TEMPORAL INTEGRATION AND COCHLEAR HEARING LOSS

Richard S. Tyler
Student, University of Western Ontario

ABSTRACT

The effect of off-frequency energy on temporal integration measurements was investigated. Temporal integration functions for unfiltered and high pass filtered sinusoids of 20 and 200 msec duration and 1 msec rise-fall times were obtained from 4 normal hearing subjects and 4 subjects with high frequency, cochlear hearing impairments. Independent of filtering, normal hearing subjects produced integration functions that were similar to those shown by other research. All four hearing impaired subjects showed abnormal temporal integration in the unfiltered condition. When forced to listen on-frequency, two of the hearing impaired subjects demonstrated normal temporal integration. It was concluded that off-frequency energy can confound the measurement of temporal integration.

INTRODUCTION

Auditory thresholds are essentially governed by two parameters, frequency and intensity. However, when signal duration is less than 200 msec, a third parameter, signal energy, becomes important and the intensity required to exceed a listener's threshold is greater for signals for short duration than for signals of long duration. This phenomenon has been called temporal integration. Research has indicated that listeners with cochlear hearing losses exhibit abnormal temporal integration, in that signal detectability is independent of duration. However, off-frequency energy produced by switching the signal may be confounding these measurements.

Garner (1947) reported that when signal duration is halved, acoustic intensity must be increased by about 3 dB for the signal to remain at threshold. Their formula, half-duration double-energy, works for signal durations between 10 and 200 msec; however, for signal durations greater than approximately 200 msec, detectability is independent of duration (Watson and Gengel, 1969). Temporal integration at durations less than 10 msec is not clearly understood (Scharf, 1970; page 185). At very short durations, some authors report an increase in threshold energy (Plomp and Bouman, 1959), while others report a constant threshold energy (Zwicker and Wright, 1963).

Temporal integration is dependent on frequency, although consistent results have not been reported in the literature. Watson and Gengel (1969) state that frequency dependency can be shown provided that a wide range of durations is used to allow for a 10 dB difference in thresholds, that a wide range of frequencies is studied (250-4000 Hz), and that a precise psychophysical method is used. Békésy audiometry was excluded in the latter stipulation. Their data suggest that the slope of the temporal integration functions is less at high frequencies than it is at low frequencies. Thus, a 16 msec duration, 250 Hz signal required about 12 dB more intensity than a 250 Hz, 512 msec duration signal to remain at the subject's threshold. However, at 4000 Hz this difference was only 6 dB. This trend is also supported by Sheely and Bilger (1964), Plomp and Bouman (1959) and others. Watson and Gengel (1969) cautioned that this effect of frequency dependency should be considered when evaluating the temporal integration for subjects with hearing losses.

Subjects with cochlear hearing losses exhibit abnormal temporal integration (Martin and Wofford, 1970; Wright, 1968). In these subjects, when duration is decreased, a smaller increase in signal intensity is required to maintain threshold responses than is required for normals. Other investigators (Watson and Gengel, 1969; Richards and Dunn, 1974) found it difficult to distinguish between the temporal integration functions of normals and hearing impaired listeners. Martin and Wofford (1970) found that to maintain threshold responses with normals, a 6 to 8 dB increase in intensity was required for a 10 msec duration signal as compared to a 500 msec duration signal. Subjects with cochlear losses, however, required approximately a 1 to 5 dB intensity increase at the shorter duration to maintain the signal at threshold.

Pederson (1973) and Pederson and Elberling (1972a, 1973) have related the degree of hearing loss to the amount of reduced temporal integration. They examined threshold responses for sinusoids of 500, 1000, 4000, and 8000 Hz at durations from 2 to 1000 msec. Subjects with acoustic trauma and presbycusis had normal temporal integration at frequencies where their thresholds were within normal limits; however, at higher frequencies where thresholds were elevated, abnormal temporal integration functions were observed.

Sanders, Josey and Kemker (1971) present evidence from three patients with surgically confirmed eighth nerve tumors. Temporal integration functions were reduced somewhat, but their responses were reported to be more like those of normal hearing subjects than cochlear hearing loss subjects. It has therefore, been proposed that the assessment of a patient's temporal integration may be an important audiological tool to differentiate between cochlear losses and eighth nerve tumors.

Abnormal temporal integration in cochlear hearing loss subjects can be interpreted in another manner. In detecting signals, these subjects may be listening to off-frequency energy, produced by switching. When a sinusoid is switched on and off, "off-frequency" energy is produced above and below the primary frequency. The amount of off-frequency energy is dependent upon the rise-fall time but is independent of signal duration. The faster the rise-fall time, the greater the off-frequency energy (Wightman, 1971).

Normal hearing subjects may be able to utilize off-frequency energy. Garner (1947) observed what appeared to be abnormal temporal integration at 250 Hz for a listener with normal hearing sensitivity. For this listener, detectability increased at durations less at 25 msec. Garner believed that at 250 Hz, energy would spread to higher frequencies where the auditory system is more sensitive. Thus, the subject could be detecting high frequency energy, instead of energy at 250 Hz. Small (1955) noted a similar abnormal temporal integration function for pulsed signals at 8000 Hz with a duty cycle of less than 40%. Under these conditions, detectability of the 8000 Hz signal did not decrease as it did for 1000 Hz, 2000 Hz, 3000 Hz and broad band noise. Small hypothesized that the auditory system capitalized on energy spread into frequency regions of the auditory system that are more sensitive.

The above studies indicate that off-frequency energy can contribute to signal detection in normals, and this off-frequency information would also be a contributing factor to temporal integration in subjects with high frequency hearing losses. When high frequency signals are presented at threshold, off-frequency energy is spread into lower frequency areas where the subject's auditory system is more sensitive. Since off-frequency energy is independent of signal duration, and if these patients were responding to off-frequency energy, signal detectability would be independent of signal duration and temporal integration would appear to be abnormal.

