COMODULATION MASKING RELEASE IN FROZEN AND RANDOMLY-SELECTED NOISE

by

Carol Mackersie

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4-24-95
Date

Harry Levitt, Ph.D.
Chair of Examining Committee

4-24-95
Date

Irving Hochberg, Ph.D.
Executive Officer

Supervisory Committee:

Mark Weiss, M.S.E.E.

Irving Hochberg, Ph.D.

THE CITY UNIVERSITY OF NEW YORK

Abstract

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Advisor: Professor Harry Levitt

This dissertation examined the effects of combining comodulation masking release (CMR) and frozen-noise masking release (FNMR). It was hypothesized that CMR and FNMR result from essentially the same cues (i.e. envelope reproducibility). This was tested by comparing CMR in frozen and randomly-selected noise. It was expected that if the same cues underlie both phenomena, CMR would not be present in frozen noise.

Subjects were tested using two noise samples (samples A and B) under four masking conditions: single-band frozen- and randomly-selected noise, and seven-band frozen- and randomly-selected noise. During the frozen-noise conditions, the same noise sample was used on each presentation. During the randomly-selected conditions, the tone was masked by either noise A or B and the "noise-alone" sample was randomly chosen from the remaining seven alternatives.

The hypothesis was supported by results of two of the five subjects who did not show CMR in frozen noise. Two of the five subjects showed smaller CMR in frozen than randomly-selected noise. One subject did not show FNMR, suggesting that she was unable to use cues available in frozen noise.

Thresholds were lower for noise sample A for all subjects. CMR and FNMR was absent for noise sample A for the majority of subjects. This was attributed to the low thresholds observed in the reference condition. Differences in the short-term RMS and envelope power spectra of the noise samples provided possible explanations for these results.

In Experiment 2, the single-band stimuli used in Experiment 1 were transposed to 6-kHz . On the basis of evidence that envelope cues may be represented in the auditory system by the pattern of phase locking, it was hypothesized that differences between noise samples A and B would be reduced at 6000 Hz.

Four subjects did not show a significant difference between thresholds for the two noise samples at 6-kHz. No subjects showed FNMR at 6-kHz, whereas four subjects showed FNMR at 1-kHz. These results support the interpretation that envelope cues were responsible for FNMR and the threshold differences between the two noise samples in Experiment 1.

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CHAPTER 1

INTRODUCTION

Detection of tones in random noise is generally thought to be determined largely by the amount of masker energy falling within a relatively narrow frequency region (critical band) surrounding the signal frequency (Fletcher, 1940). In traditional masking studies which examine the detection of tones in random noise, the waveforms of random noise maskers vary from trial-to-trial. Therefore, the "threshold" for a subject is really based on the average of a set of responses to a number of different waveforms. Although the "critical-band" view of masking explains a large body of data on detection of tones in random noise, there is evidence to suggest that additional masking results from trial-to-trial uncertainty of random noise waveforms (Pollack, 1975; Gilkey and Robinson, 1986; Raab and Goldberg, 1975). Pollack (1975) first introduced the term "informational masking" to refer to this contribution of uncertainty to threshold elevation in random noise.

Informational masking has been of interest for several reasons. Several investigators have compared responses obtained in frozen noise (for which the statistical features of the waveforms are known for each trial) to performance in random noise in the interest of estimating the relative contributions from external stimulus-related factors and internal noise (e.g. biological noise, response bias and time order effects) to the detection process, (Green, 1964; Richards, Heller, and Green, 1991; Swets, Shipley, McKey and Green, 1959). Others have used

reproducible noise as a way to more closely examine subject responses in relationship to acoustic aspects of the masker waveforms (Ahumada and Lovell, 1971; Ahumada, Marken and Sandusky, 1975; Buus, 1990; Gilkey, Robinson and Hanna, 1985; Gilkey and Robinson, 1986). Finally, several investigators have taken a direct interest in informational masking, focusing research efforts on quantifying and describing various parameters and conditions which affect this phenomenon (e.g. Neff and Green, 1987).

Since the introduction of the concept of informational masking to describe non-energy based masking produced by trial-to-trial random noise uncertainty, the use of the term has been expanded to include a variety of phenomena in which interference with some aspect of sound perception (i.e. detection or discrimination) occurs as a result of signal uncertainty, variability in context surrounding the signal, or both (Leek, Brown and Dorman, 1991; Lutfi, 1990; Watson, Kelly and Wroton, 1976). The term "informational masking" is now commonly used to refer to masking which involves interference by irrelevant sources of information (Neff, Dethlefs and Jesteadt, 1993; Leek et al., 1991). The term "uncertainty-masking" will be used in place of "informational masking" in this dissertation to avoid the implication that the masking is due to interference by irrelevant sources of information because it is also possible that the uncertainty-masking occurs as a result of limiting the use of a cue that might otherwise be available with reproducible signals. For the purposes of this dissertation, "uncertainty-masking" is defined as the "contribution of stimulus uncertainty to masking of tones in noise".

