Across- and Within-Channel Gap Detection Thresholds Yielded by Two Different Test Applications

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Abstract

Background: Individuals with auditory processing disorders show some deficits with the temporal processing of auditory signals. Gap detection measurements are commonly used to assess temporal processing skills across different listening tasks.

Purpose: The aim of this study was to compare the gap detection thresholds (GDTs) in across-channel (AC) and within-channel (WC) tasks by using two computer applications—Adaptive Tests of Temporal Resolution (ATTR) and Psycon.

Research Design: A within-subject study design.

Study Sample: Twenty-one young adults with normal hearing participated in the study.

Data Collection and Analysis: Each participant's gap detection performance was assessed using the narrowband noise stimuli of the ATTR and Psycon applications. Four conditions were administered with 2 kHz as the leading frequency marker before the gap and 1 kHz as the trailing frequency marker after the gap for AC tasks, and with 2 kHz as both the leading and trailing frequency markers for WC tasks.

Results: The results showed lower GDTs for the WC tasks than the AC tasks. Also, the GDT values for the WC tasks were lower in the ATTR than Psycon; whereas the GDT values for the AC tasks were higher in the ATTR than Psycon.

Conclusion: The differences noted in the obtained GDT values from the ATTR and Psycon applications may be attributed to subtle spectral differences in the stimuli of the two programs. The present study also indicates that because of the inherent differences in the stimuli generated by the different software, the normative values for GDTs may need to be established according to evaluation tools before drawing conclusions about clinical conditions.

Key Words: auditory perception, auditory processing disorder, gap detection threshold, psychoacoustics, temporal resolution

Abbreviations: AC = across-channel; GDT = gap detection threshold; LTASs = long-term average spectrums; NBN = narrowband noise; WC = within-channel

INTRODUCTION

The auditory system decodes information important for speech perception from basic sound dimensions that include frequency, intensity, and temporality. The recognition of rapid changes in the acoustic input over time (i.e., temporal resolution ability) is commonly tested using gap detection tasks. These tests involve the presentation of two auditory stimuli: one stimulus with a gap (hearing as two sounds) and one stimulus without a gap (hearing as one sound). The listener's task is to identify the stimulus with a gap. The least detectable level of gap duration in which a listener hears two sounds is known as the gap detection threshold (GDT). The task is measured using a within-channel (WC) gap detection test (the

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detection of a gap in a stimulus of the same center frequency before the gap and after the gap) or an across-channel (AC) gap detection test (the detection of a gap in a stimulus of two different center frequencies before the gap and after the gap) (Moore, 2013). Knowledge about temporal processing skills, including their measurement, is important for the management of an auditory processing disorder (APD). Individuals with an APD may exhibit a variety of auditory processing deficits, including binaural and temporal processing deficits (ASHA, 2005; AAA, 2010; Rawool, 2016). A variety of temporal processing deficits have been reported in the literature, including a poor ability to detect gaps within stimuli, poor temporal pattern perception, and poor temporal maintenance. These difficulties with the temporal processing of auditory signals warrant testing for an appropriate intervention. The GDT is a basic measure of one aspect of auditory temporal ability. The present investigation compared the data of the GDT values obtained from two different applications using the same gap detection tasks to shed light on the GDT variations across different testing programs that use the same tasks and procedures.

Previous research has shown that the GDT for WC tasks is lower than those for AC tasks. The GDTs for WC stimuli have ranged from 3 to 7 msec, which vary as a function of frequency (Florentine et al, 1999; Lister et al, 2011; Hess et al, 2012; Wong and McPherson, 2015). The performance of the GDT is poorer with respect to the low center frequency of narrowband noises (NBNs) compared with a better performance for NBNs with respect to the high center frequency (Shailer and Moore, 1983; Florentine et al, 1999). For example, Shailer and Moore (1983) reported that the GDTs were 22.5 msec for the NBN centered at 0.2 kHz and 3.2 msec for the NBN centered at 8.0 kHz. Furthermore, a higher GDT is required to resolve a gap in the AC stimuli compared with the GDTs for WC tasks. Although the WC tasks involve analyses of time patterns within a single frequency channel, the AC task involves analyzing a time pattern across the frequency channels of two different frequencies of the leading and trailing markers (Phillips et al, 1997; Lister et al, 2002; Lister et al, 2011; Moore, 2013). For example, the mean GDT for an AC task with center frequencies at 2 kHz for the leading marker and 1 kHz for the trailing marker of 42.6 msec was higher than the mean GDT for a WC task with center frequencies 1 kHz of 3.2 msec (Lister et al, 2011). However, the reported GDT values across different studies have shown a great variability because of instrumentation and procedure differences (Lister et al, 2011).