Off-frequency energy is dependent on rise-fall time, and a wide range of rise-fall times is reported in clinical research. Pederson and Elberling (1972a and 1973) and Pederson (1973) use the following rise-fall times: 500 Hz - 4 msec, 1000 Hz - 2 msec, 2000 Hz - 3 msec, 4000 Hz - 3.5 msec, and 8000 Hz - 1.74 msec. Wright (1968) used rise-fall times of 10 msec; Olsen, Rose and Noffsinger (1974) used 7.5 and 10 msec; Goldstein and Kramer (1960) used 7.5 msec; Harris, Haines and Myers (1958), Sanders, Josey and Kemker (1971) and Watson and Gengel (1969) used 5 msec; and Hatler and Northern (1970) used 2.5 msec.

Wright (1967) presented data on one subject with a noise induced hearing loss. The difference between threshold responses for a signal of 10 msec and 300 msec duration was about 6 dB at 5000 Hz when a 10 msec rise-fall time was used. When a fast rise-fall time (presumably somewhat less than 1 msec) was used, the threshold difference was 0 dB. Wright concluded that rapid switching produced fallacious results. He also stated that abnormal integration was observed after removing this artifact, but Wright apparently did not consider the frequency dependency mentioned by Watson and Gengel (1969). Wright recommended a 10 msec rise-fall time be used in temporal integration studies to avoid the switching artifact.

Pederson and Elberling (1972b) present results for patients with cochlear lesions. Temporal integration was examined for a 1000 Hz signal with 2 and 14 msec rise-fall times. 'Reasonable accordance' of threshold energy was observed between the two rise-fall times. In a second condition, signals of 1000 and 4000 Hz with 2 msec rise-fall times were presented to subjects in both an unfiltered and a filtered (⅓ octave filter) condition. Again, 'reasonable equality' of threshold energy was observed between the unfiltered and filtered trials for both frequencies. Pederson and Elberling concluded that temporal integration is independent of rise-fall time when their method of equivalent energy-time is used to measure the signal energy.

Spence and Feth (1974) examined temporal integration at 500 and 4000 Hz with 20 and 200 msec durations and a rise-fall time of 10 msec. Twelve subjects, six with high-frequency hearing losses and six with no evidence of aural pathology, were used. Signals were presented under unfiltered and filtered conditions, and a Békésy tracking method was employed. It was hypothesized that subjects with high-frequency hearing losses would be able to capitalize on the spread of energy because the slope of their hearing losses required high intensity levels at 4000 Hz. However, neither group demonstrated threshold shifts between the unfiltered and filtered conditions. These results were not expected for the six hearing impaired subjects.

Spence and Feth speculated that wideband masking noise might be needed to produce a decrease in detectability; however, filters were used to avoid the possibility of normal and pathological ears reacting differently to masking. They suggest that filtering may have been less effective than noise in reducing off-frequency energy since noise masks off-frequency energy, while filtering only decreases the amount of energy available to the auditory system. Watson and Gengel (1969) have hypothesized that because Békésy audiometry did not consistently display frequency effects, it might not be a precise enough technique to use in temporal integration studies. This may also be a factor in the results obtained by Spence and Feth. In addition, a 10 msec rise-fall time generates less off-frequency energy than faster rise-fall times. That is, the hearing impaired subjects used by Spence and Feth may not have been presented with sufficient off-frequency energy.

In summary, it is possible that subjects with high-frequency hearing losses are utilizing off-frequency energy in the measurement of temporal integration. This energy is dependent on rise-fall time. A fast rise-fall time will produce more off-frequency energy than a slow rise-fall time. Wright (1967) recommended a 10 msec rise-fall time to reduce off-frequency energy. Pederson and Elberling (1972b), on the other hand, suggested that rise-fall time had no effect on the measurement of temporal integration. Spence and Feth (1974) did not find significant differences between unfiltered and filtered sinusoids when a 10 msec rise-fall time and a Békésy tracking method were used.

The present experiment was designed to test the hypothesis that subjects with high-frequency hearing losses use off-frequency energy to detect short-duration, high-frequency sinusoids with fast rise-fall times. In the first experimental condition, temporal integration was measured without filtering. In the second experimental condition, high pass filtering was used to reduce off-frequency energy to a level that was well below the subjects' threshold. Results for the two experimental conditions were analyzed with respect to the energy spectrums of the unfiltered and filtered signals.

METHOD

2.1 Subjects

Four subjects with thresholds of not more than 10 dB HL at octave frequencies from 250 to 8000 Hz were selected from the university community as a control group. Thresholds were obtained using the ascending Hughson-Westlake method (Carhart and Jerger, 1959).

Four subjects with high-frequency, cochlear hearing losses were selected from the University of Western Ontario Speech and Hearing Clinic files. All subjects had a history of hearing impairment from an early age. Pure tone thresholds for these subjects were bilaterally symmetrical and indicative of a sensorineural hearing loss; word discrimination scores were similar for both ears. Threshold tone decay suggested the absence of eighth nerve tumors. None of the subjects had a history of high-level noise exposure, and their thresholds, at frequencies above the test frequencies, were not more than 15 dB better than the test frequency threshold. This requirement was established to assure that off-frequency energy than the test frequency would be considerably below a given subject's high-frequency thresholds.