Two features of uncertainty-masking distinguish it from critical-band-based masking. First, uncertainty-masking is unrelated to the energy interactions between the masker and signal (Neff and Callaghan, 1988; Watson and Foyle, 1985; Watson et al, 1976). Second, the greater the uncertainty of the masker, the greater the amount of masking (Neff and Green, 1987; Pfafflin, 1968; Watson and Foyle, 1985). Consequently, release from uncertainty-masking (i.e., improvement in threshold) is observed when masker uncertainty is reduced.

There are two established phenomena that may represent examples of release from uncertainty-masking: comodulation masking release (CMR) and frozen noise masking release (FNMR). Comodulation masking release is the improvement in threshold that occurs when the amplitude modulation envelope of the masker is reproduced in remote frequency regions. Frozen noise masking release (FNMR) is the improvement (re: detection in random noise) in detection of a tone in noise that occurs when the same noise waveform is used for each trial. The improvement in detection that characterizes both FNMR and CMR, occurs when the addition of envelope information reduces the trial-to-trial masker uncertainty. In the case of CMR, masker uncertainty is reduced by introducing amplitude envelope reproducibility across frequencies. In the case of FNMR, masker uncertainty is eliminated by using the same waveform on every presentation. It is hypothesized that the nature of the envelope reproducibility that occurs across frequency in the case of CMR, and across time in the case of FNMR, is essentially the same information.

This hypothesis was tested by examining the effects of combining comodulation- and frozen-noise-masking-release. The specific research question is: Does the combination of comodulation masking release and frozen noise masking release produce more release from masking than either source acting alone? To address this question, comodulation masking release was compared using randomly-selected noise and frozen noise. It was expected that if the same cues underlie both phenomena, CMR would not be present in frozen noise.

CHAPTER 2

REVIEW OF THE LITERATURE

Classic theories of auditory masking predict that detection of tones in noise is dependent on the masker energy within a critical band of the signal. According to the "critical-band" view, energy falling outside the critical band neither degrades nor facilitates signal detection. Relevant to this dissertation are several areas of research which challenge this view of masking by providing evidence that 1) detection of signals in noise can be enhanced (e.g. CMR) or degraded (e.g. masker uncertainty) by integrating information across critical bands and 2) in the case of narrow-band noise, listeners use cues other than masker energy in detecting tones in noise.

These topics as well as other areas relevant to this dissertation will be addressed in this chapter. These areas are: 1) the effects of masker uncertainty on detection of tones in noise; 2) detection of tones in narrow-band noise 3) comodulation release from masking and 5) combining sources of masking release.

EFFECTS OF MASKER UNCERTAINTY

Uncertainty masking has been observed using simultaneously presented stimuli (e.g. detection of tones in noise) (Buus, 1990; Gilkey, 1987; Neff and Green, 1987; Neff and Callaghan, 1988; Neff, 1991; Pfafflin, 1968; Spiegel and Green, 1982; Spiegel, Picardi and Green, 1981) as well as sequentially presented stimuli (Spiegel and Watson, 1981; Watson and Foyle, 1985; Watson et al., 1990; Watson, Kelly, Wroton, and Benbassat, 1975). Relevant to this dissertation is the literature on the

effects of masker uncertainty on the detection of simultaneously presented stimuli. A number of investigators have observed that the threshold for detection of tones is lower in frozen noise than random noise (Pfafflin, 1968; Spiegel and Green, 1982). Presumably, listeners are able to make use of information available in the frozen noise waveforms that becomes unavailable when the waveform is randomized from trial-to-trial. In some studies, the effects of uncertainty have been examined by simply varying a masking waveform from trial to trial (Pfafflin, 1968). In others, attempts have been made to emphasize manipulation of uncertainty in the frequency, intensity or temporal domains as well as a combination of these (Green and Weber, 1980; Neff and Callaghan, 1987: Watson, Foyle and Kidd, 1990).

Early studies investigating the effects of noise uncertainty used frozen noise in which either the same waveform occurred in each interval of a given trial or different waveforms were used in each interval of a trial (Green, 1964; Pfafflin and Mathews, 1966; Pfafflin, 1968). In their initial experiment, (Pfafflin and Mathews, 1966), "identical noise" trials (same noise sample in each of two intervals) were randomly mixed with "different noise" trials (different noise sample in each interval). Detection of a 312.5 Hz tone was measured in the presence of 1000 Hz wide reproducible noise selected from a pool of 12 noise samples. Detection of signals in the identical-noise conditions was not superior to detection in the different-noise conditions. This was attributed to the fact that both the reproducible and random conditions had relatively high levels of uncertainty due to random mixing of the two types of trials.

In a second study, Pfafflin (1968) compared detection of 312.5 Hz signals in 12 noise samples varied between trials to detection when the same noise sample (frozen noise condition) was used over a large number of trials (N=288). They found large differences in detection of a 312.5 Hz tone across the 12 reproducible noise samples. Unlike the previous experiment, detection of signals for a given noise sample in the frozen noise conditions was superior to that obtained when noise sample were varied between trials.