The instruments and procedures involved in assessing temporal gap detection tasks have changed progressively over time. Until 2005, the clinically available behavioral tests to measure temporal resolution tasks were very few, but included the Auditory Fusion Test—Revised by McCroskey and Keith (1996), the Random Gap Detection Test by Keith (2000), and the Gaps-in-Noise test by Musiek et al (2005). Most of these tests played a stored acoustic test stimulus with a predetermined range of gaps in the stimulus and then recorded the responses. Thus, they only required the use of an auditory mode for a response, for which participants were instructed to press a button when they heard a gap. These tests used a fixed procedure to measure GDTs that only enabled a limited number of gap duration measurements (Lister et al, 2006). For example, the Gaps-in-Noise test includes 0 to 3 silent gaps with a duration ranging from 0 to 20 msec presented in a six-second burst of broadband noise. It is administered using a compact disc player connected to a clinical audiometer (Musiek et al, 2005). In contrast to these clinical tests, experimental research studies have used several advanced signal generation and presentation tools such as Tucker-Davis Technologies for generating and presenting stimuli for gap detection measurements (Formby et al, 1993; Grose et al, 2001; Elangovan and Stuart, 2008; Hoover et al, 2015) and the MATLAB toolbox (Phillips and Hall, 2002; Hoover et al, 2015).

With the advancement of technology, clinical tests now are available which permit objective measurements of GDT using adaptive procedures and waveforms that can be generated with a wide range of gap durations. Examples of such applications include the Adaptive Tests of Temporal Resolution (ATTR) by Lister et al (2011) and Psychoacoustics (a MATLAB toolbox) by Soranzo and Grassi (2014). The ATTR has been used frequently to assess gap detection abilities under different stimulus conditions (Lister et al, 2011). The GDT values from ATTR have been reported for different populations that include normal hearing adults, children and older adults, children with cleft lip/palate, and musicians (Lister et al, 2011; Mishra et al, 2014; Ma et al, 2015; Wong and McPherson, 2015). Also, Lister et al (2011) compared their GDT data with previous studies that used ATTR and noted variations in the reported values. These authors attributed such differences to the instrumentation used to design and conduct the tasks. In addition, the available software for ATTR only enables gap detection tasks for a limited set of marker frequencies (2 kHz for WC and 2–1 kHz for AC). However, a broader range of trailer frequency conditions has been reported in the research literature, such as 2 kHz for the leading markers and 0.5–3 kHz for the trailing markers in Lister et al (2002). Another application with clinical potentiality is Psycon (Kwon, 2012), which is a Windows-based program used for designing and conducting different auditory psychoacoustic tasks, including gap detection. It uses auditory syntax (AUX) codes (i.e., scripting language) that enable the design of gap detection conditions with any desirable marker frequencies. Like ATTR, Psycon does not require complex software, hardware, and programming knowledge, and can determine the GDT with more accuracy when the gap duration is adaptively changed based on responses. In addition, Psycon enables the design of gap detection tasks with a variety of marker frequencies.

The purpose of the present study was to conduct direct comparisons of the GDTs from the Psycon V 2.18 test and the ATTR using WC and AC tasks with the same listener group with normal hearing and under similar experimental conditions. Thus, we compared the gap detection performance of the same listener group with normal hearing for the two tests (ATTR versus Psycon) using both the AC and WC conditions.