Audiograms for the hearing impaired subjects were obtained with the Block Up and Down, Two Interval Forced Choice (BUDTIF) method (Campbell and Lasky, 1968), for 500 msec peak duration signals of 500, 750, 1000, 1500, 2000, 2500, 3000, 4000, 6000 and 8000 Hz. Other frequencies were tested as needed to obtain a more descriptive threshold configuration. Rise-fall times of 25 msec were used. The BUDTIF procedure was used to accurately describe the off-frequency thresholds for the hearing impaired subjects, for it was essential to know the precise threshold level of the hearing impaired subjects in relation to the amount of off-frequency energy that was present for a given experimental test stimulus.

2.2 Stimuli

In the first experimental condition, the test frequencies were chosen to maximize the opportunity for off-frequency listening. Thus, it was desirable to have off-frequency energy as close to the subjects' off-frequency thresholds as possible. Sinusoids of 20 and 200 msec durations with 1 msec rise-fall times were used. All signals were switched at a 0 degree phase angle. In the second experimental condition, sufficient high pass filtering was introduced to reduce off-frequency energy to a level that was considerably below each subject's off-frequency threshold. The filter slopes were 96 dB per octave for the 3000, 3500, and 4000 Hz test frequencies, and 144 dB per octave for the 1500 Hz test frequency.

2.3 Apparatus

Sinusoids were generated by a General Radio 1304-B Beat Frequency Audio Generator. A Grason Stadler 1287B electronic switch gated the signals and pulses from the GS switch were used by an Iconix 177 System, for timing and gating the signals. The sinusoids were delivered to Krohn-Hite 3203 filters connected in series. The intensity of the signals was controlled by a Hewlett Packard 350 D Attenuator. The output of the attenuator was connected to a TDH-49 earphone mounted in an MX41/AR cushion. Subjects were seated in a Rayproof, double-walled, sound treated room.

2.3 Procedure

In the first experimental condition, the hearing impaired and normal hearing subjects were presented with sinusoids of 20 and 200 msec duration. The normal hearing subjects were tested at all four frequencies. In the second experimental condition, high pass filtering was used. The -3 dB points of the filter combinations were always set at the test frequency. The order of the conditions and frequencies was randomized.

The average of three runs was considered to be the threshold for each frequency.

RESULTS

3.1 Effect of Filtering

The average threshold for the normal hearing subject for the unfiltered and filtered sinusoids, are presented in Figure 1.1 At each frequency, little or no difference was observed between the normal subjects' responses during the unfiltered and filtered conditions.

Figure 2 contains threshold data for hearing impaired subject J.M. High pass filtering increased thresholds by 22.68 dB for the 20 msec duration signal, and 18.55 dB for the 200 msec duration signal.

Figure 3 contains threshold data for subject S.B. High pass filtering increased thresholds by 3.27 dB for the 20 msec duration signal, and 1.83 dB for the 200 msec duration signal.

Figure 4 contains threshold data for subject M.M. High pass filtering increased thresholds by 2.40 dB for the 20 msec duration signal, and 1.85 dB for the 200 msec duration signal.

Figure 5 contains threshold data for subject M.S. High pass filtering increased thresholds by 12.75 dB for the 20 msec duration and 12.25 dB for the 200 msec duration signal.

1 In Figure 1 through 5 the subjects' responses to the unfiltered sinusoid are used as the reference threshold.

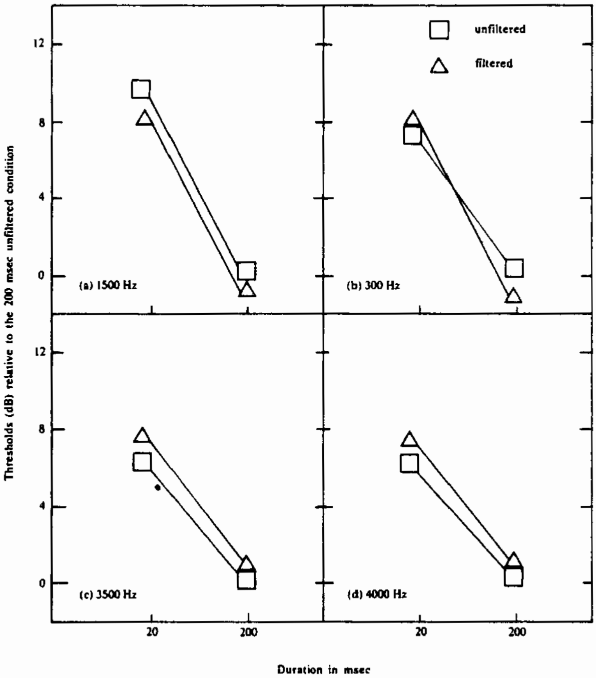

Figure 1: Magnitude of temporal integration for normal hearing subjects for unfiltered and filtered signals of [a] 1500 Hz, [b] 3000 Hz, [c] 3500 Hz and [d] 4000 Hz.

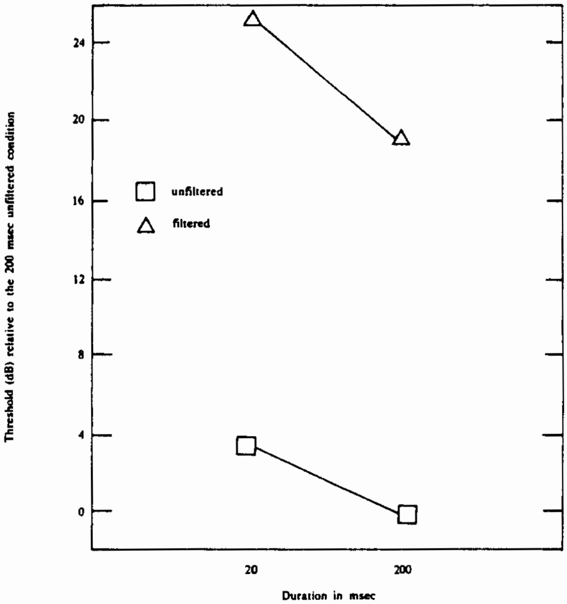

Figure 2: Magnitude of temporal integration for subject J.M. for unfiltered and filtered 1500 Hz signals.