Spiegel et al. (1981) investigated the effects of signal and masker frequency uncertainty using equal amplitude multicomponent (2-20 components) sinusoidal maskers. Masker component frequencies were randomly selected from 200 components equally spaced logarithmically between 300-3000 Hz. The signal was a sinusoid which was added in phase to one of the masker's components. Subjects were required to detect an increment in the central component of the masker under four conditions: fixed-signal/fixed-masker, fixed-signal/random-masker, random-signal/fixed-masker, and random-signal/random-masker. For the random conditions, stimuli were the same in both observation intervals and varied between trials. Masker uncertainty resulted in threshold increases of up to 6 dB for 2-20 masker components, whereas signal uncertainty raised thresholds by only 1 dB. A considerably larger reduction in performance occurred in the combined random-signal/random-masker conditions which resulted in threshold increase of about 5 to 8.5 dB as the number of masker components increased from 2-20.

Spiegel and Green (1982) reported similar effects using reproducible noise bursts (2700 Hz wide). The combinations of fixed and random signal and masker

conditions were similar to the conditions in their 1981 study. The effect of signal and masker uncertainty were similar (2-4 dB) unlike the previous experiment which showed smaller effects of signal uncertainty. The combination of both types of uncertainty raised thresholds by 8-12 dB.

Neff and Green (1987) compared the amount of masking produced by broadband maskers (0-5000 Hz) to the amount of masking produced by 200 millisecond multicomponent sinusoidal maskers whose components were randomly drawn from the same frequency range as the broadband noise. The minimum spacing between the component frequencies was 5-Hz and the amplitudes and phases were varied within trials. Thresholds for signals of 250, 1000 and 4000 Hz were measured as a function of the number of masker components. Although the number of components varied, the average overall power was held constant at 60 dB SPL, which was equal to the broadband masker. Multicomponent maskers with more than five components produced 10-20 dB more masking than the broadband masker. The largest difference between the multicomponent and broadband maskers was observed for the 1000 Hz signal. There was a large increase in the amount of masking as the number of masker components was increased from 2 to 10 components. When maskers were held constant for each interval and varied between trials, thresholds improved substantially (e.g. 22 dB improvement over variation within-trials for a 1 kHz signal with 10-component maskers). This improvement may be due to the greater availability of spectral shape information when the maskers are the same in each interval and varied between trials. Comparison of spectral shape

between the signal plus noise and noise alone intervals would be difficult when the masker waveform is different for each interval.

To reduce the contribution of critical-band based masking, Neff and Callaghan (1988) eliminated masker components falling within the estimated critical band (160 Hz) of the 1000 Hz signal. Their results showed an improvement in performance with the components around the critical band removed. For maskers with 10-100 components, an improvement of approximately 10 dB was observed, however a considerable amount of masking relative to thresholds in quiet was still produced (e.g. 30-40 dB). Although it is likely that removing components from a 160 Hz region around the signal did not completely eliminate the contribution of critical-band-based masking, it reduced it substantially. There was no effect of removing the components around the critical band for maskers with two and four components presumably because there was a lower probability that components would fall within the critical band of the signal. The large amount of masking (37-40 dB re: thresholds in quiet) produced by 2-10 components with the critical band components removed suggests that a large part of the masking was due to masker uncertainty.

The experiments conducted by Neff and colleagues randomized component amplitudes as well as frequencies in the conditions of uncertainty. An additional experiment was conducted to separate the potential influences of masker component frequency uncertainty from component amplitude uncertainty as a function of the number of masker components (Neff and Callaghan, 1988). They compared masking produced by maskers with fixed frequency/fixed amplitude components to maskers with fixed frequency/random amplitude components. There was no effect of randomly

selecting masker component amplitudes on each presentation for any of the maskers. In contrast, component frequency uncertainty increased thresholds by 5-15 dB for maskers with 10 or fewer components, but had no effect for maskers with 50 or more components. For maskers with only 2 components, randomization of masker component frequencies produce 15 dB more masking than the fixed frequency condition. These effects of frequency uncertainty were same for maskers with fixed and randomized component amplitudes.

DETECTION OF TONES IN NARROW BAND NOISE

Critical band theories of masking predict that detection of tones in noise is determined primarily by the masker energy within a critical band, however, there is some evidence to suggest that other factors may play a role in detection of tones in narrow-band noise.

Hartmann and Pumplin (1988) proposed that the detection of tones in narrow-band noise is related to the amount of amplitude fluctuation in the noise band. Narrow-band noise (100-Hz bandwidth) with minimal fluctuation was created using an algorithm formulated by one of the authors (Pumplin, 1985). Thresholds for tones masked by this "low-noise" noise were compared to thresholds using random Rayleigh-distributed-amplitude noise. They found that thresholds were approximately 5 dB lower in the maskers with small fluctuations than for the random noise.

