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I am submitting herewith a dissertation written by David Mason entitled "Effects of Tone and Inter-Stimulus-Interval Duration on the Acoustic Reflex Thresholds of Normally Hearing and Hearing-Impaired Subjects." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

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Graduate Studies and Research

EFFECTS OF TONE AND INTER-STIMULUS-INTERVAL DURATION ON THE ACOUSTIC REFLEX THRESHOLDS OF NORMALLY HEARING AND HEARING-IMPAIRED SUBJECTS

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ABSTRACT

This study investigated the effects of the duration of the inter-stimulus-interval (ISI) and the tone duration on the acoustic reflex threshold (ART) of normally hearing and hearing-impaired subjects at the tone frequencies of 250, 1000, and 4000 Hz. The ART was measured for ISI durations of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms and tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms. Significant differences were found between groups of subjects, among frequencies, tone, and ISI durations. Significant interactions between factors indicated that: (1) differences between the ARTs for the normally hearing and hearing-impaired groups increased as the tone frequency increased; (2) the differences between the groups' ARTs increased as the ISI duration decreased; (3) the ARTs for the 4000-Hz tones decreased more sharply than for either the 250 or 1000-Hz tones as the tone duration increased; (5) the ARTs decreased more as the tone duration increased when the ISI duration was long than when it was short. Additional conclusions included: (1) the level at which the ART occurs increases as the hearing threshold level of the subject increases, but the ARTs for the hearing-impaired subjects tend to occur at a lower sensation level; (2) the ART does not appear to occur at either a constant loudness or sensation level across frequencies; (3) the ART does not appear to occur at either a constant loudness or sensation level across tone durations; (4) the time constants for the ART temporal integration curves are longer

than the time constants for either loudness or hearing threshold curves, and the constants increase with increasing frequency; (5) the ARTs for short duration tones with high repetition rates are lower than for long continuous tones; (6) the amount that the ART decreases as the tone duration increases from 10 to 1000 ms with a constant ISI duration of 2000 ms, or as the ISI duration decreases from 2000 to 10 ms with a constant tone duration of 10 ms is negatively correlated with hearing threshold levels.

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CHAPTER I

INTRODUCTION

In the study of temporal summation in the acoustic reflex mechanism, most investigators have taken care to insure independent effects of sequential stimuli in eliciting the reflex by using long inter-stimulus-intervals (usually 2.5 s or longer). In the last few years, however, some interest has arisen to the effects of repeated stimuli on the acoustic reflex. When the inter-stimulus-interval (ISI) is brief, the effects of successive stimulation do not appear to be independent of one another. The purposes of studies using repeated stimuli have varied. They include attempts at developing tests of differential diagnosis for hearing disorders by evaluating the effects of repeated stimuli on the dynamics of the auditory reflex (AR) and the auditory reflex threshold (ART) (e.g. Norris et al., 1974; Feldman and Katz, 1978) and evaluating the effects of the AR on the amount of temporary threshold shift (TTS) by a fatiguing stimulus (e.g. Karlovich et al., 1972, 1977; Karlovich and Wiley, 1974).

It appears from the studies of Sesterhenn and Breuninger (1976) and Feldman and Katz (1978) that the effect of repeated stimuli on the ART is different for normally hearing and hearing-impaired listeners. The ART is reduced for both groups, but the average reduction in the ART is greater for normally hearing than for hearing-impaired listeners. The absolute value of the reduction,

however, is dependent on the frequency and repetition rate of the stimulus and the hearing threshold levels (HTL) of the subject.

A. POSSIBLE EXPLANATIONS FOR REDUCED REFLEX THRESHOLDS

Loudness

Some authors, e.g. Jerger (1975) and Ross (1968), feel that the reflex threshold is loudness governed. When a critical loudness is exceeded, then the reflex is elicited. Reduced ARTs, therefore, may be explained by the effects of repeated stimuli on loudness.

Garner (1948) found several interesting effects of repetition rate and duty cycle on loudness. He found that repeated short tones can be louder than a steady state tone despite smaller energy, and stated that this phenomenon could be explained by new components introduced by the repetition of the stimulus which effectively increased the total loudness. A pure tone is represented by a single frequency component with a certain intensity. When the duration of the tone is shortened and the tone is repeated, the intensity of the main component is reduced and new components arise. The spacing of these new components is determined by the repetition rate of the stimulus. The reduction in the intensity of the main component is determined by the duty cycle of the stimulus. The loudness of the repeated stimulus will equal the sum of the loudnesses of the components if the components are widely spaced and do not mask each other. The spacing of the components can be increased by increasing the repetition rate. The sum of the loudnesses of these components can be greater than the loudness of a pure tone if the reduction in

the loudness of the individual components relative to the pure tone is less than the reduction of their intensities. This has been shown to be true by Stevens (1936). Stevens found that at high levels, if the intensity is decreased, loudness is not decreased proportionately, but at a slower rate.

Garner also found that at high intensities, the repeated tone with the faster repetition rate and shorter duration will be louder than the repeated tone with the slower repetition rate if the duty cycle is constant. At low intensities, the series of tone pulses with longer duration and slower repetition rate will be louder than the series with the higher repetition rate and shorter pulses. At high sound pressure levels, high repetition rates seem to hold an advantage for loudness because the components are spaced more widely and less masking occurs between components. As the level approaches hearing threshold, reduction of masking appears to have less of an effect on the loudness. The total energy within a limited range of frequencies appears to be more important in determining loudness near threshold. Therefore, slower repetition rates producing closely spaced components are louder at low sound levels. In the case of the auditory reflex, assuming loudness is a factor in eliciting the reflex, it would appear that the higher repetition rate with shorter tone duration would be most desirable for reducing the ART.

A final aspect of Garner's work indicates that the loudness of repeated tone pulses relative to the loudness of a steady-state tone is frequency dependent. Repeated tone pulses are favored in the low and high frequencies. This is because the energy in the signal is

spread toward the more sensitive mid-frequency range of hearing. However, Sesterhenn and Breuninger's (1976) data indicated an increased difference in ARTs between continuous tones and repeated tone pulses only for high frequency tones.

If lowered ARTs are related to a spread of energy over a more sensitive frequency range, the difference in ARTs for continuous tones and repeated tone pulses may not be the same for normally hearing and hearing-impaired listeners. The most sensitive frequency range for a normally hearing person is between 1000 and 4000 Hz. If some of the energy from a low frequency tone, for example, was spread into this region, then some reduction in the ART may be anticipated. Since the hearing loss of impaired listeners is often greatest above 1000 Hz, this advantage would likely be reduced.

The difference in ARTs for continuous tones and repeated tone pulses also may not be the same for normally hearing and hearing-impaired listeners since the critical bandwidth in the AR mechanism is wider for the impaired ear than for the normal ear (e.g. Schwartz and Sanders, 1976; Djupesland et al., 1975). If the spectrum of a stimulus encompasses a frequency range broader than that of the critical bandwidth of the AR mechanism then the ART would be reduced. Since the critical bandwidth is wider for the hearing-impaired person than for the normally hearing person, the reduction in the ART for the impaired listener would be expected to be less. An analogous difference between these two groups of subjects has been demonstrated when ARTs for noise and continuous tones are compared. Niemeyer and Sesterhenn (1974) were the first to show that sensorineural hearing

loss was associated with a reduced difference between ARTs for pure tones and broadband noise, and that this reduced difference was a function of the degree of hearing loss. The greater the hearing loss, the less the difference between ARTs for tones and noise. This same phenomenon has also been demonstrated by Jerger (1974, 1975). Jerger (1975) theorized that due to a widening of the critical bandwidth in the case of hearing loss broadband noise is spread across fewer critical bands, and, therefore, the loudness is reduced and the ART is increased.

Temporal Summation

In the following discussion, the authors have investigated temporal summation using two or more tones separated by quiet intervals of variable durations. In these studies the tone duration was kept constant. Therefore, as the repetition rate increased or decreased the duty cycle would increase or decrease accordingly.

Zwislocki (1960, 1969) demonstrated that hearing threshold levels for short duration stimuli could be improved relative to a single stimulus if the inter-stimulus-interval between stimuli was 200 ms or less. Garner (1947) also found that as the repetition rate was increased the hearing threshold levels of normally hearing subjects were reduced. This indicated that a stimulus does not have to be continuous in order for temporal summation to occur.

If ARTs behave in a similar manner to hearing threshold levels, then the reduced ARTs demonstrated by Feldman and Katz (1978) and Sesterhenn and Breuninger (1976) for repeated tone pulses could be

attributed at least in part to temporal summation within the aural reflex mechanism. A difference between the studies of Feldman and Katz (1978) and Garner (1947), however, is that the former study indicated that the ART of a very short duration tone (30 ms) could be equal to or lower than that of a long duration tone (500 ms) if the inter-stimulus-interval was short enough, while the results of the latter study indicated that this would not happen for hearing threshold levels.

B. AIMS OF THE PRESENT STUDY

It is the purpose of this study to provide a comprehensive examination of the effects of the inter-stimulus-interval on the ART and to show how this effect interacts with stimulus duration, frequency, and the hearing threshold levels of the subjects.

This study is important from both a theoretical and practical standpoint. Previous studies have generally opted to describe data relating to temporal integration in the acoustic reflex mechanism in terms of the slope of the ART temporal integration function or the difference in ARTs for long and short duration stimuli. In the present study, the data are used to determine the time constants of the acoustic reflex mechanism in addition to showing how the ART varies with tone durations in terms of the slopes at various portions of the function and differences in the ART for short and long duration tones. This study also shows how ART temporal integration function varies when successive stimuli are treated as independent and non-independent events by the acoustic reflex mechanism.

Previous studies have shown that when the inter-stimulus-interval is short, successive stimuli are not treated independently and the ART is reduced. Because of the small number of stimulus and inter-stimulus-interval durations used in previous studies, however, little is known about the limits of the interactive effects of stimulus and inter-stimulus-interval durations. This is important from a clinical point of view, of course, when brief tone audiometry is used as a diagnostic tool with the ART being the criterion measure.

The data collected in this study also led to a discussion of other topics of interest. The relationship between the ART and loudness or intensity is not clear since reports in the literature have been conflicting. By comparing stimulus and inter-stimulus-interval effects on loudness, hearing threshold and the ART, further information has been gained. Another point of interest on which this study has been able to provide some information is the effect of the AR on TTS. Previous research has shown that the amount of TTS caused by a fatiguing stimulus is affected by the repetition rate of a separate stimulus controlling the AR. The data collected in the present study allow us to see if the reduction in TTS could be caused by a reduction of the ART by the repeated stimulus. A final point for which we have found an application for our data is the relationship between ARTs for stimuli with various temporal parameters and hearing loss. Previous studies have concentrated on comparing ARTs for stimuli with different spectrums in order to estimate the degree of hearing loss. The present study addresses itself to the possibility of comparing stimuli with different on- or off-times for the same purpose.

In the present study ARTs for repeated tone pulses are studied as a function of stimulus parameters (stimulus duration, inter-stimulus-interval duration, and frequency) and the hearing status of the subject (normal or impaired). The following null hypotheses are made:

1. There is no significant difference between the ARTs of normally hearing and hearing-impaired subjects.
2. There is no significant difference between ARTs as a function of the stimulus duration.
3. There is no significant difference in the ARTS as a function of the inter-stimulus-interval duration.
4. There is no significant difference in the ARTS as a function of the tone frequency.

In addition to the main effects expressed by the above null hypotheses, the significance of all possible interactions between factors are also investigated.

CHAPTER II

REVIEW OF LITERATURE

In this chapter the main focus will be on reviewing studies which deal with certain temporal aspects of the acoustic reflex. Included in the discussion will be the effects of stimulus and inter-stimulus-interval duration on the ART, adaptation and recovery of the AR, response latency and relaxation times of the AR. In addition, the effects of stimulus spectrum and intensity will be reviewed. Finally, the various means of estimating the degree of hearing loss by examining acoustic reflex responses will be summarized. The discussion is restricted, for the most part, to data collected on humans.

A. EFFECTS OF STIMULUS DURATION ON THE ART

Normally Hearing Subjects

Studies using pure tone stimuli. Djupesland and Zwislocki (1971) measured the sensitivity of the acoustic reflex as a function of the stimulus duration in six normally hearing subjects. The reflex was excited by a 2000-Hz tone burst which varied in duration from 5 to 3000 ms. The bursts were repeated every five seconds to avoid interactions between responses. The intensity of the signal was adjusted to satisfy one of three criteria: reflex threshold, 20%, and 50% of the maximum response. No values were given for the maximum response. The results indicated that the duration of the tone bursts had a pronounced effect on the stapedius

response. For each tone duration used, the difference in sound pressure level needed to reach each of the criterion responses remained approximately equal. The sound pressure level of the tones could be lowered about 25-30 dB as the tone duration was increased from 10 to 1000 ms while retaining the same criterion response. The majority of this increase (about 22 dB) occurred between tone durations of 10 and 100 ms. The level difference between the 10 and 1000 ms tones is about 2.5 times as much as would be required for constant loudness. This would indicate that the acoustic reflex is not elicited at a critical loudness as some authors have theorized (e.g. Ross, 1968). The results of Djupesland and Zwislocki provided some information on the locus of the auditory temporal summation. The authors stated that reflex contractions of the stapedius muscle are produced by neural activity in the superior olivary complex. Therefore, the contractions should reflect the temporal auditory summation only if the summation occurs at or below the level of the superior olive. The results indicated that the time constant of integration for the AR mechanism is about 200 ms, the same as for integration at the threshold of audibility (Zwislocki, 1960). It was concluded from this information that the locus of the auditory temporal summation must be located in the reflex arc.

Barry and Resnick (1976) obtained temporal integration functions for the acoustic reflex and behavioral responses for six normally hearing adults. The stimuli were tones with frequencies of 500, 1000, 2000, and 4000 Hz. The durations of the stimuli ranged from 10 to 1000 ms. Their results indicated that the decrease in the

threshold for the acoustic reflex as the stimulus duration increased corresponded closely to the decrease in hearing threshold levels at all the stimulus frequencies with the exception of 4000 Hz. At 500, 1000, and 2000 Hz there was a total decrease of approximately 12 dB in both the ARTs and hearing threshold levels as the tones increased in duration from 10 to 1000 ms. The slopes of the ART functions at short tone durations were only 10-15 dB/decade compared to 22 dB/decade reported by Djupesland and Zwislocki (1971). At 4000 Hz, ARTs decreased approximately 25 dB and hearing threshold levels approximately 10 dB as the tones increased in duration from 10 to 1000 ms. No time constants of integration were given.

Richards (1975) collected ART data on 10 normally hearing adults. Tone bursts with frequencies of 500, 1000, 2000, and 4000 Hz were presented with durations ranging between 20 and 200 ms. In general, the effect of shortening the duration was to raise the ART. This relation, however, was frequency dependent. As the stimulus duration decreased from 200 to 20 ms, ARTs were raised 12-13 dB at 500 and 1000 Hz, 17 dB at 2000Hz, and 23 dB at 4000 Hz. No time constants of integration were given.

Studies using noise stimuli. Djupesland et al. (1973) investigated temporal summation in the acoustic reflex mechanism using noise bursts as stimuli. Broadband noise and octave bands of noise with center frequencies of 250, 500, 1000, 2000, and 4000 Hz were used. The duration of the stimuli varied from 5 to 3000 ms. Five subjects with normal hearing were tested. The intensity of the

stimuli was adjusted until the criterion of 50% of the maximum impedance change was obtained. The relationship between intensity and duration was most similar among subjects and noise bands below a certain duration. The slope of the function below this cut-off point was approximately -22 dB per tenfold increase in duration. For longer durations, the slope of the function depended on the center frequency of the noise band. These later slopes in dB per decade were -2.1 dB at 250 Hz, -4.4 dB at 500 Hz, -7.6 dB at 1000 Hz, 0.0 at 2000 Hz, -9.3 dB at 4000 Hz, and -6.3 dB for the broadband noise. The data from this study are shown in Figure 1. It was noted in this study that the slope of the temporal summation function changes abruptly forming a "knee." This knee point varied with the center frequency of the stimulus. For noise bursts with center frequencies at or below 1000 Hz, the knee was at 50-80 ms. For white noise and for noise bands with center frequencies of 2000 and 4000 Hz, the knee was at 500-600 ms. The authors related this abrupt change in slope to changes in the stimulation of the inner ear caused by the muscle reflex itself. The latency between the onset of the stimulus and the reflex is in the range of 50 to 150 ms. When the reflex is activated, it has the effect of reducing the input to the inner ear, especially in the lower frequencies. The authors felt that this reduced input was the cause of the change in slope in the low frequencies at a duration corresponding to the onset of the reflex.

Richards and Goodman (1977) using half-octave bands of noise obtained ARTs for 10 young adults with normal hearing. The bands of noise had center frequencies of 500, 1000, 2000, and 4000 Hz.

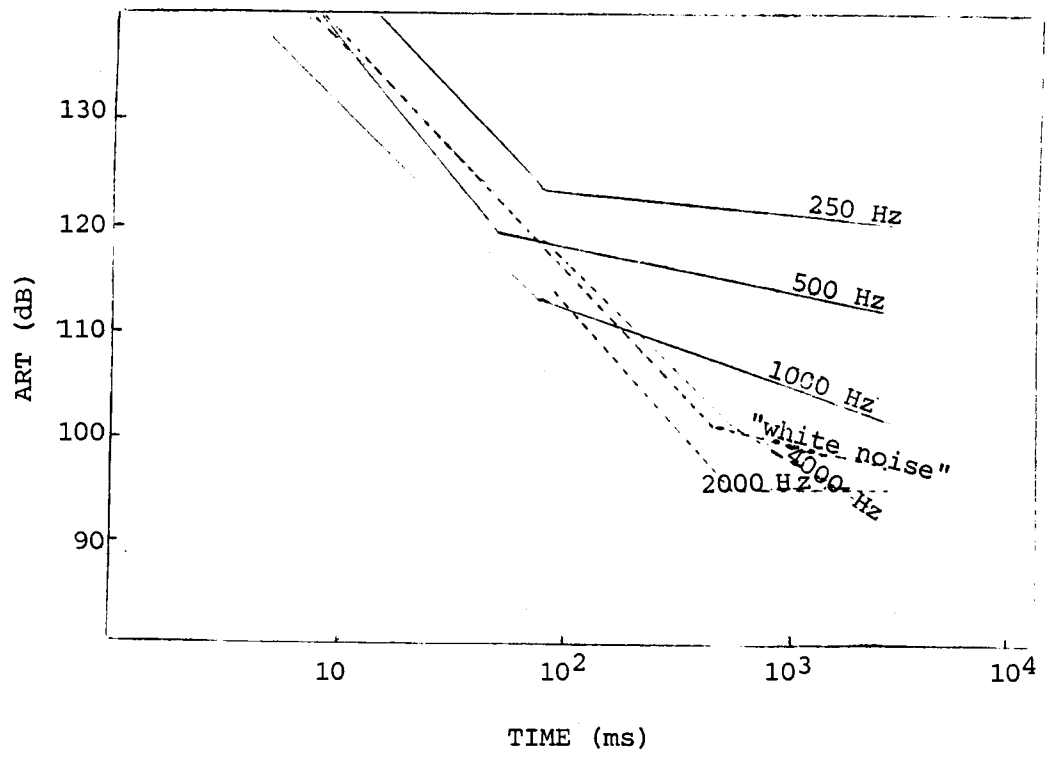

Figure 1. Data of Djupeland et al. (1973) on the relation between stimulus duration and acoustic reflex thresholds. The stimuli were octave bands of noise with center frequencies of 250, 500, 1000, 2000, and 4000 Hz. Threshold was defined as 50% of the maximum impedance change.

Broadband noise was also used as a stimulus. The durations of the stimuli were varied between 20 and 640 ms. The decrease in the ART due to increased stimulus duration was found to be dependent on the center frequency of the noise band. The ARTs for the 20- and 640-ms stimuli, respectively, were 107 and 92.5 dB when the center frequency was 500 Hz, 103.5 and 87.0 dB when the center frequency was 1000 Hz, 107.5 and 86.0 dB when the center frequency was 2000 Hz, 112.0 and 87.5 dB when the center frequency was 4000 Hz, and 109.0 and 80.0 dB when the stimulus was white noise. It was also noted in this study that ART temporal integration functions had steeper slopes than temporal integration functions obtained at hearing threshold.

Studies using both pure tone and noise stimuli. Jerger et al. (1977) obtained temporal integration functions using the ART as a criterion response. Ten normally hearing subjects participated in the study. The duration of the stimuli was varied from 10 to 500 ms. Pure tones with frequencies of 500, 1000, 3000, and 4000 Hz were used in addition to broadband and filtered noise. The filtered noise bands were centered at 1000 Hz and had high-low cut off frequencies of 950-1050, 800-1200, 600-1400, 400-2000, 200-3400, and 100-6000 Hz. The results indicated that for pure tones with frequencies of 1000 Hz and below, the trading relation between the ART and duration was approximately 10 dB/decade. For higher frequencies and broadband noise, the trading relationship was more than 20 dB per tenfold change in duration. This would indicate that ART temporal integration functions and hearing threshold temporal

integration functions are quite similar for frequencies below 1000 Hz, but the slopes for ARTs were significantly greater at high frequencies. It was also demonstrated in this study that the slope of the temporal integration function for the ARTs is affected by the bandwidth of the noise band. As the bandwidth of the band-pass filter became wider, the slope of the function became steeper. When the cut-off frequencies were 950 and 1050 Hz, the slope was 11 dB/decade. This was approximately equal to the slope of the ART temporal integration function for a 1000-Hz pure tone. When the cut-off frequencies were 100 and 6000 Hz, the slope of the function increased to 17 dB/decade. ART temporal integration functions for white noise had slopes of 20 dB/decade.

Morgan et al. (1977) measured the temporal integration characteristics of the AR at threshold and at supra-threshold levels. Functions were obtained for three subjects. Tones with frequencies between 250 and 4000 Hz and a broadband noise were used at stimuli. Durations of 25, 50, 100, 250, 500, and 1000 ms were used to elicit the reflex. Morgan et al. reported that the slope of the temporal integration functions for the ART increased as the frequency of the stimulus increased. They stated that as the duration of the stimulus increased from 25 to 250 ms the ART decreased 13 dB at 4000 Hz, 7 to 8 dB at 500 Hz, 1000 Hz and 2000 Hz, and 4 dB at 250 Hz. These results indicate that the slope of the ART temporal integration functions are less than has generally been reported in the literature. The authors attributed this to the "reduced noise floor" of the Madson ZO-70 Meter, which they used, relative to other systems.

Comparing results with the Madson ZO-70 Meter and the Zwislocki Bridge (model 3) for 2000 Hz and broadband noise stimuli, the authors found a greater difference between 25- and 250-ms stimuli with the Zwislocki Bridge (25 dB) than with the Madson (6-7 dB). The authors stated that the background-noise level does not permit measurement of impedance changes at threshold levels with the Zwislocki Bridge. This argument is not in agreement, however, with Woodford et al. (1975) or Jerger et al. (1977). Woodford et al. used the same instrumentation, but found no significant difference between thresholds for a 500-ms 1000-Hz tone. Jerger et al. used the Madson ZO-70 Meter and a signal averaging technique to further improve the signal-to-noise ratio. Jerger et al. found the slopes of the ART temporal integration curves to be 10 dB/decade or more (previously described in this chapter). When Morgan et al. defined threshold as 20% of the maximum impedance change, the results with the Madson and Zwislocki instruments were equivalent. When the duration of the noise or the 2000 Hz tone was increased from 25 to 250 ms, the SPL could be reduced approximately 29 dB while still meeting the criterion. This would indicate that the definition of threshold can have a large effect on the slope of the temporal integration curve for the ART if the Madson unit is used, but only a small effect if the Zwislocki unit is used. This latter finding is in agreement with Djupesland and Zwislocki (1971) who found temporal integration curves at the minimum detectable impedance change, 20, and 50% of maximum impedance change to be approximately parallel.

Hearing-Impaired Subjects

Woodford et al. (1975) obtained ART temporal integration functions for 10 normally hearing subjects and 6 sensorineural hearing-impaired subjects. The tone stimuli had durations ranging from 10 to 500 ms and frequencies of 500, 1000, 2000, 3000, and 4000 Hz. The results of the study were compared to those of Wright (1972) who obtained detection threshold temporal integration functions for the same frequencies. The temporal integration functions for the reflex were found to be considerably steeper than for those measured by Wright. The data of Wright indicated that the difference in hearing threshold levels between stimuli with 10- and 500-ms durations was 15 dB when averaged across frequencies with the 500-ms stimulus having the lower threshold. The data of Woodford et al. indicated greater differences for the ART, and also that these differences were frequency dependent. The difference in ARTs for the 10- and 500-ms tone durations was 20 dB at 500 Hz. The difference increased as the frequency of the tone increased. At 4000 Hz, the difference was 30 dB with the 500-ms tone having the lower ART. When Woodford et al. plotted separate ART temporal integration curves for normally hearing male subjects and normally hearing female subjects, the ART temporal integration curves were found to be constantly flatter for the normally hearing male subjects than for the normally hearing female subjects at the tone frequencies of 2000, 3000, and 4000 Hz. Many of the male subjects, although not demonstrating any permanent hearing loss, did have histories of exposure to high level noise. The history of the normally hearing

female subjects indicated no exposure to high level noise. It is known that considerable damage to the cochlea can occur without concomitant loss of hearing sensitivity (Henderson et al., 1972; Weaver, 1945). Hearing loss due to cochlea pathology has been shown to be associated with flatter threshold temporal integration functions (e.g., Sanders and Hong, 1967; Harris et al., 1958). The sex difference may, therefore, be due to a history of noise exposure resulting in a subsequent sub-clinical cochlea pathology in many of the male subjects.

Stelmachowicz and Seewald (1977) obtained ART temporal integration functions on 20 normally hearing and 20 cochlear-impaired subjects. Tones with frequencies of 500, 1000, and 2000 Hz and durations of 25 and 250 ms were used as stimuli. When the ARTs for the 25- and 250-ms tones were compared, no significant difference between the normally hearing and hearing-impaired subjects was found. At 500 Hz, the ART was 9.0 dB higher for the 25-ms tone than for the 250-ms tone for the normally hearing subjects and 11.0 dB higher for the hearing-impaired subjects. At 1000 Hz, the ARTs of both groups were 10.0 dB higher for the 25-ms tone than for the 250-ms tone. At 2000 Hz, ARTs were 11.0 and 13.0 dB higher for the 25-ms tone than for the 250-ms tone for the normally hearing and hearing-impaired subjects, respectively. Robinette (1975) also reported an inability to differentiate between normally hearing and cochlear-impaired subjects by comparing their ART temporal integration functions. Robinette attributed the overlap between normally hearing and cochlear-impaired subjects to the fact that many of the impaired

subjects had mild high frequency hearing losses. While Stelmachowicz and Seewald reported that some hearing-impaired subjects did demonstrate flattened ART integration curves, they did not state if these subjects tended to be those with the more severe hearing losses. In their discussion Stelmachowicz and Seewald reviewed a possible cause for flattened temporal integration curves obtained from auditory threshold data. Wright (1968) has suggested that in an auditory system with cochlear disturbances, there is a rapid peripheral adaptation which affects measurement of auditory thresholds as a function of duration. Wright assumes that the temporal integration mechanism is located in the central nervous system and is unaffected by damage to the cochlea. The input to the integrating mechanism, however, is affected by the damage to the cochlea, and results in the measurement of flatter temporal integration curves for the hearing-impaired subjects. Stelmachowicz and Seewald also stated that if one assumes that rapid peripheral adaptation accounts for reduced slope of the temporal integration function for cochlear-impaired systems, one could then speculate, since no difference was seen between normally hearing and hearing-impaired subjects for the ART temporal integration functions, that such adaptation does not occur at high sensation levels.

The research of Blegvad and Josephsen (1972) would indicate, however, that adaptation capable of reducing the slope of the temporal integration function can occur. These authors obtained hearing threshold temporal integration functions for 30 normally hearing subjects using pure tones with frequencies of 500, 1000, and

4000 Hz with durations ranging from 10 to 500 ms. They found that by introducing a continuous adapting noise into the contralateral ear, temporal integration functions typical of cochlear impairment could be simulated.

The research of Woodford et al. (1973) also indicates that the slope of the ART temporal integration function can be reduced by introducing an injury to the peripheral hearing mechanism. These authors found that controlled cochlear lesions, with histological verification, caused a flattening of the ART temporal integration function of the chinchilla.

B. EFFECTS OF STIMULUS ON- AND OFF-TIME ON THE ACOUSTIC REFLEX

Effects at the Acoustic Reflex Threshold

Normally hearing subjects. Sesterhenn and Breuninger (1976) found that ARTs could be lowered if the tones were presented in an interrupted rather than a continuous manner. Ten subjects were presented continuous tones and tone bursts repeated 10 times per second with a duty cycle of 75%, and ARTs were measured. The tones had frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Compared to ARTs for continuous tones, the ARTs for the repeated tone bursts were lower. Greater differences in the ARTs for continuous tones and repeated tone bursts occurred at the higher frequencies (26 dB at 8000 Hz) and smaller ART differences at the lower frequencies (5.5 dB at 500 Hz). Variability between subjects was noted, and some differences

between ARTs for continuous tones and repeated tone bursts as large as 50 dB were reported.

Jerger et al. (1977) presented tone bursts with durations of 20 ms and 500 ms with a frequency of 1000 Hz to normally hearing subjects. The off-time was varied between 750 and 5000 ms. There appeared to be no change in ARTs over this range of off-times.

Hearing-impaired subjects. Feldman and Katz (1978) studied the interaction between stimulus on- and off-times in 10 normally hearing and 10 sensorineural hearing-impaired subjects. Auditory and AR thresholds were obtained for a 1000-Hz stimulus with on-off times of 500-500 ms and 30-30 ms. The results indicated that for the normally hearing group, the average HTL was 4.7 dB higher for the 30-30 ms condition than for the 500-500 ms condition. The average ART for the 30-30 ms condition was 0.9 dB higher than for the 500-500 ms condition. For the hearing-impaired group, the average HTL was 4.0 dB greater for the 30-30 ms condition than for the 500-500 ms condition. The average ART was 0.1 dB lower for the 30-30 ms condition than for the 500-500 ms condition. Apparently the short off-time negates the elevating effect of a short stimulus duration on the ART, and results in an ART similar to that expected with much longer stimulus durations. The stimuli with short off-times behave more like a longer continuous tone for both normally hearing and hearing-impaired ears for the acoustic reflex.

Effects of On- and Off-Times above the ART

Wiley and Karlovich (1978) investigated acoustic reflex dynamics using pulsed broadband noise as the activating signal. Ten normally hearing adults served as subjects. Variations of the acoustic impedance were measured with the independent variable being the duty cycle of the signal (25, 50, and 75%). One complete cycle lasted 1, 2, 4, or 8 s. The repeated noise pulses were presented over a 120-s period. The AR followed the presentation of the noise. Each time the noise was on, the acoustic impedance increased, and each time the noise was turned off, the acoustic impedance would decrease. For each cycle, the authors recorded the highest acoustic impedance and the lowest. For example, if one cycle lasted 1 s, then there would be 120 presentations of the noise and 120 highs recorded. The noise would also be turned off 120 times and 120 lows would be measured. The major findings of the study regarding pulsed reflex dynamics were (1) that the low values of acoustic impedance increased as a function of time (0 to 120 s) for all three duty cycles, and (2) that high values of acoustic impedance increased as a function of time for the 50% and 75% duty cycles. For example, using a 75% duty cycle the first low measured was approximately 2040 ohms. The impedance of successive lows then increased until 120 s later the impedance was approximately 2160 ohms. For the 25% and 50% duty cycles the lows increased 50 and 70 ohms, respectively. For the 25, 50, and 75% duty cycles, the highs increased approximately 30, 70, and 80 ohms, respectively. A sustained tone decreased approximately 20 ohms over the 120-s period. The authors stated that the increase

in acoustic impedance over time during the off portion of the pulsed activators was probably due to the relaxation characteristics of the stapedius muscle. Specifically, the stapedius apparently did not fully relax between pulses. This effect became more pronounced with repeated presentations. This characteristic of the stapedius muscle was also used to explain an increase in the lows as the duty cycle was increased from 25 to 75%.

C. RESPONSE LATENCY AND RELAXATION OF THE AURAL REFLEX

The stapedius muscle does not begin to contract at the onset of the stimulus, instead there is a certain amount of "dead time" (a period of inactivity between stimulus and reflex onsets) which is referred to as the response latency. Again when the stimulus is terminated, the stapedius muscle does not respond instantaneously, but a certain amount of time is needed for relaxation to occur. Relaxation is seen as a reduction in the impedance change which is caused by the stimulus being turned off. It should not be confused with reflex decay or adaptation which is a reduction in the impedance change caused by the reflex while the stimulus is on going.

Normally Hearing Subjects

Dallos (1964) investigated the transitions between relaxed and active states of the acoustic reflex. Responses were recorded for six normally hearing subjects. The stimulus was a noise whose bandwidth extended from 90 to 2800 Hz. The duration of the stimulus was not specified, but appeared to be approximately 9 s from the

recordings shown. The results indicated that the onset of the response was much more rapid than the offset of the response. For the onset, the higher the stimulus intensity, the more rapid the response. The trend at the cessation was not uniform among the subjects, and no clear cut correspondence was seen between the response speed and the initial state of the reflex arc, that is, the extent of muscle contraction from which relaxation is accomplished. Complete relaxation generally took more than 1 s. The response latency, the time between tone onset and the reflex response, had a definite inverse relationship with stimulus intensity. The range of latencies was between 40 and 100 ms. The range of latencies at the offset of the stimulus was much larger. The impedance started to drop 20 to 400 ms after the offset of the stimulus depending on the subject. There was no apparent relationship with the intensity of the stimulus.

Hung and Dallos (1972) investigated reflex latencies in four normally hearing subjects. Wide-band noise and pure tones whose frequencies ranged from 200-2000 Hz were used as stimuli. Their results indicated an asymmetry between the latencies at the onset and offset of the stimulus. The speed of the on-response was faster than the off-response especially at high intensities. At intensities near threshold, the off-response was sometimes faster than the on-response. This was due to the fact that the on-response became faster as the intensity of the stimulus was increased. For the frequencies between 400 and 800 Hz, the response overshoots. It was for these frequencies that the on-responses were fastest. The reflex

at these frequencies began 20-50 ms after the onset of the stimulus and reached 100% of steady-state response by 100-150 ms after the onset of the stimulus. The responses were slowest for tone frequencies below 300 Hz, with 100% of the steady state response not being reached until approximately 500 ms after the onset of the stimulus. The on-responses for the frequencies between 1000 and 1500 Hz and noise were in the middle with 100% of the steady state response being reached between 150 and 400 ms. The results for frequencies above 1500 Hz were not reported. The off-response appeared to be dependent on neither the SPL (85-120 dB) nor frequency (200-2000 Hz) of the stimulus.

Hearing-Impaired Subjects

Norris et al. (1976) measured the times of the on-responses and the off-responses of the acoustic reflex using 23 normally hearing subjects and 23 sensorineural hearing-impaired subjects. Measurements were made 10 dB above the ART using a 1000-Hz tone with a duration of 250 ms. All measurements indicated a difference between the normal and pathological ear. The greatest differences between groups were found for the off-responses rather than the on-responses. The latency between tone onset and response onset was 129.1 and 136.5 ms for the normally hearing and hearing-impaired groups, respectively. This was slightly longer than reported by Dallos (1964) for normally hearing subjects. The time between the onset of the response and the maximum impedance change was 245.2 and 294.3 ms for the normally hearing and hearing-impaired groups,

respectively. The time between the maximum response and the return to 95% of baseline (reduction caused by the termination of the stimulus) was 282.2 ms for the normally hearing group and 595.2 ms for the hearing-impaired group. The time between the offset of the tone and return to 95% of baseline was 395.2 ms for the normally hearing group and 753.9 ms for the hearing-impaired group. No correlation was found between the degree of hearing loss and latency values within the sensorineural group. Since no subjects in the hearing-impaired group showed signs of retrocochlear hearing loss, the differences between the groups were assumed to have cochlear origins. The authors suggested that cochlear-impaired ears show a delay in the neural response to the cessation of a stimulus. Because the subjects had severe hearing losses and were selected from a population where it is likely that they may have had congenital hearing loss, some retrocochlear involvement was possible.