METHOD

Participants

Twenty-one students from undergraduate programs at the College of Applied Medical Sciences at King Saud University, with no reported hearing difficulties, participated in the study. They were bilingual with Arabic as their mother language and English as their second language. The mean age was 21.5 years with ages that ranged from 20 to 25 years. Before participating in the study, all the participants completed and passed a hearing screening at six octave frequencies at a level of 15-dB HL and had no abnormality on tympanometry with a 226-Hz probe frequency. All the participants were inexperienced with the psychoacoustic tasks involved in the study. We used audio and visual demonstrations about the procedures to explain the tasks they would perform. None of the participants had a significant history of exposure to loud noises or any cognitive impairment. All the participants signed a consent form, and their participation was voluntary and unpaid. We obtained the ethical approval for conducting research involving human participants from the Research Ethics Committee (College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia). Last, we identified some participants as outliers by using the criteria of mean ±3 standard deviation (SD), and we removed their data from the analyses because of their +3 SD. Of the 21 participants, data of participants 20 and 19 were included in the AC and WC analyses, receptively. The AC outlier (PSYCON-AC) was not one of the two WC outliers (ATTR-WC and PSYCON-WC). Thus, in total, we discarded three pairs of data from three participants to avoid biased results.

Stimuli and Instrumentation

We categorized the stimuli we used in our study as WC or AC gap stimuli, which we generated using the ATTR and Psycon v 2.18 computer programs installed on a PC laptop. For the AC condition, we used NBNs centered at 2 kHz as the leading frequency marker (before the gap) and 1 kHz as the trailing frequency marker (after the gap); for the WC condition, we used NBNs centered at 2 kHz as the leading and trailing frequency markers. The stimulus bandwidth was 1/4th octave for both conditions. The NBN stimuli played by the ATTR program were obtained from offline saved .wav files. The stimuli for the ATTR program were 16-bit resolution with a sample rate of 44100 Hz. The ATTR stimuli were created using the following step size for gap durations: 1-msec steps (gap durations between 1 and 100 msec), 2-msec steps (gap durations between 102 and 200), and 5-msec steps (gap durations between 205 and 400 msec) (Lister et al, 2011). The NBN stimuli played by the Psycon program were generated instantly with AUX codes. To derive the NBN stimuli, we used an AUX code of an 8th-order butterworth filter with a 0.5-dB passband ripple and a −40-dB stopband attenuation.

For both programs (ATTR versus Psycon), the onset of the leading marker and the offset of the trailer marker had a 10-msec gradual fall/rise with a $\cos^2$ window. Also, 1-msec fall/rise transitions were implemented before and after the gap for each stimulus to avoid any cueing factor of the signal distortion created by the edges. We used these transitions for the standard stimulus and the test stimulus. The gap in the standard stimulus was always 1-msec long along with the fall–rise transition to create the same effect as the test stimulus. The gap duration in the test stimulus was longer (based on a participant's performance as described in the procedure) with the same transitions on each edge. Overall, the duration of the leading marker for the stimuli generated by the ATTR and Psycon programs was always constant at 300 msec, and the duration of the trailer marker varied randomly between 250 and 350 msec, which included the transition duration.

Procedure

We carried out all the experimental procedures in a sound-treated room (Model: RS-142; Acoustic Systems, Austin, TX). Before their participation in the actual experiment, each participant underwent a practice session to ensure they understood the procedures involved in the study. We carried out all the practice sessions using stimuli with larger gaps (30 msec for the WC gap detection and 100 msec for the AC gap detection). We generated all the tasks using a PC notebook with a 22-bit high-definition audio sound card (Intel). We routed the stimuli from the PC notebook to an external input of a calibrated GSI-61 two-channel diagnostic clinical audiometer that was presented through supraaural headphones (TDH-50P with mod 51 ear cushion).

We constantly maintained the presentation level of the stimuli at a 60-dB HL. We selected this presentation level to reflect the stable measurement of the GDT and also to provide average comfortable levels for normal hearing listeners (Lister et al, 2011). Previous studies have reported that the stimulus presentation level alters listeners' performance on GDT up to a 40-dB SL level, over which significant improvements in GDT have not been observed (Shailer and Moore, 1983; Hess et al, 2012).