Several investigators have shown that roving overall level of stimuli on each presentation has little effect on detection of tones in narrow-band noise (Kidd, Mason, Brantley, and Owen, 1989; Richards, Heller and Green, 1991). Kidd et al. (1989)

roved the overall level of stimuli over a 32 dB range within trials to limit the use of intensity cues in the detection of tones in noise. They found that performance was unaffected by the roving level paradigm for 50 and 100-Hz wide maskers. Thresholds for tones masked by 10-Hz wide maskers were elevated by about 5 dB in the roved condition, however performance was often better than would be predicted by an energy detector model, suggesting that some other cue may be used in the detection process.

Using masker bandwidths ranging between 10 and 80 Hz, Kidd, Uchanski, Mason and Deliwala (1993) examined detection of tones in different samples of frozen noise. One of the goals of the experiment was examine the role of envelope cues in the detection of tones in narrow-band noise. The maskers were multitone complexes generated from equal amplitude tones spaced 5 Hz apart. The signal was a 1000 Hz tone added in phase to the 1000 Hz component of the masker. Detection of tones in noise was compared using 12 different 20-Hz wide noise samples. Starting phases of each of the five equal amplitude components were chosen at random for each of the 12 samples. The overall level was roved over a 10 dB range on each presentation. Thresholds across the 12 samples varied over a 15 dB range with thresholds across samples correlating positively between individual subjects. Several different analyses of the noise samples were performed in a effort to relate threshold differences to several envelope characteristics of the samples, however none of the correlations were significant.

Six different masker samples were also used to examine thresholds as a function of center frequency (300-3000 Hz). Thresholds varied over a 15 dB range

across noise samples. There was a high correlation between frequency and thresholds for the various noise samples. The amplitude envelope for a specific noise sample is based on the component phase values (independent of center frequency), therefore similar relationships among thresholds across center frequencies supports the importance of envelope information in detection of tones in narrow band noise. The authors concluded that this finding provides evidence for the existence of envelope information in the noise samples despite the failure to show correlations between thresholds and specific envelope characteristics of the noise samples. A possible explanation for the absence of significant correlations is the possibility that the nature of the envelope cues important for detection varied across the 12 noise samples.

In a similar study, Green and colleagues examined detection of tones in narrow-band (20-Hz wide) noise (Green, Berg, Dai, Eddins, Onsan, and Nguyen, 1992). The maskers consisted of five-tone complexes spaced 5-Hz apart. The amplitudes and phases were randomly chosen on each presentation for one of the maskers. A second type of masker consisted of equal amplitude components for which only phases were randomized. Overall level was randomized over a 20 dB ranges to decrease the reliability of level-based cues. For the equal-amplitude masker, thresholds were more than 10 dB lower than would be predicted from cues based on overall level, and 3-4 dB less than predicted for the random amplitude masker. Predictions based on changes in the envelope power spectrum for a signal spectrally centered in the maskers were within 1 dB for the equal amplitude masker and within 2 dB (predicting greater sensitivity) for the random amplitude masker. They

concluded that changes in the shape of the envelope power spectrum was a likely detection cue.

A failure to predict detection of tones in narrow-band noise based on overall level was also reported by Richards (1992) in a study which examined detection of a 2000 Hz tone in equal energy noise which ranged in duration from 50-200 ms and in bandwidth from 50-320 Hz. Predictions of thresholds using envelope-based models and a model based on waveform zero crossings demonstrated that there was sufficient information in both the envelope and zero-crossings of the maskers to account for psychophysical detection results.

COMODULATION MASKING RELEASE

The term comodulation masking release (CMR) has been used to described the release from masking of a signal that occurs when a secondary masker with same temporal envelope is added outside the critical masking band. Comodulation masking release has been studied using two basic stimulus paradigms: the "bandwidening" paradigm, in which the threshold of a tone is measured in the presence of a single band of amplitude modulated noise as a function of noise bandwidth and the "flanking-band" paradigm in which threshold is measured in the presence of two or more separate bands of noise remote in frequency, but sharing the same temporal envelope (Hall, Haggard and Fernandes, 1984). The noise band centered on the tone is known as the signal-band and the noise bands remote from the signal frequency are known as flanking-bands. The terms "comodulated" or "correlated" noise are

often used to refer to noise which has across frequency coherence of the temporal envelope.

METHODOLOGICAL CONSIDERATIONS

A variety of methods and stimuli have been used to study CMR. Some of the methodological considerations are summarized below.

Reference condition used to quantify CMR: Two reference conditions have been used to quantify CMR. Some studies compare signal threshold in multiple bands of noise with uncorrelated envelopes to thresholds obtained in correlated noise bands. CMR is defined as the difference between the uncorrelated and correlated noise conditions "CMR(U-C)". Other studies use the threshold obtained with a single band of noise (signal-band) as the reference condition and define CMR as the difference between thresholds in the single-band condition (reference) and the threshold with the addition of comodulated flanking-bands "CMR(R-C)".