D. EFFECTS OF THE STIMULUS SPECTRUM ON THE AURAL REFLEX

Normally Hearing Subjects

Effects of two-tone frequency separation. Djupesland and Zwislocki (1973) measured the critical bandwidth of the AR mechanism using six subjects with normal hearing. ARTs were measured using two-tone complexes. The difference in frequency between the tones was variable. The complexes had center frequencies of 300, 1000, and 3000 Hz. The results indicated that a sharp transition occurs in the level of the ART at a bandwidth of 300 Hz for a center frequency of

300 Hz, at 1000 Hz for a center frequency of 1000 Hz and at 3000 Hz for a center frequency of 3000 Hz. When the separation between the tones of the complex was less than the values stated above, ARTs for the two-tone complexes were 3-6 dB below the ART for a single tone. At large frequency separations in the two-tone complexes, a single tone had to be approximately 10 dB more intense than each component in the complex for an equal response to occur. The authors stated that the results were in some ways similar and some ways dissimilar to the results of psycho-acoustic studies which have examined critical bandwidth. Summation of sound components outside the AR critical band affect the muscle reflex about the same amount as it affects loudness. The critical band which manifests itself in the AR is much larger, however, than the critical band for loudness. According to this study, it is three to six times larger, with the difference increasing as the center frequency increases.

Similarly, using two-tone separations Popelka et al. (1976) measured the critical bandwidth of the AR mechanism. Ten normally hearing subjects participated. Two-tone complexes with center frequencies of 250, 500, 1000, 2000, and 4000 Hz were used as stimuli. The general finding of this experiment was that ARTs decrease monotonically with increased bandwidth. The decrease was accelerated at values of bandwidth which were approximately equal to the center frequency. Studies such as Djupesland and Zwislocki (1973) have described the ART-Bandwidth function using two straight line segments. In this study, with more points in the region of the break, the data were found to be better described by a curvilinear function.

Effects of spectral density on the ART. Some studies have used tone complexes to measure the critical bandwidth of the AR mechanism. Others have used filtered noise or a combination of tone complexes and filtered noise. These different types of stimuli vary in their spectral density which has been shown to affect the ART by Popelka et al. (1976) in a different section of the study described previously.

Popelka et al. (1976) measured the ARTs of normally hearing subjects using stimuli with various numbers of components. Filtered Gaussian noise with a bandwidth of 3062 Hz and a logarithmic center frequency of 1000 Hz was used for a maximal spectral density condition. A two-component tone complex with a frequency separation equal to the bandwidth of the filtered Gaussian noise was used for a minimal spectral density condition. Spectral density was then varied between these two limiting cases using tone complexes with increasing numbers of components equally spaced in log frequency. The results of this study indicated that a tone complex having approximately 5 to 9 components spaced in equal musical intervals produced reflex thresholds as low as filtered Gaussian noise with a logarithmic center frequency of 1000 Hz and a bandwidth of 3062 Hz.

Measurement of the AR critical band with filtered noise. Gorga et al. (1980) investigated the effects of stimulus bandwidth on the ART. Six young adults with normal hearing participated in the study. The activating stimuli were (1) a 1000 Hz pure tone, (2) noise bands varying in bandwidth from 62 to 336 Hz linearly centered

around 1000 Hz, (3) noise bands varying in bandwidth from 420 to 1500 Hz geometrically centered around 1000 Hz, and (4) low-pass filtered noise at 8000 Hz. Each of these signals was also used for loudness measurements. The ART for the narrowest band of noise was 3.5 dB less than that of the pure tone. No further decrease in the ART was observed until the bandwidth was approximately 1000 Hz. The effect of the signal bandwidth on loudness perception was found to be similar to the effect on the ART. The loudness did not start to increase until the bandwidth reached 1000 Hz. The loudness measures were not in agreement with the findings of other studies such as Zwicker (1957) and Scharf (1959, 1976). The data of Gorga, however, would indicate that loudness and the ART are affected in a similar manner by changes in the bandwidth of the noise.

Measurements of the AR critical band with filtered noise and tone complexes. Popelka et al. (1974) obtained ARTs for normally hearing subjects in order to investigate the size of the critical band at 1000 Hz. The reflex-activating signals consisted of a 1000-Hz tone, six bands of noise centered about 1000 Hz, and broad-band noise limited by the frequency response characteristic of the ear-phone. The six bands of noise centered about 1000 Hz had bandwidths of 10, 20, 100, 300, 1155, and 2042 Hz. The signals with bandwidths of 10-300 Hz were obtained directly from a sine-random generator and were centered linearly around 1000 Hz. The signals having bandwidths of 1155 and 2042 Hz were obtained by filtering broad-band noise. These latter two bandwidths were centered logarithmically about 1000

Hz. The bandwidth of the broad-band noise was approximately 5780 Hz. The results indicated that the reflex threshold for the 1000-Hz tone was about 4 dB higher than for the narrowest noise band used (10 Hz). Reflex thresholds were constant for bandwidths less than 700 Hz, and became lower for bandwidths wider than the 700-Hz "critical bandwidth."

Flottorp et al. (1971) investigated the critical bandwidth of the acoustic reflex mechanism in 16 normally hearing subjects. Filtered noise and four-tone complexes of variable bandwidth were used as stimuli to obtain the ARTs. The stimuli had center frequencies of 250, 500, 1000, 2000, and 4000 Hz. The results indicated a sudden decrease in the ART at a bandwidth that was approximately equal to the center frequency of the stimulus. The authors interpreted the breaking point as a demonstration of a band limited integrating mechanism in the reflex arc. Comparing the results to psychophysical experiments, the critical band was found to be wider and the change in threshold more rapid in the AR mechanism.

Hearing-Impaired Subjects

ARTs for noise stimuli. In another section of the study by Popelka et al. (1976), ARTs were measured for seven hearing-impaired subjects using filtered noise stimuli with varying bandwidths. Center frequencies of 500, 1000, 2000, and 4000 Hz were used. The results of this study indicated that the loss of hearing sensitivity in the high frequencies affects the ART for wide band stimuli. When the center frequency of the signals was remote from the region of

greatest hearing loss (4000 Hz), the ARTs became elevated as the frequency range of the noise was widened to extend into the hearing loss region. For example, there was no difference between the ARTs of normally hearing subjects and hearing-impaired subjects when the noise stimulus had a center frequency of 500 Hz and a bandwidth of 100 Hz (both approximately 90 dB), but for the same center frequency and a bandwidth of 3000 Hz the normally hearing subjects' ARTs were reduced to 80-85 dB while the hearing-impaired subjects' ARTs were raised to 90-95 dB. As the center frequency approached 4000 Hz, the ARTs were elevated even for narrow bands of noise. For a center frequency of 4000 Hz and a bandwidth of approximately 500 Hz, ARTs for normally hearing subjects were approximately 92 dB while those for hearing-impaired subjects were about 102 dB. It appears that the ART is elevated in proportion to the amount of noise energy in the spectral region corresponding to the region of impaired hearing.

The relation between pure tone and noise stimuli. Johnsen et al. (1976) obtained ARTs for subjects with various hearing threshold levels. Pure tones ranging in frequency from 500 to 2000 Hz and white noise were used as stimuli. ARTs for pure tones were largely independent of the amount of hearing loss. ARTs for hearing-impaired subjects were similar to those for normally hearing subjects when the stimuli were pure tones. ARTs for a white noise stimulus, however, appeared related to the degree of impairment. Normally hearing subjects had ARTs for white noise stimuli in the 65-75-dB SPL range while those subjects with moderate to severe hearing losses had ARTs

for white noise stimuli in the range of 80-110-dB SPL. The authors stated that since white noise delivers most of its energy to the basal part of the cochlea, high frequency hearing loss appears to be particularly important for ARTs for noise.

Critical Bandwidth for Hearing-Impaired Subjects

Djupesland et al. (1975) measured the critical bandwidth for subjects suffering from Meniere's Syndrome using the AR. The rationale for the study was to gain insight into the exact locus of the critical band mechanism. Meniere's Syndrome was chosen since the disease is located in the cochlea. If the critical band mechanism is primarily of cochlear origin, alteration of the cochlear function may be expected to affect the critical band mechanism. Both normally hearing and hearing-impaired subjects were tested. Two-tone complexes with center frequencies of 300, 1000, and 3000 Hz were used as stimuli. For normally hearing subjects, there was a sharp change in the ART when the tones of the complex were separated by 250-300 Hz for a center frequency of 300 Hz, by 1000 Hz for a center frequency of 1000 Hz, and by 3000 Hz for a center frequency of 3000 Hz. For the hearing-impaired group, no critical bands could be demonstrated for seven of the nine subjects at any of the test frequencies. For the remaining two subjects, critical bands could only be demonstrated at 1000 and 3000 Hz. The size of these bands differed from those found in the normally hearing group, being about 2000 Hz for a center frequency of 1000 Hz and 1500 Hz for a center frequency of 3000 Hz. This indicates that for two of the hearing-impaired subjects the

critical band was less wide at 3000 Hz than for the normal group. The authors interpreted their findings to indicate cochlear origin of the critical band mechanism.

Schwartz and Sanders (1976) measured the critical bandwidth for both normally hearing and hearing-impaired subjects at 1000 and 2000 Hz using ARTs. Complexes of two tones with variable frequency separation were used as stimuli. The median critical bandwidth was clearly greater for the hearing-impaired subjects than for the normally hearing subjects. For normally hearing subjects, the range of the measured critical bandwidth at 1000 Hz was 450-1030 Hz with a median value of 865 Hz. At 2000 Hz, the range was 1025-2165 Hz with a median value of 1650 Hz. For hearing-impaired subjects, the range of the measured critical bandwidths at 1000 Hz was 1025-2165 Hz with a median value of 1135 Hz. At 2000 Hz, the range was 1150-3150 Hz with a median value of 2430 Hz. When the hearing-impaired group was divided according to severity of hearing loss (mild-to-moderate and severe), a tendency for greater widening of the critical bandwidth with increased hearing loss was evident especially at 1000 Hz. The median value of the critical bandwidth measured at 1000 Hz was 1000 Hz for subjects with mild-to-moderate hearing loss and 1205 Hz for those with severe hearing loss. At 2000 Hz these values were 2365 Hz for the mild-to-moderate group and 2572 Hz for the severe group. The difference between groups was not significant at 2000 Hz. The reason for this study was to see if widening of the critical bandwidth for hearing-impaired subjects could explain the results of tests which try to predict degrees of hearing loss by comparing ARTs

for tones and noise. Jerger (1975) theorized that the difference between ARTs for tones and noise is reduced in cases of hearing loss relative to normal hearing because of a widening of the critical bandwidth which tends to reduce the loudness of the noise and raise the ART for noise. Schwartz and Sanders made predictions of hearing loss for each subject using Jerger's method. At 2000 Hz, there was no significant difference in the critical bandwidth between those predicted to have mild-to-moderate hearing loss and those predicted to have severe hearing loss. At 1000 Hz, there was a significant difference, but not in the expected direction. Those predicted to have milder hearing loss had wider critical bandwidths. It was concluded, therefore, that results of Jerger's test for predicting hearing loss could not be explained by the widening of critical bands in the case of hearing loss.

E. CALCULATING HEARING LOSS FROM ACOUSTIC REFLEX THRESHOLDS

An investigation by Niemeyer and Sesterhenn (1974) dealt with the relation between ARTs for pure tones and noise. Both normally hearing and hearing-impaired subjects were tested. ARTs were obtained using pure tones with frequencies of 500, 1000, 2000, and 4000 Hz. These four ARTs were then averaged. An ART was also obtained for a white noise stimulus. Hearing threshold levels were then obtained for pure tones with frequencies of 500, 1000, 2000, and 4000 Hz, and the four data points were averaged. The difference between the white noise ART and the average ART for pure tones was found to be correlated with the difference between the average ART for pure

tones and the average HTL for pure tones (the sensation level at which the ART occurs). This correlation was positive. If the difference between the averages of the hearing threshold levels and pure-tone ARTs was large, then the difference between the average of the ARTs for pure-tones and the ART for the noise stimulus would also be large. It was found possible to calculate the average of the hearing threshold levels by subtracting from the average of the ARTs for tones, 2.5 times the ART for noise. For 73% of the cases, the average hearing threshold level was predicted within 10 dB; 17% within 15 dB, and 10% within 20 dB. In the case of sloping audiograms, the results became less exact. The investigators, therefore, studied the difference between the average ART for tones and the ARTs for low and high pass noise. What the authors referred to as low-pass noise was actually a mixture of 12 pure tones ranging in frequency from 100 to 1600 Hz. The high pass noise was 12 pure tones ranging in frequency from 1800 to 13500 Hz. For normally hearing subjects, these differences were approximately 15 dB for the low-pass condition and 20 dB for the high-pass condition. For subjects with sloping audiograms, the difference between the ARTs for high-pass noise and the average ART for tones was equal to or less than the difference between the average ART for tones and the ART for low-pass noise. This information could, therefore, be used to predict sloping or flat audiograms.

Jerger et al. (1974) described two methods where ARTs for pure tones and white noise were used to predict the severity of hearing loss. The first method was referred to as the weighted formula. In this method the ARTs for tones of 500, 1000, and 2000 Hz were not of

equal importance in calculating the value to determine degree of hearing loss. Jerger (1975) recommended that the weighted formula should be abandoned in favor of an unweighted formula. In only 4% of the cases, using the unweighted formula, was there a serious error in prediction. The unweighted formula is as follows:

$$D = PT\ AR - WN\ AR + C$$

where PT AR is the sum of the pure tone ARTs at 500, 1000, and 2000 Hz divided by 3. All these values are in HTL. WN AR is the white noise ART in SPL. C is the biological calibration correction of 25 dB - (PT AR - WN AR) obtained on 10 normal subjects. The value of D is used to predict the degree of hearing loss. If the value is 20 dB or greater, the person is assumed to have normal hearing. As the value becomes less, hearing loss is classified as mild to moderate, severe or profound. Jerger's theory of why there is a smaller difference between ARTs for tones and noise for the sensorineural hearing-impaired ears than for normal ears was based on loudness summation. He states that the abnormal widening of the critical bands for the AR in cases of hearing loss plus the loss of high frequency sensitivity would have a greater effect on the total loudness of a broad-band noise than a tone. It is assumed in this theory that the ART is reached when any signal exceeds a critical loudness. The theory states that due to the widening of the critical bands, the noise is spread across fewer bands and loudness summation is reduced. In addition, the sloping frequency response typically seen in sensorineural hearing loss attenuates the relative loudness contribution of the critical bands in the high frequency region.

Jerger (1975) also demonstrated that the difference between ARTs for high- and low-pass noise could be used effectively to predict the slope of audiograms. A 2600 Hz cut-off frequency was used for both the high-pass and low-pass noise. If the ART for the high-pass noise was less than, equal to, or greater than the ART for low-pass noise, the audiogram was classified as flat, gradually sloping or steeply sloping, respectively. The prediction of hearing loss was equally good for all three categories.

Another method for prediction of hearing loss has been developed by Popelka et al. (1976). This method has come to be known as the bivariate method. Test results are plotted on a graph. For each subject, the ARTs for pure tones with frequencies of 500, 1000, and 2000 Hz were averaged. The average ART for these three frequencies was the value of the y-coordinate on the graph. This value tended to be higher for hearing-impaired subjects than for normally hearing subjects. The value of the x-coordinate on the graph was the ART for wide-band noise divided by the three frequency average of the pure tone ARTs. This ratio was approximately 1.0 for the hearing-impaired subjects since their ARTs for tones and noise were approximately equal. The ratio for normally hearing subjects was less since their ARTs for noise tended to be less than their ARTs for tones. Therefore, points for the hearing-impaired subjects usually fell in the upper right hand portion of the graph and the points for the normally hearing subjects in the lower left hand portion of the graph.

Popelka and Trumpf (1976) and Margolis and Fox (1977) have shown that the bivariate method is effective when patients exhibit at least 32 dB of hearing loss in the speech frequencies. Silman and Gelfand (1979), however, have shown a large degree of overlap for the results of normally hearing subjects and hearing-impaired subjects whose hearing loss is restricted to the region above 2000 Hz.

The relative effectiveness of the four methods of predicting hearing loss which have been discussed thus far has been investigated by Keith (1977) and Margolis and Fox (1977). Keith's research indicates that the method of Niemeyer and Sesterhenn (1974) and the unweighted formula of Jerger (1975) yield comparable results and are preferable to the weighted formula of Jerger. Keith's research also indicates that the ability to predict slopes of audiograms by comparing the ARTs for high- and low-pass noise is poor. Margolis and Fox found that the bivariate method of Popelka et al. (1976) was superior to the Niemeyer-Sesterhenn and Jerger's methods in that it reduced the number of false positives while correctly identifying hearing losses in excess of 32 dB at a rate of 93%.

Sesterhenn and Breuninger (1977) have developed a method to predict hearing loss at individual frequencies. The method has been referred to as the preactivation method since a 8000-Hz tone is used to preactivate the reflex arc. This preactivating tone has the effect of reducing the ART for a second tone. To obtain reduced ARTs, first, the reflex threshold for the 8000-Hz tone is determined. The level of this tone is then adjusted so that it is as near threshold as possible without eliciting the reflex. The test tone (125-4000

Hz) is then added to the preactivating tone. The level of the 8000-Hz tone is held constant and the level of the test tone is lowered until no reflex activity can be observed. On the average, ARTs are reduced 20-30 dB with the greater reduction occurring in the lower frequencies. The difference between normal and reduced ARTs was referred to as dL2. The difference between hearing threshold levels and normal ARTs was referred to as dL1. The authors stated that dL1 could be computed from the following equation:

$$dL1=k \cdot dL2$$

Since dL2 varied with the frequency of the test tone, the value of k varied with the test frequency. The authors considered the threshold determinations to be satisfactory. However, deviations up to 30 dB were noted in some cases.

Norris et al. (1974) developed a method to determine the presence or absence of hearing loss at individual frequencies. The method is called the reflex relaxation index (RRI). Norris et al. obtained RRIs for both normally hearing and hearing-impaired individuals at 500, 1000, and 2000 Hz. The first step in this procedure is to record the AR elicited by a pulsed tone 20 dB above the ART. The tone is pulsed at a rate of 2.5/sec and has a 50% duty cycle. The recording of the AR for such a stimulus shows maxima during the stimulus on-time and minima during the stimulus off-time when the stapedius muscle relaxes. The height of the maxima and the difference between the height of the minima and maxima (the excursion width) are then measured. If the excursion width is 30% or more of the height of the maxima, normal hearing is indicated, and if it is

less than 30%, hearing loss is indicated. Using this criterion, normal hearing was differentiated from impairment 85-90% of the time, depending on the stimulus frequency. It should be noted, however, that the average hearing threshold levels of the hearing-impaired group were very high (61.3 dB at 500 Hz, 67.8 dB at 1000 Hz, and 72.2 dB at 2000 Hz). It is likely that more errors would occur as the hearing threshold levels of the impaired subjects approached normal.

F. GROWTH OF THE AURAL REFLEX AS A FUNCTION OF INTENSITY

Normally Hearing Subjects

Gelfand et al. (1981) obtained acoustic reflex growth functions for four normally hearing adult subjects. Stimulus frequencies of 500, 1000, and 2000 Hz, and stimulus durations of 20, 200, and 1000 ms were used. The purpose of the study was to investigate interactions among duration, frequency, and intensity affecting the growth of the aural reflex. The findings of this study were (1) temporal summation functions obtained at levels above the ART are steeper than temporal summation functions obtained at the ART. This effect was small at 500 Hz, but increased at 1000 and 2000 Hz. (2) When the impedance change due to the acoustic reflex is plotted as a function of the sensation level (re ART) the slope of the function is steeper when the stimuli are long (1000 ms) than when they are short (20 ms).

Wilson and McBride (1978) obtained acoustic reflex growth functions on eight adults with normal hearing. The reflex-eliciting

stimuli consisted of pure tones with frequencies of 250, 500, 1000, 2000, and 4000 Hz, and broadband noise. Two results of this study not directly related to reflex growth, but which have some bearing on the procedures of the present study, were (1) reflex thresholds were 3.5 dB lower when a 660-Hz probe tone was used than when a 220-Hz probe tone was used; (2) there was no difference between thresholds when the criterion for the ART involved a change in conductance or when it involved a change in susceptance. Further results of this study were (1) the impedance change caused by the reflex increases with stimulus intensity increments at least to levels of 116-dB SPL, which was the limit of the study, except with the 4000-Hz activator; (2) broadband noise and 1000-Hz stimuli produce the largest reflex magnitudes while 250-Hz stimuli produce the smallest; (3) the slopes for the pure tone functions were steeper than those for broadband noise; (4) at 116-dB SPL, only 4000 Hz attains saturation, and the slope analysis indicates that the higher the stimulus frequency, the lower the sound pressure level at which saturation of the growth function occurs. The authors stated that this last finding was consistent with Tietze's (1969) model of reflex adaptation, which postulated that reflex adaptation is initiated with signal onset and that the rate of adaptation is faster as the stimulus frequency is increased.

Djupesland et al. (1967) investigated the size and duration of acoustically elicited impedance changes. The subjects for the study were young adults with normal hearing. The stimulus frequencies were 250, 1000, 2000, and 4000 Hz. The results of this study indicated

that the sound pressure level at which the ART is elicited is lowest at 250 Hz (87.3 dB), and increases slightly towards 4000 Hz (91.2 dB). The growth of the reflex above the ART was measured in 2-dB steps up to a maximum AR sensation level of 28 dB. The growth was expressed in terms of the percentage of the difference between the impedance measured at the ART and the maximum impedance. For the stimulus frequency of 250 Hz the maximum impedance was reached at a level of about 18 dB above the ART. The increase in the impedance with increased intensity of the stimulus tone at 4000 Hz was not as rapid as for 250 Hz. Even at 28 dB above the ART the increase in impedance caused by the presentation of the 4000-Hz tone was not more than 60% to 70% of the maximum increase in impedance at 250 Hz. At 1000 and 2000 Hz for equal AR sensation levels, the increases in impedance (re the impedance at the ART) were considerably greater than at 4000 Hz and only slightly smaller than at 250 Hz. Furthermore, the maximal impedance at 1000 and 2000 Hz were about the same as for 250 Hz, although they occurred at about 28 dB above ART compared to 18 dB at 250 Hz.

Hearing-Impaired Subjects

Beedle and Harford (1973) measured the acoustic reflex growth as a function of intensity for 10 normally hearing subjects and 10 subjects with cochlear hearing losses who demonstrated loudness recruitment. Functions were obtained at 500, 1000, and 2000 Hz. Acoustic reflexes were recorded graphically. The height of the reflex was measured and then converted to changes in the air volume

in a closed ear canal assumed to be due to the middle ear muscle contraction. A pen deflection of 1 mm represented a 10 mm^3 decrease in the air volume of the closed ear canal. The results indicated that the rate of growth of the acoustic reflex is more rapid for normal ears than for the hearing-impaired ears. Normal ears showed steeper slopes and this difference increased as the frequency of the stimuli increased. The change in volume as the sound level was increased from the ART to 16 dB above the ART was 20-30 mm^3 for the hearing-impaired subjects at each frequency. For the normally hearing subjects, the change was approximately 40, 50, and 60 mm^3 at 500, 1000, and 2000 Hz, respectively.

Silman et al. (1978) reported some observations in a case of acoustic neuroma. Reflex growth was measured at both ears as a function of intensity using stimuli with frequencies of 500 and 1000 Hz. The pure tone stimuli were raised in 5-dB steps above the ART. For the 1000-Hz stimuli, normal growth was observed at both ears. Normal growth was also observed for the 500-Hz stimuli at the left ear. When the 500-Hz stimuli were directed to the right ear (the involved ear), the reflex magnitude decreased with increasing stimulus level. The right ear also demonstrated abnormal reflex decay at 500 Hz, but not at 1000 Hz. The authors speculated that the partially damaged neural population could not maintain the density of firings for more than a momentary threshold response.

G. ADAPTATION AND RECOVERY OF THE ACOUSTIC REFLEX

Reflex decay or adaptation, although it reflects a relaxation of the stapedius muscle, is different from what has been called reflex relaxation. Reflex relaxation refers to the response of the stapedius muscle to the offset of the stimulus. Reflex decay or adaptation refers to a decline in the size of the reflex while the stimulus is on. In order for the reflex to return to its original magnitude, the stimulus has to be turned off, allowing the muscle a period of rest. The time needed before a full response can again be elicited is the recovery time. This aspect of the acoustic reflex has received little attention.

Adaptation of the Acoustic Reflex

Normally hearing subjects. Givens and Seidmann (1979) measured reflex decay for 28 young adult subjects with normal hearing. The stimuli consisted of tones with frequencies of 500, 1000, 2000, and 3000 Hz which were presented for 10 s at 0, 5, 10, 15, and 20 dB re ART. Reflex decay was reported as the percent of decline in the response relative to the initial level of the response. For example, if the initial response was maintained for the full 10 s, then 0% decay would be reported. The data indicated that the median percent of adaptation declined as the AR sensation level increased. For example, given that 50% reflex decay has to be reached to be considered significant, half the ears demonstrated significant reflex decay for a 2000-Hz tone at the ART, but only 22.6% of the ears

demonstrated significant reflex decay at an AR sensation level of 20 dB. The only frequency at which the median percent of adaptation was greater than 50% at all AR sensation levels was 3000 Hz. A trend was also noticed for increasing adaptation with increasing frequency. Adaptation ranged from 16.6% at 500 Hz to 66.7% at 3000 Hz when the AR sensation level was constant at 10 dB.

Habner and Snyder (1974) measured the time needed for the reflex magnitude to decline 50% (half-life time). Sixty-eight subjects with normal hearing participated in the study. The AR was recorded 10 dB above the ART for tones with frequencies of 500, 1000, 2000, and 4000 Hz. For the vast majority of ears, the half-life time was not measured at 500 and 1000 Hz because the decay was so slow. For the ears that showed more rapid reflex decay, the half-life was still usually greater than 10 s at 500 and 1000 Hz. At 2000 and 4000 Hz, the majority of ears demonstrated a more rapid reflex decay than at the lower frequencies. The mean half-life times were 13.4 and 8.9 s at 2000 and 4000 Hz, respectively.

Adaptation of the acoustic reflex was measured by Wilson et al. (1978) using tones of 500, 1000, 2000, and 4000 Hz and broadband noise. The stimuli were presented to seven subjects with normal hearing at sound pressure levels of 96, 104, and 112 dB for 180 s. Reflex adaptation was found to be evident in all conditions. The onset time of adaptation was defined as the post-stimulus time at which the reflex response was diminished to 90% of its peak value. At 2000 and 4000 Hz, the level of the stimulus had little effect on the onset time (2-3 s for all conditions). For all other stimuli, the

adaptation onset time increased with the stimulus level. This was most evident at 500 Hz where the adaptation onset time increased from 12 to 22 s as the SPL of the tone increased from 96 to 112 dB. It was also noted that at all stimulus levels the adaptation onset time decreased with increasing frequency. At a sound pressure level of 96 dB, adaptation onset occurred at approximately 12 s for the 500 Hz tone and the broadband noise, 5 s for the 1000 Hz tone and 2 s for the 2000 and 4000 Hz tones. The half-life of the AR was also found to vary directly with the stimulus intensity and inversely with stimulus frequency. As the stimulus level increased from 96 to 112 dB, the half-life times increased from 76.6 to 145.3 s at 500 Hz, 20.8 to 55.9 s at 1000 Hz, 6.2 to 12.5 s at 2000 Hz, 3.5 to 4.2 s at 4000 Hz and 74.5 to 122.3 s for the broadband noise. It can also be seen from this same data that as the frequency of the tone increased the half-life time decreased.

Borg and Odman (1979) studied the time course of decay of the ipsilateral (measurement made at the same ear as the tone is presented) and contralateral (measurement made at the opposite ear to which the tone is presented) acoustic reflex responses. The stimulus was a 2000-Hz tone, and 10 normally hearing subjects participated. The stimulus was presented at a level at which the maximum response was obtained. The authors then measured the time it took for the response to decay to 40% of the maximum. This time was similar for the ipsilateral and contralateral reflexes, but the variability among the subjects was large. The duration of the stimulus had to be between 5 and 20 s before the reflex decayed to 40% of maximum.

Djupesland et al. (1967), previously cited in the section on the growth of the reflex, measured the duration of the impedance change elicited by pure tone stimuli. The test frequencies were 250, 1000, and 4000 Hz. A continuous stimulus was presented 10 dB above the ART, and the time needed for the reflex to decay completely was measured in seconds. A 4000-Hz stimulus tone did not maintain an impedance change for more than a short time (0-70 s). At 1000 Hz, the impedance change lasted from 22 to 137 s. At 250 Hz, the impedance change was maintained for such a long period that the test was stopped before any obvious reduction occurred.

Hearing-impaired subjects. Colletti (1974) investigated adaptation of the acoustic reflex in 24 patients with Meniere's disease. Tone stimuli with frequencies of 500 and 1000 Hz were presented 10 dB above the ART for 10 seconds. Under these conditions, if the half-life time of the response was 5 s or less, it was considered pathological. In only one of these subjects was the adaptation abnormal. This subject had an average hearing loss of 70-80 dB. This subject also had normal roentgenograms of the internal auditory meatus and a normal corneal reflex. Neither neurological nor vestibular examination provided evidence of an acoustic cerebellopontine angle tumor. The results of this subject indicate, therefore, that abnormal reflex decay which usually is indicative of retrocochlear hearing loss may be seen in subjects with severe cochlear hearing loss. The authors stated that the abnormal response could be a result of retrograde degenerative processes due

to severe damage to the hair cells of the cochlea. The results of the other 23 subjects indicate that normal reflex decay will usually be seen in subjects with cochlear hearing loss.

Recovery of the Acoustic Reflex

Borg and Odman (1979) studied recovery of the stapedial reflex from adaptation. A 2000-Hz pure tone was presented to normally hearing subjects until the reflex had decayed to 40% of its peak. The silent period needed before the response was able to return to its peak value was then measured. Both ipsilateral and contralateral responses were measured. No difference was seen between the ipsilateral and contralateral recovery patterns. On the average, recovery was complete after approximately 1.0 s, 50% recovery was seen after 250-ms pauses, and pauses less than 50 ms were followed by very little recovery. The variance of responses were large, however, with complete recovery taking 10.0 s for one subject.

H. SUMMARY

In this chapter, a number of stimulus parameters have been reviewed which affect the acoustic reflex threshold. These parameters are: (1) the stimulus duration (on-time duration), (2) the inter-stimulus-interval duration (off-time duration), and (3) the stimulus spectrum.

The results of studies on stimulus duration show that the ART increases (more than 30 dB in some studies) as the stimulus duration is decreased. The amount that the ART increases is dependent on the

frequency of the stimulus and the hearing threshold levels of the subject. The temporal integration function is flatter for low frequency stimuli than for high frequency stimuli. The function is also flatter for hearing-impaired subjects than for normally hearing subjects.

Studies on the stimulus spectrum have demonstrated that a critical bandwidth for the AR mechanism exists. This critical bandwidth for normally hearing subjects is approximately equal to the center frequency of the stimulus. Other studies have shown that the critical bandwidth is broader for hearing-impaired subjects than for normally hearing subjects and this broadening is positively correlated with hearing threshold levels.

In the study of temporal integration, researchers have usually used inter-stimulus-intervals several seconds in duration. Long ISIs are used to insure independence of stimuli effects. Their rationale for this is based on studies which have shown that the AR takes up to 3.0 s to relax after the stimulus has been turned off. Studies have shown, however, that the off-time can be as short as 750 ms with little or no effect on the ART. For short off-times (less than 75 ms), it is known that the ART for short duration stimuli (less than 30 ms) is reduced.

Past studies of the effects of the inter-stimulus-interval duration have used a small number of stimulus duration-ISI duration pairs. Therefore, little is known about the interaction between these two parameters. There is also an absence of research on how ISI effects on the ART vary with frequency and hearing threshold

levels. It was the purpose of this study, therefore, to provide a comprehensive examination of inter-stimulus-interval effects on the ART, and how they interact with stimulus duration, frequency, and the hearing threshold levels of the subjects.

It has also been shown in this chapter that all tests, with the exception of Norris et al. (1974), which try to estimate degrees of hearing loss by examining ARTs are based on comparing ARTs for stimuli varying in their frequency spectrum. In this study, the ability to predict hearing loss based on ART shifts due to stimulus or ISI duration will also be investigated.

CHAPTER III

METHODS

In the present study, ARTs were obtained on 10 normally hearing and 10 hearing-impaired subjects. The stimuli were repeated tone bursts with on-times of 10, 20, 50, 100, 200, 500, and 1000 ms in combination with off-times of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms. The tone frequencies were 250, 1000, and 4000 Hz.

A. SUBJECTS

Ten normally hearing and 10 sensorineural hearing-impaired subjects were chosen for this study. The average age of the normal group was 27 years and the average age of the hearing-impaired group was 34 years. Within both groups, all subjects were less than 50 years of age. Young subjects were sought since it has been demonstrated in studies such as Jerger et al. (1978) and Silman (1979) that aging tends to affect the level at which the ART occurs.

All normally hearing subjects had hearing threshold levels at or below 15 dB (ANSI, S3.6, 1970) at all octave frequencies between 250 and 8000 Hz. The hearing-impaired subjects had hearing threshold levels higher than 25 dB (ANSI, S3.6, 1970) at two or more of these frequencies and at one or more of the test frequencies (250, 1000, and 4000 Hz). For five of the subjects, hearing loss was apparently noise induced. Onset of hearing loss for each of these subjects was in early adulthood, and each reported a history of noise exposure.

The hearing loss of four subjects was idiopathic. Three of these subjects reported onset of hearing loss during childhood and the fourth during adulthood. The hearing loss of the last subject was congenital, and was due to an Rh incompatability. Within the hearing-impaired group both sloping and flat audiograms were represented and hearing losses ranged from mild to severe. The differences among subjects allowed comparisons to be made within the group to detect possible trends on how the degree of hearing loss or shape of the audiogram could affect the ARTs.

Since both conductive and retrocochlear hearing losses tend to greatly elevate the threshold of the acoustic reflex, all subjects had to meet the following criteria:

1. Normal middle ear compliance and pressure, bilaterally.
2. No gaps between air conduction and bone conduction thresholds greater than 5 dB.
3. Normal tone decay (Carhart, 1957).

The average thresholds for the test ears of the normally hearing and hearing-impaired group are shown in Table 1.

B. INSTRUMENTATION

The instrumentation used in this study for the generation of the stimuli (a series of tone pulses) and measurement of the ARTs are shown in Figure 2. A pure tone signal was generated by a variable frequency oscillator (Wavetek, VGC 136). The frequency of the tone was measured with an electronic frequency counter (Hewlett Packard, 5233L). The output of the oscillator was fed to an

Table 1. The average hearing threshold levels (dB) for the normally hearing and hearing-impaired groups. Thresholds were obtained at the octave frequencies between 250 and 8000 Hz.

