the ability of the listener to detect the gap. In addition, NBN stimuli allow measurement of GDTs in specific frequency regions. Due to the ability to measure various frequency bands, the use of NBN allows greater flexibility for test conditions and experimental hypotheses. One can measure within-channel processing, as well as across-channel processing.

One study from the USF Psychoacoustics Lab compared within-channel GDTs established to BBN stimuli and to NBN stimuli (Lister, Roberts, Krause, DeBiase, and Carlson, 2011). Thirty young listeners with normal hearing participated in the study (mean age = 25.2 years). An adaptive 2-interval, 2-alternative forced choice procedure was used to establish GDTs. The standard interval contained a 1 millisecond (ms) gap, while the gap size in the other interval varied adaptively. Presentation order of the two intervals was randomized. Stimuli were presented at two levels: 80 dB SPL and the listener's highest comfortable loudness (HCL).

The BBN stimuli were created from Gaussian Noise and had a 4 ms duration. The NBN stimuli were also created from Gaussian noise and filtered to a ¼ octave bandwidth centered on 1000 or 2000 Hz. Stimulus duration was 300 ms before the gap and varied randomly between 250-300 ms following the gap to control any duration cues. The NBN stimuli were shaped to have a 1 ms rise-fall time at the offset of the first NBN and onset for the second NBN and a 10 ms rise-fall time at the onset of the first NBN and the offset of the second NBN.

Results of this study showed across-channel GDTs to be significantly larger than within-channel thresholds in both the BBN and NBN stimuli conditions. No significant difference between GDTs was found using an 80 dB SPL presentation level and the listener's HCL for any of the test conditions. Also, there was no significant difference between within-channel GDTs established using BBN stimuli (mean = 3.2 ms, SD = 1.9) and NBN stimuli (mean = 3.2 ms, SD = 0.9). These results support the use of NBN stimuli for establishing GDTs, which is especially useful for a population with hearing loss or suspected hearing loss and for establishing both within-channel and across-channel GDTs.

Test Paradigm: Fixed or Adaptive

Lister, Roberts, Shackelford, and Rogers (2006) compared a traditional, psychophysical, lab based procedure (or PLP) for establishing GDTs, a commercially available test (the RGDT), and a new computer based procedure, the Adaptive Tests of Temporal Resolution (ATTR). Both the PLP and the ATTR used a 2-interval, 2-alternative forced choice procedure. The RGDT is a clinical test that uses a non-adaptive (fixed) procedure to randomly present BBN stimuli in fixed gaps via CD. The PLP uses customized computer software with Tucker-Davis hardware to generate and present stimuli. Note that due to the specialized nature of the PLP software and hardware, it is not used clinically. The ATTR is a computer-based program that uses offline wav files of noise to generate and present stimuli adaptively. For this study, white noise burst stimuli were used for both the PLP and the ATTR. Thirty adults (mean age = 25 years) with normal hearing participated in the study. Both within- and across-channel GDTs were measured. Four ms noise bursts were used to establish GDTs with the ATTR, 230 micro-second (μs) noise bursts were used with the RGDT, and both 4 ms and 230 μs noise bursts were used when establishing GDTs with the PLP. Initial test GDTs and re-test GDTs (1 week later) were measured.

GDT thresholds were significantly smaller for both of the 2-alternative forced choice procedures (PLP: 4 ms mean = 3.20 ms, 230 μs mean = 1.2 ms; ATTR: mean = 2.23 ms) as compared to the fixed method (RGDT: mean = 6.96 ms). GDTs measured using the PLP and ATTR were not significantly different. There was no significant difference between test and retest GDTs for any of the procedures. This study shows that GDTs, comparable to those obtained with the research "gold standard" PLP, can be effectively established with the ATTR computer based software.

Computer Sound Card

Since the ATTR can effectively be used with a standard computer, and sound cards can vary from computer to computer, the lab examined GDTs using two standard, but different computer sound cards: a Lynx One sound card and a Turtle Beach sound card (Lister, Roberts, Krause, DeBiase, and Carlson, 2011). Within- and across-channel GDTs were established using NBN and BBN stimuli (as described above). Young listeners (mean = 25.2 years) with normal hearing participated in the study.

No significant differences were found between within-channel BBN GDTs, within-channel NBN GDTs, or across-channel NBN GDTs. The use of different sound cards (Lynx One and Turtle Beach) did not make a difference in GDTs, regardless of stimulus condition. Therefore, as long as the computer has a standard quality sound card, GDTs can be established without the use of special computer technology or hardware.