The magnitude of CMR is usually larger for the CMR(U-C) contrast. This measure, however, may be influenced by within-channel cues as well as by interference produced by uncorrelated flanking bands. Because CMR is generally viewed as a phenomenon involving comparison of information across critical-bands, differences which are observed within a critical band generally not considered "true" CMR. Consequently, several investigators have maintained that CMR (U-C) overestimates the "true" magnitude of across-frequency CMR. Evidence for the existence of within-critical-band cues has been found in CMR studies using a band-widening paradigm. For example, CMR(U-C) measured as a function of increasing

bandwidth has been reported for sub-critical bandwidths (e.g. 3.5 dB using a 50-Hz bandwidth). Studies which use a flanking-band paradigm have shown that thresholds in the presence of uncorrelated flanking bands are 1-3 dB worse than in a single band. This occurs despite the fact that the flanking bands fall outside the critical band of the signal. This finding, which has been referred to as an "interference effect" may be yet another example of masking due to uncertainty in which energy outside the signal's critical band disrupts detection (Fantini, Moore and Schooneveldt, 1993; Schooneveldt and Moore, 1987).

Type of masker used: At least three different types of masking noise have been used to study CMR. One type of noise is produced by multiplying low pass noise (e.g. 12-Hz bandwidth) by a sinusoid (e.g. Schooneveldt and Moore, 1989a). This has been referred to as "multiplied noise". An alternative method (e.g. Hall, 1987) involves multiplying filtered Gaussian noise (e.g. 990-1010) by a tone complex (e.g. components = 1600, 1700 and 1800 Hz) to produce six 20 Hz bands. The upper bands are then removed by filtering. This type of noise has been referred to as multiplied/filtered noise. The third type of noise reported in the CMR literature consists of sinusoidally amplitude modulated (SAM) complexes which have been produced by adding together SAM tones in phase (Grose and Hall, 1989). All three types of noise have produced substantial CMR.

Moore, Hall, Grose and Schooneveldt (1990b) compared CMR(R-C) obtained with multiplied and multiplied/filtered noise. They found that thresholds for the reference condition were fairly stable across subjects using Gaussian (multiplied/filtered) noise (range 73.8-75.5 dB), whereas intersubject variability was

greater using the multiplied noise (range 64.2-73.5). Consequently, variability in CMR was greater for multiplied noise (range .2 dB-4.9 dB for a 600 Hz flanking band) than for multiplied/filtered noise (5.7-8.2 dB for a 600 Hz flanking band). Subjects with the smallest CMR for the multiplied noise had the lowest thresholds for the single-band reference condition.

STIMULUS PARAMETERS WHICH AFFECT CMR

A number of stimulus parameters have been shown to affect the magnitude of comodulation masking release. Some of the parameters relevant to this dissertation are discussed below.

Asynchrony of the masker and signal: A number of studies have compared CMR in continuous noise and simultaneously-gated noise (Fantini et al., 1992; Hall and Grose, 1990; McFadden, 1986; McFadden and Wright, 1992). Results of these studies have been mixed.

Some studies did not show differences in the magnitude of CMR for continuous and gated noise (McFadden, 1986; Hall and Grose, 1990). Hall and Grose (1990) did not find a difference between CMR(R-C) magnitude in continuous and gated noise when all the bands were comodulated. They did find, however, that temporal asynchrony restored some detectability that had been reduced by replacing some of the comodulated flanking-bands with uncorrelated bands.

In contrast, other investigators have found that CMR(R-C) is larger in continuous noise than in gated noise. Fantini et al. (1992) found that thresholds in the reference condition were similar for the gated and continuous noise conditions, however in the presence of the two flanking bands, thresholds were generally lower in the presence of continuous noise than in gated noise. Consequently, CMR was greater in the presence of continuous noise, whose duration (and onset) was different than the signal. The disparity between the results of this study and previous studies was unexplained, however differences in stimuli, conditions and subjects may have contributed to these differences.

McFadden and Wright (1992) investigated the effects of increasing the onset asynchrony between the signal and masker by increasing the portion of the masker preceding the signal. The segment of the masker preceding the signal has been referred to as the masker "fringe" (Gilkey, 1987; McFadden and Wright, 1990; McFadden and Wright, 1992). CMR increased as the masker fringe was increased from 5 to 255 ms. They found large individual differences in listeners' abilities to use the fringe cues.

Modulator bandwidth (rate of modulation) and masker bandwidth: The largest CMR is seen at low rates of modulation. CMR decreases at a function of increased modulator bandwidth (Hall and Grose, 1989; Schooneveldt and Moore, 1989b). Largest CMR is seen for modulator bandwidths of 50 Hz and less. Experiments involving the addition of one or more flanking bands have shown that CMR increases as the bandwidth of the flanking bands decrease (Moore and Schooneveldt, 1990;

Schooneveldt and Moore, 1987). This has been attributed to the fact that narrower bandwidths results in slower fluctuations.

CMR as a function of signal frequency.