	Frequency (Hz)					
	250	500	1000	2000	4000	8000
Normal group	5.0	4.5	5.0	5.0	8.0	7.5
Hearing-impaired	35.5	40.5	46.0	50.0	57.0	55.0

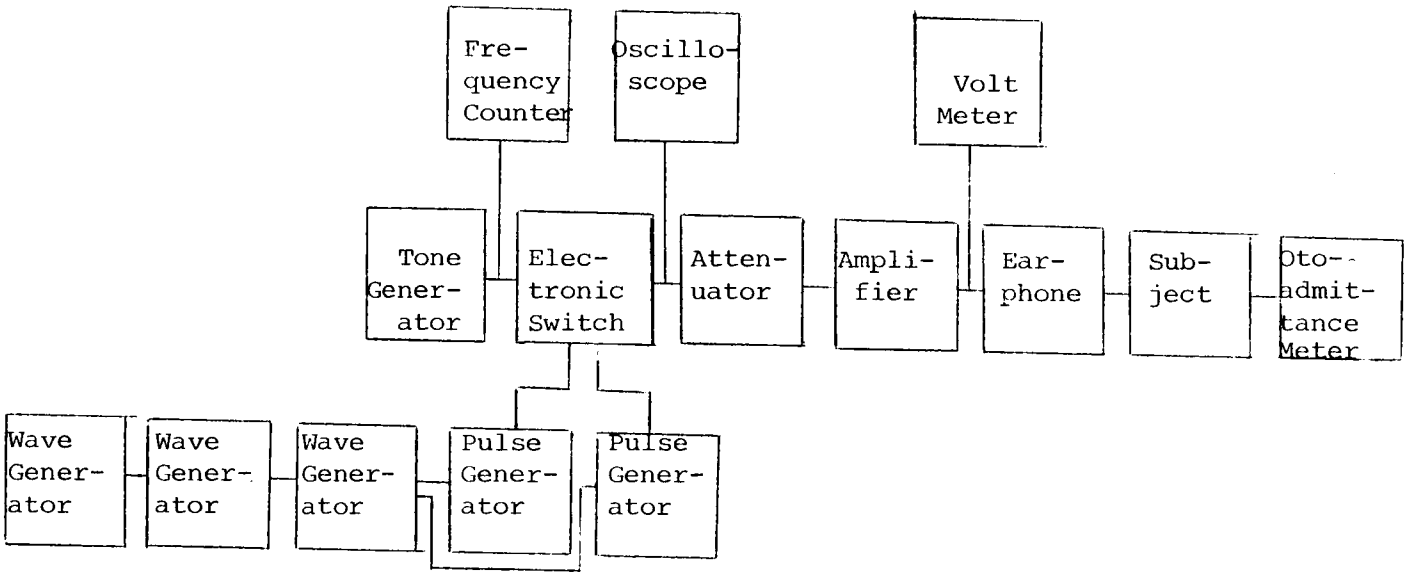

Figure 2. Block diagram of the instrumentation used for the generation and measurement of tone pulses and the measurement of ARTs.

electronic switch (Grason-Stadler, 829E) which was controlled by a series of timers (Tektronix 161 and 162 sawtooth and pulse generators). The first wave generator produced a sawtooth wave which lasted 10 s, and activated a second wave generator which produced a 4-s sawtooth wave (the period during which the repeated tones were presented). The second wave generator activated the third wave generator which produced waves corresponding to the repetition period. Each wave produced by the third wave generator would activate the pulse generators which controlled the duty cycle of the signal. The duration of the tone pulses and the inter-stimulus-intervals were measured at the output of the switch with the use of a cathode ray oscilloscope (Tektronix, 5103N). The output of the switch was fed to an attenuator (Hewlett Packard, 350D) and an amplifier in order to control the level of the stimulus being fed to the earphone (TDH-50). The reflex was measured at the contralateral ear with the use of a Grason-Stadler oto-admittance meter (Grason-Stadler, 1720). A 660-Hz probe tone was used since ARTs are lower with this frequency than with the 220-Hz probe tone (Wilson and McBride, 1978).

C. STIMULI

The tone frequencies used in this study were 250 Hz, 1000 Hz, and 4000 Hz. These frequencies were chosen to examine possible frequency effects on ARTs elicited by repeated tone pulses. Sesterhenn and Brueninger (1976) have demonstrated that the difference between ARTs for continuous tones and repeated tone pulses is dependent on the frequency of the tone, being greater at high

frequencies than at low frequencies. The slope of the ART temporal integration function is approximately the same for each of the test frequencies at short durations (durations less than 50-100 ms). The slope of the functions change, however, for durations longer than 80-200 ms. The point at which the slope of the function changes is dependent on frequency (greater duration for high frequency tones than low frequency tones), and the slope for longer duration tones tends to be steeper for high frequency than for low frequency tones (Djupesland et al., 1973).

The stimulus durations used in this study were 10, 20, 50, 100, 200, 500, and 1000 ms. The durations were limited to 1000 ms because the effect of duration on the ART is small for greater durations (Djupesland and Zwislocki, 1971). These durations also allowed several points to be measured below and above the duration at which the slope of the temporal integration function for the ART changes (Djupesland et al., 1973). This range of durations was also adequate to investigate the interactive effects of stimulus and inter-stimulus-interval durations on the ART.

The durations of the inter-stimulus-intervals used in this study were 10, 20, 50, 100, 200, 500, 1000, and 2000 ms. These inter-stimulus-interval durations in conjunction with the stimulus durations allowed the ART to be measured for a rather large number of duty cycles and repetition rates. Differences in ARTs due to changes in the inter-stimulus-interval duration could be measured for each stimulus duration. Although Jerger et al. (1977) did not find any effect of inter-stimulus-interval duration on ARTs when the

inter-stimulus-interval was greater than 750 ms, the 1000- and 2000-ms inter-stimulus-intervals were included for two reasons. First, they provided a baseline from which to measure the effects of shortening the inter-stimulus-interval duration. Second, study of the relaxation time of the acoustic reflex indicates that inter-stimulus intervals with durations of 1.0 s or more could be needed before successive reflexes would be independent (Dallos, 1964). Therefore, some small differences in the ART could be anticipated as the duration of the inter-stimulus-interval is increased over 1000 ms.

The total duration of the sequence of repeated tone pulses was 4.0 s. It was expected that the duration over which the tones were repeated may affect the ART. For example, repeated short tones over a 1.0-s period may have a lower ART than for the same tones repeated over a 0.5-s period just as a 1.0-s continuous tone would be expected to have a lower ART than a 0.5-s continuous tone. The total duration was, therefore, made long enough so that no further reduction in the ART for longer durations would be expected for continuous tones. Djupesland et al. (1973) found that ARTs for continuous tones continued to improve slightly up to 3.0 s at some frequencies. A silent interval of 6.0 s was presented between the sequences of repeated tone pulses in the present study. According to the data of Borg and Odman (1979) this silent interval was long enough in duration to allow recovery from any adaptation caused by the stimulus presentation. This silent interval was also long enough so that one sequence of repeated tone pulses would not have

an effect on the ART for the next sequence of repeated tone pulses.

D. CALIBRATION

The earphone used in this study was calibrated at each of the test frequencies using a voltmeter (Hewlett Packard), an artificial ear, and a sound level meter (Bruel and Kjaer, 2203).

When the input to the earphone was adjusted to 1.0 V (with the attenuator set at 30 dB), the SPL at the output of the earphone was measured to be 117 dB at 250 Hz, 121 dB at 1000 Hz, and 119 dB at 4000 Hz. Within the range of SPLs used in testing, the attenuation was linear. Each time four or five subjects were tested, the output of the earphone was measured in the manner described above. Changes in the SPL output of the earphone did not exceed 2 dB at any test frequency from one calibration to the next.

At the beginning of each test session, the amplification was adjusted so that there was a 1.0-V input to the earphone at 1000 Hz when the attenuator was set at 30 dB. This was done with a continuous 1000 Hz pure tone.

E. PROCEDURE

For each subject, only one ear was tested. If both ears met the criteria for subject selection, then the test ear was selected in the following manner: if hearing thresholds were asymmetrical then the better ear was tested; if the hearing thresholds were asymmetrical, then the right ear was tested. If only one ear met the criteria for

subject selection, then that ear became the test ear. The test ear refers to the ear to which the stimuli, the repeated tone pulses, were presented and not the ear to which the probe tone for measuring the AR was presented.

For each of the possible on-time off-time pairs (see Figure 3), the ART was obtained in the following manner. The SPL was increased in 10 dB steps until an easily observable AR was seen. The stimulus level was then reduced in 2-dB steps. The experimenter used a descending rather than an ascending method because he felt it was easier to observe when the AR first disappeared rather than when it first appeared. There were two criteria for threshold. First, there had to be an observable deflection from baseline (the admittance measured when no stimulus is presented) in association with a stimulus presentation. Second, there had to be an increase in the magnitude of the deflection with an increase in the stimulus level. The same procedure was then repeated to insure that no mistake was made in measuring the ART. If the ART measured on the second trial was within 2 dB of the first, then the results of the first trial were taken as threshold. In the vast majority of the cases no further test trials were needed. In a few cases, an obvious mistake was made in the first or second measurement of the ART. In these cases, a third trial was conducted, and this measurement was taken as threshold if it was in agreement with either the first or second trial. In all cases, the result of the third trial was within 2 dB of either the first or second trial.

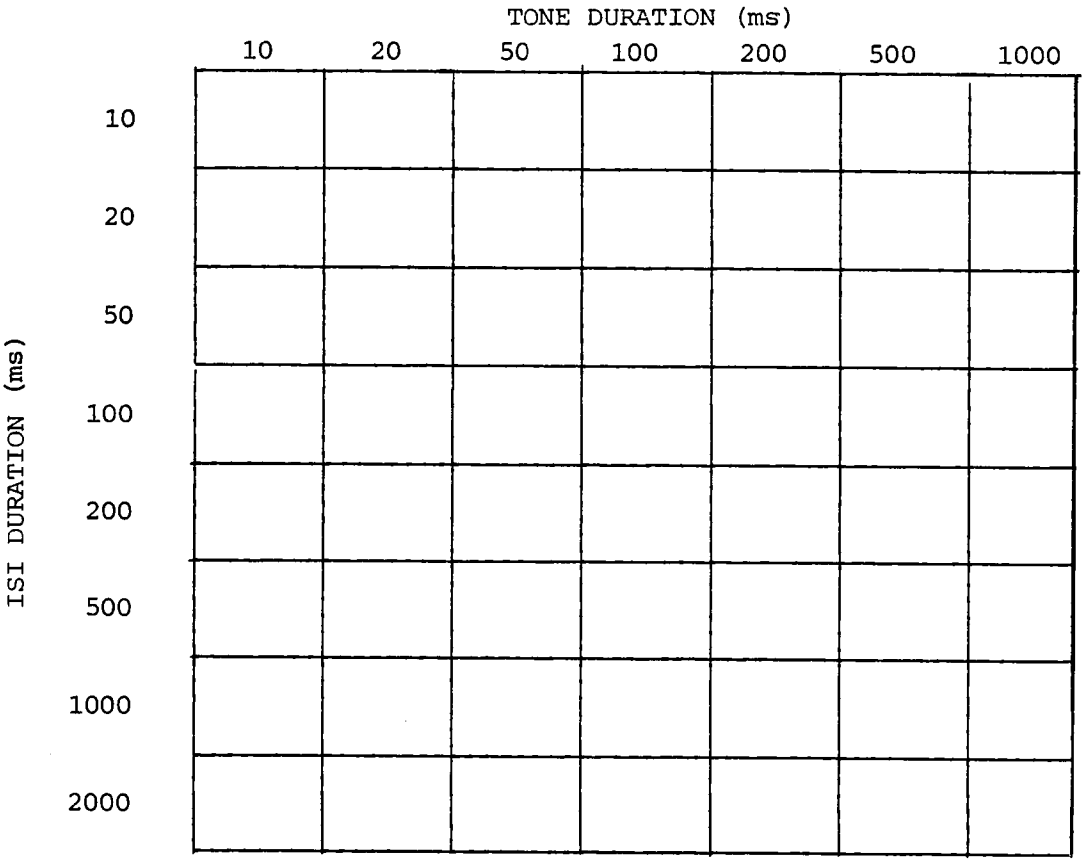

Figure 3. Cells created by all possible pairings of tone and inter-stimulus-interval durations.

The ART was recorded as the attenuator setting (dB) at which the least observable deflection of the otoadmittance meter occurred. These results were later converted to SPL.

The number of conditions to be tested for each subject was 159. This took approximately six hours for each subject. The total test time was divided into two to six sessions depending on the subject's availability. The testing was done in a quiet room, and the subjects were given a break of approximately 10 minutes after every half-hour of testing.

CHAPTER IV

RESULTS AND DISCUSSION

Auditory reflex thresholds were obtained for 10 normally hearing and 10 hearing-impaired subjects. The ARTs were measured with seven tone durations ranging from 10 to 1000 ms, eight inter-stimulus-intervals ranging in duration from 10 to 2000 ms, and three frequencies (250, 1000, and 4000 Hz). The criterion measure was the lowest sound pressure level (dB) at which the AR was observed. The appendix contains the complete data for all subjects. Subjects 1-10 make up the hearing-impaired group, and subjects 11-20 the normally hearing group.

Since a minimum of two sessions were needed to complete all conditions, some conditions, randomly selected, were repeated at both sessions in order to observe any difference in ARTs between sessions. The maximum difference in ARTs observed was 4 dB for any one condition. The results, therefore, appear to be reliable.

A. RESULTS

Average Data for Each Condition

The data gathered in this study have been summarized in Figures 4 through 15 and in Tables 2 through 7. In these figures and tables, ARTs for normally hearing or hearing-impaired subjects have been averaged, and presented for each combination of tone duration, ISI duration and frequency.

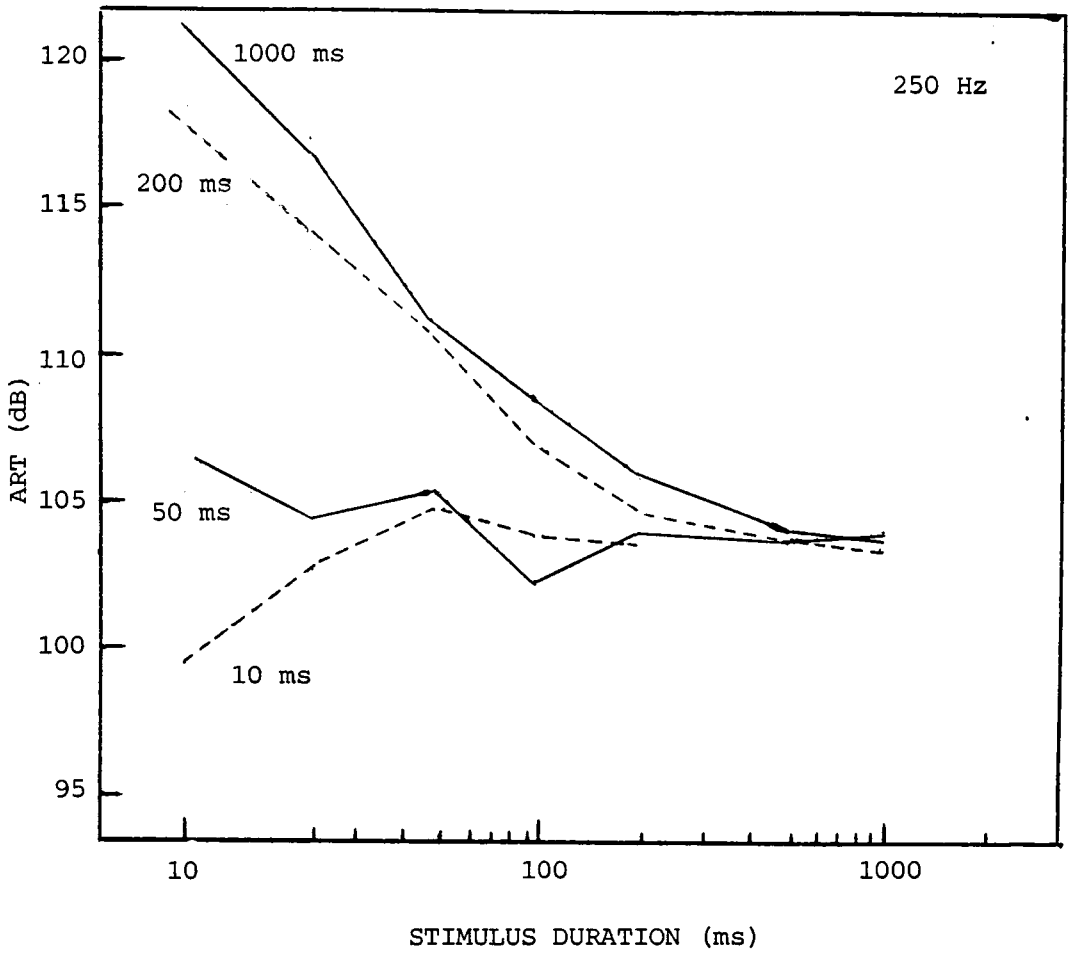

Figure 4. Average ARTs for 10 normally hearing subjects at 250 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

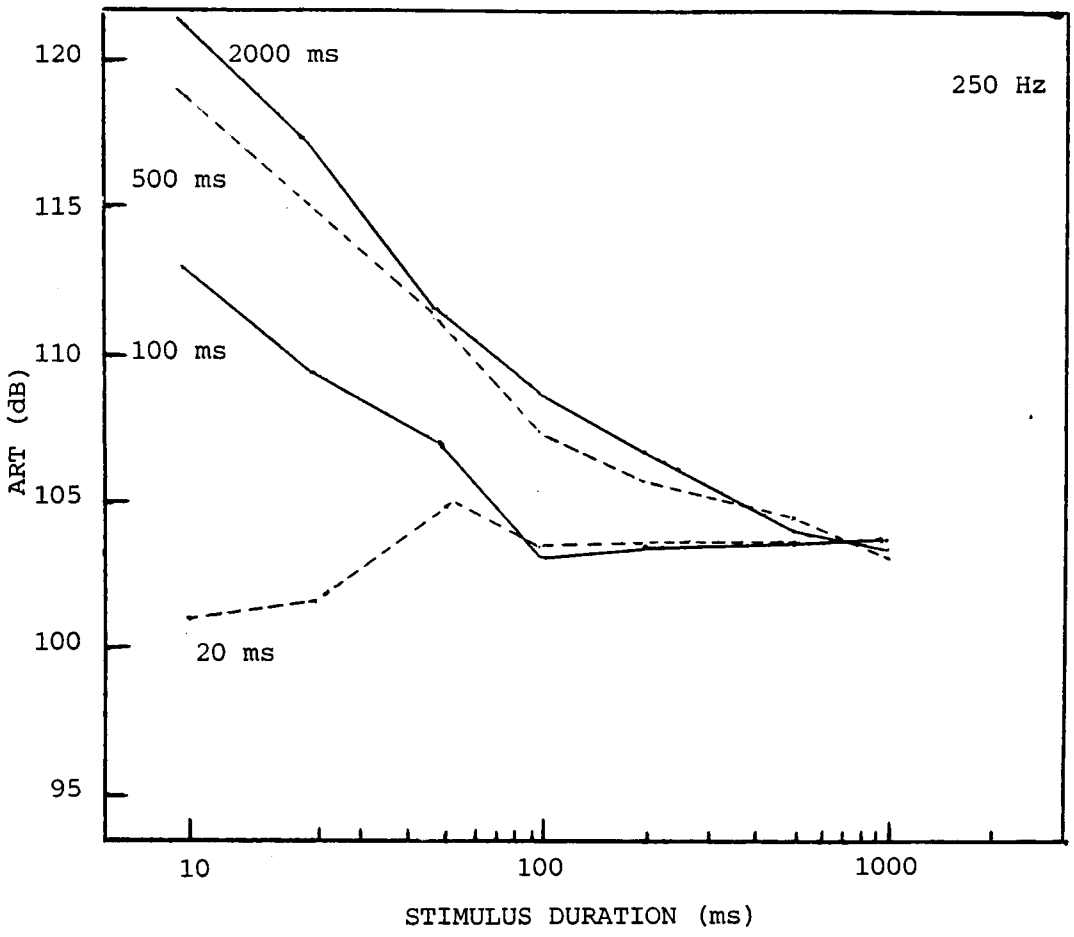

Figure 5. Average ARTs for 10 normally hearing subjects at 250 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

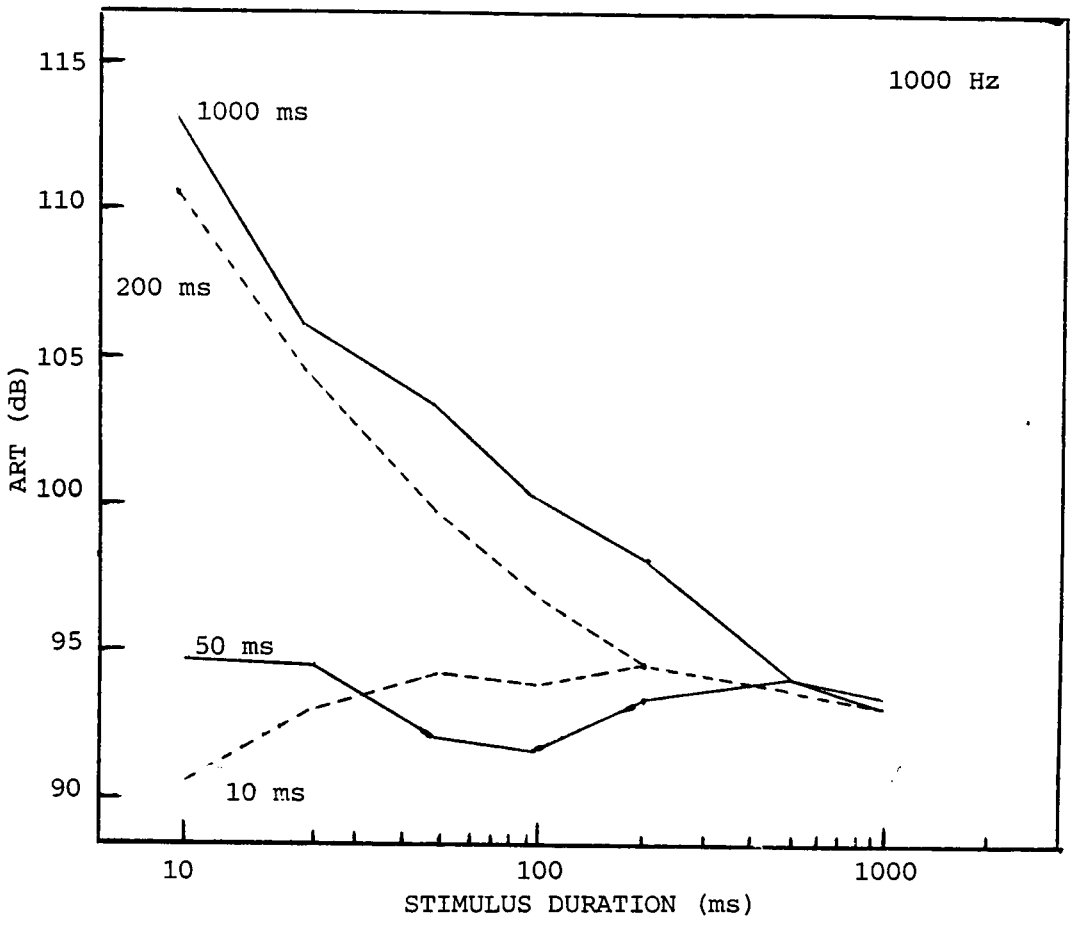

Figure 6. Average ARTs for 10 normally hearing subjects at 1000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus interval.

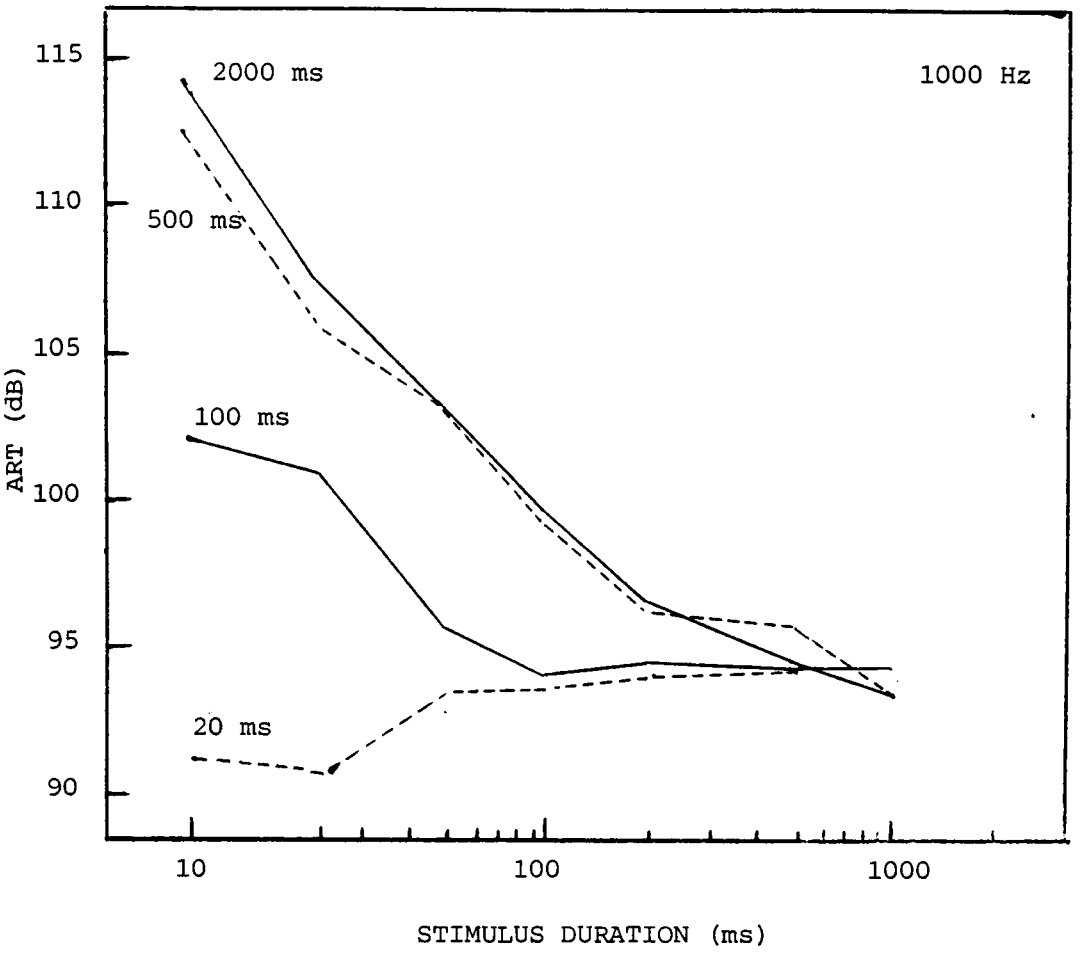

Figure 7. Average ARTs for 10 normally hearing subjects at 1000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

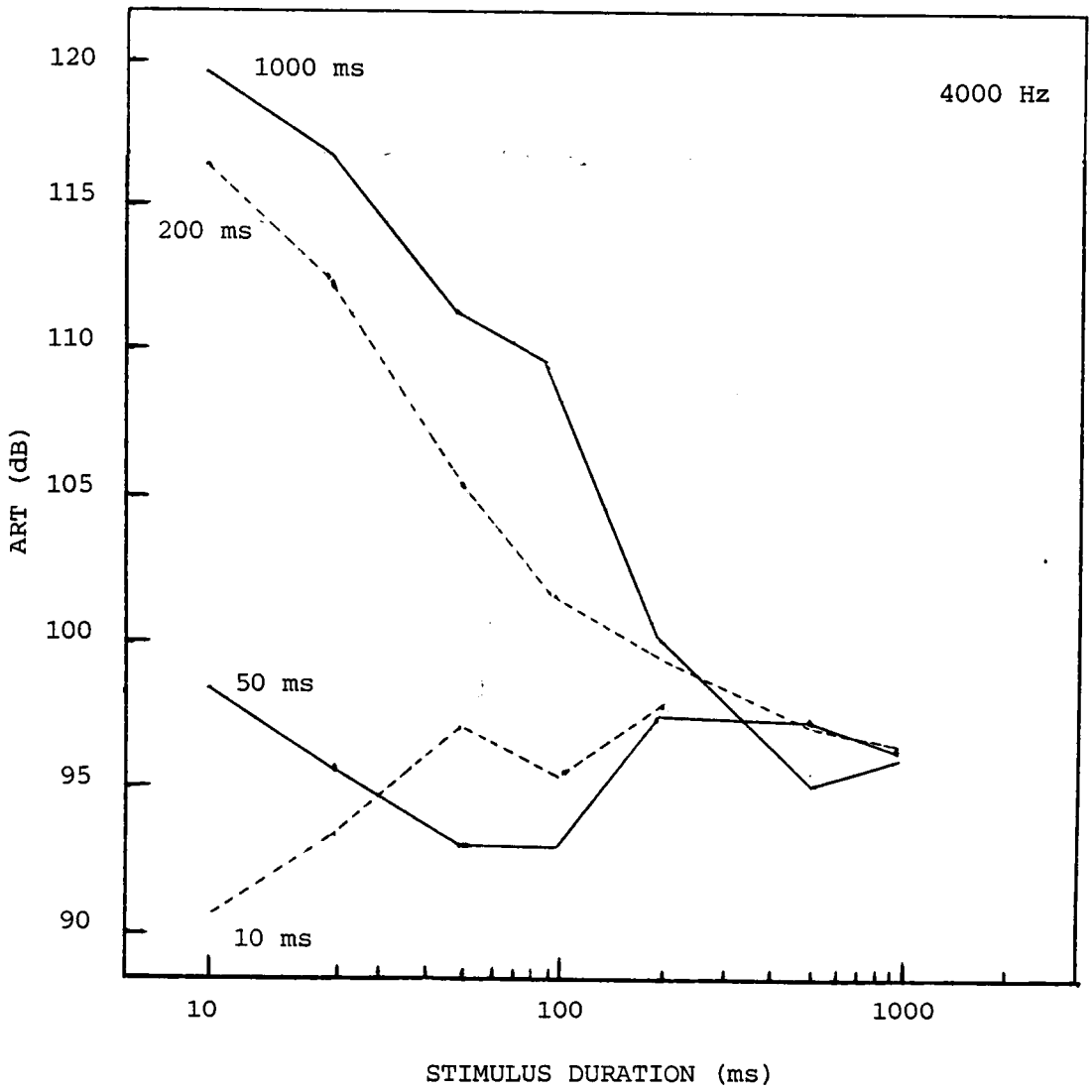

Figure 8. Average ARTs for nine normally hearing subjects at 4000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

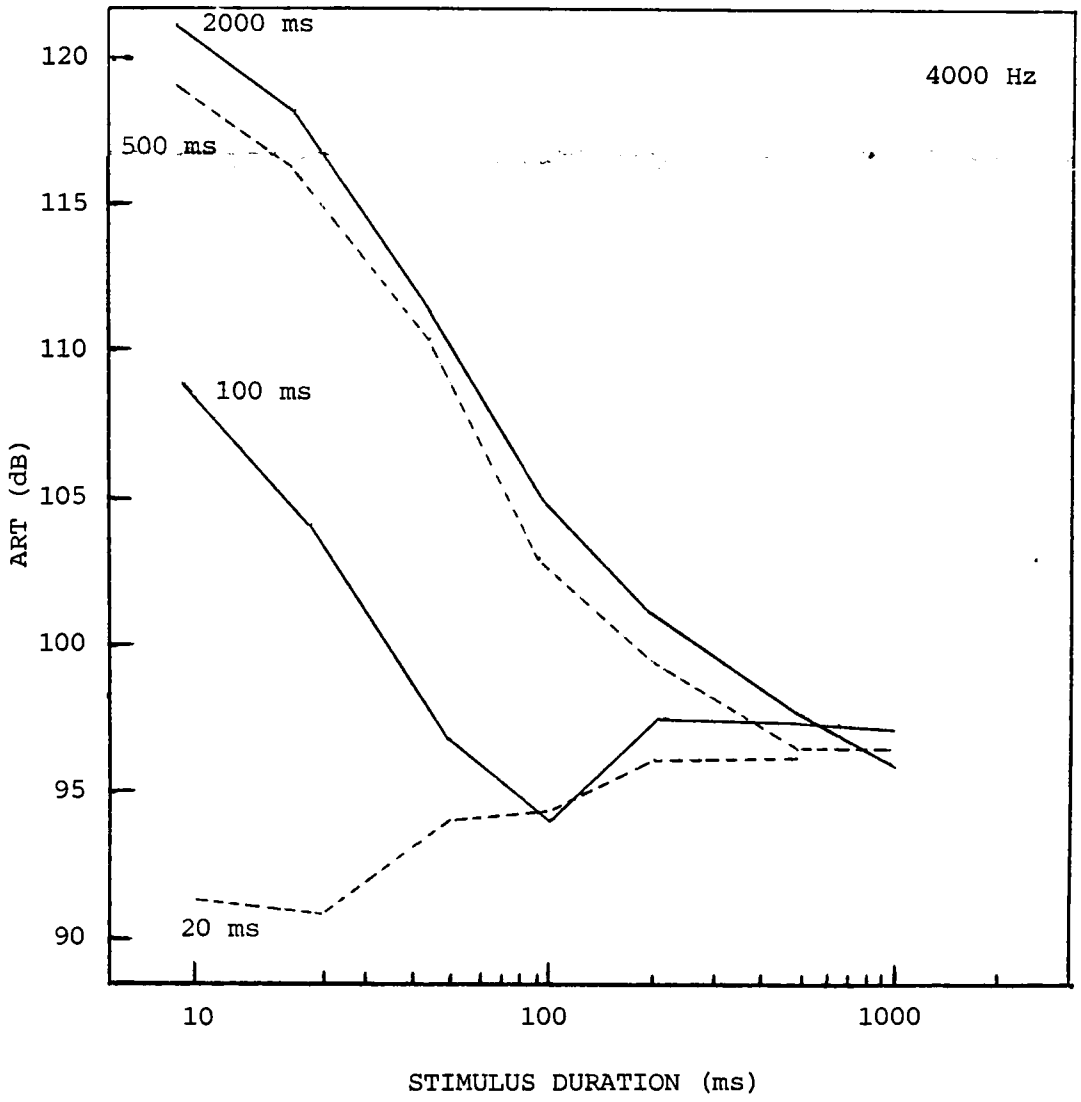

Figure 9. Average ARTs for nine normally hearing subjects at 4000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

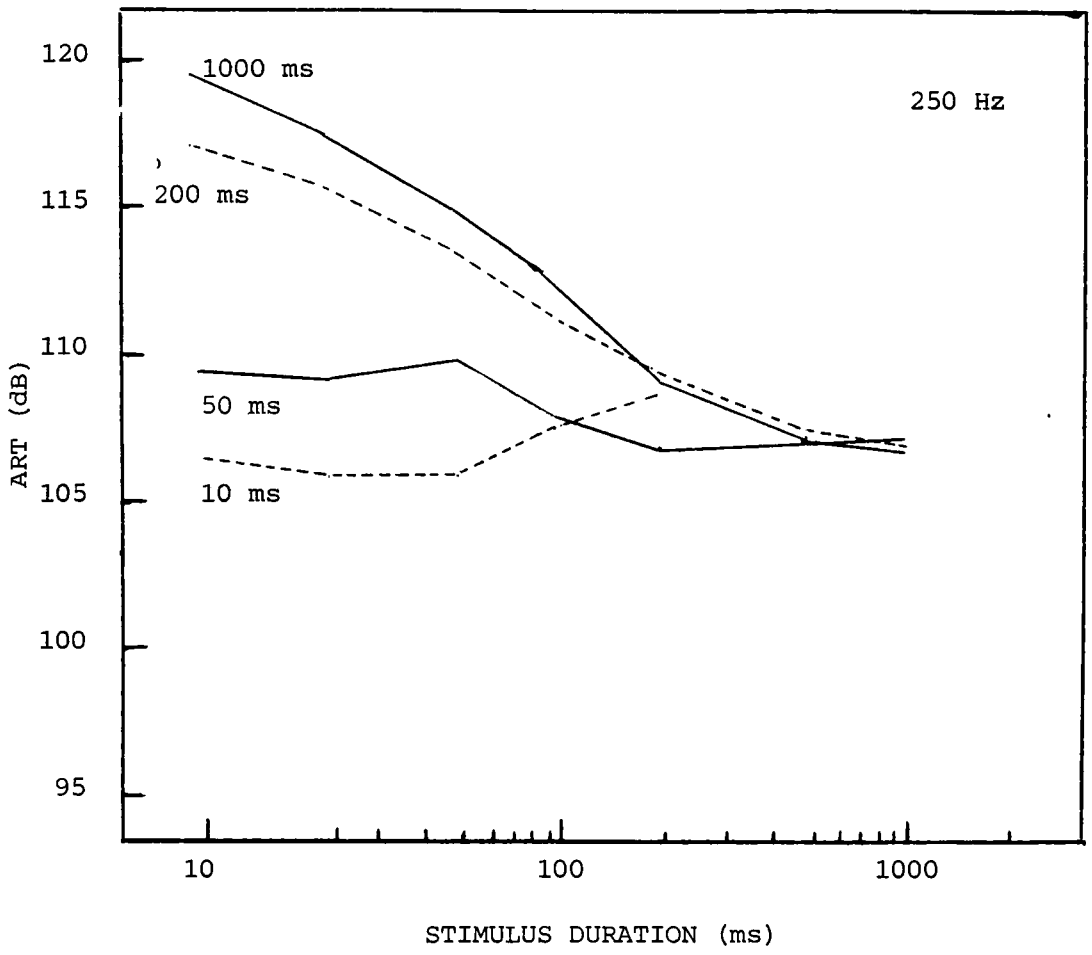

Figure 10. Average ARTs for 10 hearing-impaired subjects at 250 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