We used a two-alternative forced-choice procedure, and each trial presented a set of a standard stimulus and a test stimulus in a randomly changed order. The interstimulus interval was always 500 msec. We instructed all participants to listen carefully to both stimuli in each trial and then to identify the stimulus that they perceived to have a gap within it. If they perceived that both stimuli had gaps, they were asked to choose the stimulus with the longer gap. The standard stimulus contained a constant 1-msec gap, whereas the gap duration of the test stimuli was varied as per a two-down one-up adaptive procedure. We asked each participant to use a wireless keyboard/mouse to click a visual block on the PC screen that corresponded to the signal they perceived as interrupted or containing a gap. After each response, the participants received visual feedback about the correctness of their response on screen, which was followed by the next trial. The adaptive procedure for ATTR used a two-down one-up procedure with a step size of factor 1.2. The procedure continued up to eight adaptive runs and if the measured GDT was in the factor of 2 as detailed by Lister et al (2011). With respect to the Psycon program, we designed a similar two-down and one-up adaptive procedure using an AUX script, according to the instructions provided in the Psycon manual. These procedures enabled us to compute the GDT to a response criterion of 70.6% (Levitt, 1971; Brown, 1996). A step size with a factor of 1.2 of the gap duration in the test stimulus was used to estimate the initial five response reversal points, which was changed to a factor of 1.05 for the remaining six reversals. We considered an average of the final four reversal points to be the determined GDT. For the ATTR program, we calculated the GDT to be the geometric mean of the last six response reversals out of a total of eight response reversal points (for more details, refer to Lister et al (2011). The averages of individual SD in milliseconds across all conditions were 1.67 (ATTR-WC), 0.62 (PSYCON-WC), 15.16 (ATTR-AC), and 2.23 (PSYCON-AC).

Each participant participated in four conditions: (a) ATTR-AC condition (2–1 kHz); (b) PSYCON-AC condition (2–1 kHz); (c) ATTR-WC condition (2 kHz); and (d) PSYCON-WC condition (2 kHz). Participants completed the four conditions in one testing session. We tabulated and analyzed the lowest GDT at each condition.

RESULTS

Table 1 provides data on the descriptive statistics (in msec) for the GDTs of each stimulus condition. We conducted a paired sample *t* test to compare the GDT values obtained using the ATTR and Psycon programs. We found a significant *t* value for the AC GDT comparison, $t_{(19)} = 2.12$, $p = 0.048$. The obtained GDT value was significantly higher in the ATTR-AC condition (39.32 msec) than the PSYCON-AC condition (32.69 msec). Figure 1 depicts the GDTs of the two stimulus conditions. The Pearson correlation indicated a positive correlation between the GDT value of the ATTR-AC and the PSYCON-AC conditions, $r = 0.56$, $p = 0.01$. In addition, we found a significant *t* value for the WC GDT comparison, $t_{(18)} = -5.89$, $p < 0.001$. The obtained GDT value was significantly higher in the PSYCON-WC condition (8.33 msec) than the ATTR-WC condition (3.33 msec). Figure 2 depicts the GDTs of the two stimulus conditions. The Pearson correlation indicated no correlation between the GDT values of the ATTR-WC and the PSYCON-WC conditions, $r = 0.090$, $p = 0.714$.

DISCUSSION

The aim of this study was to compare the GDT values obtained from two different computer applications (ATTR and Psycon) with the same group of listeners using AC and WC tasks. As shown in Table 1, the obtained GDT values were lower for the WC conditions than the AC conditions. This result indicates that the identification of shorter silences among stimuli of same frequencies is easier than the identification of shorter silences among stimuli of different frequencies. These findings are consistent with earlier investigations (Lister et al, 2011; Mishra et al, 2014; Mishra and Panda, 2016). Furthermore, the average GDT obtained with the ATTR-WC paradigm (3.38 msec) was similar to the reported average of 3 msec for a young adult group in the Lister et al (2011) study. The ATTR-AC GDT value of 39.32 msec in the present study closely approximates the average GDT of 42.6 msec reported by Lister et al (2011). However, the average GDT of the ATTR-AC paradigm used in the present study was slightly higher than the GDT value of 30 msec obtained with the young adult group in the Lister et al. (2011) study. Overall, these results indicate that the experimental procedures used in the present study had a good validity and also that the ATTR application used in the present study had a good consistency with different hardware.