Studies that have evaluated CMR as a function of signal frequency (250-8000 Hz), have shown that CMR does not change substantially with signal frequency up to 4000 Hz (Haggard, Hall and Grose, 1990; Hall, *et al.*, 1989; Schooneveldt and Moore, 1987). CMR is reduced at frequencies above 4000-Hz, however (Fantini et al, 1992; Schooneveldt and Moore, 1987). Fantini and colleagues compared the magnitude of CMR at various signal frequencies for gated and simultaneous maskers. For maskers which are gated simultaneously with the signal, CMR was similar at .5 and 2-kHz, but absent at 6-kHz. In the presence of continuous maskers, CMR was larger than in gated maskers and was present at all three frequencies, however CMR was smaller at 6-kHz than at the other frequencies. These investigators proposed that the onset asynchrony between the signal and maskers provided an additional cue in the continuous masker condition that more easily permitted listeners to perceptually separate the signal and masker. The greater magnitude CMR observed with continuous noise was attributed to the lower thresholds in the comodulated conditions, an interpretation which is consistent with the results of Zera and Green (1993) who showied that onset asynchrony is most effective as a cue when across-frequency comparisons are possible.

Frequency separation between the flanking and signal bands: The magnitude of CMR increases as the frequency separation between the flanking- and signal-band

decreases (Hall et al., 1984; Hall, Grose and Haggard, 1990; McFadden, 1986; Schooneveldt and Moore, 1987).

Schooneveldt and Moore (1987) observed CMR functions that had two distinct components: a sharply tuned component restricted to flanking-bands close to the signal frequency, and a broadly tuned component observed at all flanking-band frequencies. The sharply tuned component, which occurred when the signal- flanking bands were within the same critical band, was attributed to beating of signal-band and flanking-band carrier frequencies. The masking release observed in the sharply tuned component was dependent on within-channel cues and was not considered to reflect true CMR.

Cohen and Schubert (1985) found that CMR was very small or absent when flanking-bands were separated from the signal-band by an octave or more. They proposed that decorrelation of the flanking-band and signal band envelopes due to the traveling wave delay may have accounted for this finding. In contrast, Cohen (1991) showed CMR over a three-octave range when the flanking-band was lower in frequency and higher in level than the signal-band.

CMR with multiple flanking bands: Several investigators have reported that CMR increases when additional flanking bands are added (Hall and Grose, 1990; Hall, Grose & Haggard, 1988; McFadden and Wright, 1987). Hall and Grose (1990) showed that CMR continued to increase with up to eight 20-30 Hz wide flanking bands, although the magnitude of changes was not large beyond the addition of six flanking bands. Frequency separation between the noise bands was never closer than one critical bandwidth in order to avoid the beating effects observed by

Schooneveldt and Moore (1987). CMR was approximately 8 dB for a single flanking band, 12 dB for two flanking bands added closest to the signal frequency and nearly 16 dB with eight flanking bands.

Overall intensity effects. Moore and Shailer (1991) investigated CMR as a function of overall level. CMR was measured for a 700 Hz sinusoid using six 20 Hz wide flanking bands as a function of spectrum level variations of 0-40 SPL. Thresholds in single-band reference condition remained the same (relative to the masker spectrum level) as the overall noise level increased. However, thresholds in the comodulated noise decreased with increasing masker spectrum levels up to 30 dB. CMR increased from less than 2 dB to 15 dB at a level of 30 dB/Hz SPL.

CMR and stimulus uncertainty.

Grose and Hall (1990) investigated the effect of signal frequency uncertainty by randomizing the placement of the signal in an array of nine comodulated bands. Thresholds were higher in the random frequency condition than in the fixed-frequency condition. The effect of randomizing signal frequency appeared to be larger for the uncorrelated noise condition than for the comodulated noise condition, which resulted in slightly greater CMR (U-C) in the random frequency condition.

The effect of masker uncertainty has been studied by comparing thresholds and CMR(U-C) under several conditions of envelope uncertainty (Wright and McFadden, 1990). Thresholds were compared for randomly-selected noise samples which were different within a trial to thresholds for frozen noise samples which were fixed within a trial. In some conditions, trials which contained correlated noise bands were intermixed with trials which contained uncorrelated noise bands. The authors

reported that "CMR remained constant" across the random- and fixed-sample conditions; however, their data appear to show that CMR is approximately 3-dB smaller in the fixed-sample condition than in the random-sample condition when correlated and uncorrelated conditions were not intermingled within a block of trials. Unfortunately, there is no discussion of variability in the data nor are any statistical analyses reported, so it is difficult to determine whether this difference is significant. The smaller CMR in frozen noise shown in this study, if significant, partially supports the hypothesis of the current experiment, i.e. that CMR is smaller in frozen noise.

CMR AND AUDITORY GROUPING

Investigators have hypothesized that the magnitude of CMR may be larger under conditions which promote perceptual segregation of the signal and masker. Perceptual segregation may be enhanced by conditions which are conducive to auditory grouping of the flanking- and signal-bands. A number of factors have been shown to encourage auditory grouping of different signals, including common amplitude modulation, frequency and intensity similarities, and simultaneous onset (see Bregman, 1990 for review).