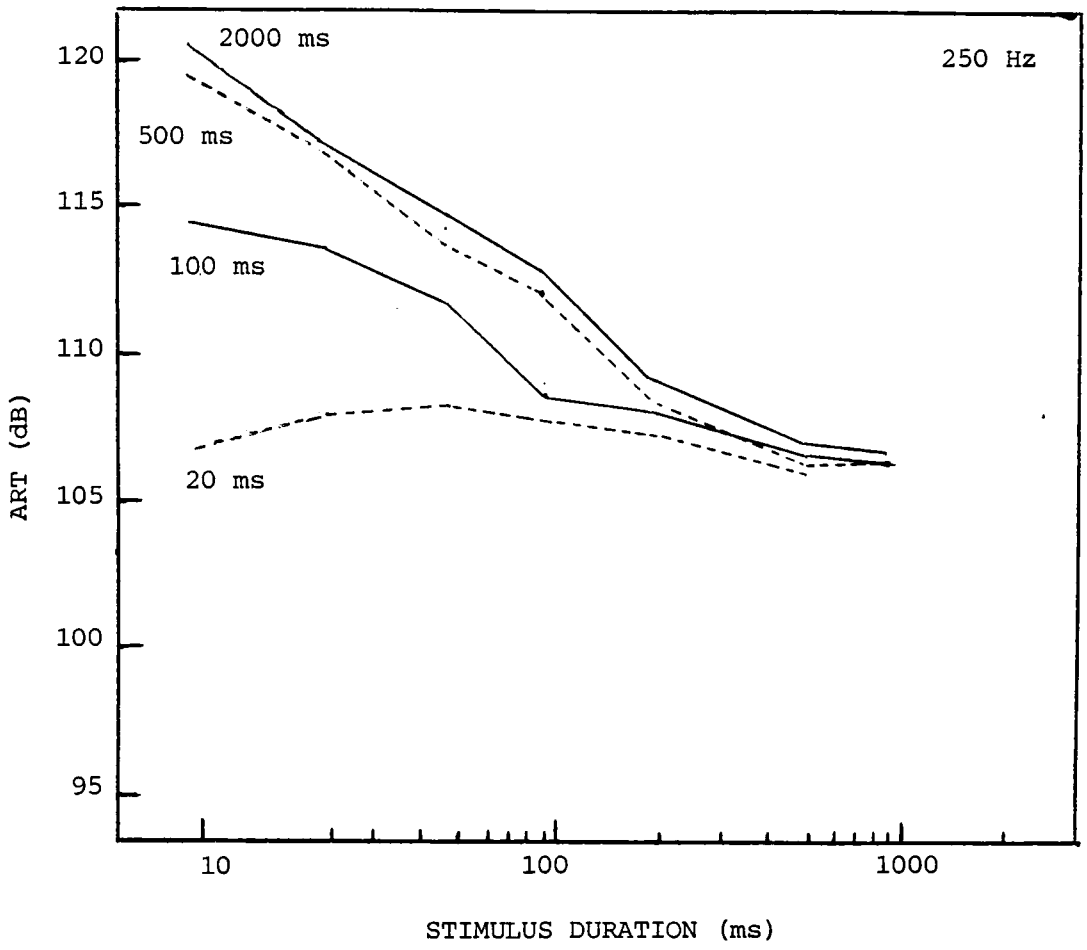

Figure 11. Average ARTs for 10 hearing-impaired subjects at 250 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

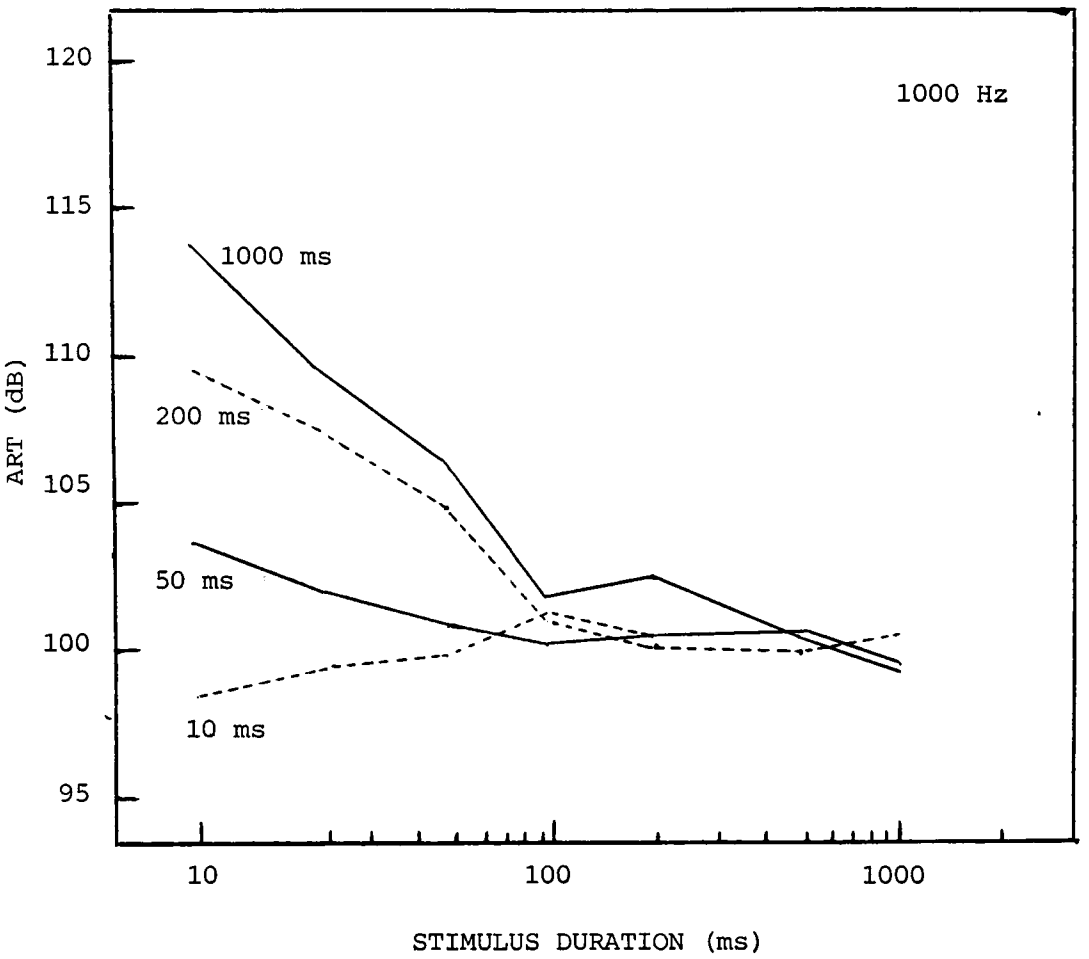

Figure 12. Average ARTs for 10 hearing-impaired subjects at 1000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

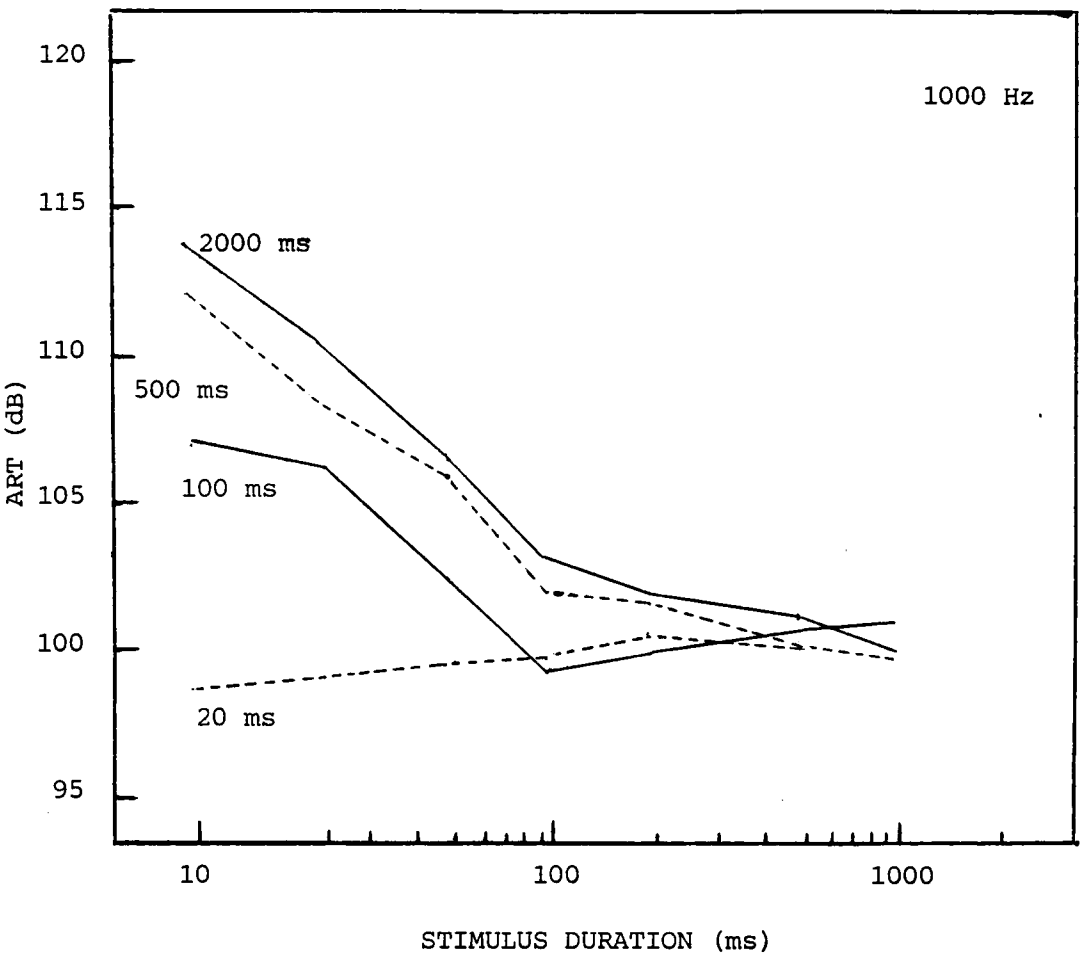

Figure 13. Average ARTs for 10 hearing-impaired subjects at 1000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

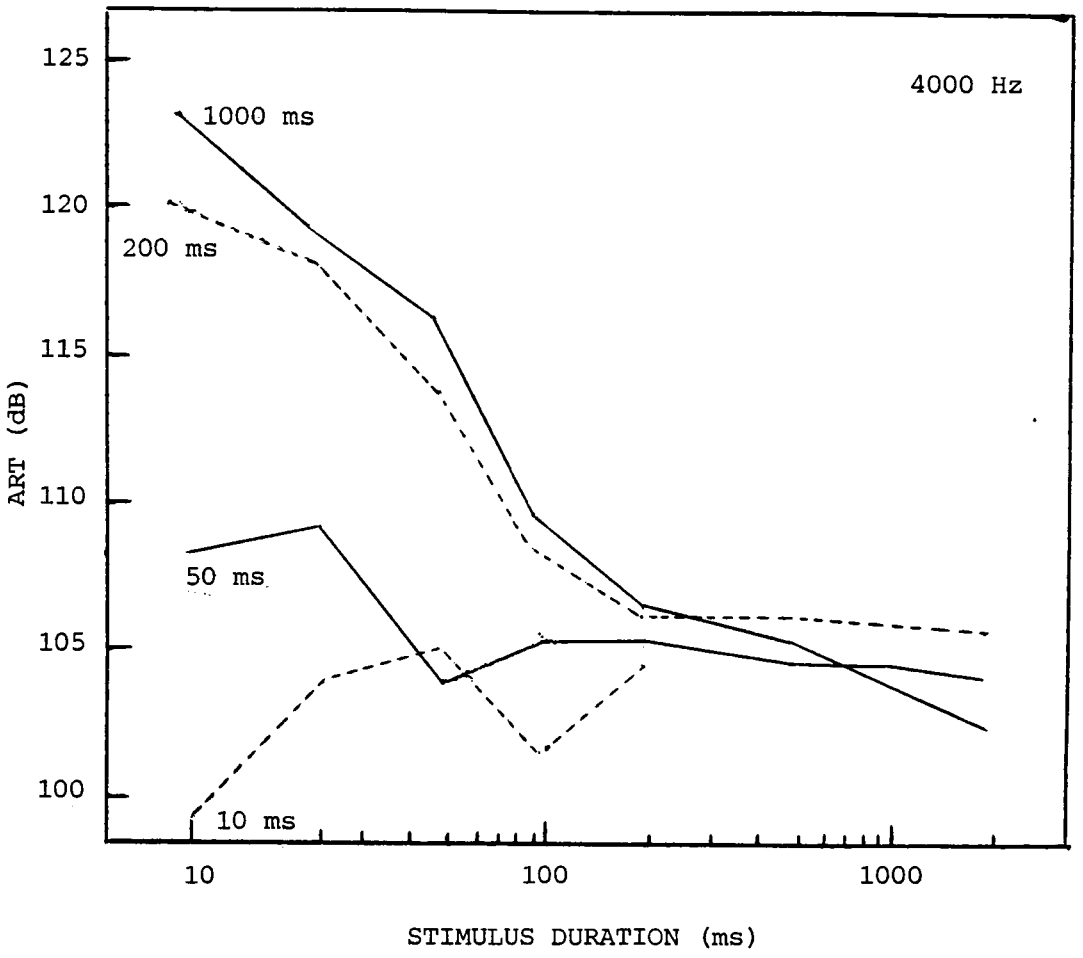

Figure 14. Average ARTs for five hearing-impaired subjects at 4000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval.

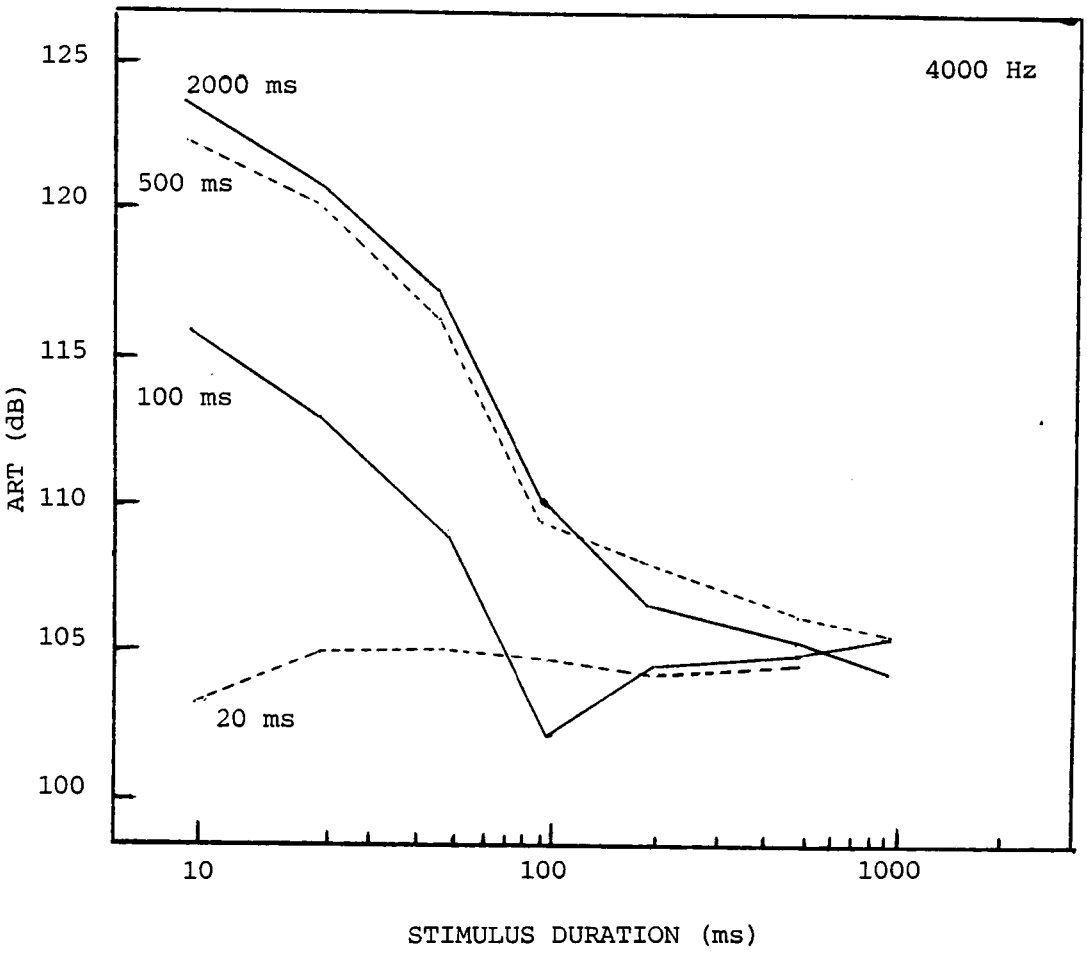

Figure 15. Average ARTs for five hearing-impaired subjects at 4000 Hz. For the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, average data are given for inter-stimulus-intervals of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus interval.

Table 2. The average sound pressure levels in dB (re 20μPa) at which the ART occurred for each test condition at 250 Hz. These values are for 10 normally hearing subjects, and correspond to the data points shown in Figures 4 and 5.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	99.4	102.8	104.4	103.4	103.2	-	-
20	101.2	101.8	105.2	103.2	103.2	103.4	-
50	106.4	104.6	105.0	101.8	103.6	103.8	103.8
100	112.6	109.6	106.8	102.6	103.0	103.4	104.0
200	117.8	113.6	110.4	106.6	104.8	103.4	103.2
500	119.0	115.0	111.0	107.0	105.2	105.0	103.0
1000	121.4	116.6	110.8	108.2	105.6	103.8	103.6
2000	122.2	117.0	111.2	108.4	106.0	104.4	103.4

Table 3. The average sound pressure levels in dB (re 20 μPa) at which the ART occurred for each test condition at 1000 Hz. These values are for 10 normally hearing subjects, and correspond to the data points shown in Figures 6 and 7.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	90.6	93.2	94.2	94.0	95.0	-	-
20	91.2	90.6	93.0	93.0	93.8	94.0	-
50	94.8	94.4	92.8	92.2	94.0	94.8	94.0
100	102.0	100.6	95.2	93.4	94.6	94.0	94.6
200	110.4	104.6	99.8	96.4	95.0	94.2	94.0
500	112.4	106.0	103.0	98.6	96.4	95.4	93.8
1000	113.0	106.6	103.6	100.0	98.0	94.8	94.0
2000	114.0	107.2	103.0	99.8	97.0	94.6	93.8

Table 4. The average sound pressure levels in dB (re 20 μPa) at which the ART occurred for each test condition at 4000 Hz. These values are for nine normally hearing subjects, and correspond to the data points shown in Figures 8 and 9.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	90.4	93.1	96.2	95.1	96.8	-	-
20	91.6	90.7	94.2	94.7	96.0	96.0	-
50	98.0	95.1	92.9	92.9	96.7	96.4	95.5
100	108.7	104.2	96.7	94.2	97.1	95.8	95.6
200	116.2	112.2	105.1	101.7	98.0	96.0	95.6
500	119.1	116.0	110.0	102.7	99.1	95.1	95.1
1000	119.6	116.9	110.4	104.7	99.8	94.7	95.1
2000	121.1	117.8	110.7	104.9	101.1	96.7	94.4

Table 5. The average sound pressure levels in dB (re 20 μPa) at which the ART occurred for each test condition at 250 Hz. These values are for 10 hearing-impaired subjects, and correspond to the data points shown in Figures 10 and 11.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	106.2	105.4	105.4	107.0	108.0	-	-
20	106.4	107.8	108.2	107.6	107.2	105.4	-
50	109.6	109.2	109.8	107.2	105.8	106.2	106.4
100	114.4	113.4	111.4	108.8	108.6	106.6	106.4
200	116.8	115.4	113.6	111.8	109.2	107.0	106.2
500	119.4	117.0	114.0	112.2	108.4	106.2	106.4
1000	119.8	117.0	115.0	112.6	109.0	106.6	106.0
2000	120.2	117.2	115.0	113.0	109.2	107.0	106.8

Table 6. The average sound pressure levels in dB (re 20 μPa) at which the ART occurred for each test condition at 1000 Hz. The values are for 10 hearing-impaired subjects, and correspond to the data points shown in Figures 12 and 13.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	98.0	99.0	99.8	101.0	100.2	-	-
20	98.8	99.0	99.4	99.8	100.2	99.8	-
50	103.4	102.0	100.2	100.0	100.2	100.4	99.4
100	106.8	105.8	102.6	98.8	99.4	100.6	100.8
200	109.6	107.4	104.4	100.8	100.0	100.0	100.4
500	112.0	108.4	105.8	102.0	101.6	99.8	99.4
1000	113.6	109.6	106.6	101.8	102.4	100.2	99.2
2000	113.8	110.4	106.8	103.4	102.0	101.4	99.6

Table 7. The average sound pressure levels in dB (re 20 μPa) at which the ART occurred for each test condition at 4000 Hz. These values are for five hearing-impaired subjects, and correspond to the data points shown in Figures 14 and 15.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	99.1	103.8	104.9	102.0	104.0	-	-
20	103.8	104.9	104.9	104.3	104.0	104.9	-
50	108.0	108.9	103.8	105.1	105.1	104.2	104.2
100	116.0	113.1	108.9	102.2	104.2	104.9	105.1
200	120.6	118.0	114.0	108.0	106.0	106.0	105.1
500	122.4	120.0	116.0	109.1	107.8	105.8	105.1
1000	123.0	119.3	116.2	109.1	106.2	105.1	102.0
2000	123.5	121.3	117.1	110.0	105.8	105.1	104.0

Analysis of the Data

The following is a summary of the hypotheses concerning main effects tested in this study.

Hypotheses 1a-d: There is no significant difference between the following:

(a) ARTs of the normally hearing and hearing-impaired groups;

(b) ARTs for stimulus frequencies of 250, 1000, and 4000 Hz;

(c) ARTs for stimulus durations of 10, 20, 50, 100, 200, 500, and 1000 ms;

(d) ARTs for inter-stimulus-intervals of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms.

A four factor analysis of variance (Lee, 1975) was performed in order to test these hypotheses. A summary of the results from the analysis of variance is presented in Table 8.

The results of this analysis indicate that there is a significant difference ($F=467.24$; $df=1/2544$; $p < .0001$) between the ARTs of the normally hearing group (101.81 dB) and the hearing-impaired group (107.17 dB). Therefore, Hypothesis 1a is rejected. The mean ART of the normally hearing group is 5.36 dB lower than the mean ART for the hearing-impaired group (see Figure 16).

When data for all subjects, tone and ISI durations are combined, there is a significant difference ($F=387.96$; $df=2/2544$; $p < .0001$) among ARTs measured with tone frequencies of 250 Hz (108.55 dB), 1000 Hz (100.11 dB) and 4000 Hz (104.81 dB). Therefore, Hypothesis 1b is rejected. The mean ARTs at 250 and 4000 Hz are

Table 8. Summary table for the analysis of variance.

Source	DF	ANOVA SS	F Value	PR > F
Group (G)	1	22853.97	467.24	0.0001
Frequency (F)	2	37951.65	387.96	0.0001
Inter-stimulus-interval (ISI)	7	32499.61	94.92	0.0001
Tone duration (D)	6	35757.24	121.84	0.0001
G*F	2	3120.10	31.89	0.0001
G*ISI	7	1286.75	3.76	0.0005
G*D	6	377.61	1.29	0.2597
F*ISI	14	1848.65	2.70	0.0006
F*D	12	1496.24	2.55	0.0024
ISI*D	39	33820.72	17.73	0.0001
G*F*ISI	14	225.35	0.33	0.9905
G*F*D	12	267.69	0.46	0.9401
G*ISI*D	39	1517.19	0.80	0.8143
F*ISI*D	78	2271.48	0.60	0.9981
G*F*ISI*D	78	479.69	0.13	1.0000

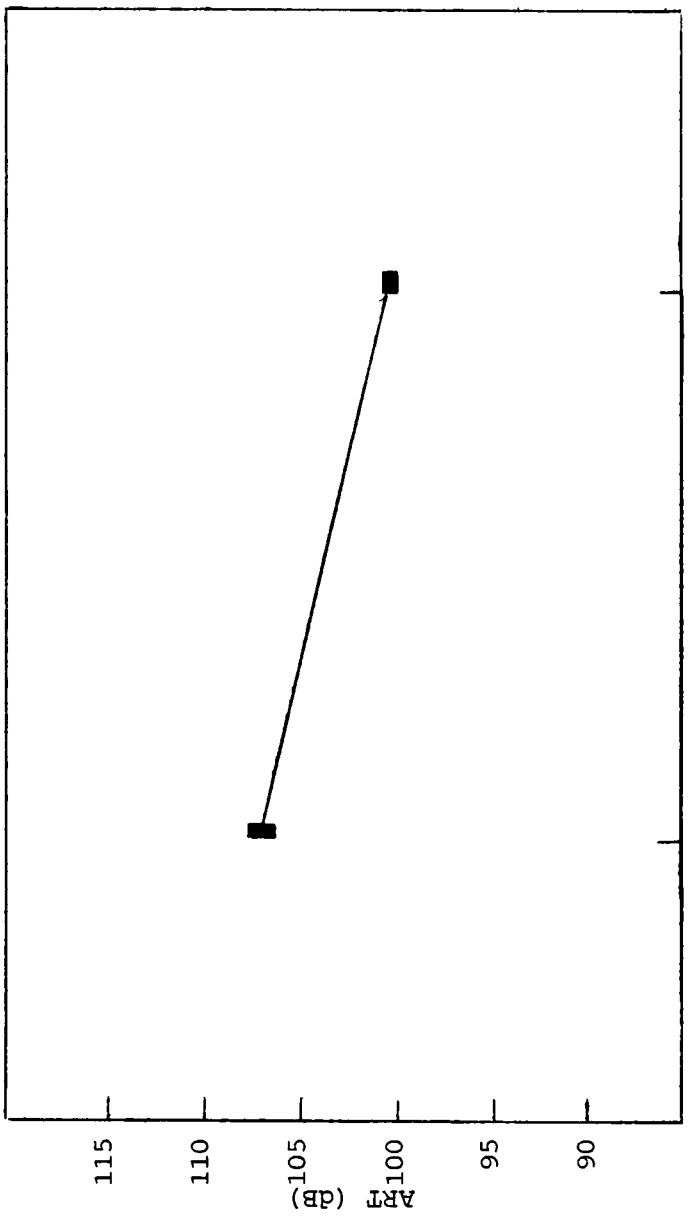

Figure 16. The average ART levels (re 20 μPa) for normally hearing and hearing-impaired groups.

8.44 and 4.70 dB higher than the ART at 1000 Hz, respectively (see Figure 17).

When data for all subjects, tone frequencies, and ISI durations are combined, there is a significant difference ($F=121.84$; $df=6/2544$; $p < .0001$) among ARTs for tone durations of 1000 ms (100.53 dB), 500 ms (101.02 dB), 200 ms (102.03 dB), 100 ms (102.86 dB), 50 ms (105.61 dB), 20 ms (107.99 dB), and 10 ms (109.96 dB), and, therefore, Hypothesis 1c is rejected. A Duncan's Multiple-Range Test (Bruning and Kintz, 1968) indicates that all the differences between ARTs are significant with the exceptions of the differences among ARTs for tone durations of 1000 ms and 500 or 200 ms, and between ARTs for tone durations of 200 and 100 ms. The mean ART increases 9.43 dB as the tone duration is reduced from 1000 to 10 ms (see Figure 18). The increase in the ART with reduction in the tone duration appears small because of averaging across all ISI durations. As the ISI becomes smaller, tone duration has less of an effect on the ART.

When data for all subjects, tone frequencies, and tone durations are combined, there is a significant difference ($F=94.92$; $df=7/2544$; $p < .0001$) among ARTs for inter-stimulus-interval durations of 2000 ms (108.13 dB), 1000 ms (107.65 dB), 500 ms (107.30 dB), 200 ms (106.17 dB), 100 ms (103.51 dB), 50 ms (101.25 dB), 20 ms (100.09 dB), and 10 ms (99.85 dB). Hypothesis 1d is, therefore, rejected. A Duncan's Multiple-Range Test, with an alpha level of 0.001, indicates that there is no significant difference among the ARTs at ISI durations of 10, 20, and 50 ms, and at ISI durations of 200, 500,

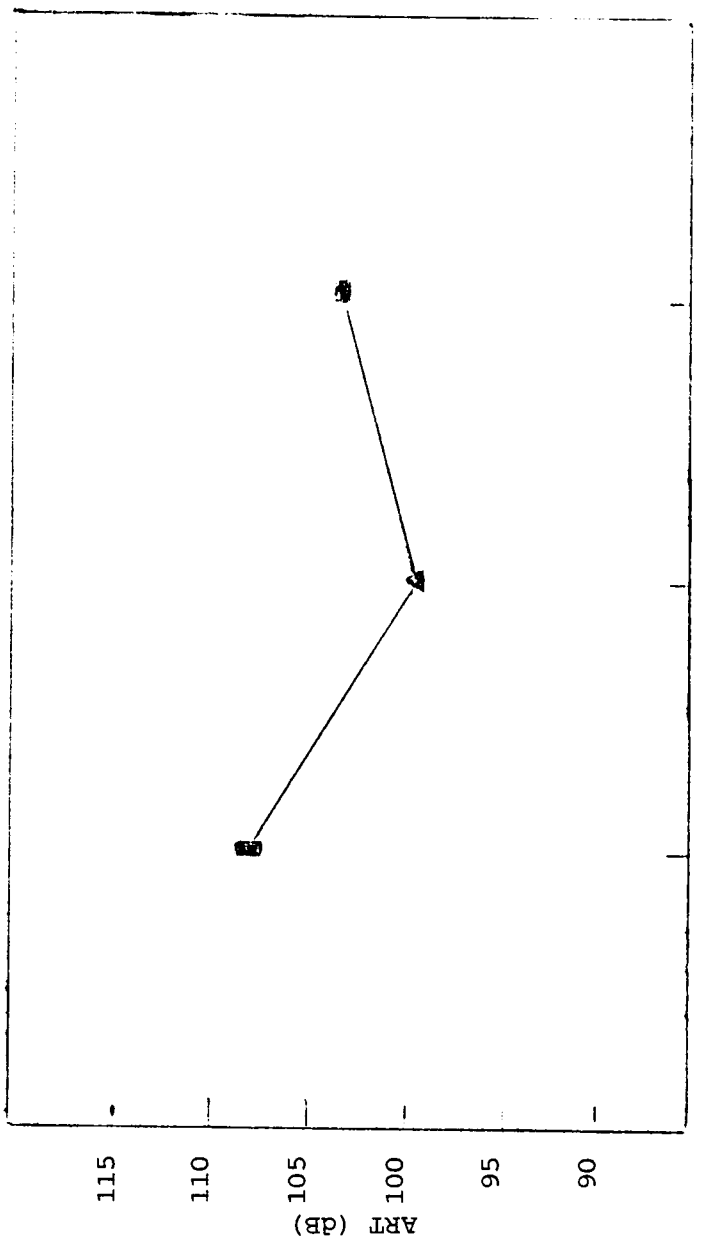

Figure 17. The average ART levels (re 20 μPa) at 250, 1000, and 4000 Hz.

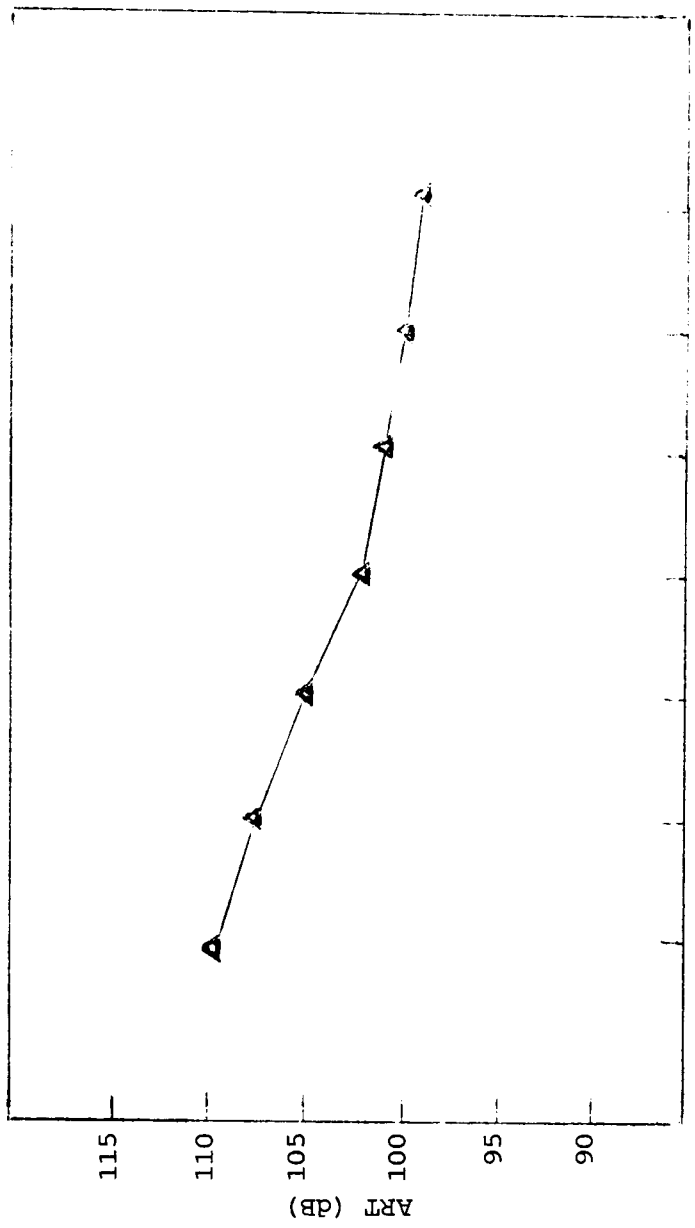

Figure 18. The average ART levels (re 20 µPa) for tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms.

and 1000 ms, and at ISI durations of 1000 and 2000 ms. Differences among ARTs at all other ISI durations were significant. The increase in the ART as the ISI is increased from 10 to 2000 ms is shown in Figure 19.

The analysis of variance was also used to test for interactions between variables. The possibility of significant interactions between or among the factors tone duration, ISI duration, tone frequency, and groups was tested.

There is a significant interaction ($F=31.89$; $df=2/2544$; $p < .0001$) between groups and tone frequency. The difference between the ARTs of the normally hearing and hearing-impaired groups increases as the tone frequency increases. These differences were 3.15 dB at 250 Hz, 4.99 dB at 1000 Hz, and 7.96 dB at 4000 Hz. The mean ARTs are shown in Figure 20.