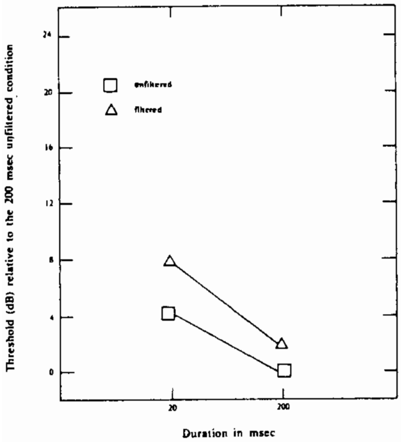

Figure 3: Magnitude of temporal integration for subject S.B. for unfiltered and filtered 3000 Hz signals.

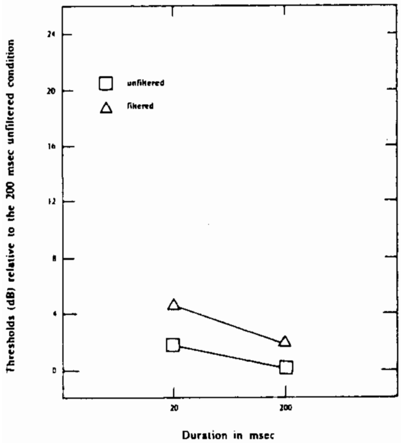

Figure 4: Magnitude of temporal integration for subject M.M. for unfiltered and filtered 3500 Hz signals.

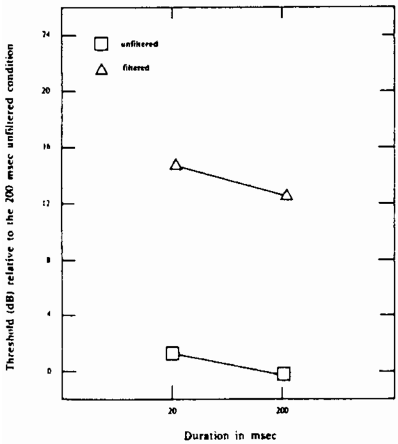

Figure 5: Magnitude of temporal integration for subject M.S. for unfiltered and filtered 4000 Hz signals.

3.2 Effect of Duration

The average magnitude of temporal integration, (the threshold difference between 20 and 200 msec duration signals), for the normal hearing subjects, as seen in Figure 1, was approximately 6 to 10 dB, and is independent of filtering. However, a wide range in the magnitude of temporal integration was observed with subjects L.T. (10.0 dB for the 1500 Hz signal), and J.F. (2.25 dB for the 4000 Hz signal).

The magnitude of temporal integration for the hearing impaired subject was as follows: (1) J.M. (Figure 2) was 2.75 for the unfiltered condition and 6.88 for the filtered condition; (2) S.B. (Figure 3) 4.03 dB in the unfiltered condition and 5.92 dB in the filtered condition; (3) M.M. (Figure 4) 1.87 dB in the unfiltered condition and 2.42 dB in the filtered condition; and (4) M.S. (Figure 5) 1.5 dB in the unfiltered condition and 2.00 dB in the filtered condition.

DISCUSSION

An examination of Figure 1, reveals that for the four normal hearing subjects there were no systematic differences between the unfiltered and filtered conditions in the present experiment. These results were expected because off-frequency energy was at least 40 dB below the subjects' off-frequency thresholds, and therefore, filtering out off-frequency energy was not expected to have any effect on threshold levels. Spence and Feth (1974) found similar results with their normal hearing subjects.

The temporal integration functions of normal hearing subjects in previous research resembles the temporal integration functions that were obtained for the normal hearing subjects in the present study. The magnitude of temporal integration was approximately 7.5 dB for all frequencies (Figure 1), whereas, Dallos and Johnson (1966) reported an average magnitude of temporal integration for eight subjects of approximately 6 dB at 1000 Hz. Watson and Gengel (1969) reported temporal integration functions for four normal hearing listeners. The interpolated thresholds for 20 versus 200 msec duration signals in their study reveals approximately a 6 dB difference at 1000 Hz and a 5 dB difference at 4000 Hz. Spence and Feth (1974) show an average increase of 10 dB for 20 versus 200 msec duration signals for six normal hearing subjects, at both 500 and 4000 Hz.

In the present study, one normal hearing subject (J.F.) had a magnitude of temporal integration at 4000 Hz of only 3.50 dB in the unfiltered condition. These results appear representative of the wide range of normal temporal integration functions reported in previous research. Richards and Dunn (1974) provide temporal integration functions of twenty normal hearing subjects for a 1000 Hz signal with 10 msec rise-fall times. Thresholds were obtained by a tracking method and the method of limits. Five subjects had temporal integration magnitudes of 4 dB or less. Twelve subjects had magnitudes between 4 and 8 dB, and three had magnitudes of more than 8 dB.

Signal spectrums were compared to the subjects' 500 msec thresholds as an aid to understanding the results. The spectrums were positioned 1 dB below the 500 msec threshold at the test frequency. This provides a relative measure of the amount of off-frequency and on-frequency energy available.