Onset/offset asynchrony. The effectiveness of onset/offset asynchrony in promoting the perceptual segregation of auditory sources has led to comparisons of the magnitude of CMR under various conditions of asynchrony between the flanking- and signal-bands. McFadden (1986) found that for 75-100 Hz wide noise bands, flanking-band delays of greater than 1.6 ms relative to the signal-band produced a

substantial reduction in CMR, but small CMRs persisted for delays of up to 12-15 ms. Moore and Schooneveldt (1990) observed that the effect of this delay decreased as the bandwidth of the noise decreased. Noise bandwidths of 6.25 Hz were unaffected by delays of up to 20 ms. This has been attributed to a greater envelope coherence between noise bands of smaller bandwidths for the time delays used in this study.

Grose and Hall (1993) examined the effect of onset/offset asynchrony between the flanking- and signal-bands for signal-bands which were greater in duration than the flanking bands resulting in onset/offset asynchronies ranging from 0 to 100 ms. CMR decreased as asynchrony between the signal- and flanking-bands increased and was completely eliminated for onset/offset asynchronies of greater than 50 ms. These results are consistent with the idea that onset/offset asynchrony between the signal-and flanking-bands disrupt perceptual grouping of these comodulated noise bands. The results of studies showing that CMR is larger when the masking bands are synchronous with one another, but asynchronous with the tone onset, reflect a situation in which perceptual segregation may be promoted by signal/masker onset asynchronies (see previous section on masker/signal asynchrony).

Common amplitude modulation. Several studies show that increasing the number of flanking bands increases CMR magnitude compared to a single flanking-band (Hall and Grose, 1989; Hall and Grose, 1990). When two of the six flanking bands are replaced by bands with different temporal envelopes ("deviant bands"), CMR is substantially reduced (Hall and Grose, 1989). Interestingly, if the deviant bands are then comodulated with one another, this interference can be reduced and

continues to improve slightly as more codeviant bands are added. These results support the idea that auditory grouping plays a role in CMR.

Spectral proximity in an auditory streaming paradigm. Auditory streaming studies have shown that sounds presented sequentially can be perceptually segregated into separate auditory streams and perceived as separate sources of sound (see Bregman, 1990 for review). Grose and Hall (1993) used an auditory streaming paradigm to further study the possible role of auditory grouping in the CMR phenomenon. They preceded the presentation of the comodulated bands by a sequence of flanking bands close in frequency designed to "capture" the comodulated bands into an auditory stream separate from the signal-band. Results showed that CMR was reduced from 12 dB to 7 dB when the capture bands were added. This finding supports the idea that CMR is enhanced under conditions which encourage perceptual grouping of the signal-bands and flanking-bands.

PROPOSED MECHANISMS FOR CMR

Two general classes of explanations have been proposed to account for comodulation masking release: the "across-channel" explanations which involve a comparison of information across critical bands and the "within-channel" explanations which involve the use of information within a critical band.

Within-channel cues.

Envelopes cues.

Moore and Glasberg (1987) examined the role of two within-channel cues based on masker envelope. One possible cue is related to the changes in the pattern

of phase locking of neurons which coincide with fluctuations in the masker envelope. The second possible cue is the reduction of modulation depth which occurs when the signal is present. Comparisons were made between a non-fluctuating masker (80 dB sinusoid) and a fluctuating masker (a pair of sinusoids with an overall level of 80 dB centered at the frequency of the single sinusoid). Release from masking was defined as the threshold difference between the fluctuating and non-fluctuating maskers. The frequency of the signal was always 1.8 times that of the masker. This frequency separation between the signal and masker resulted in a condition similar to a typical CMR experiment in which detection could potentially involve comparison of information across critical bands.

To evaluate the role of modulation depth as a detection cue, thresholds obtained using a fixed modulation depth (50%; 9.5 dB peak-valley ratio) were compared to thresholds obtained in maskers whose modulation depth was randomized from peak-to-valley ratios ranging from 5.7 to 18.8 dB. Thresholds were expected to be higher for the random modulation condition if detection cues depended on modulation depth, however results were similar for the two conditions failing to support modulation depth as a cue for detection.

To examine the role of phase locking, thresholds were measured as a function of signal frequency which ranged from 450-9495 Hz. Phase locking is markedly reduced above 4000-5000 Hz, thus any release from masking based phase locking would be expected to be reduced in the high frequencies. The results supported this idea showing considerable less masking release in the high frequencies (5-9 dB) than in the mid-frequencies (14-16 dB). The persistence of masking release in the high

frequencies even with randomization of modulation depth suggested that release from masking could not be entirely explain by within-channel cues. They concluded that across-channel cues must be involved.