There is a significant interaction ($F=3.76$; $df=7/2544$; $p < .0005$) between groups and inter-stimulus-intervals. The difference between the normally hearing and hearing-impaired group's ARTs are greatest when the inter-stimulus-intervals are shortest, and become smaller as the inter-stimulus-intervals become longer. This interaction is shown in Figure 21.

There is no significant interaction ($F=1.29$; $df=6/2544$; $p > .01$) between groups and tone durations. The differences in mean ARTs between the two groups are similar across all tone durations when data for all ISIs and frequencies are combined.

There is a significant interaction ($F=2.70$; $df=14/2544$; $p < .0006$) between frequencies and inter-stimulus-intervals. At

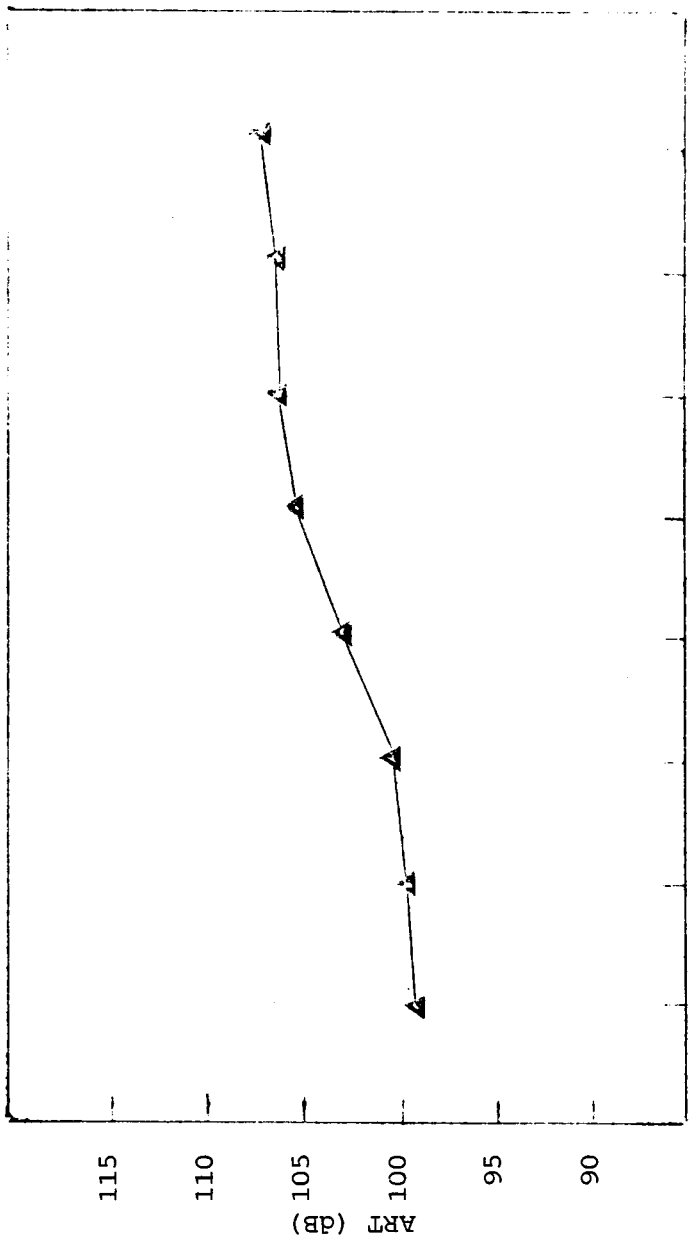

Figure 19. Average ART levels (re 20 μPa) for inter-stimulus-interval durations of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms.

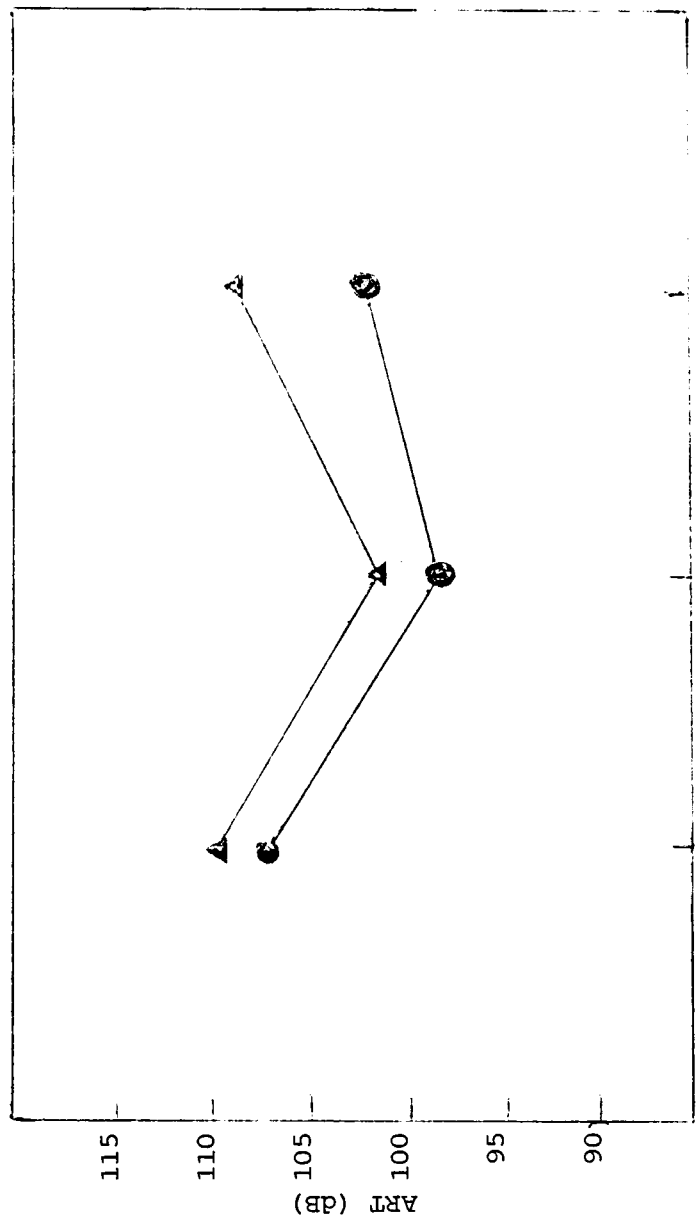

Figure 20. Average ART levels (re 20 μPa) at the frequencies 250, 1000, and 4000 Hz for the normally hearing group (●) and the hearing-impaired group (▲).

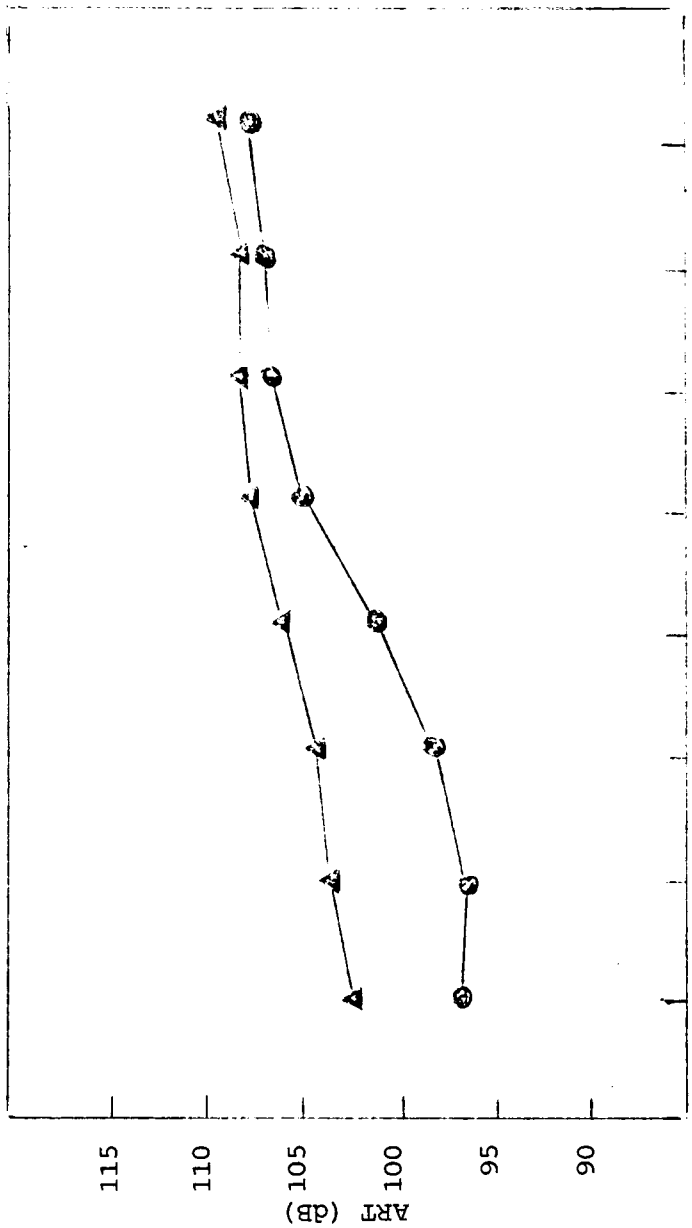

Figure 21. Average ART levels (re 20 μPa) at the inter-stimulus-interval durations of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms for the normally hearing group (●) and the hearing-impaired group (▲).

250 and 1000 Hz, ARTs increase approximately 7 dB as the ISI is increased from 10 to 2000 ms. At 4000 Hz, however, ARTs increase approximately 11 dB under the same conditions. The mean ARTs for these conditions are shown in Figure 22 and Table 9.

There is a significant interaction ($F=2.55$; $df=12/2544$; $p < .0024$) between frequency and tone duration. At 250 and 1000 Hz, ARTs increase by a similar amount as the tone duration is shortened from 1000 ms to 10 ms (8.4 dB), but at 4000 Hz the ART increases by a greater amount (11.6 dB). This interaction is shown in Figure 23 and Table 10. The values shown in Figure 23 and Table 10 are averages which include all subjects and inter-stimulus-intervals.

There is a significant interaction ($F=17.73$; $df=39/2544$; $p < .0001$) between inter-stimulus-intervals and tone durations. For short inter-stimulus-intervals (10 and 20 ms), the ART increases as the tone duration increases up to 50 ms, and remains approximately constant for tone durations between 50 and 500 ms. For longer inter-stimulus-intervals (50-2000 ms), the ART decreases as the tone duration increases. The amount that the ART decreases depends on the duration of the inter-stimulus-interval. The longer the inter-stimulus-interval, the more the ART decreases. The mean ARTs for these conditions are shown in Figures 24 and 25, and Table 11.

There is no significant interaction ($F=0.33$; $df=14/2544$; $p > .01$) among groups, frequency, and inter-stimulus-intervals. This indicates that the increase in the difference between the mean ARTs of the groups as frequency increases (shown by the significant

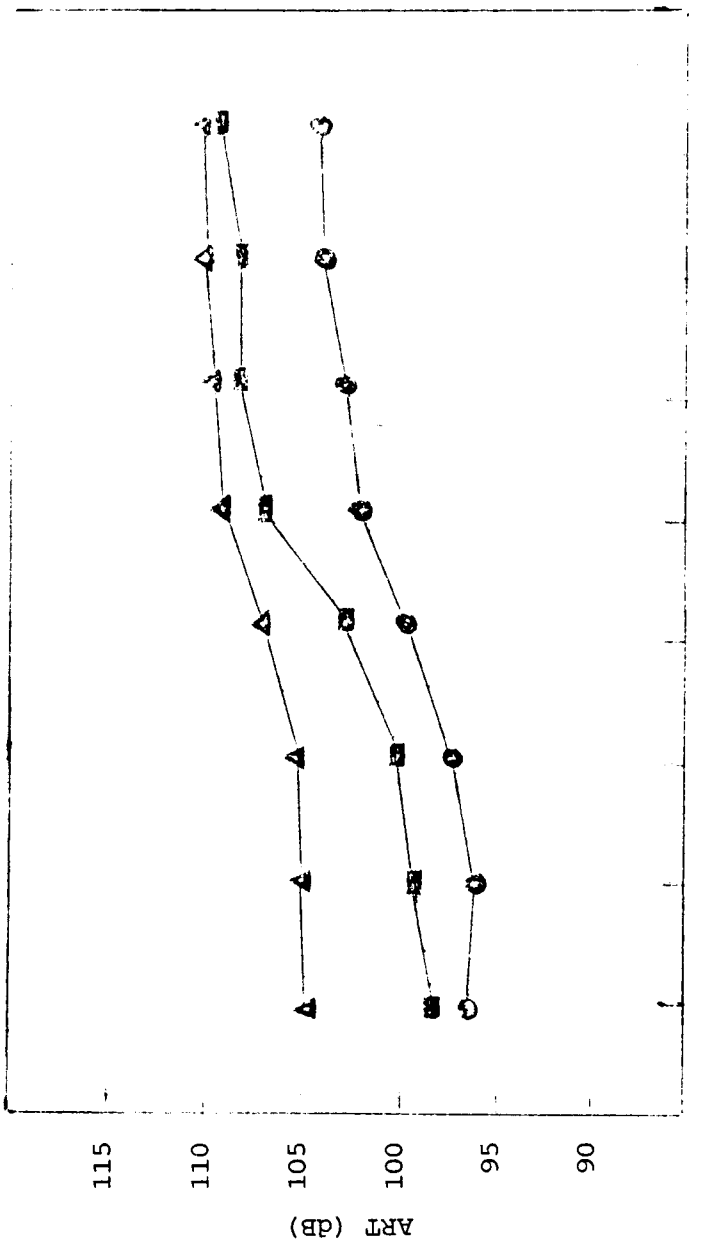

Figure 22. Average ARTs at the inter-stimulus-intervals of 10, 20, 50, 100, 200, 500, 1000, 2000 ms for the frequencies 250 Hz (▲), 1000 Hz (●), and 4000 Hz (■).

Table 9. The average sound pressure levels (dB) at which the ART occurred when the ISI durations were 10, 20, 50, 100, 200, 500, 1000, and 2000 ms for the frequencies 150, 1000, and 4000 Hz. The data have been averaged across all subjects and tone durations. These values are the same as shown in Figure 22.

Freq.	ISI Duration (ms)							
(Hz)	10	20	50	100	200	500	1000	2000
250	104.5	105.1	105.9	107.9	110.0	110.6	111.1	111.5
1000	96.5	96.1	97.3	99.2	101.2	102.5	103.1	103.3
4000	98.5	99.2	100.5	103.3	107.3	108.8	108.7	109.5

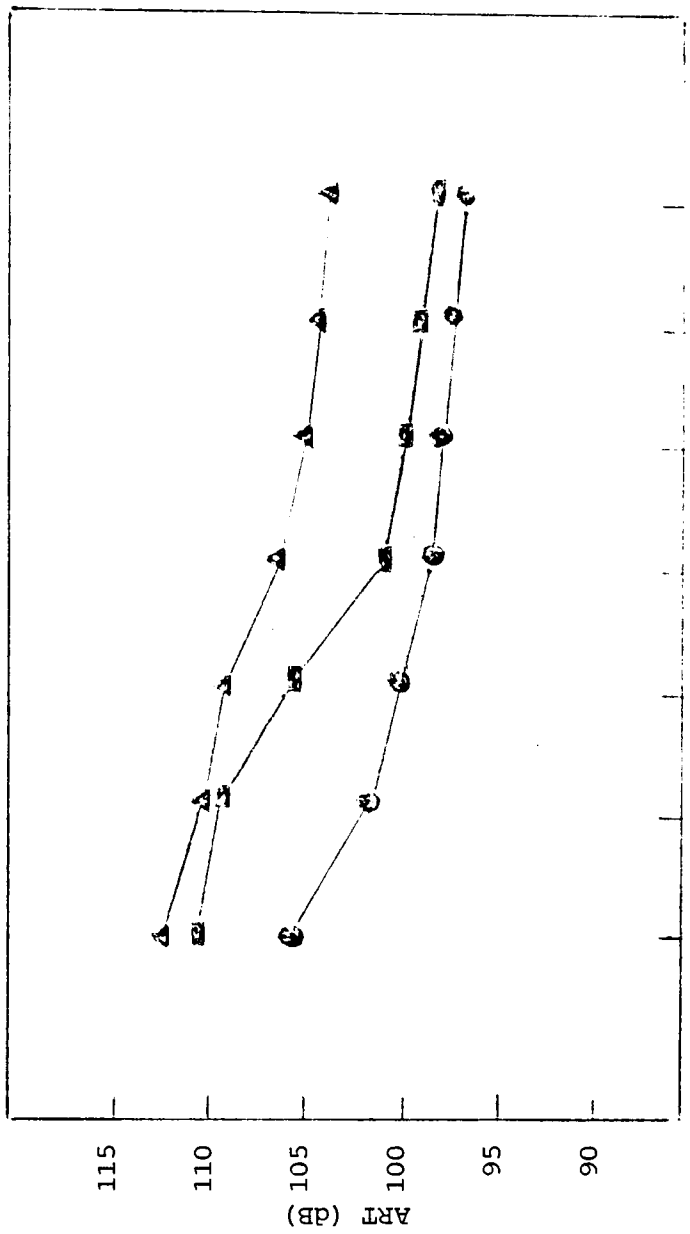

Figure 23. Average ARTs at the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms for the frequencies 250 Hz (▲), 1000 Hz (●), and 4000 Hz (■).

Table 10. The average sound pressure levels (dB) at which the ART occurred when the tone durations were 10, 20, 50, 100, 200, 500, and 1000 ms for the frequencies 250, 1000, and 4000 Hz. The data have been averaged across all subjects and ISI durations. These values are the same as shown in Figure 23.

Freq.	Tone Duration (ms)						
(Hz)	10	20	50	100	200	500	1000
250	113.3	111.5	109.8	107.6	106.3	105.2	104.9
1000	105.3	102.8	100.6	98.4	98.1	97.4	96.9
4000	111.3	109.7	106.4	102.5	101.7	100.5	99.7

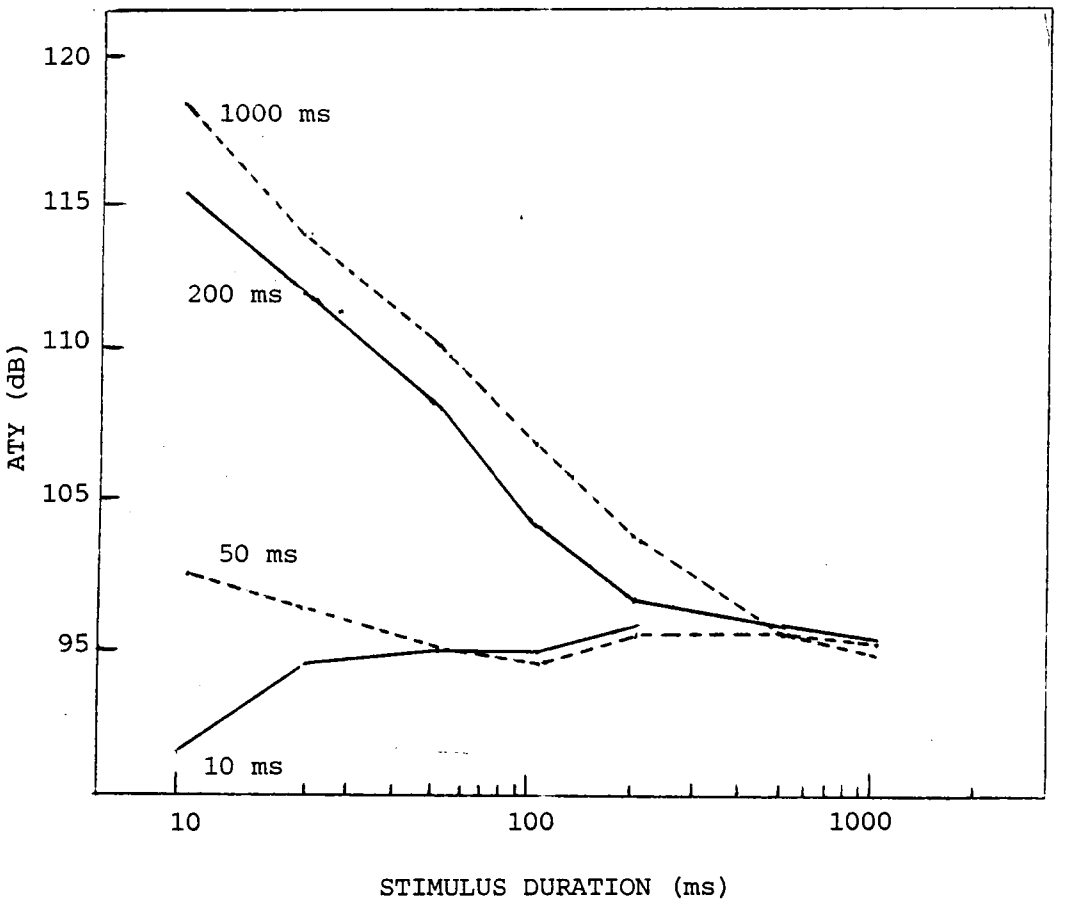

Figure 24. Average ARTs for the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms. The duration of the inter-stimulus-interval is shown in the figure for each curve. The values were obtained by averaging across all subjects and frequencies.

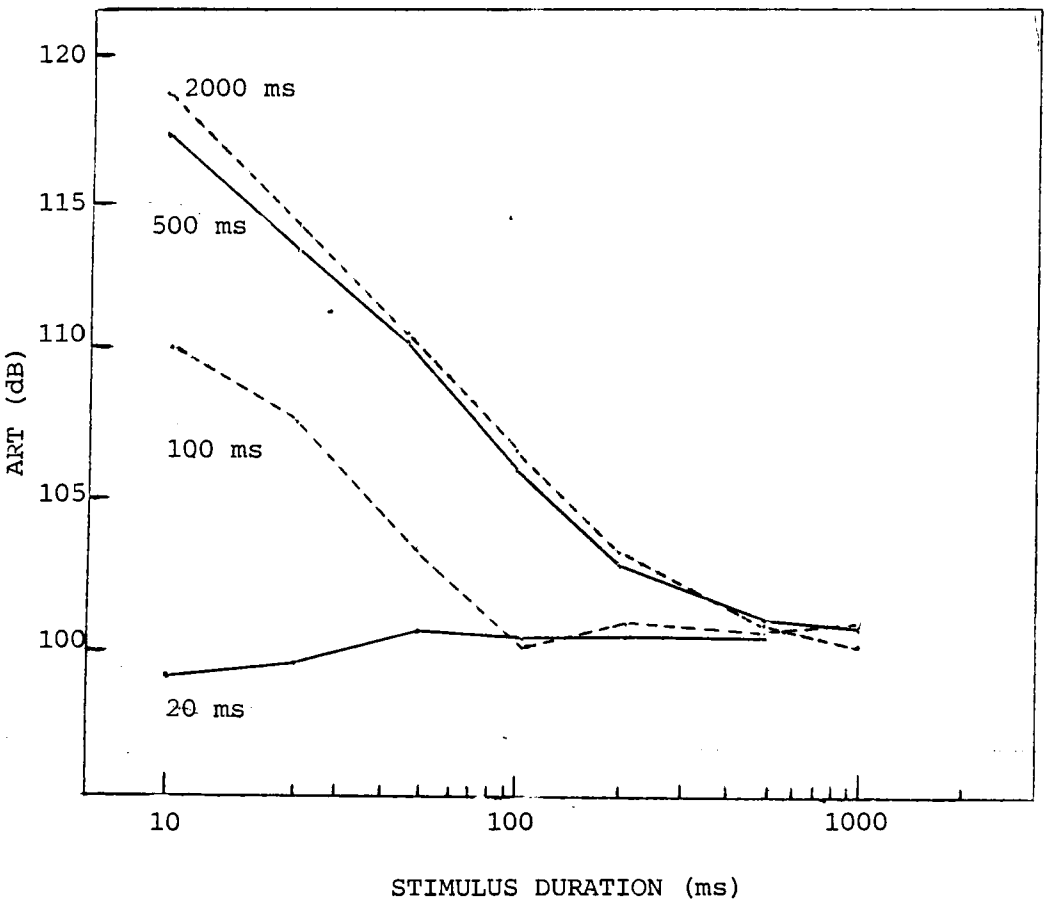

Figure 25. Average ARTs for the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms. The duration of the inter-stimulus-interval is shown in the figure for each curve. The values were obtained by averaging across all subjects and frequencies.

Table 11. The average sound pressure levels (dB) at which the ART occurred for tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms when the ISI durations were 10, 20, 50, 100, 200, 500, 1000, and 2000 ms. The values were obtained by averaging across all subjects and frequencies, and correspond to the points shown in Figures 24 and 25.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	97.3	99.5	100.8	100.4	101.2	-	-
20	98.8	99.1	100.8	100.4	100.7	100.6	-
50	103.4	102.4	100.8	99.9	100.9	101.0	100.6
100	110.1	107.8	103.6	100.0	101.2	100.9	101.1
200	115.2	111.9	107.9	104.2	102.2	101.1	100.8
500	117.4	113.7	110.0	105.3	103.1	101.2	100.5
1000	118.4	114.3	110.4	106.1	103.5	100.9	100.0
2000	119.1	115.2	110.6	106.6	103.5	101.5	100.3

group by frequency interaction) is approximately constant for all inter-stimulus intervals.

There is no significant interaction ($F=0.46$; $df=12/2544$; $p > .01$) among groups, frequencies, and tone durations. This indicates that the differences in ARTs between groups across frequencies remain approximately constant for all tone durations.

There is no significant interaction ($F=0.60$; $df=78/2544$; $p > .01$) among frequencies, inter-stimulus-intervals, and tone durations. This indicates that the interaction between inter-stimulus-intervals and tone durations which was found significant is about the same for all frequencies tested.

There is no significant interaction ($F=0.80$; $df=39/2544$; $p > .01$) among groups, inter-stimulus-intervals, and tone durations. This indicates that the inter-stimulus-interval by tone duration interaction which was found significant is similar for both the normally hearing and hearing-impaired groups.

There is no significant interaction ($F=0.13$; $df=78/2544$; $p > .01$) among groups, frequencies, inter-stimulus-intervals, and tone durations.

B. DISCUSSION

Effects of Frequency on the ARTs of Normally Hearing Subjects

Comparison of data with previous studies. Figure 17, page 85, shows the average ART at each frequency. These averages are 108.5 dB at 250 Hz, 100.1 dB at 1000 Hz, and 104.8 dB at 4000 Hz.

These averages are considerably higher than have been reported in other studies because the data have been averaged across all tone durations, ISIs, and groups.

In order to compare data with other studies, Table 12 was constructed. This table shows the average SPL at which ARTs were obtained in several studies for normally hearing subjects. The data reported are for long duration stimuli (1.0 s or the longest duration used if less than 1.0 s). The data reported for the present study are for a 1.0 s ISI while the data for the other studies are for ISIs of 1.0 s or longer.

It can be seen from Table 12 that the range of ARTs reported at each frequency is 5 to 10 dB. This range can be attributed to a number of factors including differences in the stimulus or ISI duration, subject sample, instrumentation, and testers. The study in which ARTs were measured under conditions most similar to the present study was Margolis and Popelka (1975). A direct comparison can be made between the studies for conditions using a 1.0-s tone duration and a 1.0-s ISI. It can be seen in Table 12 that the ARTs were obtained at a level 3 to 4 dB higher in the present study than in the study by Margolis and Popelka. Since Margolis and Popelka reported a standard deviation of 3 to 4 dB, the small differences can be attributed to sampling error.

Sensation levels at which the ARTs occur. The values reported in Table 12 for the present study are generally in the midrange of values reported in the other studies cited except at 1000 Hz where the

Table 12. A sample of studies showing the range of SPLs (dB) at which the ART can be expected for the frequencies between 250 and 4000 Hz.

Study	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Popelka et al. (1974)	110.0	95.0	89.0	93.0	96.0
Flottorp et al. (1971)	108.0	92.0	90.0	89.0	96.0
Woodford et al. (1975)		89.0	90.0	92.0	95.0
Margolis and Popelka (1975)	99.7	97.7	91.0	90.1	91.5
Mason (1983)	103.6		94.0		95.1

means are slightly higher for the present study. In each study, however, the highest SPL required to obtain an aural reflex was at 250 Hz, the next highest at 4000 Hz, and the lowest at 1000 Hz. This rank order is the same as for hearing thresholds (ANSI, S3,6, 1970) indicating that ARTs may be obtained at approximately equal sensation levels across frequencies. In order to investigate this hypothesis, the average HTL was calculated for the normally hearing group. The values were 5.0 dB at 250 Hz, 5.0 dB at 1000 Hz, and 8.0 dB at 4000 Hz. These values were then converted to SPLs using the ANSI standard cited above. The equivalent SPLs were 29.5 dB at 250 Hz, 11.5 dB at 1000 Hz, and 17 dB at 4000 Hz. Therefore, the sensation levels at which the ARTs were obtained were 74.1 dB, 82.5 dB, and 78.1 dB at 250, 1000, and 4000 Hz, respectively. This range appears to be too large to assume a constant sensation level for the ARTs across frequencies.

The relationship between loudness and the ART. No loudness measures were made in the present study. Therefore, in order to investigate the possibility of ARTs occurring at equal loudnesses, average data concerning equal loudness contours had to be taken from another study. Using the equal loudness contours of Robinson and Dadson (1956), it would be expected that the ARTs for the 250-Hz tone and the 4000-Hz tone would be 1.0 and 10.0 dB less than for the 1000 Hz tone, respectively, if the equal loudness assumption was met. The 250 Hz tone reaches the 100 phon line at approximately 99 dB, the 1000 Hz tone at 100 dB, and the 4000 Hz tone at approximately 90 dB.

The actual measurements, however, indicated that the average ART at 250 Hz was 9.6 dB greater than at 1000 Hz, and the average ART at 4000 Hz was 1.1 dB greater than at 1000 Hz. Therefore, differences in SPL needed to obtain ARTs across frequencies appear dissimilar to differences in SPL needed to obtain equal loudness across frequencies.

Effects of Frequency on the ARTs of Hearing-Impaired Subjects

The relationship between degree of hearing loss and the ART across frequencies. The data of the present study indicate a significant group by frequency interaction. It can be seen in Figure 20, page 89, that differences in mean ARTs between groups increase as the frequency of the stimulus increases. This can be attributed to the greater degree of hearing loss in the higher frequencies for the hearing-impaired group, and possibly to a change in the relationship between hearing threshold levels and ARTs at 4000 Hz compared to lower frequencies. Silman and Gelfand (1981), for example, have shown that ARTs increase with increased hearing threshold levels. It should be noted, however, that there is not a 1 dB increase in ARTs for each 1 dB increase in hearing threshold levels. Silman and Gelfand reported that ARTs at 1000 Hz for subjects with hearing threshold levels of 45 dB were approximately 4 dB higher than for the ARTs of subjects with normal hearing. In the present study, the average hearing threshold level of the subjects in the hearing-impaired group at 1000 Hz was 46 dB. Their average ARTs were 5 dB greater than the average ARTs of the subjects in the normally hearing group.

The study by Silman and Gelfand indicated that as the HTL of the subject increases from 0 to 60 dB, the SPL at the ART increases slowly (for frequencies between 500 and 2000 Hz). On this portion of the function, the ART increased approximately 1 dB for every 12 dB increase in HTL. For higher HTLs, the ART increased more rapidly (approximately 2 dB for every 3 dB increase in HTL). Similar results have been obtained by Jerger et al. (1978), Margolis and Fox (1977), Popelka et al. (1976) and Silman and Gelfand (1979). There appeared to be no significant difference among the frequencies examined. The ARTs increased a total of approximately 26 dB at 500 and 2000 Hz, and 22 dB at 1000 Hz as the HTL increased from 0 to 90 dB. As has been pointed out, the results of the present study are within 1 dB of what would be expected from the data of Silman and Gelfand (1981) at 1000 Hz. If the tone frequency has no effect on the relation between ART and HTL, then the results of the present study at 250 Hz and 4000 Hz should also be in agreement with the results of Silman and Gelfand. At 250 Hz, the average HTL of the hearing-impaired group was 35.5 dB and the average ART increased 2.5 dB above that of the normally hearing group. This is in good agreement with Silman and Gelfand. The same trend, however, does not hold at 4000 Hz. At this frequency, the average ART was 6.9 dB higher for the hearing-impaired subjects who exhibited the reflex than for the normally hearing subjects. The average HTL for the hearing-impaired subjects was 45 dB. This difference in ARTs is about 3.0 dB larger than Silman and Gelfand observed at 2000 Hz. That the increase in ARTs with increasing HTLs is greater at 4000 Hz than at lower frequencies has also been shown by

Popelka et al. (1976). These authors found a 12 dB increase in ARTs relative to normally hearing subjects for hearing-impaired subjects with an average HTL of 54.1 dB. According to Silman and Gelfand, only a 5-6 dB increase in the ART would be expected for this level of hearing thresholds. This could indicate that the ART increases at a faster rate with increasing HTLs at 4000 Hz than at lower frequencies and/or the point at which the ART starts to increase more rapidly with increasing HTLs is at a lower level for 4000 Hz than for lower frequencies.

Absence of the reflex at high HTLs. Another difference between 4000 Hz and lower frequencies appears to be the HTL for which the acoustic reflex can no longer be elicited. At 4000 Hz, none of the four subjects with HTLs at or above 65 dB exhibited an acoustic reflex at less than 125 dB SPL. There were three subjects with HTLs at or above 65 dB at 1000 Hz and one subject with an HTL above 65 dB at 250 Hz, but in each of these cases the reflex could be elicited. Therefore, this study is in agreement with Silman and Gelfand in that ARTs can be obtained at frequencies below 4000 Hz for subjects with severe hearing losses of cochlear origin. At 4000 Hz, however, it appears less likely that ARTs can be obtained for subjects with severe cochlear hearing losses. Since the sensation level at which the ART can be measured has some implications for the differential diagnosis between cochlear and retrocochlear hearing losses, further study of the relation between HTL and ART at high frequencies would seem warranted.

Temporal Integration Curves for the ARTs of Normally Hearing Subjects

In this section, the effect of tone duration on the ART will be examined for a constant ISI duration (2000 ms). In a later section, the interaction between tone and ISI duration will be discussed.

Temporal integration curves for ARTs at various frequencies. In Figures 26 through 28 temporal integration curves for the ART have been plotted for the frequencies 250, 1000, and 4000 Hz.

The present study is in accord with Djupesland et al. (1973) in that the slopes of the integration functions at the shorter durations were apparently independent of frequency. The difference in the ARTs for 10- and 50-ms tone durations was 11.0 dB, 11.0 dB, and 10.4 dB at 250, 1000, and 4000 Hz, respectively. At longer durations, however, the temporal integration functions for the ART at the various tone frequencies are different. The difference in ARTs for tone durations of 100 and 1000 ms were 5.0, 6.0, and 10.5 dB at 250, 1000, and 4000 Hz, respectively. This attribute of the temporal integration functions for the ART shown in the present study is also consistent with the findings of Djupesland et al. (1973).