Off-frequency energy was close to the predetermined 500 msec duration thresholds for hearing impaired subject J.M. at frequencies below 1100 Hz (Figure 6). The signal spectrum was at threshold at 900 Hz and was 3 dB above threshold at 750 Hz. However, filtering reduced all measureable off-frequency energy to levels significantly below the subject's thresholds, and at 1200 Hz signal energy was greater than 40 dB below threshold. When the test signal was filtered, thresholds were increased by approximately 20 dB (Figure 2). The fact that thresholds were significantly increased in the filtered condition indicates that off-frequency energy had contributed significantly to the detection of the unfiltered signal. Because off-frequency energy is a product of rapidly switching the signal, the same amount of off-frequency energy would be available for both signal durations. Thus, in the unfiltered condition, off-frequency energy, was, to some extent, contributing to signal detection. Thresholds were, therefore, only slightly affected by changing the duration in the unfiltered condition.

The magnitude of temporal integration was 2.75 dB in the unfiltered condition. This magnitude was much smaller than the magnitudes observed in the normal hearing subjects at this frequency, and it can be described as abnormal temporal integration, of the type typical of subjects with cochlear hearing losses. Filtering the sinusoids resulted in a 6.88 dB magnitude of temporal integration, which is within the range of results obtained for the four normal hearing subjects in the present study. Thus, J.M. was utilizing off-frequency energy in the unfiltered condition, and his temporal integration appeared to be abnormal. However, when off-frequency energy was removed, the results are representative of a normal temporal integration function.

Subject S.B. was tested at 3000 Hz (Figure 7) and off-frequency energy was 2-3 dB below threshold from 750 to 1200 Hz. When filtering was used, thresholds, increased by 3.72 dB for the 20 msec and 1.83 dB for the 200 msec duration signal (Figure 3). This result can be explained by the fact that, although absolute off-frequency energy is independent of signal duration, the energy at the primary frequency is greater for longer duration signals. Therefore, off-frequency energy will be somewhat less, relative to energy at the primary, in the longer 200 msec duration signal as compared to the 20 msec signal duration.

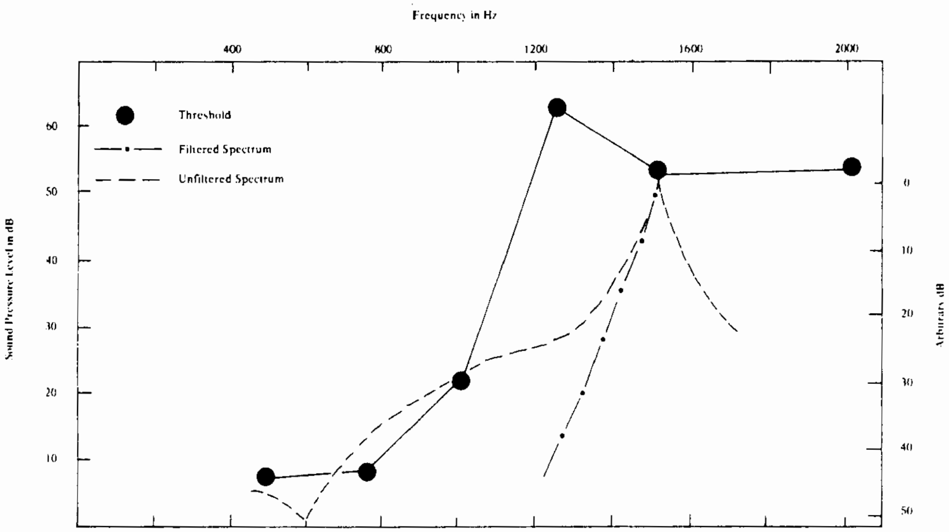

Figure 6: Thresholds for subject J.M. and spectrums for 20 msec unfiltered and filtered 1500 Hz signals.

The magnitude of temporal integration for subject S.B. was 4.03 dB in the unfiltered condition. This magnitude is slightly smaller than the magnitude observed with normal hearing subjects at 3000 Hz. Therefore, subject S.B. exhibited an abnormal temporal integration magnitude in the unfiltered condition. Under the filtered condition, the magnitude of temporal integration was 5.92 dB. This result is within the limits of normal temporal integration. For subject S.B., then, temporal integration appeared abnormal in the unfiltered condition. However, filtering eliminated the off-frequency energy and when only on-frequency energy was available for the subject to attend to, temporal integration was within normal limits.

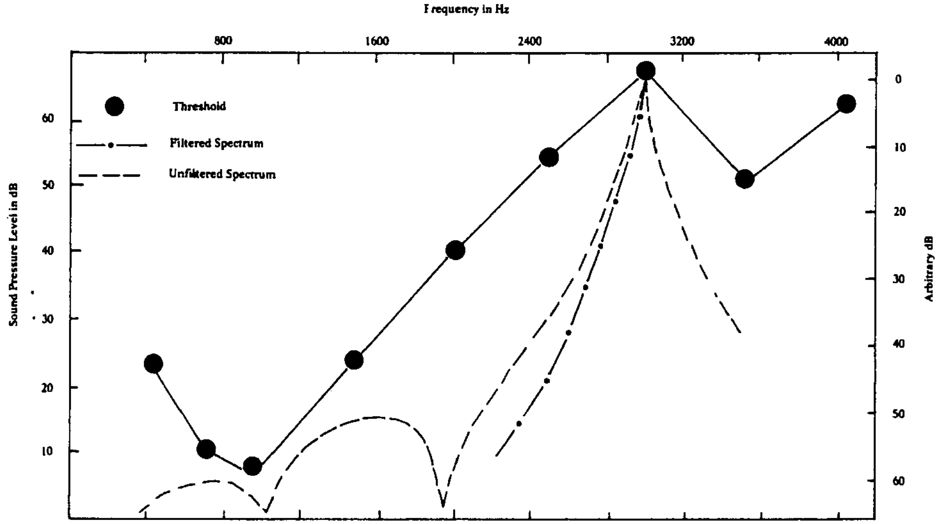

Figure 7: Thresholds for subject S.B. and spectrums for 20 msec unfiltered and filtered 3000 Hz signals.