Moreover, the present study found significant differences between the ATTR and Psycon programs

Table 1. Means and Standard Deviation (in msec) for the GDTs of Each Stimulus Condition

	Mean	SD	N
ATTR-AC	39.32	15.65	20
PSYCON-AC	32.69	14.16	20
ATTR-WC	3.33	1.79	19
PSYCON-WC	8.33	3.41	19

across stimulus conditions. The GDTs were lower in the ATTR-WC condition than the PSYCON-WC condition. The difference in the average GDT among the applications for the WC was 5 msec. The large GDT obtained with the PSYCON-WC paradigm (8.33 msec) was similar to the reported average GDT of 8.4 msec for same marker frequency in the Florentine et al (1999) study. Also, the GDTs were lower in the PSYCON-AC condition than the ATTR-AC condition. Although significant, such differences in the AC GDTs were not large between the ATTR and Psycon programs as is shown in Figure 1. The difference in the average GDT among the computer applications for the AC tasks was 6.63 msec. In addition, the ratio of GDTs for AC relative to WC was higher for the ATTR than Psycon in which the AC/WC was 11.8 for ATTR but only 3.92 for Psycon. Last, the correlational analysis revealed that the GDTs of the AC paradigm that were obtained with different computer applications were positively correlated compared with the GDTs of the WC paradigm which were not correlated across the two applications.

Notably, differences exist in the reported GDTs obtained with the two computer programs, despite the use of the same hardware, stimuli, and listener group. As a possible source of differences in GDT values, we conducted acoustic analyses of the ATTR and Psycon stimuli used in the present study and generated long-term average spectrums (LTASs) using Praat version 6.0.14 (Boersma and Weenink, 2016). The two WC stimuli and two AC stimuli were recorded for ATTR and Psycon as direct audio input from the clinical audiometer

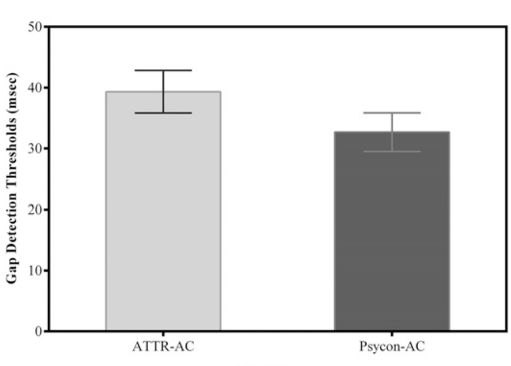

Figure 1. GDT values with standard errors as a function of the AC stimulus condition.

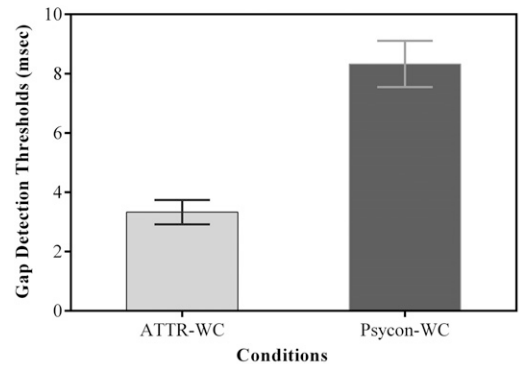

Figure 2. GDTs values with standard errors as a function of the WC stimulus condition.

using a 44.1-kHz sampling rate, and the data were saved as .wav audio files. We used Praat to produce LTASs for these audio files. These spectrums are depicted in Figures 3 and 4 for the WC and AC paradigms, respectively.