The significant frequency by duration interaction is also consistent with other studies on the effect of frequency on temporal integration in the acoustic reflex mechanism. These studies and the present study have shown that the differences in the ARTs caused by changes in the stimulus duration become more pronounced as the frequency is increased from 250 to 4000 Hz (Barry and Resnick, 1976;

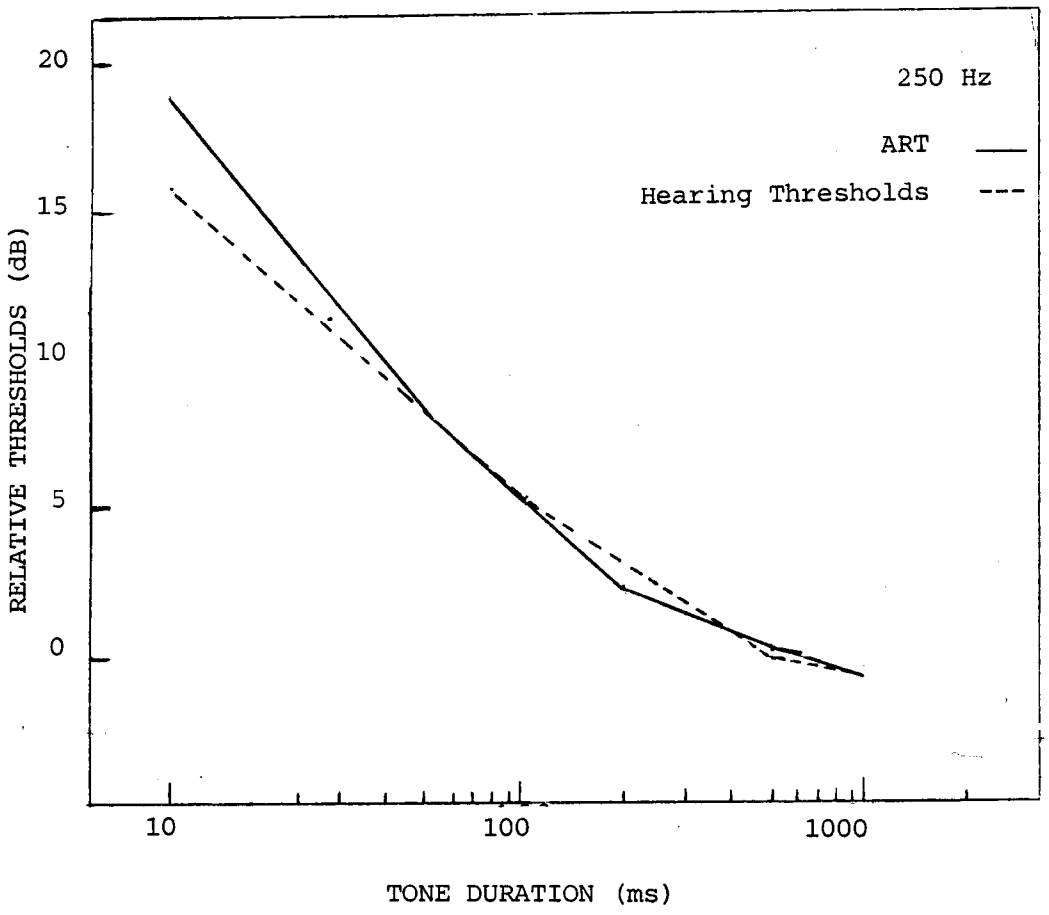

Figure 26. ART and hearing threshold temporal integration curves. The ART curve is represented by the solid line, and the hearing threshold curve is represented by the dashed line. Both curves show the shift in threshold (AR or hearing) with decreasing tone duration relative to the threshold at 1000 ms. Both curves are for normally hearing subjects at 250 Hz. The hearing thresholds are masked thresholds, and have been taken from Nabelek (1978).

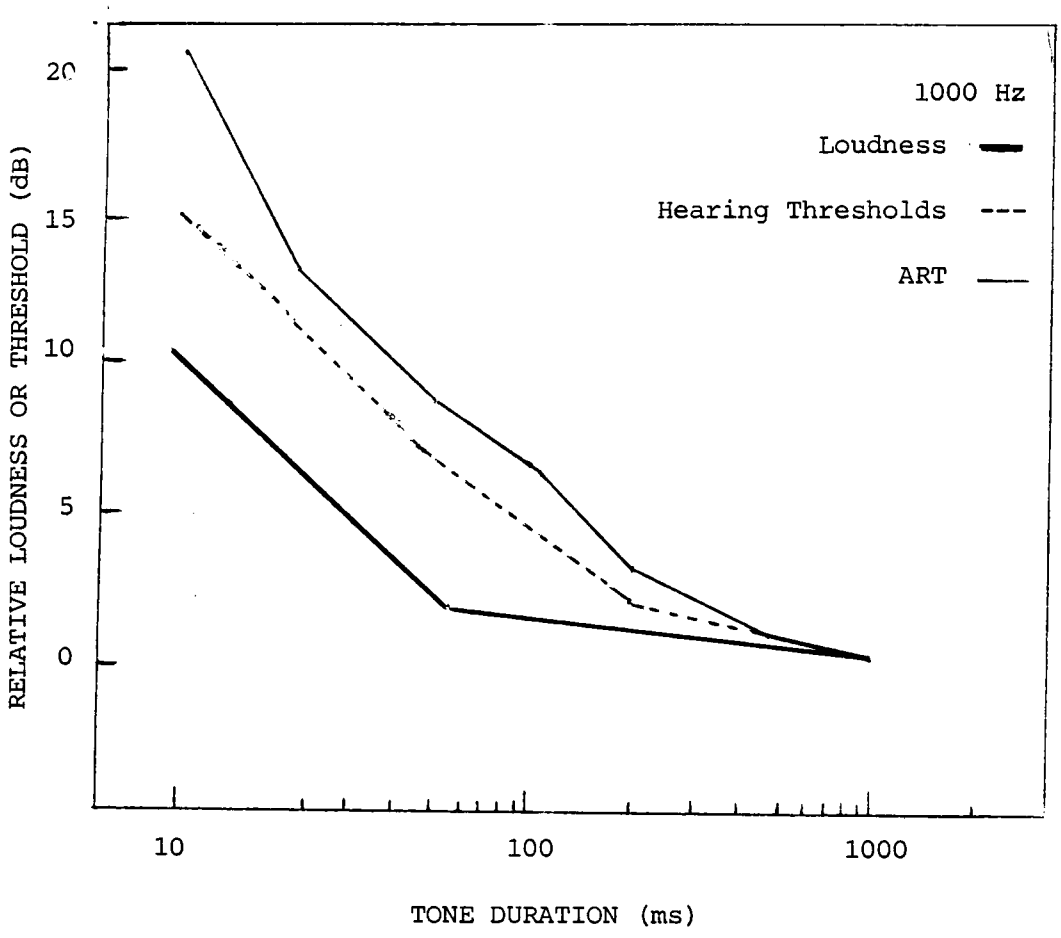

Figure 27. Temporal integration curves for loudness (thick solid line), hearing thresholds (dashed line), and ARTs (thin solid line). The data have been plotted relative to the loudness, hearing threshold, or ART for a 1000-ms tone. All curves are for normally hearing subjects at 1000 Hz. The hearing thresholds are masked thresholds, and have been taken from Nabelek (1978). The loudness temporal integration curve has been taken from Richards (1975).

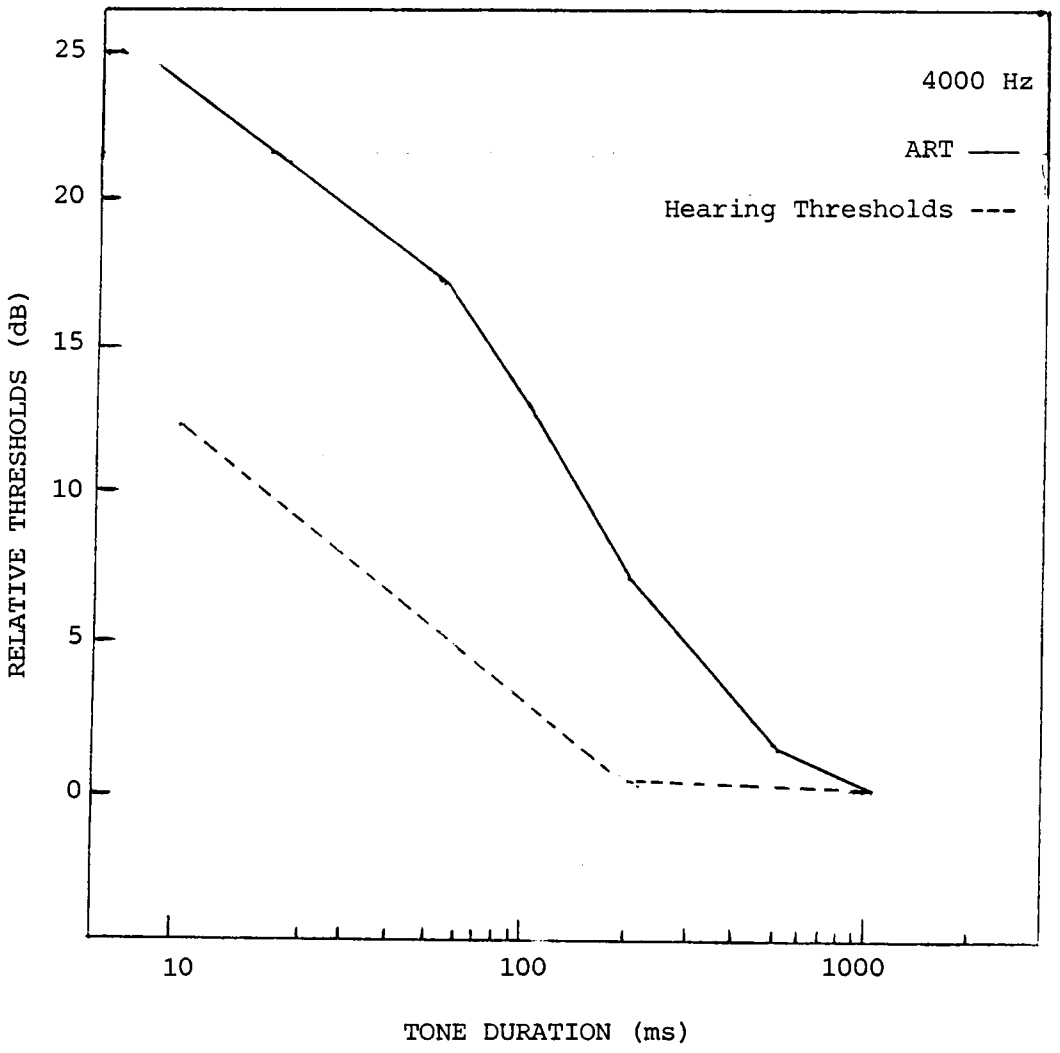

Figure 28. Temporal integration curves for hearing thresholds (dashed line) and ARTs (solid line). The data have been plotted relative to the threshold, either hearing or acoustic reflex, for a 1000-ms tone. Both curves are for normally hearing subjects. The hearing thresholds are masked thresholds at 3300 Hz, and have been taken from Nabelek (1978). The ARTs are for 4000 Hz tones.

Richards, 1975; Richards and Goodman, 1977; Jerger et al., 1977). As the stimulus duration was reduced from 1000 to 10 ms, the ART increased 18.8, 20.2, and 26.7 dB at 250, 1000, and 4000 Hz, respectively.

Comparison of the temporal integration curves for the ART, loudness, and hearing threshold. Barry and Resnick (1976) and Stelmachowicz and Seewald (1977) have compared temporal integration curves for the ART and hearing thresholds. Their conclusions were that the two curves were similar at 500, 1000, and 2000 Hz, indicating that the ART occurs at a constant sensation level for all tone durations. At 4000 Hz, the slope of the ART temporal integration curve was significantly greater than for the hearing threshold temporal integration curve. This indicates that the sensation level at which the ART occurs increases as the tone duration is shortened at 4000 Hz.

In order to compare the results of the present study to results for hearing thresholds, hearing threshold temporal integration curves taken from Nabelek (1978) have been added to Figures 26 through 28. In Figure 27, a curve showing the temporal integration for loudness (Richards, 1977) has also been added.

It can be seen in Figure 27 that the temporal integration curve for loudness is not similar to the temporal integration curve for the ART. When the tone duration is 50 ms or less the SPL has to be increased in order to maintain equal loudness. It can be inferred from this that if all tones were presented at equal SPLs, maximum

loudness would be reached by a tone duration of 50 ms, and would not change for longer durations. The main difference between the temporal integration curves for loudness and the ART, therefore, occurs at durations greater than 50 ms where a constant loudness is maintained by a constant SPL, but where the ART is still decreasing with increasing durations. In the present study, ARTs decreased up to 1000 ms (the longest tone duration tested). Djupesland et al. (1973) found the ART to decrease with increasing stimulus duration up to 3000 ms. That the loudness of a tone does not increase with increases in duration beyond 50 to 100 ms has been consistent across studies (Richards, 1977; Small et al., 1961; Creelman, 1963; McFadden, 1975). It appears, therefore, that the ART does not occur at a constant loudness across tone durations. This is most evident at durations greater than 100 ms.

In Figure 28, it can be seen that at 4000 Hz the temporal integration curves for the ART and hearing threshold are not similar. The slope of the ART function is greater than that of the hearing threshold curve. This is in agreement with Barry and Resnick (1976).

The temporal integration curves for the ART and hearing threshold are most similar at 250 and 1000 Hz (Figures 26 and 27). Although the curves are similar, it does not appear that the ART occurs at a constant sensation level across all tone durations. First, at durations between 10 and 50 ms the slope of the ART function appears to be greater than that of the hearing threshold function. At 250 and 1000 Hz, the slope of the temporal integration

curve for the ART is approximately 15 dB/decade. In Table 13, it can be seen that the slopes between 10 and 50 ms measured in this study are about the average of what has been measured in other studies which have used the ART as a criterion measure. In all but one instance (Barry and Resnick, 1976 at 1000 Hz), the slope on this portion of the curve was measured to be greater than 10 dB per decade. The slope of the hearing threshold temporal integration curve is approximately 10 dB per decade on this segment of the curve (Garner, 1947; Garner and Miller, 1947; Green et al., 1957; Nabelek, 1978). For stimuli less than 10 ms in duration, absolute thresholds do increase at a rate greater than 10 dB per decade (Garner, 1947). This is related to the spread of energy over the frequency domain in the case of short tone durations. If the energy in the stimulus falls outside of certain frequency limits, then it is not integrated. For stimuli less than 10 ms, this occurs, and, therefore, the intensity of the stimulus has to be increased in order to reach threshold. The reason why the slope of the ART function increases for stimuli below 50 ms is not known. It does indicate, however, that for this portion of the function the intensity times duration is not constant. If the tone is shortened, the intensity has to be increased a disproportionate amount.

A second difference between temporal integration curves for ARTs and hearing thresholds occurs at long stimulus durations. There appears to be a divergence of the ART and hearing threshold curves which is more easily seen as the frequency increases. At 250 Hz, the points on the two curves are intermingled until at 50 ms

Table 13. The slopes of ART temporal integration curves in dB/ decade at durations between 10 and 50 ms as measured in various studies.

Study	4000	1000	250-500
Barry and Resnick (1976)	20	7	14
Woodford et al. (1975)	19	15	14
Singh and Greenburg (1976)	15	13	12
Djupesland et al. (1973)	22	22	22
Mason (1983)	14	15	15

the slope of the ART curve increases. At 1000 Hz, the ART and hearing threshold curves diverge at 500 ms, and at 4000 Hz, this occurs at 1000 ms. This difference could be related to the durations at which minimum thresholds are obtained. Hearing thresholds have usually been shown to reach a minimum value by 1000 ms (Plomp and Bouman, 1959; Watson and Gengel, 1969). Nabelek (1978) found that hearing thresholds reached a minimum value at approximately 1000 ms, and then began to increase again for longer durations at 1000 and 2000 Hz. ARTs, however, appear to reach minimum values at durations greater than 1000 ms. Djupesland et al. (1973) found that ARTs continued to be lowered for durations up to 3000 ms, and Morgan et al. (1977) found that the ART did not reach an asymptotic value by 1000 ms.

Another manner by which differences in the temporal integration functions for the ART and hearing thresholds can be shown is by the time constant, τ. Temporal integration implies at least a momentary storage of energy, and the energy storing device is finite in its capacity. The time constant describes this ability to store energy and has been used as a parameter in equations for curves used to fit data.

Estimated time constants for hearing thresholds have shown a wide range. Time constants found by Watson and Gengel (1969) were between 50 and 160 ms, Nabelek's (1978) were between 147 and 278 ms, and Stiegel and Bilger's (1975) were between 200 and 580 ms. In each case, the trend was for the time constant to decrease as the frequency increased.

Nabelek (1978) fit his data using the following equation:

$$L_{th} = 10\log \frac{W(1+a(\tau-t)/t)}{1-e^{-t/\tau}} + L_{ps}$$

In this equation L_{th} is the masked threshold level in dB re $10^{-12}W/m^2$, L_{ps} is the noise spectral level, a is a constant, γ is the time constant, W is the critical bandwidth in Hz, and t is the tone duration. The data in the present study were fitted using the same equation with the exception that W and L_{ps} were omitted since they apply to masked thresholds. The time constants for the ART temporal integration curves were found to be 517 ms at 250 Hz, 786 ms at 1000 Hz, and 1301 ms at 4000 Hz. It appears, therefore, that the time constants for the ART temporal integration curves tend to be longer than for hearing threshold temporal integration curves, and the time constants for the ART curves do not decrease as the frequency increases, but on the contrary, they increase with frequency.

Temporal Integration Curves for the ARTs of Hearing-Impaired Subjects

The interaction between tone duration and groups was found not to be significant. This indicates that as the tone duration is decreased the ART increases in a similar manner for both the normally hearing and hearing-impaired subjects.

It should be pointed out that previous research has not been consistent on this matter. For example, Woodford et al. (1975) found that the temporal integration curves for the ART of subjects with sensorineural hearing loss were flatter than for normally

hearing subjects. Stelmachowicz and Seewald (1977) on the other hand, found no difference between the slopes of the ART temporal integration functions for hearing-impaired and normally hearing subjects.

It appears from looking at the data for individual subjects in the present study that the discrepancies in the results of previous studies may be related to the severity of the hearing losses of the subjects tested. For example, at 1000 Hz subjects 1, 3, and 9 had HTLs of 25, 15, and 25 dB, respectively. The total increase in the ARTs of these subjects as the tone duration was reduced from 1000 to 10 ms (ISI=2000 ms) was +18, +26, and +24 dB, respectively. Subjects 4, 5, and 6 had the most severe hearing losses in the group at 1000 Hz. Their thresholds were 70, 65, and 70 dB, respectively. Under the same conditions, their ARTs shifted +6, +12, and +12 dB, respectively. It appears, therefore, that if a group included only subjects with severe hearing losses, then significant differences could be found between groups. If all the subjects in the hearing-impaired group had mild hearing losses, however, then differences between them and normally hearing subjects would he hard to detect.

Effects of Inter-Stimulus-Interval Duration on the ART

The results of this study indicate that there is a significant difference among ARTs due to the duration of the ISI. As the ISI duration increases, the mean ART also increases (see Figure 19, page 88). The average ARTs are 99.9, 100.1, 102.5, 106.2, 107.3,

107.7, and 108.1 dB for ISI durations of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms, respectively.

These means were derived by averaging across groups, tone durations, and frequencies. Since the relationship among the means for the ISI durations depends upon the group, tone duration, or frequency in question, as evidenced by the significant interactions between ISI effects and these factors, the effects of ISI durations on the ART will be examined within each group, tone duration, and frequency.

In the following sections, it will be convenient to use an abbreviation when referring to a condition with specific tone and ISI durations. The form tone duration-ISI duration will be used. For example, 500-500 would indicate a condition with a 500-ms tone and a 500-ms ISI duration.

The Interaction between ISI and Tone Durations

The ISI duration by tone duration interaction is depicted in Table 11, page 98, and Figures 24 and 25, pages 96 and 97. When the duration of the tone is short, differences in the ART caused by changing the ISI duration are large. The effect of the ISI duration then becomes progressively smaller as the tone duration becomes longer. As the ISI duration increases from 10 ms to 2000 ms, the ART increases 21.8, 15,7, 9.8, 6.2, and 2.3 dB for tone durations of 10, 20, 50, 100, and 200 ms, respectively. At the 500-ms tone duration, the ART increases 0.9 dB as the ISI duration increases from 20 to 2000 ms, and at the 1000-ms tone duration the ART

decreases 0.3 dB as the ISI duration is increased from 50 to 2000 ms. These values are averages which include data from both groups and all frequencies. Since there are no significant three-way interactions, however, the trends should be the same regardless of frequency or group.

Comparison with previous studies on reduced ARTs for repeated short tones. The results shown in Figures 24 and 25, pages 96 and 97, are similar to those of previous studies concerning the ART for repeated tone pulses.

Feldman and Katz (1978) compared ARTs for repeated 1000-Hz tone pulses with 500-ms tone and 500-ms ISI durations and with 30-ms tone and 30-ms ISI durations. The difference in the ARTs for normally hearing subjects under these two conditions was less than 1 dB with the lower ART for the 500-500 condition. In the present study, there was no condition with a 30-ms tone and ISI duration. The closest conditions with a 50% duty cycle were the 20-20 and 50-50 conditions. The ARTs for both these conditions were lower than for the 500-500 condition. The average ARTs were 95.4 dB, 92.8 dB, and 90.6 dB for the 500-500, 50-50, and 20-20 conditions, respectively, at 1000 Hz (see Figures 6 and 7, pages 65 and 66, and Table 3, page 76. Although Feldman and Katz reported the 500-500 condition to have a slightly lower ART than a 30-30 condition and the present data indicate that the ART for the 500-500 condition is somewhat higher, the trends of the studies are similar in that the ART for a short duration tone can be lowered by a significant amount by reducing the

ISI duration. Feldman and Katz compared their data with that of Djupesland et al. (1973). They found that the ART for the 30-30 condition was approximately 23 dB less than the ART Djupesland et al. reported for a 30-ms stimulus. In the study by Djupesland et al. the tones were presented at the rate of one every five seconds. In the present study, the average ART for a 1000-Hz 20-ms tone was reduced 16.6 dB as the ISI duration was shortened from 2000 to 20 ms. It appears from examining Figures 6 and 7, pages 65-66, that the ART for the 20-ms tone could be reduced by any amount within this 16.6-dB range by simply varying the ISI duration. This is also true at each test frequency for tone durations up to 200 ms, although the range of ARTs will vary according to the tone duration (see Figures 4-9, pages 63-68, and Tables 2-4, pages 75-77.

The results of the present study and those of Sesterhenn and Breuninger (1977) indicate that the ART for repeated short tones can be lower than the ART for a long duration tone under certain conditions. Sesterhenn and Breuninger found that ARTs for tone pulses with 75-ms durations and ISI durations of 25 ms were 5 to 8 dB lower than ARTs for continuous tones on the average in the frequency range between 250 and 4000 Hz. As the frequency increased the ART tended to be lowered by a greater amount. In the present study several conditions were found for which the ARTs were consistently lower than those for the 1000-2000 condition by at least 1 dB. At 250 Hz, the ARTs were 103.4, 99.4, 101.2, 101.8, and 101.8 dB for the 1000-2000, 10-10, 10-20, 20-20, and 100-50 conditions, respectively. At 1000 Hz, the ARTs were 93.8, 90.6, 91.2, 90.6, 92.8, and 92.2 for

the 1000-2000, 10-10, 10-20, 20-20, 50-50, and 100-50 conditions, respectively. At 4000 Hz, the ARTs were 94.4, 90.4, 93.1, 91.6, 90.7, 92.9, and 92.9 dB for the 1000-2000, 10-10, 10-20, 20-10, 20-20, 50-50, and 100-50 conditions, respectively. These results indicate that there are several conditions under which the ART for a short duration tone can be lower than for a long duration tone. The conditions which most consistently yielded lower ARTs were 10-10, 10-20, 20-20, and 100-50, with the lowest ART associated with the 10-10 condition at each frequency. Unlike Sesterhenn and Breuninger, the amount which the ART was reduced relative to a 1000-ms tone did not seem related to frequency. For example, under the 10-10 condition ARTs were reduced 4.0 dB at 250 Hz, 3.2 dB at 1000 Hz, and 4.0 dB at 4000 Hz relative to the 1000-2000 condition. The number of conditions under which the ART was reduced, however, did increase with increased frequency. There were four such conditions at 250 Hz, five at 1000 Hz, and six at 4000 Hz. It appears that repeated short duration tone pulses with short ISI durations (especially the 10-10 condition) may be helpful in eliciting the aural reflex in cases where no ART can be obtained for a continuous tone. Since the presence or absence of a reflex is a factor in differentiating cochlear and retro-cochlear hearing loss, this could be an important consideration for audiologists.

ISI durations needed for independent effects of successive stimuli on the ART. Another important question in the study of temporal integration and brief-tone audiometry when using the ART as a criterion measure is how close together in time do the tones have to be before there is an interaction of their effects, and the ART is lowered. This problem has been touched previously by Jerger et al. (1977). They measured the amplitude of reflexes elicited by 500- and 20-ms 1000-Hz tones with ISI durations between 750 and 5000 ms. Within this range of ISIs, there was no change in the amplitude of the reflex. This would indicate that if the ART was defined as a percentage of the maximum response, then there would be no difference in ARTs among these ISI durations. In the present study, it was found that the point at which there is an interaction between the effects of the tones is dependent both on the tone and ISI durations. Referring to Figures 29 and 30 and Table 14, it can be seen that the results of the present study are in agreement with those of Jerger et al. When the ISI duration is 500 ms or more, there is little effect on the ART regardless of the tone duration. As the ISI duration increases from 500 to 2000 ms, the ARTs change +2.3, +1.7, +0.3, +1.6, +1.2, +0.1, and -0.1 dB for the tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms, respectively. It can also be noted that if the tone duration is 500 ms or more, the ART remains approximately constant for all ISI durations. The highest ART for the 500-ms tone is when the ISI duration is 2000 ms (98.6 dB) and the lowest is when the ISI duration is 100 ms (97.7 dB). The highest ART for the 1000-ms tone is when the ISI duration is 100 ms (98.1 dB)

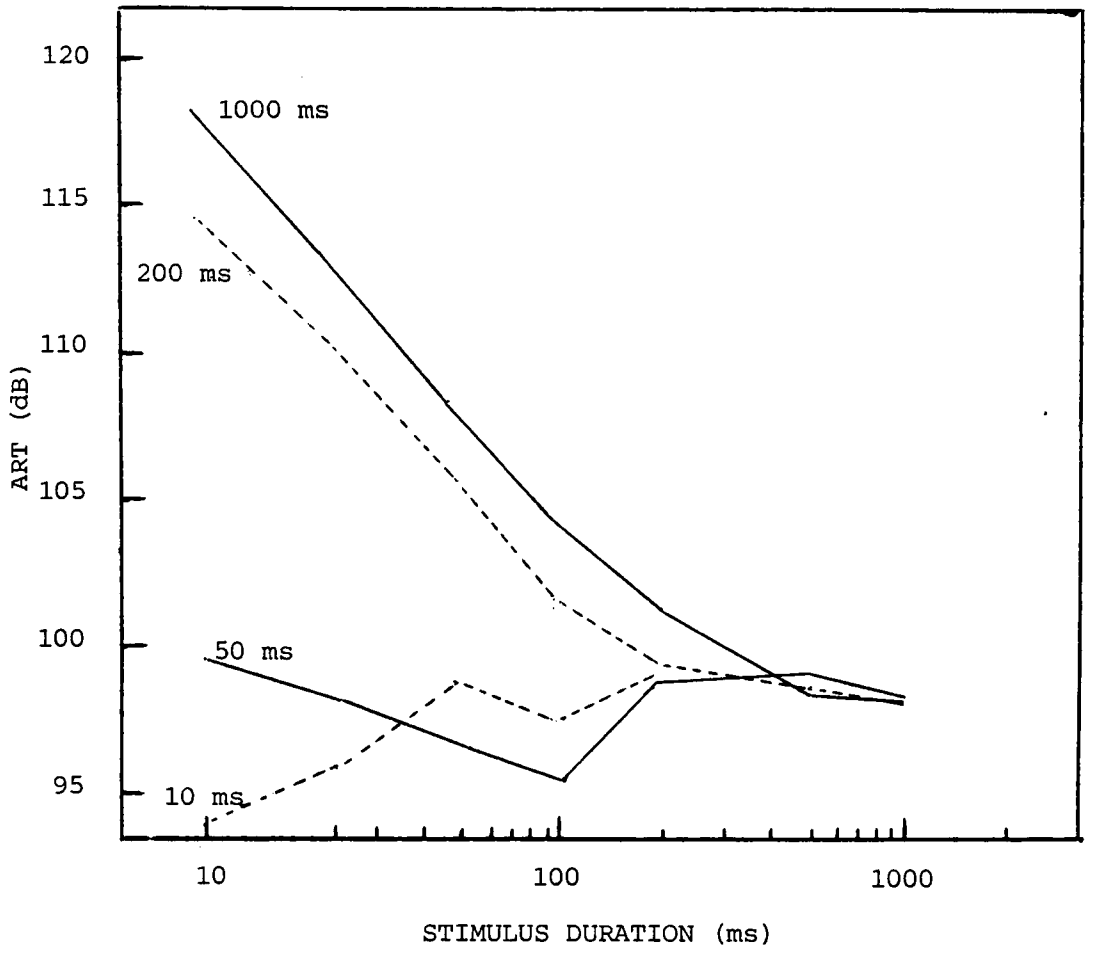

Figure 29. Average ARTs for normally hearing subjects at tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms for inter-stimulus-interval durations of 10, 50, 200, and 1000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval. Data for the tone frequencies 250, 1000, and 4000 Hz have been averaged.

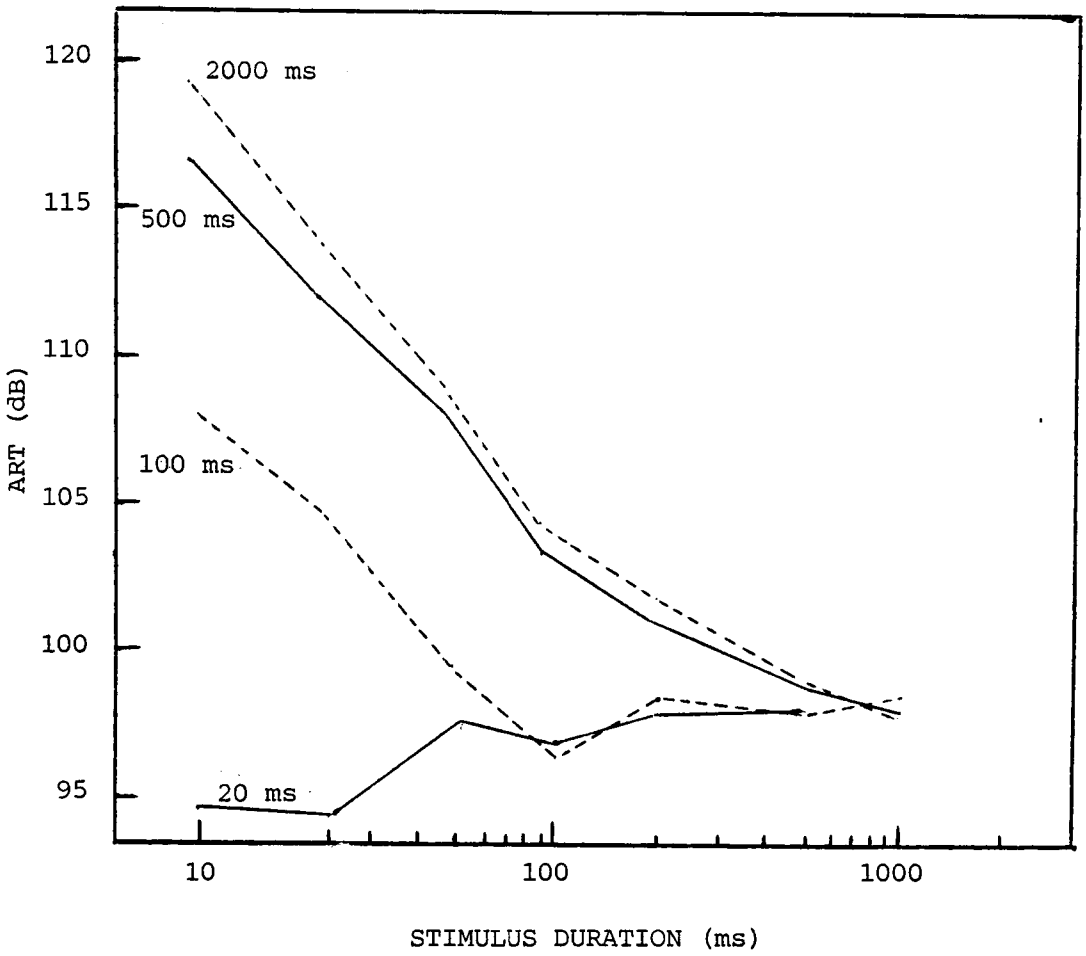

Figure 30. Average ARTs for normally hearing subjects at tone durations of 10, 20, 50, 100, 200, 500, and 1000 ms for inter-stimulus-interval durations of 20, 100, 500, and 2000 ms. Each curve is labeled according to the duration of the inter-stimulus-interval. Data for the tone frequencies 250, 1000, and 4000 Hz have been averaged.

Table 14. The sound pressure levels in dB (re 20 μPa) at which the ART occurred for each test condition. The results for the frequencies 250, 1000, and 4000 Hz have been averaged together. The values are for normally hearing subjects, and correspond to the data points shown in Figures 29 and 30.

ISI Duration (ms)	Tone Duration (ms)						
	10	20	50	100	200	500	1000
10	93.5	96.3	98.3	97.5	98.3	-	-
20	94.7	94.4	97.5	97.0	97.7	97.8	-
50	99.7	98.0	96.9	95.6	98.1	98.3	97.8
100	107.8	104.8	99.6	96.7	98.2	97.7	98.1
200	114.8	110.1	105.1	101.6	99.3	97.9	97.6
500	116.8	112.3	108.0	102.8	100.2	98.5	97.3
1000	118.0	113.7	108.3	104.3	101.1	97.8	97.6
2000	119.1	114.0	108.3	104.4	101.4	98.6	97.2

and the lowest is when the ISI duration is 2000 ms (97.2 dB). Therefore, the range of ARTs for both the 500- and 1000-ms tones are less than 1 dB. There also appears to be no pattern for which ISI durations will have the highest and lowest ARTs when the tone duration is 500 or 1000 ms.

The effects of the ISI duration are most noticeable when the tone duration is short, and the majority of the change in the ART occurs at ISI durations less than 200 ms. At an ISI duration of 200 ms, the average ART for a 10-ms tone was 114.8 dB. The lowest ART for the 10-ms tone was obtained when the ISI duration was 10 ms (93.5 dB). Therefore, between ISI durations of 200 and 10 ms the ART for the 10-ms tone changed 21.3 dB. Between the ISI durations of 200 and 20 ms, ARTs for 20-ms tones were reduced 16.7 dB. Between the ISI durations of 200 and 50 ms, ARTs for 50-ms tones were reduced 8.2 dB. Between the ISI durations of 200 and 50 ms, ARTs for 100-ms tones were reduced 6.0 dB. Between the ISI durations of 200 and 20 ms, ARTs for 200-ms tones were reduced 1.6 dB.

Comparison of ISI effects on the ART, loudness, and hearing threshold level for stimuli of varying duration. The effects of the ISI duration shown in this and previous studies on the ART are similar in some respects and dissimilar in others to the effects of ISI duration on hearing thresholds and loudness. Therefore, some studies pertaining to the effects of ISI duration on hearing thresholds and loudness will be reviewed, summarized, and compared to the results of the present study.

Garner (1947) studied the effects of repetition rate on hearing thresholds. In his study 15-ms tone bursts with frequencies of 250, 1000, and 4000 Hz were used. The subjects had normal hearing. The repetition rate of the tones was varied between 1/4 per second (one every four seconds) and 33 per second (a 50% duty cycle). Garner's results indicated that integration of energy occurs at repetition rates of five per second and greater. This would indicate that an ISI duration of 200 ms or less is needed before integration takes place. For repetition rates greater than five per second, it was expected that the hearing threshold would decrease by a factor of 3 dB when the repetition rate increased by a factor of 2, if the ear was integrating all the energy. For example, if the hearing threshold was 6 dB at a repetition rate of five per second, then the hearing threshold should be 3 dB at a repetition rate of 10 per second. The results indicated, however, that the change in threshold was not that great for repetition rates between 5 and 33 per second. The actual change in hearing threshold was less than 1 dB per doubling of the repetition rate with only a small variation between frequencies. It would seem, therefore, that this method of increasing the total energy is not as efficient in terms of threshold values as is increasing the total duration of a relatively isolated stimulus.