Age Effects

Another consideration when examining GDTs is age. GDTs are a tool that can be used to assess temporal processing in children with auditory processing disorder, as well as a useful tool for measuring temporal processing skills of older adults who report difficulties understanding speech in noise. Lister, Roberts, and Lister (2011) examined within- and across-channel thresholds across the life span. GDTs were obtained from 29 children (mean age = 9.2 years), 30 young adults (mean age = 26.8 years) and 60 older adults (mean age = 69.7 years). The children were divided into three age groups: 7 years to 8 years 11 months (n = 13), 9 years to 10 years 11 months (n = 8), and 11 years to 12 years 11 months (n = 8). Narrow band noise stimuli, similar to the stimuli in Lister, Roberts, Krause, DeBiase, and Carlson (2011), were used. No significant difference between ears for the young adults and older adults had been found in previous studies, so binaural thresholds were obtained.

For the children's age groups, within-channel GDTs established for the left ear (LE) of the 7-8 year olds (mean = 8 ms, SD = 3.48) were significantly larger than the LE within-channel GDTs for the 11-12 year olds (mean = 4 ms, SD = 1.02). Across-channel GDTs established for the right ear (RE) of the 7-8 year olds (mean = 97 ms, SD = 33.30) were significantly larger than the RE across-channel GDTs for the 11-12 year olds (mean = 50 ms, SD = 21.74). There were no other significant differences between age groups or ears on either the within- or across-channel conditions for the children. Since main effect of ear was not significant for the children, the GDTs for each condition were averaged across ear for each child. Examining GDTs across the lifespan, a developmental effect was observed. Binaural GDTs become smaller with increasing age among the children, smallest overall for the young adult group, and then increased with age among the older adults (For more details, see Table 1 in Lister, Roberts, and Lister, 2011).

Psychophysical Paradigms

The lab investigated psychophysical paradigms in a study by Miskoweic, Lister, McArdle, and Hnath Chisolm (2012). Listeners were 48 older adults (mean age = 67.7 years) with pure tone averages of $\leq$ 45 dB HL. The ATTR (Lister et al., 2006) was used to present stimuli. The ATTR used a 1 ms standard interval and a target that adapted by a factor of 1.2. Stimuli were narrow bands of noise centered on 1000 or 2000 Hz. The first markers (NBN before the gap) were 150 ms in duration and the second markers (NBN following the gap) varied from 250-300 ms in duration to decrease duration cues. Stimuli were presented at the listeners' HCL.

GDTs were measured using a 3-interval forced choice procedure in which a standard containing a 1 ms gap was presented, then two alternatives were randomly presented: one with a 1 ms gap and one with a varying gap size. The listener was instructed to choose the interval containing the "oddball" interval (with the longest gap). GDTs were also measured using a 2-interval forced choice procedure. Two intervals were randomly presented, one containing the standard 1 ms gap and one with a varying gap size. The listener was instructed to choose the interval with the longer gap.

Results showed within-channel GDTs were slightly smaller for the older adults using the 2-interval forced choice procedure (mean = 8.0 ms, SD = 3.5) as compared to the 3-interval forced choice procedure (mean = 9.2 ms, SD = 3.1). No difference was found between the two across-channel listening paradigms. These results suggest that a 2-interval forced choice procedure can yield slightly smaller GDTs in a within-channel paradigm in an older population. The number of intervals used in a forced choice procedure (2 versus 3) have no effect on across-channel GDTs in an older population.

Electrophysiological Recording of GDTs

Lister, Maxfield, and Pitt (2007) measured GDTs using evoked potentials. In this study, the P1-N1-P2 auditory evoked response was measured in 12 young adults (mean age = 25.8 years) with normal hearing. Stimuli were NBN centered at 1000 and 2000 Hz. Both within-channel (2000-2000 Hz) and across-channel (2000-1000 Hz) conditions were used. Four auditory evoked potential conditions were used for each of the within-channel and across-channel conditions: 1) at the listener's established behavioral GDT, 2) at a supra-threshold gap, 3) at a sub-threshold gap, and finally, 4) at a standard gap of 1 ms. Four hundred tokens were used for each of the eight conditions.