Subject M.M. was tested at 3500 Hz, but off-frequency energy was considerably lower, relative to her thresholds, than for other subjects (see Figure 8). Off-frequency energy was 8 dB below her threshold at 1000 Hz, and more than 8 dB below threshold at other frequencies. When filtering was used to remove off-frequency energy, thresholds were increased only 2.40 dB for the 20 msec and 1.85 dB for the 200 msec duration signal (Figure 4). Therefore, since filtering had only a slight effect on thresholds, it appears that off-frequency energy was not a major factor in the detection process. An explanation of the small threshold shift can be obtained by examining the relative level of the off-frequency energy. Figure 8 reveals that off-frequency energy was at least 8 dB below threshold for the 20 msec unfiltered signal. Therefore, filtering out this energy would not be expected to have the effect it had on other subjects.

The magnitude of temporal integration for subject M.M. was 1.87 dB in the unfiltered condition, and this magnitude is considered an indication of abnormal temporal

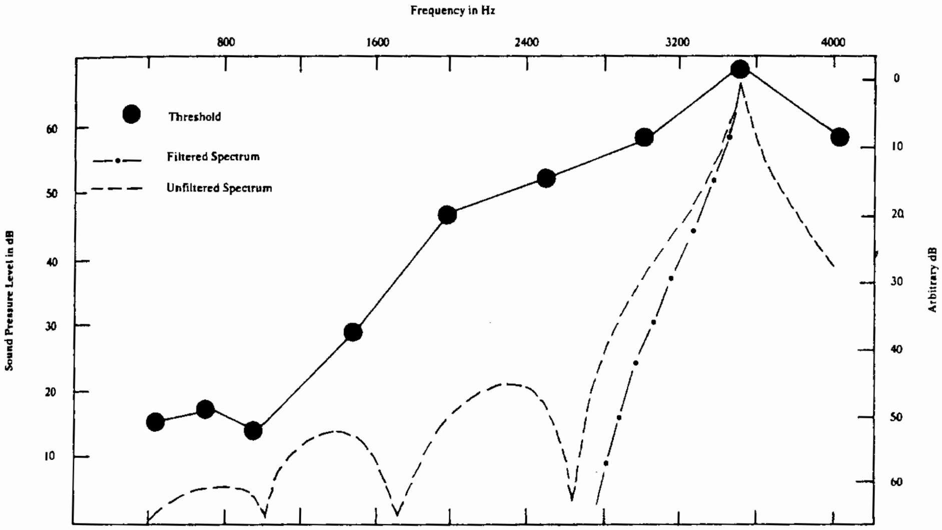

Figure 8: Thresholds for subject M.M. and spectrums for 20 msec unfiltered and filtered 3500 Hz signals.

integration. When filtering was used, the magnitude of temporal integration was 2.42 cB. This pattern of temporal integration can still be considered evidence of abnormal temporal integration. Since filtering off-frequency energy had little effect on the thresholds of subject M.M., off-frequency listening was not a confounding problem in the evaluation of her temporal integration. Therefore, M.M. had a temporal integration profile which can be considered abnormal.

Subject M.S. was tested at 4000 Hz and a comparison of his thresholds and the 20 msec test signal spectrums are given in Figure 9. Off-frequency energy was close to this thresholds from 1000 Hz to 2000 Hz and from 2200 Hz to 2500 Hz. When off-frequency energy was filtered out, thresholds for both the 20 and 200 msec signal were increased by more than 12 dB (Figure 5). This threshold shift is evidence that off-frequency energy contributed significantly to the detection process in the unfiltered condition.

In the unfiltered condition, the magnitude of temporal integration for subject M.S. was 1.50 dB, and can be classified as abnormal temporal integration as compared to the results of the four normal hearing subjects. In the filtered condition, the magnitude of temporal integration remained very small, 2.00 dB, and is also classified as abnormal temporal integration. Although the results obtained when filtering was used suggested that off-frequency energy was contributing to the detection process in the unfiltered condition for subject M.S., an abnormal temporal integration function was observed even when only on-frequency information was available to attend to.

A problem is apparent in interpreting 'normal' temporal integration. In the present study, normal hearing subject J.F., had temporal integration magnitudes of 3.50 and 2.25 dB, for the unfiltered and filtered conditions respectively. As previously mentioned, Richards and Dunn (1974) have also reported a wide variation of results for normal hearing listeners. Without a clear picture of what should be classified as normal or abnormal temporal

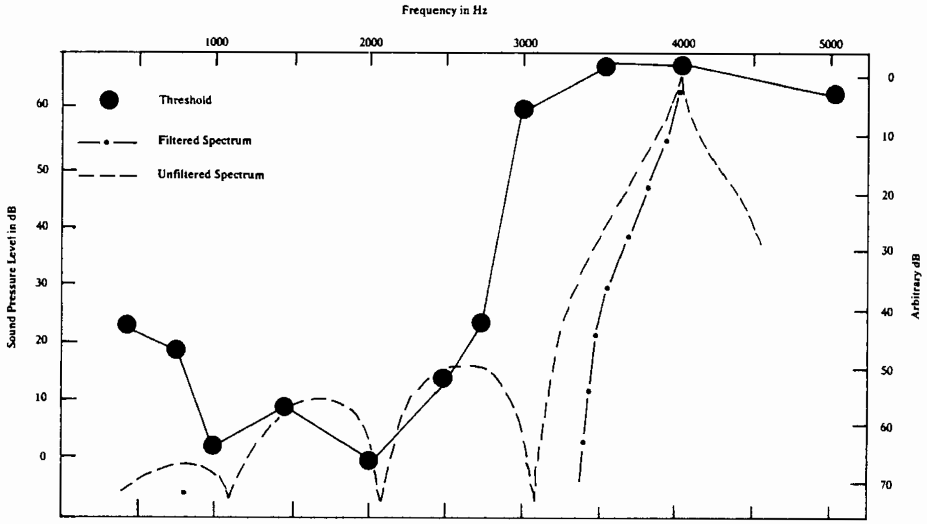

Figure 9: Thresholds for subject M.S. and spectrums for 20 msec unfiltered and filtered 4000 Hz signals.

integration, categorizing of subjects M.M. and M.S. as having abnormal temporal integration functions becomes tentative and there is a definite need for normative data on the temporal integration phenomena.