Jerger and Jerger (1966) obtained hearing thresholds using tone durations of 200 ms and ISI durations which varied between 500 ms and 20 ms. For normally hearing subjects, hearing thresholds were found to remain constant regardless of the ISI duration. This

result indicates that there is no interaction among the effects of repeated tones when the tone duration is 200 ms and the ISI is 20 ms or more. The results are in agreement with Garner (1947) since all repetition rates used in this study were less than five tones per second.

Zwislocki (1960) used pairs of 1000-Hz tone bursts with durations of 10 ms in order to measure the sensitizing effect of the first tone burst on the second. The intensity of the first tone burst was 6 dB greater than the second, and threshold measurements were made for the second tone burst. The results indicated that the threshold for the second tone decreased as the ISI duration decreased. A maximum reduction of 3 dB in the hearing threshold was reached at an ISI duration of 200 ms, and the threshold remained at that level for shorter ISI durations (10 ms being the shortest ISI duration used).

Zwislocki (1960) also measured hearing thresholds using 10-ms 1000-Hz tone bursts pairs with each burst being of equal amplitude. When the ISI duration decreased from 1000 ms to 200 ms, the threshold decreased 3 dB. Since this is the same result as when the subject's threshold to the second burst was measured, true integration does not seem to be taking place. If the integration of energy was taking place, the threshold for the pair should be less than for either burst singularly. Between ISI durations of 200 and 5 ms, the hearing threshold for the pair continued to improve, whereas, the threshold for the second burst did not. Over this range of ISI durations, integration seems to be measured, and the 1 dB threshold reduction is

in agreement with Garner (1947). When the 10-ms bursts were separated by a 5-ms ISI, the threshold was approximately 3 dB less than for a single 10-ms tone, and equal to a single 20-ms tone. It can be concluded, therefore, that perfect integration of energy can be accomplished for non-continuous tones if the repetition rate is high.

In summary, it appears that in order for temporal integration for thresholds to occur, the period (tone on-time plus off-time) has to be approximately 200 ms or less. When the tone duration is 200 ms or more, little reduction in the hearing threshold will be observed regardless of the ISI duration. If the ISI duration is greater than 200 ms, some reduction in the hearing threshold, which may not be related to temporal integration, occurs. Garner (1947), for example, attributed the improvement of these thresholds to probability. Since several tones are being presented, the chance of hearing at least one is greater than if only one is presented.

Probability is also a factor in measuring the ART. It is not the probability of the subject hearing the sound, however, but rather the probability of the tester observing a response. When a single tone is presented, the tester has two chances to observe the reflex. The first time is when the tone is presented and the impedance at the ear drum increases, and the second is at the tone off-set when the impedance returns to baseline. When repeated tones are used as stimuli, the aural reflex is more easily observed under some conditions than others. For the 200-200 condition, the meter will swing back and forth rhythmically 10 times during a 4 second period,

and the tester has many chances to observe the reflex. For the 10-10 condition, the impedance change is observed as a continuous deflection on the meter, and the tester has only the on-set and off-set to determine if the reflex has occurred. Therefore, some of the reduction in the ART between ISIs of 2000 and 200 ms may be related to the number of chances the tester has to observe the occurrence of the reflex.

The results of the present study are similar to the results of studies measuring hearing thresholds for repeated short tones in two respects. First, as the tone duration increases the effect of the ISI duration becomes less. Jerger and Jerger (1966) found that hearing thresholds for a 200-ms tone are not affected by the ISI duration. In Figures 29 and 30, pages 122-123, and in the previous discussion, it has been shown that the ART for tone durations of 200 ms could vary as much as 4 dB depending on the ISI duration. All the averaged ARTs for tone durations of 500 ms were within 1 dB. Although it appears that the effects of ISI duration can be seen at longer tone durations in the case of the ART than in the case of hearing thresholds, the trend for reduced ISI effects as the tone duration increases holds for both cases. Second, the effects of ISI duration on short duration tones is most evident when the ISI duration is less than 200 ms. Garner (1947), using a 15-ms tone, concluded that in order for the integration of energy to occur, the tones must be presented at a rate of at least five per second. Garner did see some threshold change for slower repetition rates, but attributed this to the fact that the listener had more chances to detect the tone. In

the present study, the ART for 10- and 20-ms tones was reduced sharply when the ISI duration was less than 200 ms. As can be seen in Figures 29 and 30, pages 122-123, and Table 14, page 124, when the ISI duration was reduced from 2000 ms to 200 ms the ART was lowered 4.3 dB for the 10-ms tone and 3.9 dB for the 20-ms tone. As the ISI was reduced from 200 to 100 ms, the ART was lowered 7.0 dB for the 10-ms tone and 5.3 dB for the 20-ms tone. It appears to be the case in both studies, therefore, that temporal summation of short duration tones, whether measured by hearing thresholds or ARTs, is affected relatively little by the ISI duration when the ISI duration is greater than 200 ms.

The major difference between the results of the present study and those of Garner (1947) or Zwislocki (1960) is that the ART is reduced more than hearing thresholds as the repetition rate is increased. Garner (1947), for example, reported that as the repetition rate was increased from 1/2 to 33 tones per second hearing thresholds for a 15-ms tone were reduced approximately 4.5 dB. In the present study, ARTs for a 10-ms tone were reduced 24.4 dB as the ISI duration was shortened from 2000 to 20 ms. These ISI and tone durations would correspond to approximately the same repetition rates as were used by Garner. For a 20-ms tone under the same conditions, the reduction of the ART was 19.5 dB which is still much larger than reported by Garner for hearing thresholds. These results would indicate that for a given tone duration, the sensation level at which the ART occurs becomes less as the ISI duration is

shortened. This occurs because the ART is being reduced at a greater rate than the hearing thresholds.

The duration of the ISI has also been shown to affect the loudness of tone and noise bursts. As with hearing thresholds and ARTs, the effect of the ISI duration on loudness is greatest within certain time limits. Both temporal summation of loudness and loudness enhancement (or sensitization) have also been demonstrated for non-continuous tones in a fashion similar to hearing threshold levels. A difference between the effects of the ISI duration on hearing thresholds and loudness is that they appear to be greater for loudness than for hearing thresholds. In this regard, the effects of ISI duration on ARTs seem to be more similar to the effects on loudness than the effects on hearing thresholds.

In order to clarify these points, several studies pertaining to the effects of ISI and stimulus duration on loudness will be reviewed and summarized. The results will then be compared to the present study.

Pollack (1958) presented noise bursts with durations between 0.1 and 1000 ms separated by ISI durations of 10 to 3160 ms to normally hearing subjects. The loudness of the repeated noise bursts was compared to the loudness of a continuous noise with a SPL of 82 dB. The results of this study indicated that for each ISI duration, the burst level could be decreased as the duration of the noise burst increased with a slope of 10 dB per decade while maintaining a loudness equal to the 82-dB continuous noise. When the burst duration approached 10% of the total cycle, the interrupted noise was

approximately equal in loudness to the continuous noise at the same burst level. With further increases in burst duration, the relative burst level of the interrupted noise became less than the level of the equally loud continuous noise. Another finding was that there was little change in the loudness of noise bursts of 100 ms or more regardless of the ISI duration.

Garner (1948) conducted a similar study using 1000 Hz tone pulses instead of noise pulses. The tone pulses had durations between 1 and 50 ms, and were presented at rates between 5 and 100 per second. The results of this study indicated that the intensity level of the repeated tone pulses can be consistently decreased as the repetition rate increases, and maintain equal loudness. Therefore, it can be assumed that the loudness increases as the repetition rate increases if intensity is constant. The rate, however, at which the intensity can be decreased, or the loudness increased, changes as a function of the duration of the tone. The shorter the duration of the tone, the greater the rate of change in intensity or loudness. Another point of interest was that under certain conditions the intensity level of the repeated tone pulses was less than the continuous tone when judgements of equal loudness were made. The test conditions for which this occurred were a 1-ms tone with a repetition rate of 100 tones per second, a 5-ms tone with repetition rates of 50 or 100 tones per second, a 10-ms tone with a repetition rate of 50 tones per second, and a 20-ms tone with a repetition rate of 25 tones per second. It is likely that other such conditions could have been found, but the duty cycle of the test conditions never exceeded 50%.

A final aspect of this study indicated that when the duty cycles of two conditions were equal, the condition with the shorter tone duration and higher repetition rate would be louder.

In addition to temporal integration of loudness, another phenomenon which occurs with repeated tones has been termed loudness enhancement. The difference between loudness enhancement and temporal integration of loudness can be seen when the judgements required of the listener are compared. If a pair of tones separated by some ISI duration are presented to a listener, and he judges the loudness of the pair to be greater than the loudness of a standard tone of equal intensity then temporal integration has occurred. The loudness of the pair is greater than the loudness of either of the tones separately. Loudness enhancement occurs when the second tone in the pair is judged to be louder than the standard tone. In this case, the loudness of the pair may not be louder than each of the tones individually.

Studies on loudness enhancement such as Irwin and Zwislocki (1971), Zwislocki and Sokolich (1974), and Zwislocki et al. (1974) indicate that the loudness level of the second tone in a two-tone pair can be enhanced as much as 3 dB when the tones in the pair are equal in frequency, intensity, and duration. Loudness enhancement is greatest when the time interval between tones is 50 to 200 ms, although some enhancement can be seen when the ISI duration is as long as 500 ms. Zwislocki and Sokolich also found that if the first tone (the conditioning tone) of the pair is at 60 dB and the second tone is at 40 dB, then the enhancement can be as much as 12 dB.

In summary, these studies on the loudness of repeated stimuli seem to indicate that the ISI duration is an important factor in determining the loudness of the stimuli. How much the loudness is increased is determined by the specific conditions under which the stimuli are presented. When the duration of the stimuli is greater than 100 ms, the ISI duration has essentially no effect. As the duration of the stimuli is reduced, the effect of the ISI duration becomes greater. The loudness of stimuli with durations less than 100 ms can be affected by increases in the ISI duration beyond 1000 ms. When the loudness of repeated stimuli is compared to a continuous stimulus, they are judged to be equally loud at equal intensity levels when the stimulus duration is approximately 10% of the total duration of the cycle. For example, repeated 10-ms stimuli with ISI durations of 90 ms (the duration of the cycle would then be 100 ms) at 80 dB would be judged approximately equal in loudness to an 80-dB continuous stimulus. When the duration of the stimuli becomes a greater percentage of the cycle duration, then the repeated stimuli can be judged louder than a continuous stimulus of equal intensity. This is especially true for short duration tones. The results of studies using repeated stimuli are probably affected both by temporal summation of loudness and loudness enhancement. How much of the results can be attributed to each is unknown since the effects are confounded. It would be interesting, however, to measure the loudness enhancement over 3, 4, or 5 tones, and see if a single tone in the series would approach the loudness of a long series of tone bursts.

In order to compare the effects of ISI duration on loudness and the ART, results from Pollack (1958) and the present study have been plotted in Figure 31. The ARTs plotted in this graph are for normally hearing subjects averaged across frequencies. The points from Pollack's study are indicative of the loudness of repeated noise bursts determined by normally hearing listeners.

It can be seen from this comparison that the curves for the ART and loudness are generally dissimilar. The ART and loudness curves are most similar when the ISI is 10 ms. The ARTs for stimulus durations between 10 and 200 ms are equal to or lower than ARTs for the 1000-2000 condition when the ISI is 10 ms. The ARTs on this curve also tend to become lower as the tone durations are shortened. The loudness curve for the 10-ms ISI shows that the burst levels for repeated stimuli are less than or equal to the level of an equally loud continuous noise, and the relative burst level decreases as the burst duration decreases.

The loudness and ART curves for ISIs of 100 and 1000 ms are different. For an ISI of 1000 ms, the ART increases gradually as the tone duration is reduced from 1000 to 200 ms. For still shorter durations, there is a sharp increase in the ART. The total increase in the ART as the tone durations decreased from 1000 to 10 ms was 20.4 dB. The loudness of repeated stimuli with ISI durations of 1000 ms, however, remained constant with an approximately constant burst level as the burst duration was reduced from 1000 to 100 ms. For shorter burst durations, the level of the stimuli had to be increased in order to maintain equal loudness. As the burst duration

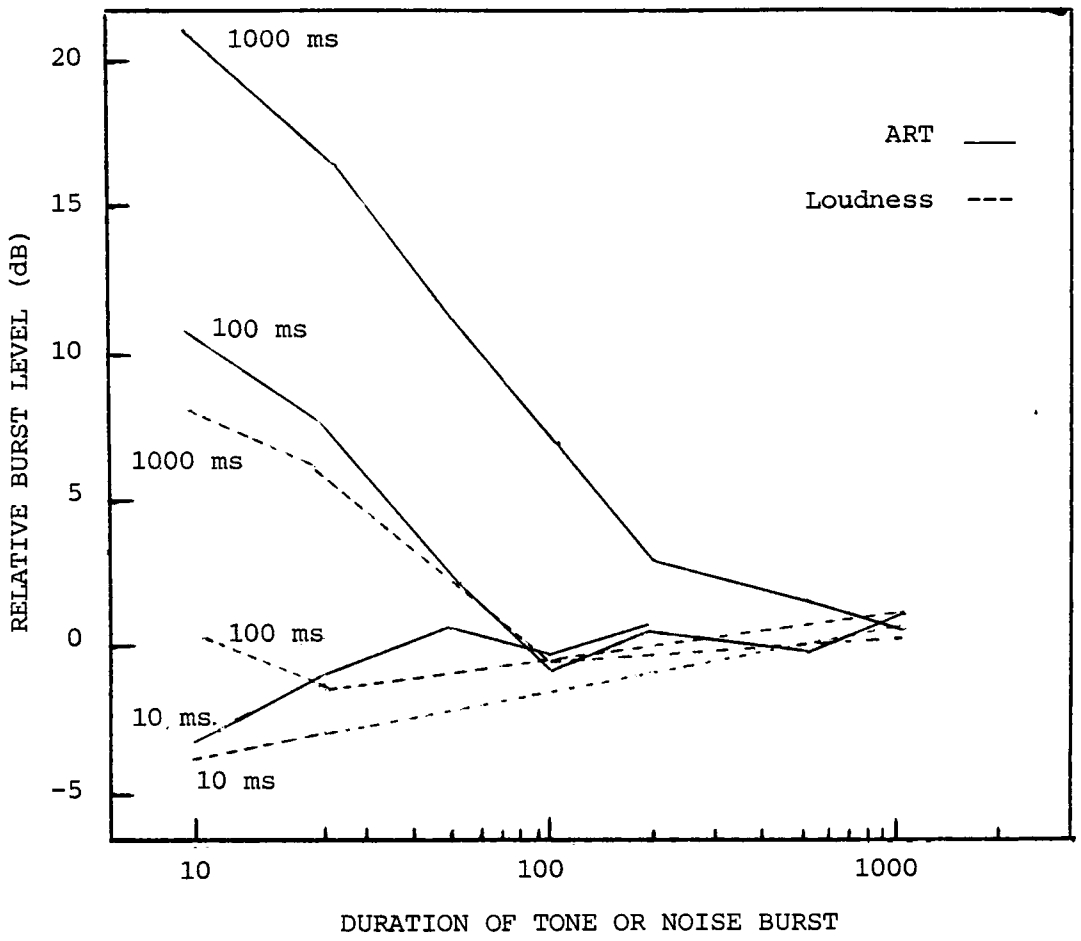

Figure 31. Equal loudness contours for repeated white noise bursts are shown by the dashed lines. Each curve is labeled according to the duration of the inter-stimulus-interval. These equal loudness contours have been taken from Pollack (1958). The solid lines show the acoustic reflex thresholds for repeated tone bursts. The reflex thresholds are plotted relative to the reflex threshold for repeated tone bursts with 1000-ms tone and inter-stimulus-interval durations. These curves are also labeled according to the inter-stimulus-interval. All data are for normally hearing subjects. The acoustic reflex data are averaged across the tone frequencies of 250, 1000, and 4000 Hz.

was decreased from 100 to 10 ms, the burst level had to be increased about 8.0 dB in order to maintain equal loudness. As the burst duration decreased from 100 to 10 ms, the ART increased approximately 13 dB. For an ISI duration of 100 ms, the burst level of the repeated stimuli never varied more than 2 dB from the level of a continuous noise while maintaining equal loudness as the burst durations of the repeated stimuli were reduced from 1000 to 10 ms. For burst durations between 1000 and 100 ms the curve for the ART is similar to the curve for loudness in that the ART also remained approximately constant. For shorter burst durations, however, while the loudness remained constant at a constant burst level, the ART increased at a rate of approximately 10 dB per decade.

In the case of both loudness and the ART, the effect of the ISI duration appears greatest at short burst durations. For a burst duration of 10 ms, the burst level needed for equal loudness changes approximately +12 dB as the ISI duration is reduced from 1000 to 10 ms. The change in the ART under the same conditions is +25.6 dB. When the burst duration is 100 ms, equal loudness is achieved for ISI durations between 10 and 1000 ms in a range of burst levels of about 3 dB. This range is reduced to 1-2 dB when the burst duration is 1000 ms. With burst durations of 100 ms, the range of ARTs is about 7 dB. Similar to loudness, the range of ARTs is small when the burst duration is 1000 ms, approximately 1 dB.

Summary. In summary, the effects of tone and ISI duration are different among hearing thresholds, loudness, and ARTs. The ART appears to be more sensitive to changes in ISI or tone duration than either hearing threshold or loudness. The differences in ARTs with changes in tone or ISI duration are greater than the differences in loudnesses or hearing thresholds. The range of tone or ISI durations which affect the ART is also greater than for loudness or hearing thresholds. It can be concluded, therefore, that the ART occurs at neither a constant loudness nor a constant sensation level re hearing threshold. What does trigger the reflex is unknown, needing further research. Some possibilities are the subject's threshold of discomfort, and the waveform of the stimulus. McCandless and Miller (1972) and McCandless (1975) reported that the reflex occurs at approximately the same level as where the subject reports discomfort. Margolis and Popelka (1975) stated that the differences in ARTs for wide-band noise and tones may be related to the peak factor (ratio of peak sound pressure to rms sound pressure) which is generally greater for wide-band noise than for tones or narrow-band stimuli. The apparent differences between ARTs and intensity and loudness could also be a product of the means by which we measure the reflex. EMG studies on the stapedius muscle could possibly show a different relationship between the ART and loudness or intensity.

The Interaction Between ISI and Groups

Differences between the ARTs of normally hearing and hearing-impaired subjects as a function of the ISI duration. The interaction between ISI duration and groups has been shown to be significant. The ARTs at each ISI duration are shown in Figure 21, page 90, for each group. These ARTs are averaged data for all tone frequencies and durations. The trend shown in this figure is for the difference in ARTs between groups to increase as the ISI duration is decreased. The differences in ARTs between groups are 4.0, 3.7, 4.4, 4.9, 6.2, 7.0, 7.3, and 6.1 dB at the ISI durations of 2000, 1000, 500, 200, 100, 50, 20, and 10 ms, respectively. At each ISI duration, the ARTs for the hearing-impaired subjects were higher than for the normally hearing subjects.

In a previous section, it has been shown that the ARTs for short duration tones are reduced as the duration of the ISI decreases. As the duration of the tone increases, the effect of the ISI on the ART becomes less until at tone durations of 500 and 1000 ms the ART remains approximately constant regardless of the ISI duration. Therefore, the increased difference between groups indicates that ARTs for short duration tones are reduced more when the ISI duration decreases in the case of normally hearing subjects than in the case of hearing-impaired subjects.

The research of Felman and Katz (1978) supports this interpretation. These authors found that the ARTs for 1000-Hz tones with 30-ms on- and off-times and 500-ms on- and off-times were

approximately equal (less than 1-dB difference) for both normally hearing and hearing-impaired subjects. When this relationship between the ARTs for 30-ms and 500-ms tones are compared to the relationship that exists when the ISI is several seconds in duration, it is evident that the ART for the 30-ms tone has been reduced as much as 25 dB (Djupesland et al., 1973). Other studies (e.g. Woodford et al., 1973 and 1975) have indicated that the differences in ARTs between 30- and 500-ms tones is greater for normally hearing than for hearing-impaired subjects. According to Woodford et al. (1975), the difference in ARTs between 30- and 500-ms tones would be approximately 30 dB for normally hearing subjects and 10 dB for hearing-impaired subjects. Since ARTs were equal in the 30-30 and 500-500 conditions for both normally hearing and hearing-impaired subjects in the study by Feldman and Katz, it is likely, therefore, that the ART for the 30-ms tone was reduced more for the normally hearing subjects than for the hearing-impaired subjects.

The correlation between differences in ARTs across ISI durations and hearing threshold levels. In the preceding section, the significant interaction between ISI duration and groups was attributed to a greater difference in ARTs across ISI durations for hearing-impaired subjects than for normally hearing subjects at short durations. In order to investigate this further, the correlation between hearing threshold levels and differences in ARTs for tones of the same duration but different ISI durations was calculated using the data obtained in the present study. The correlation was

calculated at each test frequency (250, 1000, and 4000 Hz). The first factor was the hearing threshold level of each subject. The second factor was the difference in the ARTs of each subject between the 10-10 and 10-2000 conditions. The Pearson Product-Moment Correlations (Bruning and Kintz, 1968) were r-0.47 at 250 Hz, r-0.68 at 1000 Hz, and r-0.73 at 4000 Hz. Each of these correlations was significant at an alpha level of 0.05. The negative correlations indicate that subjects with high hearing threshold levels tended to have small differences between ARTs for 10-ms tones with ISI durations of 10 and 2000 ms, and as the hearing threshold levels approached normal the difference in ARTs became larger.

An explanation for the group by ISI interaction based on temporal integration. The reduction in the ART which is seen as the ISI duration is shortened is probably related to temporal integration. In studies already reviewed, it has been shown that temporal integration can occur at hearing threshold when the stimulus is not continuous. Therefore, explanations of why temporal integration curves are flatter for hearing-impaired subjects than for normally hearing subjects may also be useful in explaining differences in the ART-ISI functions for the two groups.

Wright's (1968) explanation of why temporal integration curves are different for normally hearing subjects and hearing-impaired subjects is based on adaptation. Wright states that measured threshold values as a function of duration can be influenced by the peripheral hearing mechanism and the central hearing mechanism, With the term

peripheral hearing mechanism, he seems to be referring to processes by which an acoustic event is transformed to a neural event and transmitted to the central hearing mechanism. With the term central hearing mechanism, he seems to be referring to the area in the central nervous system where the physiological process of temporal summation occurs. Wright assumes that in the case of cochlear hearing loss the central hearing mechanism is not disturbed, and differences between hearing-impaired and normally hearing subjects in measured threshold values as a function of duration must be caused by the impaired peripheral hearing mechanism. He states that what appears to happen is a rapid peripheral adaptation which reduces the input to the integrating mechanism. This would imply that differences between normally hearing and hearing-impaired subjects would become more apparent as the stimulus increased in duration.

If differences in ARTs between normally hearing and hearing-impaired subjects are due to a reduced input to the integrating mechanism caused by adaptation, then their thresholds for the acoustic reflex should be equal under conditions where no adaptation occurs. Such a condition would require (1) a short duration stimulus (shorter than the time needed for onset of adaptation) and (2) a slow repetition rate since both neural (Peake, 1964a, b) and psychoacoustic (Carterette, 1955) measurements have shown that adaptation increases as the repetition rate increases. The condition in the present study that best meets these requirements is the one with a 10-ms tone and a 2000-ms inter-stimulus-interval duration. Under this condition the average ART of the normally

hearing group was 119.1 dB, and the average ART of the hearing-impaired group was 119.2 dB. As the repetition rate increases, adaptation increases, and the ARTs for the two groups should separate. The ARTs for the hearing-impaired group would be expected to remain relatively high and the ARTs for the normally hearing subjects would be reduced. For the condition with a 10-ms tone duration and a 200-ms inter-stimulus-interval duration, the average ART for the hearing-impaired subjects was 115.7 dB, and the average ART for the normally hearing subjects was 114.8 dB. As the repetition rate was further increased so that the 10-ms tone was paired with a 10-ms inter-stimulus-interval, the average ART for the hearing-impaired group was 101.1 dB, and the average ART for the normally hearing group was 93.5 dB. These data, therefore, follow a pattern which would be predicted by Wright's theory on why temporal integration curves are flatter for hearing-impaired subjects than for normally hearing subjects.

Although the data in the present study follow a pattern which would be expected from Wright's explanation of temporal integration curves for subjects with cochlear type hearing losses, other evidence would indicate that the explanation may not be correct. First, in the majority of cases, subjects with sensorineural hearing loss do not show any adaptation or decay of the acoustic reflex (Colletti, 1974). Second, subjects with VIIIth nerve lesions, who do show abnormal tone decay, have temporal integration curves for hearing thresholds similar to normally hearing subjects (Sanders et al., 1969).

The Interaction between ISI and Frequency

The interaction between ISI and frequency is shown in Figure 22, page 92. The values at 250 Hz, which were averaged across groups and tone durations were 104.5, 105.1, 105.9, 107.9, 110.0, 110.6, 111.1, and 111.5 dB at ISIs of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms, respectively. At 1000 Hz, the values were 96.5, 96.1, 97.3, 99.2, 101.2, 102.5, 103.1, and 103.3 dB at ISI durations of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms, respectively. At 4000 Hz, the values were 98.5, 99.2, 100.5, 103.3, 107.3, 108.8, 108.7, and 109.5 dB at ISI durations of 10, 20, 50, 100, 200, 500, 1000, and 2000 ms, respectively.

It can be seen in Figure 22 that the curves for 250 and 1000 Hz are approximately parallel. The significant interaction between ISI and frequency comes about because the values at 4000 Hz are more similar to the values at 1000 Hz for short ISI values (100 ms and less), and more similar to the values at 250 Hz for long ISI durations (200 ms and greater).

At short ISI durations, it has been shown that tone duration has little effect, the ARTs at short tone durations being similar to those at long tone duration. Therefore, when averages are made across tone durations, the difference between frequencies remains approximately constant. When the ISI reaches 200 ms, greater differences in the ARTs are seen across tone durations. At 4000 Hz, the increase in the ART as the tone duration is shortened is greater than at 1000 or 250 Hz. Therefore, when the ARTs for all tone durations

are averaged, the resulting value will increase more rapidly for 4000 Hz data than for 250 or 1000 Hz data.

The Relation between the ART and Temporary Threshold Shift

Karlovich et al. (1977), Karlovich et al. (1972) and Karlovich and Wiley (1974) have studied the effect of the acoustic reflex on temporary threshold shift. Hearing thresholds were obtained at 1000 Hz, and then the subjects were exposed to a continuous 1000-Hz tone at 110 dB for three minutes. Post-exposure thresholds were then obtained at 1000 Hz, and the difference between these thresholds and the pre-exposure thresholds were measured. During exposure to the 1000 Hz tone, a broad band noise at 100-dB SPL was presented to the contralateral ear according to one of the following patterns: (1) continuous; (2) pulsed with a repetition period between 9 ms and 40 s. A 50% duty cycle was employed in conditions where the noise was pulsed. A control condition was also included in which no noise was presented. Apparently, the addition of the noise increased the activity of the stapedius muscle, although this was not measured. The results indicated that the temporary threshold shifts were significantly less when the repetition period was 180 or 360 ms than for any other condition. Temporary threshold shifts among the continuous and control conditions and the condition where the repetition period was 9 ms were not significantly different.

These results are not what would be expected from the data in the present study. The authors did not measure the ARTs for the various pulsed conditions, but from the present study, it would be

expected that the 9-ms condition would have the lowest ART. Since the pulsed noise was presented at a constant level, the noise in the condition with the 9-ms repetition period would be presented at the greatest sensation level re ART. Therefore, if it can be assumed that the growth of the reflex is the same for all conditions, the impedance change associated with the 9-ms condition should be the greatest, and afford the greatest protection from threshold shift.

Since conditions where the ART would be expected to be higher than the 9-ms condition afforded the best protection from temporary threshold shift, the results of studies by Karlovich and others probably can not be explained by the relative ARTs of the various conditions. An alternative explanation would be based on the changes that occur during the pulsing of the stimulus. For the 9-ms condition, the pulsing is too rapid for the reflex to follow and would likely decay in a similar fashion to a continuous noise. Within approximately 75 s the impedance change would be expected to decay to about half its original value (Wilson et al., 1978). Therefore, for the majority of the exposure time, the reflex would give little protection. The reflex for the 180- and 360-ms conditions may not decay as fast, in fact the impedance change during the tone on-times may increase over time as Wiley and Karlovich (1978) have shown for a 1-s repetition period. Another advantage for the 180- and 360-ms periods would be that the reflex would not return to baseline during the off-times (Norris, 1976). For longer periods, the reflex would return to baseline during the off-times, and the ear would receive little protection during that time.

Predicting Hearing Status from Differences between ARTs for Various ISI-Tone Duration Conditions

Individual data from the present study were evaluated in order to investigate the ability to classify subjects as normally hearing or hearing-impaired according to differences in ARTs for conditions with various ISI and tone durations. The differences in ARTS between the 10-2000 and 10-10 conditions were calculated to determine the status of hearing using ISI information, and the differences between the 10-2000 and 1000-2000 conditions were calculated to determine the status of hearing using tone duration information. The cut-off values at each frequency used to classify a subject as hearing-impaired or normally hearing were chosen so that the greatest number of correct classifications were made. These values were 18 dB for ISI data and 16 dB for tone duration data at 250 Hz, 16 dB for both ISI and tone duration data at 1000 Hz, and 24 dB for ISI data and 22 dB for tone duration data at 4000 Hz. Hearing thresholds of 25 dB or more were considered impaired and 20 dB or less normal. The results are shown in Tables 15 and 16.

Probably the most grievous error an audiologist could make when trying to classify the hearing status of a subject using ART data would be to say a person has normal hearing when he actually has impaired hearing since treatment would then be withheld. The overall results indicated this type of error occurred six times (22%) when classifications were made according to the ISI and three times (11%) when classifications were made according to the tone duration. Both results are considerably poorer than the 4% error reported by Jerger

Table 15. Matrices indicating predictions of hearing status and actual hearing status for subjects at 250, 1000, and 4000 Hz using inter-stimulus-interval data.

	Predicted Status					
	250 Hz		1000 Hz		4000 Hz	
Actual Status	Normal	Impaired	Normal	Impaired	Normal	Impaired
Normal	7	4	11	0	9	2
Impaired	2	7	4	5	0	9

Table 16. Matrices indicating predictions of hearing status and actual hearing status for subjects at 250, 1000, and 4000 Hz using tone duration data.

	Predicted Status					
	250 Hz		1000 Hz		4000 Hz	
Actual Status	Normal	Impaired	Normal	Impaired	Normal	Impaired
Normal	7	4	8	3	7	4
Impaired	1	8	2	7	0	9

(1975). The error reported by Jerger, however, was what he considered significant error. A significant error would be when a person has at least a moderate degree of hearing loss and is classified as normal. All errors where impaired hearing was classified as normal in the present study were limited to five subjects. Three of the six errors made when using ISI data and all three errors using tone duration data occurred at frequencies where the subjects' hearing thresholds were 25 dB. The remaining three errors were made where hearing thresholds were between 35 and 60 dB. This indicates that the errors were made generally when the subjects' hearing losses were mild. Also an interesting similarity among these subjects was that four of the five subjects for whom errors were made had flat (HTL at 4000 Hz was less than or equal to 15 dB greater than at 250 Hz) or positively sloping (HTLs decreased as the frequency increased) audiograms, and the fifth subject had a flat audiogram up to 3000 Hz (the error made in his case was at 250 Hz) with a precipitous drop in hearing thresholds at 4000 Hz and above. Of the five hearing-impaired subjects for whom no errors were made, all had sloping audiograms (HTLs increasing at least 10 dB between 250 and 1000 Hz, and at least 25 dB between 250 and 4000 Hz).

A problem with methods which compare ARTs for broadband noise and tones in order to predict hearing status is that a large number of normally hearing subjects are classified as hearing impaired (false positives). Keith (1975) evaluated the method of Niemeyer and Sesterhenn (1974), the weighted formula of Jerger et al. (1974), and the unweighted formula pf Jerger (1975). The percentage of false

positives was 23.1% for Niemeyer and Sesterhenn's method, 15.5% for Jerger's unweighted formula, and 32.7% for Jerger's weighted formula. In the present study, when data from all frequencies were combined, false positive errors were made in 18% of the cases when ISI data were used and in 33% of the cases when tone duration data were used.

It appears from this comparison that comparing ARTs for stimuli that vary in the temporal domain can be as effective for predicting hearing status as comparing ARTs for tones and noise. Further investigation with a larger sample would seem warranted.

CHAPTER V

SUMMARY AND CONCLUSIONS

A. SUMMARY

The purpose of this study was to investigate the effects of stimulus frequency, stimulus duration, inter-stimulus-interval duration and hearing status on the ART. The interactions between and among these parameters were also studied.

ARTs were obtained on 10 normally hearing and 10 hearing-impaired subjects. Data were obtained on each subject for seven stimulus durations (10, 20, 50, 100, 200, 500, and 1000 ms), eight inter-stimulus-interval durations (10, 20, 50, 100, 200, 500, 1000, and 2000 ms), and three frequencies (250, 1000, and 4000 Hz). ARTs were obtained for each possible condition except the stimulus duration-ISI duration pairs 1000-10, 1000-20, and 500-10 at each of the three frequencies. The total number of conditions, therefore, was 159.

An analysis of variance indicated significant differences between groups of subjects, among frequencies, stimulus, and ISI durations. Significant interactions were also found between groups and frequency, groups and ISI duration, frequency and ISI duration, frequency and tone duration, and tone duration and ISI duration.

B. CONCLUSIONS

The following conclusions were drawn from the data:

1. ARTs for hearing-impaired subjects occur at a higher SPL than for normally hearing subjects. ARTs increase less than 1 dB, however, for each 1 dB increase in the subject's hearing threshold level. This indicates that the ARTs occur at a lower sensation level for the hearing-impaired subjects than for the normally hearing subjects.

2. For the three test frequencies, ARTs are lowest when the tone frequency is 1000 Hz, and increase at 4000 and 250 Hz, respectively. The ARTs across frequencies occur neither at a constant sensation level nor a constant loudness.

3. The ART temporal integration function (with an ISI of 2000 ms) is generally different from temporal integration functions for loudness or hearing thresholds. The temporal integration curves for the ART and hearing threshold are more similar at 250 Hz than at either 1000 or 4000 Hz. The temporal integration curve for the ART at 250 Hz does not diverge from the temporal integration curve for hearing threshold until the stimulus duration is 50 ms or less. As the frequency of the stimulus increases, the divergence of the two curves occurs at longer stimulus durations. When the two curves diverge, the sensation level of the ART increases. The time constant also differentiates the ART and hearing threshold temporal integration curves. The time constants for thw ART curves are generally greater than for the hearing threshold curves. Also, whereas the time

constant decreases with increasing frequency for hearing thresholds, the time constant increases with increasing frequency for the ART curves.

4. The ART for tones of short durations depend on the duration of the ISI between them. The ART tends to decrease with decreasing ISI duration. The amount of this reduction depends on the tone duration. It decreases as the tone duration increases, until at tone durations of 500 and 1000 ms all ARTs, regardless of the ISI duration, are within 1 dB. The lowering of the ART for short tone durations with decreasing ISI durations causes the ART temporal integration curves to become flatter as the ISI decreases.

The reduction in the ART with decreasing ISI durations does not appear to be closely related to reductions in hearing thresholds or increased loudness under similar conditions.

5. The ARTs for short duration tones coupled with short duration ISIs can be lower than for long duration tones. The condition with 10-ms tone and 10-ms ISI durations had the lowest ART.