An examination of Figures 3 and 4 reveals some spectral differences in the stimuli of the two programs. The Psycon NBNs for the WC and AC stimuli had steeper slopes covering a narrower frequency range with side lobes below 1 kHz and at 6 kHz, respectively. By contrast, the ATTR NBNs for the WC and AC stimuli had gradual slopes covering a wider NBN bandwidth (i.e., range of marker frequencies). It seems that these spectral differences may have contributed to the differences in the GDT across the four conditions. With respect to the WC tasks, the additional spectral information due to a wider NBN bandwidth for the ATTR stimuli may have facilitated gap detection compared with the Psycon stimuli with a narrower NBN bandwidth, which did not facilitate gap detection. The WC task involved the analysis of time patterns within a single frequency channel. As a result, the corresponding auditory neural activations of the target stimulus were stimulated. The wider NBN bandwidth of the ATTR-WC stimuli may have enabled the listeners to more quickly detect the onset of a trailing marker. With respect to the AC tasks, the wider NBN bandwidth for the ATTR stimuli may have interfered with the listeners' gap detection process compared with the Psycon stimuli with a narrower NBN bandwidth. The AC task involved the analyses of the time patterns across frequency channels that stimulated different auditory neural activations related to the leading and trailing markers. The wider NBN bandwidth (lesser depth in the spectrum of AC for ATTR) of the ATTR stimuli may have impacted the listeners' perception of the gap compared with their interaction with the narrower range of the Psycon stimuli. However, the GDT differences between the two programs with respect to the AC tasks were not large compared with the differences involved in the WC tasks, which was due to the

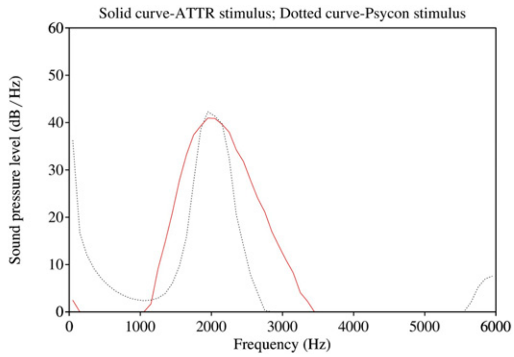

Figure 3. LTAS of WC stimuli plotted in 100-Hz bandwidths. The solid line indicates the spectrum of the ATTR-generated stimulus, and the dotted line indicates the spectrum of the Psycon-generated stimulus. (This figure appears in color in the online version of this article.)

similarity between the two programs with respect to the AC stimuli. Last, the differences in the details of the procedure itself for the two programs—as described in the aforementioned method—may also have contributed to the different GDT results (e.g., differences in the adaptive step size procedure).

Overall, the present study highlights the importance of establishing or using normative data specific to the evaluation measures due to the inherent differences in the stimuli generated by different computer software. The present study also shows that the GDTs of the AC tasks are a more reliable measure for comparison across the different gap detection tests. Clinicians who use gap detection measurements to evaluate auditory processing difficulties may need to obtain in-clinic normal referenced data that use the same equipment and applications before drawing any conclusions about clinical conditions.

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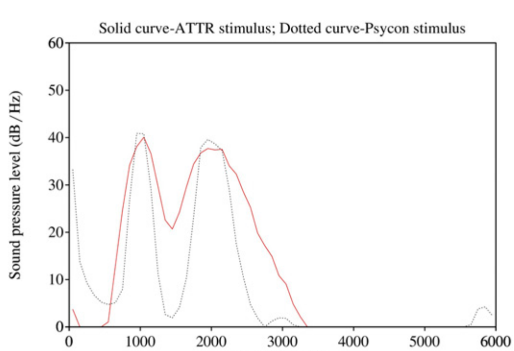

Figure 4. LTAS of AC stimuli plotted in 100-Hz bandwidths. The solid line indicates the spectrum of the ATTR-generated stimulus, and the dotted line indicates the spectrum of Psycon-generated stimulus. (This figure appears in color in the online version of this article.)

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