In the present study, one subject, (M.M.), with a high frequency hearing loss, exhibited an abnormal temporal integration function which was virtually unaffected by filtering. This result was explained by the fact that off-frequency energy was 8 dB or more below off-frequency thresholds, and therefore, it would have had little effect on the detection process. In a second subject (M.S.), also showing abnormal temporal integration in the unfiltered condition, filtering increased thresholds by 12 dB, indicating that off-frequency energy was contributing to the detection process in the unfiltered condition. However, even after this off-frequency energy was removed, results suggested the presence of abnormal temporal integration. The two other hearing impaired subjects (J.M. and S.B.) exhibited abnormal temporal integration in the unfiltered condition, but when off-frequency energy was removed, thresholds increased suggesting that off-frequency energy was contributing to the detection process in the unfiltered condition. As a consequence of the filtering, it was found that these subjects had temporal integration functions which could be considered normal.

The results of all four hearing impaired subjects are in agreement with the hypothesis that when off-frequency energy is close to off-frequency thresholds, off-frequency energy can be used to detect high frequency sinusoids of short durations and fast rise-fall times. All hearing impaired subjects had abnormal temporal integration in the unfiltered condition. When high-pass filtering forced on-frequency listening, two hearing impaired subjects were shown to have normal temporal integration functions and two were shown to have functions which can be described as abnormal. In addition, one of the normal hearing subjects had a temporal integration profile at 4000 Hz which could be considered abnormal.

This latter evidence indicated that a thorough understanding of normal auditory temporal integration is needed.

Watson and Gengel (1969), Harris, Haines and Myers (1958) and Sanders (1971) also found an overlap between normal and abnormal temporal integration functions. Some normal hearing listeners provided results which appeared abnormal, while other results from subjects with cochlear hearing losses appeared normal. These findings were replicated in the present study. The results also indicate that not all subjects with cochlear hearing losses appear to have abnormal temporal integration mechanisms.

The findings of the present experiment are not in agreement with those of Pederson and Elberling (1972b) who stated that "reasonable good accordance" of temporal integration functions was obtained between 2 msec and 14 msec rise-fall times for subjects with cochlear hearing losses. The test frequency used in the Pederson and Elberling study was 1000 Hz; subject threshold date were not given and off-frequency energy may not have been close enough to the subjects' off-frequency thresholds to make off-frequency listening possible. Pederson and Elberling also tested patients with cochlear losses at 1000 Hz and 4000 Hz using 2 msec rise-fall times under an unfiltered condition and with a ⅓ octave band filter. "Reasonable equality" was obtained between the two conditions. Again, these results are difficult to evaluate, without knowledge of the subjects' audiograms.

The results of the present experiment are also in conflict with the results reported by Spence and Feth (1974). They determined that off-frequency energy was not a problem in testing temporal integration functions of subjects with high-frequency hearing losses. However, they used 10 msec rise-fall times, which do not produce as much off-frequency energy as the 1 msec rise-fall times used in the present study.

The results of the present study are in agreement with the findings of Wright (1967). He obtained different temporal integration results when two different rise-fall times (fast and 10 msec) were used on one subject. Using 10 msec rise-fall times would produce much less off-frequency energy, and Wright concluded that the 10 msec rise-fall times should be used in studies of temporal information to reduce off-frequency energy.

Another interesting finding in the present study was the fact that a small amount of off-frequency energy affected on-frequency thresholds to such a large degree. For subject S.B., off-frequency thresholds energy was 2-3 dB below threshold. Yet filtering out this energy resulted in an elevation of threshold of 4 dB. For M.S., off-frequency energy was 3-4 dB above threshold, and filtering produced a threshold shift of over 12 dB. For J.M., off-frequency energy was 2-3 dB above threshold, and filtering produced a threshold shift of over 20 dB. In understanding how this information could be so useful in the detection process, it is important to remember that 'threshold' is not a energy barrier which must be crossed in order for detection to occur and it may not even be an actual physical property of the auditory system (Green and Swets, 1966; pages 117 to 148). Threshold is dependent upon the signal duration and spectrum, the earphone cushion, the psychophysical method and other nonsenory variables. It is a statistical concept, defined in this study, as a point where the subject could maintin a 75% correct criteria for the BUDTIF procedure. Threshold is, therefore, not a fixed level, and as the results of this study suggest, off-frequency energy below a statistically determined threshold can be used to augment the detection of a sinusoid of high frequency.

Results of the present study suggest that energy as much as an octave apart can combine in some fashion to contribute to the detectability of the total signal. Green (1958) found that sinusoidal paris, widely separated in frequency, were more detectable than either of the individual sinusoids. The amount of off-frequency energy available to each subject was an uncontrollable factor in the present experiment and varied amounts of energy available to different frequency regions would be expected to have unique effects on the detection of signals. As this experiment did not examine the effect of different bandwidths of off-frequency energy, further research into this area seems warranted.

Results from the present study indicate that off-frequency energy should be minimized when measuring temporal integration of hearing impaired subjects.