6. The difference in the ARTs for 10-ms tones with ISIs of 2000 and 10 ms is negatively correlated with hearing thresholds. As the hearing threshold level of the subject increases, the amount that the ART is reduced with the shortening of the ISI decreases. This relationship becomes more apparent as the frequency increases.

7. From the comparisons made in this study among the ART, intensity, and loudness, conclusions on what physical or psychological parameter triggers the AR can not be made.

C. IMPLICATIONS FOR FURTHER RESEARCH

The following topics are suggested for further research:

1. It is likely that there is some attribute of a sound stimulus or a psychological response to the stimulus that is closely related to the triggering of the acoustic reflex. In this study and previous studies, intensity and loudness have been examined, but these parameters have not been found to be constant at the ART. Future investigators may want to look at the relation between the ART and other parameters. For example, if the acoustic reflex is a protective mechanism, then it may be triggered by the level of discomfort aroused by the stimulus.

2. This study has shown a relationship between ART shifts for short duration stimuli with long and short ISI durations and hearing threshold levels. Further investigation into this topic with a larger number of hearing-impaired subjects would seem warranted to see how well the severity of hearing loss could be categorized according to the differences in the ART. A comparison with other methods which predict HTLs from analyzing ARTs could also be done.

3. Time constants have seldom been used to describe temporal integration curves for the ART. Rather, slopes, "knee points," and total threshold shifts have been employed. Therefore, fitting models to the ART curves which have the time constant as a parameter may be worthy of study.

4. Previous research has shown that the protective ability of the acoustic reflex (measured by temporary threshold shift of

hearing thresholds) can be increased by using repeated stimuli. The conditions under which the acoustic reflex has its lowest threshold, and conditions which provide the greatest protection do not seem to be closely related. Measures of temporary threshold shift may be affected by the decay of the reflex. A study on the adaptation of the reflex using repeated stimuli would provide more information on this topic.

5. In the present study, repeated tones were presented over a 4-s period. If the tone burst was 10 ms and the repetition period was 20 ms, then the tone burst would be presented 200 times. It appears that under this condition the ART can be reduced 20 dB or more relative to a single 10-ms tone burst. If the burst was only repeated 5 or 10 times, however, it is likely that the reduction in threshold would be less. It would be interesting to see how the ART is affected by the total period when the repetition rate and duty cycle are kept constant.

6. From the data of the present study and that of Silman and Gelfand (1981), it appears that the percentage of subjects demonstrating no AR increases rapidly for frequencies over 1000 Hz. Since the presence or absence of a reflex is important for differential diagnosis of hearing disorders, a study showing the percent of no responses as a function of HTL for high frequencies seems needed.

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APPENDIX

APPENDIX

INDIVIDUAL DATA FOR ALL TEST CONDITIONS

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	104.0	108.0	104.0	106.0	112.0	-	-
20	108.0	110.0	110.0	106.0	114.0	104.0	-
50	110.0	108.0	112.0	108.0	108.0	106.0	108.0
100	120.0	112.0	114.0	112.0	114.0	106.0	108.0
200	118.0	120.0	116.0	116.0	110.0	108.0	106.0
500	120.0	120.0	118.0	118.0	108.0	106.0	108.0
1000	122.0	118.0	118.0	118.0	108.0	108.0	110.0
2000	122.0	120.0	118.0	118.0	112.0	106.0	108.0

Subject: 1
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	86.0	88.0	88.0	88.0	90.0	-	-
20	88.0	92.0	86.0	88.0	90.0	88.0	-
50	90.0	90.0	90.0	88.0	88.0	88.0	88.0
100	100.0	92.0	94.0	88.0	88.0	86.0	90.0
200	102.0	100.0	96.0	92.0	92.0	86.0	88.0
500	106.0	102.0	98.0	92.0	92.0	90.0	88.0
1000	108.0	102.0	98.0	92.0	92.0	88.0	90.0
2000	108.0	102.0	98.0	92.0	92.0	90.0	90.0

Subject: 1
Frequency: 1000 Hz

Figure 1-A. Individual data for all test conditions.

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	102.0	108.0	108.0	104.0	110.0	-	-
20	104.0	114.0	112.0	108.0	106.0	110.0	-
50	116.0	114.0	108.0	114.0	114.0	110.0	110.0
100	124.0	116.0	114.0	114.0	106.0	108.0	110.0
200	122.0	120.0	120.0	114.0	114.0	112.0	108.0
500	122.0	120.0	120.0	114.0	110.0	112.0	112.0
1000	124.0	120.0	118.0	116.0	112.0	110.0	110.0
2000	124.0	122.0	120.0	116.0	110.0	110.0	110.0

Subject: 1
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	86.0	84.0	86.0	88.0	88.0	-	-
20	86.0	86.0	84.0	84.0	88.0	88.0	-
50	86.0	84.0	86.0	86.0	86.0	86.0	86.0
100	90.0	88.0	88.0	84.0	84.0	88.0	88.0
200	94.0	88.0	88.0	86.0	86.0	84.0	84.0
500	92.0	90.0	88.0	86.0	86.0	86.0	86.0
1000	90.0	90.0	88.0	86.0	88.0	86.0	86.0
2000	92.0	90.0	88.0	90.0	86.0	88.0	86.0

Subject: 2

Frequency: 1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	100.0	94.0	94.0	94.0	98.0	-	-
20	98.0	102.0	94.0	96.0	94.0	92.0	-
50	102.0	98.0	94.0	98.0	90.0	92.0	92.0
100	106.0	104.0	98.0	102.0	96.0	94.0	92.0
200	114.0	106.0	102.0	100.0	94.0	94.0	96.0
500	112.0	106.0	100.0	102.0	94.0	100.0	96.0
1000	108.0	106.0	106.0	102.0	98.0	94.0	94.0
2000	110.0	106.0	106.0	106.0	94.0	96.0	98.0

Subject : 2

Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	104.0	106.0	106.0	104.0	106.0	-	-
20	108.0	106.0	108.0	112.0	106.0	106.0	-
50	108.0	110.0	104.0	112.0	102.0	104.0	106.0
100	120.0	116.0	110.0	104.0	104.0	108.0	108.0
200	124.0	116.0	114.0	112.0	104.0	110.0	110.0
500	130.0	124.0	114.0	108.0	110.0	106.0	108.0
1000	130.0	122.0	118.0	110.0	108.0	110.0	106.0
2000	130.0	122.0	118.0	112.0	106.0	106.0	106.0

Subject: 2
Frequency: 4000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	108.0	100.0	96.0	106.0	104.0	-	-
20	108.0	106.0	100.0	108.0	100.0	102.0	-
50	102.0	106.0	118.0	104.0	100.0	100.0	102.0
100	116.0	114.0	116.0	114.0	108.0	98.0	100.0
200	118.0	112.0	118.0	112.0	112.0	100.0	102.0
500	122.0	118.0	118.0	106.0	106.0	100.0	100.0
1000	122.0	120.0	118.0	112.0	106.0	100.0	100.0
2000	124.0	120.0	118.0	112.0	104.0	106.0	104.0

Subject: 3
Frequency: 250

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	108.0	100.0	104.0	106.0	102.0	-	-
20	108.0	106.0	98.0	102.0	106.0	104.0	-
50	106.0	102.0	108.0	100.0	104.0	106.0	104.0
100	116.0	118.0	108.0	108.0	104.0	104.0	104.0
200	112.0	116.0	110.0	106.0	106.0	104.0	106.0
500	124.0	118.0	112.0	108.0	106.0	104.0	102.0
1000	130.0	120.0	114.0	106.0	110.0	102.0	104.0
2000	130.0	120.0	114.0	106.0	108.0	106.0	104.0

Subject: 3
Frequency: 1000

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	106.0	102.0	108.0	100.0	104.0	-	-
20	106.0	104.0	106.0	100.0	102.0	100.0	-
50	108.0	106.0	100.0	102.0	104.0	102.0	102.0
100	108.0	110.0	106.0	98.0	100.0	104.0	100.0
200	110.0	110.0	106.0	104.0	108.0	106.0	100.0
500	110.0	108.0	104.0	106.0	108.0	100.0	102.0
1000	110.0	110.0	106.0	102.0	106.0	104.0	100.0
2000	110.0	108.0	106.0	104.0	106.0	104.0	100.0

Subject: 4
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	110.0	106.0	108.0	106.0	108.0	-	-
20	108.0	108.0	110.0	106.0	106.0	106.0	-
50	108.0	110.0	104.0	108.0	108.0	106.0	106.0
100	112.0	112.0	110.0	110.0	106.0	108.0	108.0
200	112.0	110.0	108.0	108.0	108.0	108.0	108.0
500	112.0	112.0	108.0	108.0	108.0	106.0	106.0
1000	112.0	112.0	108.0	108.0	108.0	106.0	106.0
2000	112.0	112.0	108.0	108.0	108.0	108.0	106.0

Subject: 4
Frequency: 1000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	104.0	104.0	106.0	114.0	110.0	-	-
20	98.0	108.0	116.0	112.0	110.0	114.0	-
50	112.0	112.0	116.0	114.0	110.0	118.0	114.0
100	110.0	116.0	118.0	112.0	112.0	114.0	116.0
200	118.0	118.0	120.0	114.0	114.0	116.0	114.0
500	120.0	120.0	118.0	116.0	118.0	116.0	116.0
1000	122.0	120.0	118.0	116.0	116.0	116.0	112.0
2000	122.0	120.0	118.0	116.0	116.0	116.0	114.0

Subject: 5
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	106.0	104.0	108.0	110.0	108.0	-	-
20	104.0	104.0	110.0	108.0	108.0	108.0	-
50	112.0	110.0	110.0	112.0	110.0	110.0	108.0
100	110.0	112.0	110.0	106.0	106.0	108.0	110.0
200	114.0	112.0	112.0	106.0	106.0	108.0	106.0
500	116.0	110.0	112.0	108.0	110.0	108.0	108.0
1000	116.0	114.0	112.0	108.0	108.0	108.0	106.0
2000	116.0	114.0	112.0	110.0	108.0	110.0	104.0

Subject: 5
Frequency:1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	112.0	114.0	114.0	112.0	112.0	-	-
20	114.0	114.0	112.0	116.0	112.0	110.0	-
50	118.0	112.0	116.0	112.0	112.0	110.0	114.0
100	118.0	122.0	114.0	112.0	114.0	114.0	112.0
200	122.0	120.0	120.0	118.0	118.0	112.0	112.0
500	130.0	130.0	122.0	118.0	112.0	110.0	110.0
1000	130.0	130.0	122.0	120.0	116.0	110.0	110.0
2000	130.0	130.0	122.0	120.0	118.0	110.0	110.0

Subject: 6
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	112.0	110.0	112.0	110.0	110.0	-	-
20	114.0	110.0	110.0	110.0	110.0	108.0	-
50	118.0	114.0	114.0	108.0	110.0	110.0	110.0
100	118.0	118.0	108.0	110.0	108.0	110.0	112.0
200	120.0	118.0	114.0	110.0	110.0	110.0	110.0
500	122.0	120.0	116.0	110.0	108.0	110.0	104.0
1000	122.0	120.0	118.0	112.0	110.0	108.0	108.0
2000	122.0	120.0	118.0	114.0	110.0	110.0	110.0

Subject: 6
Frequency: 1000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	108.0	104.0	104.0	104.0	102.0	-	-
20	108.0	106.0	108.0	106.0	102.0	102.0	-
50	110.0	110.0	106.0	102.0	102.0	102.0	102.0
100	112.0	106.0	106.0	106.0	104.0	102.0	102.0
200	110.0	108.0	104.0	106.0	104.0	102.0	102.0
500	110.0	108.0	104.0	106.0	102.0	102.0	104.0
1000	110.0	108.0	106.0	102.0	104.0	104.0	106.0
2000	110.0	108.0	106.0	104.0	102.0	102.0	102.0

Subject: 7
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	98.0	100.0	98.0	100.0	100.0	-	-
20	96.0	98.0	100.0	100.0	98.0	100.0	-
50	102.0	102.0	102.0	102.0	100.0	100.0	102.0
100	110.0	102.0	102.0	98.0	102.0	102.0	102.0
200	112.0	110.0	104.0	102.0	102.0	102.0	102.0
500	112.0	110.0	108.0	108.0	104.0	102.0	104.0
1000	112.0	110.0	108.0	106.0	106.0	104.0	102.0
2000	112.0	110.0	108.0	106.0	106.0	104.0	102.0

Subject: 7
Frequency: 1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	114.0	118.0	116.0	114.0	116.0	-	-
20	120.0	120.0	114.0	112.0	118.0	116.0	-
50	118.0	124.0	118.0	114.0	118.0	118.0	118.0
100	124.0	124.0	118.0	114.0	118.0	116.0	116.0
200	130.0	130.0	120.0	116.0	118.0	114.0	116.0
500	130.0	130.0	124.0	118.0	118.0	120.0	116.0
1000	130.0	130.0	124.0	118.0	118.0	118.0	114.0
2000	130.0	130.0	124.0	120.0	118.0	118.0	116.0

Subject: 7
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	106.0	108.0	104.0	106.0	112.0	-	-
20	108.0	110.0	110.0	106.0	114.0	104.0	-
50	110.0	108.0	112.0	108.0	108.0	106.0	108.0
100	120.0	112.0	114.0	112.0	114.0	106.0	108.0
200	118.0	120.0	116.0	116.0	110.0	108.0	106.0
500	120.0	120.0	118.0	118.0	108.0	106.0	108.0
1000	122.0	118.0	118.0	118.0	108.0	108.0	110.0
2000	122.0	120.0	118.0	118.0	112.0	106.0	108.0

Subject: 8
Frequency: 250 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	80.0	86.0	86.0	88.0	86.0	-	-
20	84.0	84.0	86.0	86.0	86.0	86.0	-
50	92.0	90.0	88.0	88.0	86.0	86.0	86.0
100	94.0	92.0	92.0	82.0	84.0	86.0	86.0
200	96.0	94.0	92.0	88.0	84.0	86.0	90.0
500	96.0	94.0	92.0	88.0	88.0	88.0	88.0
1000	98.0	96.0	94.0	90.0	88.0	90.0	82.0
2000	98.0	96.0	94.0	92.0	88.0	88.0	86.0

Subject: 8
Frequency: 1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	84.0	86.0	90.0	88.0	92.0	-	-
20	86.0	88.0	90.0	88.0	94.0	90.0	-
50	90.0	92.0	92.0	88.0	92.0	90.0	88.0
100	94.0	96.0	92.0	88.0	90.0	92.0	88.0
200	100.0	102.0	96.0	90.0	88.0	90.0	90.0
500	102.0	102.0	100.0	96.0	96.0	90.0	90.0
1000	106.0	104.0	102.0	96.0	92.0	90.0	86.0
2000	106.0	104.0	102.0	94.0	94.0	92.0	88.0

Subject: 8
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	100.0	108.0	110.0	110.0	108.0	-	-
20	98.0	104.0	110.0	110.0	108.0	108.0	-
50	106.0	112.0	106.0	108.0	108.0	110.0	108.0
100	112.0	116.0	112.0	104.0	110.0	112.0	110.0
200	118.0	118.0	116.0	112.0	104.0	108.0	110.0
500	120.0	116.0	116.0	116.0	114.0	104.0	106.0
1000	122.0	116.0	116.0	116.0	112.0	108.0	102.0
2000	122.0	116.0	116.0	114.0	112.0	108.0	108.0

Subject: 9
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	88.0	98.0	94.0	98.0	96.0	-	-
20	92.0	90.0	96.0	96.0	96.0	96.0	-
50	100.0	100.0	88.0	94.0	98.0	98.0	94.0
100	98.0	104.0	98.0	90.0	98.0	100.0	96.0
200	112.0	106.0	104.0	96.0	96.0	100.0	96.0
500	118.0	106.0	106.0	96.0	100.0	94.0	94.0
1000	118.0	108.0	106.0	94.0	98.0	96.0	94.0
2000	118.0	116.0	108.0	98.0	100.0	98.0	94.0

Subject: 9
Frequency: 1000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	92.0	100.0	104.0	100.0	96.0	-	-
20	100.0	96.0	100.0	98.0	96.0	102.0	-
50	108.0	104.0	96.0	98.0	100.0	100.0	100.0
100	118.0	114.0	110.0	92.0	104.0	100.0	104.0
200	130.0	122.0	120.0	108.0	106.0	104.0	102.0
500	130.0	124.0	122.0	110.0	104.0	100.0	100.0
1000	130.0	122.0	120.0	106.0	102.0	98.0	94.0
2000	130.0	130.0	122.0	108.0	100.0	100.0	100.0

Subject: 9
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	114.0	112.0	114.0	118.0	118.0	-	-
20	118.0	114.0	116.0	116.0	116.0	118.0	-
50	118.0	120.0	118.0	116.0	116.0	116.0	114.0
100	122.0	122.0	116.0	116.0	114.0	116.0	116.0
200	122.0	122.0	118.0	120.0	118.0	116.0	114.0
500	130.0	124.0	122.0	116.0	114.0	118.0	114.0
1000	130.0	124.0	122.0	120.0	116.0	114.0	116.0
2000	130.0	124.0	122.0	118.0	116.0	116.0	116.0

Subject: 10
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	106.0	114.0	114.0	116.0	114.0	-	-
20	108.0	112.0	114.0	118.0	114.0	114.0	-
50	120.0	118.0	112.0	114.0	112.0	114.0	110.0
100	120.0	120.0	116.0	112.0	114.0	114.0	112.0
200	122.0	120.0	116.0	114.0	110.0	112.0	114.0
500	122.0	122.0	118.0	116.0	114.0	110.0	114.0
1000	130.0	124.0	120.0	116.0	116.0	114.0	114.0
2000	130.0	124.0	120.0	118.0	114.0	112.0	114.0

Subject: 10
Frequency: 1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	94.0	100.0	106.0	102.0	100.0	-	-
20	96.0	100.0	98.0	102.0	102.0	102.0	-
50	110.0	98.0	100.0	100.0	100.0	104.0	100.0
100	118.0	108.0	104.0	98.0	98.0	98.0	100.0
200	118.0	112.0	110.0	100.0	98.0	98.0	98.0
500	124.0	118.0	110.0	102.0	96.0	96.0	100.0
1000	130.0	122.0	110.0	104.0	100.0	98.0	96.0
2000	130.0	122.0	110.0	106.0	100.0	98.0	96.0

Subject: 11
Frequency: 250 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	84.0	86.0	86.0	86.0	86.0	-	-
20	86.0	82.0	84.0	86.0	86.0	88.0	-
50	88.0	90.0	84.0	88.0	84.0	88.0	86.0
100	104.0	98.0	94.0	84.0	82.0	86.0	86.0
200	106.0	100.0	94.0	88.0	84.0	84.0	88.0
500	108.0	100.0	98.0	90.0	86.0	84.0	90.0
1000	108.0	98.0	94.0	90.0	92.0	90.0	84.0
2000	108.0	102.0	96.0	92.0	90.0	86.0	84.0

Subject: 11
Frequency: 1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	90.0	92.0	96.0	90.0	92.0	-	-
20	92.0	90.0	90.0	90.0	92.0	92.0	-
50	100.0	92.0	90.0	90.0	94.0	92.0	90.0
100	120.0	100.0	94.0	90.0	92.0	94.0	90.0
200	118.0	114.0	104.0	94.0	90.0	90.0	90.0
500	120.0	118.0	106.0	96.0	90.0	90.0	90.0
1000	120.0	114.0	106.0	98.0	98.0	90.0	90.0
2000	120.0	116.0	106.0	100.0	96.0	94.0	90.0

Subject: 11
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	106.0	108.0	104.0	104.0	104.0	-	-
20	108.0	106.0	106.0	102.0	104.0	104.0	-
50	110.0	108.0	104.0	108.0	104.0	104.0	106.0
100	114.0	110.0	108.0	110.0	104.0	104.0	106.0
200	116.0	112.0	110.0	110.0	106.0	104.0	102.0
500	118.0	112.0	110.0	106.0	106.0	102.0	102.0
1000	120.0	112.0	110.0	110.0	104.0	102.0	106.0
2000	122.0	114.0	110.0	112.0	106.0	102.0	104.0

Subject: 12
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	98.0	98.0	96.0	94.0	94.0	-	-
20	96.0	94.0	94.0	94.0	94.0	96.0	-
50	96.0	96.0	94.0	94.0	94.0	96.0	96.0
100	100.0	98.0	98.0	96.0	96.0	98.0	94.0
200	106.0	102.0	100.0	96.0	94.0	96.0	94.0
500	110.0	106.0	104.0	102.0	100.0	98.0	96.0
1000	112.0	108.0	104.0	102.0	98.0	96.0	96.0
2000	114.0	108.0	104.0	102.0	98.0	96.0	96.0

Subject: 12
Frequency: 1000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	92.0	96.0	94.0	92.0	94.0	-	-
20	92.0	92.0	94.0	92.0	94.0	96.0	-
50	96.0	92.0	92.0	92.0	94.0	96.0	96.0
100	100.0	96.0	96.0	96.0	98.0	94.0	92.0
200	104.0	102.0	100.0	98.0	100.0	94.0	94.0
500	106.0	104.0	104.0	102.0	100.0	94.0	96.0
1000	108.0	106.0	106.0	102.0	100.0	96.0	96.0
2000	112.0	110.0	108.0	102.0	100.0	96.0	96.0

Subject: 12
Frequency: 4000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	106.0	108.0	112.0	108.0	108.0	-	-
20	106.0	108.0	112.0	108.0	106.0	110.0	-
50	112.0	112.0	114.0	108.0	106.0	110.0	108.0
100	118.0	116.0	116.0	108.0	106.0	110.0	108.0
200	120.0	120.0	118.0	112.0	110.0	110.0	108.0
500	122.0	120.0	118.0	116.0	112.0	112.0	108.0
1000	122.0	120.0	118.0	116.0	112.0	110.0	108.0
2000	124.0	120.0	118.0	116.0	112.0	110.0	108.0

Subject: 13
Frequency: 250 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	104.0	108.0	106.0	106.0	104.0	-	-
20	106.0	102.0	106.0	106.0	106.0	102.0	-
50	108.0	106.0	104.0	106.0	102.0	100.0	102.0
100	112.0	108.0	106.0	102.0	100.0	100.0	100.0
200	116.0	112.0	110.0	104.0	104.0	102.0	100.0
500	120.0	116.0	114.0	108.0	104.0	104.0	98.0
1000	120.0	118.0	116.0	110.0	106.0	100.0	102.0
2000	124.0	118.0	114.0	110.0	104.0	100.0	98.0

Subject: 13
Frequency: 1000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	104.0	106.0	102.0	104.0	102.0	-	-
20	106.0	108.0	104.0	102.0	102.0	104.0	-
50	110.0	106.0	106.0	104.0	104.0	102.0	106.0
100	112.0	110.0	112.0	106.0	106.0	102.0	102.0
200	116.0	112.0	110.0	110.0	106.0	102.0	100.0
500	116.0	112.0	112.0	108.0	104.0	106.0	106.0
1000	116.0	112.0	110.0	110.0	106.0	108.0	106.0
2000	118.0	112.0	112.0	110.0	108.0	108.0	104.0

Subject:14

Frequency: 250 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	88.0	88.0	86.0	88.0	88.0	-	-
20	88.0	90.0	86.0	88.0	86.0	88.0	-
50	92.0	90.0	90.0	86.0	90.0	88.0	92.0
100	98.0	102.0	96.0	90.0	92.0	86.0	90.0
200	104.0	100.0	94.0	94.0	92.0	88.0	88.0
500	106.0	100.0	98.0	94.0	90.0	92.0	92.0
1000	106.0	102.0	98.0	96.0	98.0	92.0	88.0
2000	106.0	102.0	100.0	96.0	94.0	94.0	92.0

Subject: 14
Frequency: 1000

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	92.0	98.0	94.0	94.0	98.0	-	-
20	94.0	92.0	94.0	94.0	96.0	96.0	-
50	92.0	94.0	94.0	94.0	98.0	94.0	98.0
100	120.0	116.0	110.0	94.0	100.0	96.0	98.0
200	124.0	122.0	104.0	106.0	102.0	98.0	96.0
500	130.0	130.0	114.0	102.0	96.0	96.0	102.0
1000	130.0	130.0	116.0	100.0	98.0	96.0	102.0
2000	130.0	130.0	118.0	100.0	104.0	100.0	96.0

Subject: 14
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	102.0	104.0	106.0	102.0	104.0	-	-
20	102.0	102.0	102.0	102.0	104.0	104.0	-
50	104.0	102.0	102.0	100.0	102.0	104.0	100.0
100	106.0	106.0	106.0	106.0	104.0	106.0	104.0
200	112.0	106.0	110.0	106.0	104.0	102.0	102.0
500	114.0	110.0	108.0	106.0	104.0	106.0	102.0
1000	114.0	110.0	108.0	104.0	106.0	104.0	102.0
2000	114.0	110.0	108.0	104.0	102.0	104.0	102.0

Subject: 15
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	96.0	96.0	96.0	94.0	100.0	-	-
20	90.0	94.0	94.0	94.0	96.0	98.0	-
50	92.0	92.0	94.0	90.0	94.0	100.0	94.0
100	102.0	98.0	94.0	98.0	100.0	98.0	98.0
200	108.0	102.0	104.0	98.0	104.0	100.0	96.0
500	112.0	112.0	112.0	98.0	100.0	98.0	94.0
1000	110.0	112.0	108.0	102.0	102.0	98.0	100.0
2000	114.0	112.0	106.0	98.0	96.0	98.0	98.0

Subject: 15
Frequency: 1000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	90.0	90.0	96.0	96.0	100.0	-	-
20	88.0	90.0	92.0	94.0	96.0	98.0	-
50	100.0	96.0	94.0	90.0	94.0	100.0	96.0
100	108.0	102.0	94.0	94.0	94.0	100.0	100.0
200	116.0	112.0	104.0	96.0	102.0	102.0	94.0
500	116.0	112.0	112.0	102.0	102.0	100.0	94.0
1000	116.0	112.0	110.0	108.0	102.0	100.0	94.0
2000	116.0	110.0	108.0	106.0	100.0	100.0	96.0

Subject: 15
Frequency: 4000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	104.0	104.0	104.0	108.0	108.0	-	-
20	108.0	106.0	106.0	108.0	108.0	104.0	-
50	116.0	110.0	108.0	104.0	108.0	104.0	104.0
100	116.0	114.0	110.0	102.0	102.0	102.0	106.0
200	124.0	122.0	112.0	110.0	108.0	104.0	106.0
500	124.0	124.0	114.0	112.0	112.0	108.0	106.0
1000	130.0	130.0	114.0	110.0	110.0	104.0	104.0
2000	130.0	130.0	114.0	110.0	110.0	104.0	104.0

Subject: 16
Frequency: 250 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	92.0	94.0	94.0	96.0	98.0	-	-
20	92.0	96.0	90.0	96.0	92.0	96.0	-
50	100.0	98.0	98.0	96.0	94.0	98.0	96.0
100	106.0	108.0	98.0	94.0	96.0	94.0	98.0
200	116.0	110.0	100.0	96.0	98.0	94.0	100.0
500	118.0	110.0	104.0	100.0	100.0	98.0	94.0
1000	118.0	110.0	106.0	102.0	98.0	96.0	96.0
2000	118.0	108.0	104.0	102.0	100.0	96.0	96.0

Subject: 16
Frequency: 1000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	96.0	94.0	98.0	98.0	102.0	-	-
20	98.0	100.0	98.0	100.0	100.0	102.0	-
50	104.0	104.0	98.0	94.0	102.0	104.0	100.0
100	110.0	112.0	100.0	98.0	96.0	98.0	102.0
200	114.0	114.0	106.0	102.0	100.0	98.0	100.0
500	116.0	114.0	112.0	100.0	106.0	98.0	96.0
1000	118.0	114.0	112.0	108.0	100.0	96.0	98.0
2000	124.0	114.0	104.0	104.0	106.0	98.0	96.0

Subject: 16
Frequency: 4000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	102.0	106.0	108.0	106.0	106.0	-	-
20	104.0	100.0	112.0	106.0	106.0	100.0	-
50	108.0	110.0	108.0	102.0	108.0	102.0	102.0
100	116.0	112.0	108.0	106.0	108.0	106.0	106.0
200	122.0	114.0	112.0	108.0	106.0	102.0	102.0
500	122.0	114.0	110.0	108.0	106.0	106.0	100.0
1000	130.0	116.0	108.0	108.0	108.0	102.0	102.0
2000	130.0	118.0	110.0	106.0	106.0	106.0	106.0

Subject: 17
Frequency: 250 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	86.0	90.0	92.0	90.0	90.0	-	-
20	86.0	84.0	88.0	88.0	90.0	86.0	-
50	96.0	90.0	90.0	86.0	92.0	86.0	86.0
100	96.0	94.0	86.0	90.0	92.0	88.0	88.0
200	114.0	100.0	96.0	92.0	88.0	88.0	86.0
500	114.0	96.0	94.0	94.0	88.0	86.0	84.0
1000	116.0	98.0	96.0	92.0	90.0	88.0	88.0
2000	114.0	100.0	94.0	92.0	90.0	88.0	88.0

Subject: 17
Frequency: 1000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	92.0	98.0	102.0	100.0	102.0	-	-
20	94.0	94.0	100.0	98.0	102.0	98.0	-
50	112.0	100.0	94.0	94.0	102.0	100.0	98.0
100	120.0	114.0	96.0	94.0	102.0	100.0	98.0
200	124.0	122.0	120.0	112.0	100.0	100.0	98.0
500	130.0	130.0	124.0	114.0	102.0	96.0	94.0
1000	130.0	130.0	124.0	114.0	104.0	96.0	94.0
2000	130.0	130.0	124.0	116.0	102.0	100.0	94.0

Subject: 17
Frequency: 4000 Hz

ISI DURATION (MS) \ STIMULUS DURATION (MS)	10	20	50	100	200	500	1000
10	106.0	108.0	110.0	108.0	106.0	-	-
20	108.0	112.0	110.0	110.0	104.0	106.0	-
50	112.0	112.0	112.0	104.0	106.0	104.0	106.0
100	116.0	112.0	108.0	104.0	106.0	112.0	106.0
200	122.0	116.0	112.0	110.0	104.0	108.0	108.0
500	120.0	118.0	112.0	108.0	108.0	112.0	104.0
1000	122.0	118.0	114.0	112.0	104.0	108.0	108.0
2000	122.0	118.0	114.0	112.0	110.0	108.0	106.0

Subject: 18
Frequency: 250 Hz

Figure 1-A. (Continued)

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	92.0	92.0	96.0	94.0	94.0	-	-
20	96.0	94.0	92.0	92.0	92.0	94.0	-
50	96.0	96.0	92.0	92.0	96.0	96.0	92.0
100	98.0	98.0	96.0	92.0	98.0	96.0	94.0
200	114.0	104.0	100.0	96.0	96.0	96.0	96.0
500	114.0	106.0	102.0	98.0	98.0	96.0	96.0
1000	116.0	106.0	104.0	98.0	98.0	96.0	94.0
2000	116.0	106.0	104.0	100.0	98.0	96.0	94.0

Subject: 18
Frequency: 1000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	98.0	96.0	106.0	102.0	98.0	-	-
20	100.0	94.0	100.0	102.0	96.0	96.0	-
50	102.0	96.0	102.0	98.0	98.0	98.0	98.0
100	104.0	100.0	96.0	98.0	98.0	96.0	96.0
200	124.0	112.0	102.0	104.0	98.0	98.0	102.0
500	130.0	122.0	108.0	108.0	100.0	96.0	98.0
1000	130.0	130.0	114.0	104.0	98.0	94.0	98.0
2000	130.0	130.0	114.0	108.0	104.0	98.0	98.0

Subject: 18
Frequency:4000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	84.0	94.0	98.0	98.0	98.0	-	-
20	92.0	90.0	102.0	100.0	100.0	100.0	-
50	96.0	102.0	102.0	102.0	104.0	102.0	106.0
100	106.0	110.0	102.0	100.0	100.0	98.0	102.0
200	116.0	114.0	110.0	100.0	104.0	102.0	104.0
500	118.0	114.0	114.0	102.0	102.0	100.0	102.0
1000	120.0	118.0	114.0	106.0	104.0	100.0	104.0
2000	122.0	118.0	114.0	106.0	104.0	102.0	102.0

Subject: 19
Frequency: 250 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	80.0	90.0	96.0	102.0	106.0	-	-
20	90.0	88.0	102.0	96.0	106.0	98.0	-
50	96.0	100.0	96.0	96.0	104.0	102.0	102.0
100	108.0	108.0	94.0	98.0	98.0	100.0	104.0
200	114.0	112.0	106.0	104.0	96.0	98.0	98.0
500	116.0	110.0	108.0	104.0	104.0	102.0	100.0
1000	118.0	110.0	110.0	108.0	104.0	96.0	96.0
2000	120.0	112.0	108.0	106.0	104.0	96.0	96.0

Subject: 19
Frequency: 1000 Hz

Figure 1-A. (Continued)

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	82.0	88.0	90.0	96.0	96.0	-	-
20	86.0	84.0	90.0	92.0	96.0	94.0	-
50	92.0	98.0	88.0	98.0	96.0	94.0	96.0
100	106.0	106.0	92.0	96.0	96.0	94.0	94.0
200	110.0	108.0	106.0	104.0	92.0	94.0	96.0
500	112.0	106.0	108.0	102.0	98.0	94.0	94.0
1000	114.0	108.0	106.0	102.0	98.0	94.0	94.0
2000	116.0	110.0	108.0	102.0	98.0	94.0	94.0

Subject: 19
Frequency: 4000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	86.0	90.0	94.0	94.0	96.0	-	-
20	82.0	86.0	100.0	92.0	96.0	100.0	-
50	86.0	86.0	94.0	86.0	94.0	102.0	100.0
100	104.0	98.0	94.0	86.0	96.0	96.0	100.0
200	112.0	108.0	100.0	100.0	102.0	102.0	102.0
500	112.0	108.0	102.0	102.0	102.0	102.0	100.0
1000	110.0	108.0	102.0	102.0	102.0	102.0	100.0
2000	110.0	108.0	102.0	102.0	102.0	102.0	102.0

Subject: 20
Frequency: 250 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	86.0	90.0	94.0	90.0	90.0	-	-
20	82.0	82.0	94.0	90.0	90.0	94.0	-
50	84.0	86.0	86.0	88.0	90.0	94.0	94.0
100	96.0	94.0	90.0	90.0	92.0	94.0	94.0
200	106.0	104.0	94.0	96.0	94.0	96.0	94.0
500	106.0	104.0	96.0	98.0	94.0	96.0	94.0
1000	106.0	104.0	100.0	100.0	94.0	96.0	96.0
2000	106.0	104.0	100.0	100.0	96.0	96.0	96.0

Subject: 20
Frequency: 1000 Hz

ISI DURATION (MS)	STIMULUS DURATION (MS)						
	10	20	50	100	200	500	1000
10	82.0	86.0	90.0	88.0	90.0	-	-
20	80.0	80.0	90.0	90.0	92.0	92.0	-
50	84.0	84.0	84.0	86.0	92.0	90.0	88.0
100	90.0	92.0	92.0	88.0	98.0	90.0	90.0
200	112.0	104.0	100.0	100.0	98.0	90.0	90.0
500	112.0	108.0	102.0	98.0	98.0	92.0	92.0
1000	110.0	108.0	100.0	106.0	100.0	90.0	90.0
2000	112.0	110.0	106.0	106.0	100.0	90.0	90.0

Subject: 20
Frequency: 4000 Hz

Figure 1-A. (Continued)

VITA

David Mason was born in Danielson, Connecticut on October 13, 1951. He attended Saint James elementary school, and graduated from Killingly High School in 1969. He attended the University of Connecticut through 1973, at which time he received a Bachelor of Arts degree in speech pathology. In August 1975, he was married to Deborah Lisa Bernstein. He attended The University of Tennessee, Knoxville, and received a Master of Arts degree in audiology in June 1977. His son, Matthew, was born in June 1978, and his son, Daniel, was born in November 1980. He received his Doctor of Philosophy degree in August 1983.