Results were reported for the 2nd marker (recorded at Fz) in the four listening conditions. No difference in latency across conditions for P1 or N1 was found. P2 latencies were significantly longer in the within-channel condition as compared to the across-channel condition. In regards to amplitude, P1 and N1 amplitude were significantly larger for across-channel conditions as compared to within-channel conditions. For gap duration, P1 amplitude was significantly smaller for the standard gap as compared to the supra-threshold gap. In addition, P1 amplitude was significantly smaller for sub-threshold, as compared to GDT. These results suggest that P2 latencies and P1-N1-P2 amplitudes can reflect acoustic changes in the second marker, as well as changes in gap duration.

In a similar study, Lister, Maxfield, Pitt, and Gonzalez (2011) measured evoked potentials elicited from 24 older adults (mean age = 63 years) with minimal or no hearing loss using the same within-channel and across-channel conditions. Overall, within-channel wave morphology for the older listeners was poor in the standard, sub-threshold, and GDT condition. However, wave morphology for the older listeners is similar to the wave morphology for the younger listeners for the across-channel conditions. For the older listeners, N1 latency was significantly shorter for the within-channel condition, as compared to the across-channel condition. In regards to amplitude for the older listener's waveforms, P1 amplitude differed across gap duration, and was significantly larger for across-channel conditions as compared to within-channel conditions. Comparing the results of the younger listeners to the older listeners, overall larger P1 amplitudes and longer latencies for P2 for the older listeners were found. Interestingly, P1 amplitude for the across-channel condition was larger for the older listeners and increased in amplitude as the gap duration increased. These results suggest that the older listeners were having more difficulty processing temporal information as compared to the younger listeners.

Summary

The Psychoacoustics Lab at the University of South Florida has conducted numerous studies in an effort to find a reliable, valid psychophysical measure of GDTs. In the process of investigation, several facts have come to light. GDTs are sensitive to condition (within-channel versus across-channel markers) and age. NBN stimuli allows for greater test flexibility. A 2-interval forced choice paradigm yields smaller within-channel GDTs as compared to a 3-interval forced choice paradigm in an older population. The ATTR is a stable and sensitive measure that can be easily used clinically. GDTs can effectively be examined using electrophysiological measures.

The results of these studies have helped develop new ways to measure GDTs, both within- and across-channel. A new clinical measure, the ATTR, has been developed and found to be effective. With this new adaptive measure, GDTs can be established with children seven years of age and older in the clinic.

References

Eddins, D., Hall, J., & Grose, J. (1992). The detection of temporal gaps as function of frequency region and absolute noise bandwidth. *The Journal of the Acoustical Society of America,* 91(2), 1069-1077.

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(9), 467–474.

Keith R. (2000). Random Gap Detection Test [manual]. St. Louis, USA: Auditec of St. Louis.

Lister, J.J., Maxfield, N.D., & Pitt, G.J. (2007). Cortical responses to gaps in noise: Within and across channel conditions. *Ear and Hearing,* 28(6), 862-878.

Lister, J.J., Maxfield, N.D., Pitt, G.J., & Gonzalez, V.B. (2011). Auditory evoked response to gaps in noise: Older Adults. *International Journal of Audiology*, 50(4), 211-225.

Lister, J.J., Roberts, R.A., Krause, J.C., DeBiase, D., & Carlson, H. (2011). An adaptive test of temporal resolution: Within-channel and across-channel gap detection. *International Journal of Audiology*, 50(6), 375-384.

Lister, J.J., Roberts, R.A., & Lister, F.L. (2011). An adaptive test of temporal resolution: Age effects. *International Journal of Audiology*, 50(6), 367-374.

Lister, J.J., Roberts, R.A., Shackelford, J., & Rogers, C.L. (2006). An adaptive test of temporal resolution. *American Journal of Audiology*, 15(2), 133-140.

Miskoweic, B., Lister, J.J., McArdle, R., & Hnath Chisolm, T. (2012). Influence of psychophysical paradigm and marker duration on NBN gap detection. Audiology Doctoral Project, University of South Florida, Tampa, FL.

Musiek, F., Shinn, J., Jirsa, R., Bamiou, D., Baran, J., & Zaidan, E. (2005). GIN (gaps-in-noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear and Hearing*, 26(6), 608-618.

Snell, K., Ison, J., & Frisina, D. (1994). The effects of signal frequency and absolute bandwidth on gap detection in noise. *Journal of the Acoustical Society of America*, 96(3), 1458-1464.