SUMMARY

The purpose of the present study was to determine if off-frequency energy was contributing to the detection process in the evaluation of temporal integration in subjects with high-frequency hearing losses.

Four subjects with high-frequency cochlear hearing losses and four normal hearing subjects were tested at different frequencies with 1 msec rise-fall times. High pass filtering was used in a second condition to remove off-frequency energy.

Independent of filtering, normal hearing subjects produced integration functions which were similar to that of other research. All four hearing impaired subjects showed abnormal temporal integration in the unfiltered condition. Three of these subjects, whose off-frequency thresholds were close to off-frequency energy, showed an increase in threshold when filtering was used. For the fourth subject, it was felt that off-frequency energy was significantly below threshold so as not to effect her detection process.

When these subjects were forced to listen on-frequency, two subjects had normal temporal integration and two could be considered to have abnormal temporal integration. Thus, the results indicate the off-frequency listening can be a confounding problem in the evaluation of temporal integration for hearing impaired subjects, and that not all subjects with cochlear hearing losses can be expected to show abnormal temporal integration.

Reprint requests should be mailed to:

Richard S. Tyler
Wendell Johnson Speech and Hearing Center
University of Iowa,
Iowa City, Iowa, U.S.A.

ACKNOWLEDGEMENTS

My sincerest appreciation is extended to Dr. John Booth for his guidance throughout the development of this research. I also wish to thank Dr. Joseph Corcoran, Dr. James Stouffer, Dr. Seppo Tuomi and Mr. Richard Winkelaar.

REFERENCES

Campbell, R.A., and Lasky, E.Z. (1968). "Adaptive threshold procedures: BUDTIF," **J. Acoust. Soc. Amer.** 44, 537-541.

Carhart, R., and Jerger, J.F. (1959). "Preferred method for clinical determination of pure-tone thresholds," **J. Speech Hear. Dis.** 24, 330-345.

Garner, W.R. (1947). "The effect of frequency spectrum on temporal integration," **J. Acoust. Soc. Amer.** 19, 808-815.

Goldstein, R., and Kramer, J.C. (1960). "Factors affecting thresholds for short tones," **J. Speech Hear. Res.** 3, 249-256.

Green, D.M. (1958). "Detection of multiple component signals in noise," **J. Acoust. Soc. Amer.** 30,904-911.

Green, D.M., and Swets, J.A. (1966). **Signal Detection Theory and Psychophysics.** (J. Wiley and Sons, New York).

Harris, J.D., Haines, H.L., and Myers, C.K. (1958). "Brief tone audiometry," **A.M.A. Arch. Otolaryn.** 67, 699-713.

Hatler, K.W., and Northern, J.L. (1970). "Clinical application of temporal summation," **J. Aud. Res.** 10, 72-78.

Martin, F., and Wofford, M. (1970). "Temporal summation of brief tones in normal and cochlear impaired ears," **J. Aud. Res.** 10, 82-86.

Olsen, W.O., Rose, D.E., and Noffsinger, E. (1974). "Brief tone audiometry with normal, cochlear and eighth nerve tumor patients," **Arch. Otolaryn.** 99, 185-189.

Pederson, C.B. (1973). "Brief-tone audiometry in patients with acoustic trauma", **Acta Otolaryng.** 75, 323-333.

Pederson, C.B., and Elberling, C. (1972a). "Temporal integration of acoustic energy in normal hearing persons," **Acta Otolaryng.** 74, 398-405.

Pederson, C.B., and Elberling, C. (1972b). "Temporal integration measured by brief-tone audiometry," **J. Aud. Res.** 12, 279-284.

Pederson, C.B., and Elberling, C. (1973). "Temporal integration of acoustic energy in patients with presbyacusis," **Acta Otolaryng.** 75, 32-37.

Plomp, R., and Bouman, M.A. (1959). "Relation between hearing threshold and duration for tone pulses," **J. Acoust. Soc. Amer.** 31, 749-758.

Richards, A.M., and Dunn, J. (1974). "Threshold measurement procedures in brief-tone audiometry," **J. Speech Hear. Res.** 17, 446-454.

Sanders, J.W., Josey, A.F. and Kemker, F.H. (1971). "Brief-tone audiometry in patients with VIII nerve tumors," **J. Speech Hear. Res.** 14, 172-178.

Scharf, B. (1970). "Critical Bands" in **Foundations of Modern Auditory Theory**, J.V. Tobias, Ed. (Academic Press, New York), Vol. 1, 159-202.

Sheely, E., and Bilger, R. (1964). "Temporal integration as a function of frequency," **J. Acoust. Soc. Amer.** 36, 1850-1857.

Small, A.M. (1959). "Note of the threshold of pulsed signals as a function of duty cycle and carrier frequency," **J. Acoust. Soc. Amer.** 27, 794.

Spence, M., and Feth, L.L. (1974). "Effects of off-frequency detection in brief-tone audiometry," **J. Speech Hear. Res.** 17, 576-588.

Watson, C.S., and Gengel, R.W. (1969). "Signal duration and signal frequency in relation to auditory sensitivity," **J. Acoust. Soc. Amer.** 46, 989-997.

Wightman, F.L. (1971). "Detection of binaural tones as a function of masker bandwidth," **J. Acoust. Soc. Amer.** 50, 623-636.

Wright, H.N. (1967). "An artifact in the measurement of temporal summation at the threshold of audibility," **J. Speech Hear. Dis.** 32, 354-359.

Wright, H.N. (1968). "The effect of sensori-neural hearing loss on threshold duration functions," **J. Speech Hear. Res.** 11, 842-852.

Zwicker, E., and Wright, H.N. (1963). "Temporal summation for tones in narrow band noise," **J. Acoust. Soc. Amer.** 35, 691-699.