Suppression of forward masking. In modulated noise, thresholds may be partially determined by forward masking by the preceding peaks. Hall et al. (1984) suggested that addition of a flanking-band may suppress the corresponding peaks in the signal-band, resulting in a release from masking. Suppression may be responsible for part of the CMR effect observed in the monaural experiments, however it fails to account for the relatively large CMR seen in dichotic experiments (Schooneveldt and Moore, 1989a). In addition, the frequency regions of comodulation masking release are not consistent with the suppression patterns reported by Shannon (1976). He found that suppression was substantially greater for high frequencies suppressing lower frequencies, however CMR is as large and sometimes larger for flanking bands below the signal frequency (Hall *et al.*, 1984).

Across-channel cues.

Most investigators agree that CMR involves the use of across-frequency differences in modulation pattern as a cue in detection of the signal. There have been several hypotheses of how this might occur.

Dip listening.

Buus (1985) proposed that the modulation pattern in the flanking band provides information regarding the location of the dips in the on-frequency band. Listeners may "listen in the dips" of the masker where the signal to noise ratio is most favorable. This may be a process involving weighting by the auditory system such that

weighting would be high when masker energy is low (i.e. in the dips of the amplitude modulated noise) and weighting would be low when masking energy is high (peaks of the noise).

Equalization-cancellation hypothesis.

Another process may be similar to the equalization-cancellation model proposed by Durlach (1963) to account for binaural masking-level differences. This process would involve the use of across-frequency cues by the subtracting the flanking-band masker envelope from the on-frequency masking envelope. The presence of the signal and masker together in the on-frequency band would produce a higher amplitude envelope than the flanking band alone, providing potentially useful information for signal detection.

Correlation detection.

It has also been suggested that CMR is determined by the ability to detect a difference in correlation between the flanking-band and the on-frequency band (Richards, 1987). Detection would occur when the addition of the signal causes the correlation between the on-frequency and flanking band to fall below some criterion level. There is evidence supporting a relationship between the magnitude of CMR and the degree of correlation, however is no direct evidence showing that CMR thresholds correspond to equal changes in correlation between the flanking and signal-bands when the signal is added under various conditions.

EXPERIMENTAL TESTS OF PROPOSED MECHANISMS

Hall and Grose (1988) measured CMR using a narrow-band noise (10 Hz) as a signal instead of a sinusoid. The signal-band and the signal were identical. Comodulation masking release would not be expected if CMR is dependent on suppression or listening in the valleys of the masker because the envelope fluctuations of the signal were the same as the masker. The average CMR for the noise-signal was approximately 8 dB, which was very similar to the CMR measured for a sinusoidal signal in the same experiment. These findings do not support a the "dip listening" or "suppression" mechanisms as the primary determinants of CMR.

The findings of Hall, Grose and Haggard, (1988) in which CMR was found for two-component signals in two narrow-band maskers and three-component signals in three narrow-band maskers cannot be explained by detection strategies based on listening in the dips of the masker or by strategies based on differences in modulation depth across frequencies. Across-frequency differences in modulation depth would be reduced by presenting signals in each of the flanking bands because changes in modulation depth would occur for both the signal-band and the flanking-bands. Dip-listening would be disrupted because the location of the dips could shift depending on the phase relationship between the signal and the maskers on each presentation.

In contrast, other studies appear to support the "dip-listening model" (Grose and Hall 1989; Moore, Glasberg and Schooneveldt, 1990). Grose and Hall (1989) measured CMR as a function of the position of a train of tone-bursts in multitone maskers which were sinusoidally amplitude modulated at a 10 Hz modulation rate. Masker components were either in phase with the modulation (coherent) or out of

phase (incoherent). CMR, which was defined as the difference in thresholds for these two conditions, was found when the train of tone-bursts occurred in the minima of the center component of the masker envelope, but not when the tone-bursts were positioned in the maxima.

In a series of four experiments, Hall and Gross (1991) attempted to resolve the issue of the relative importance of energy in the dips and peaks of the maskers. They consistently found that CMR existed when the signal occurred only in the dips of the masker, but not when it occurred only in the peaks a finding which supports the dip listening hypothesis. In one experiment, however, substantial CMR was found when the addition of the signal resulted in a uniform change to both the peaks and dips of the masker. In this case, CMR occurred even though there was no signal-to-noise advantage in the masker dips, a finding which does not appear to support the dip listening hypothesis. The investigators proposed both sets of results could be explained by assuming that listeners use of the dip information for comparison across frequency rather than simply integrating energy in the masker dips.

Hall and Grose (1988) attempted to disrupt cues based on envelope-amplitude differences by randomizing the level of the flanking-band over a 6 dB range on each presentation. This produced across-frequency differences in the non-signal as well as the signal intervals. The average CMR was nearly 7 dB. These results would be consistent with detection strategies based on the envelope pattern or degree of correlation between envelopes.

The importance of across-frequency correlation between the signal-band and flanking-band envelopes has been demonstrated by measuring CMR as a function of

masker bandwidth and time delay between the envelopes of the signal-band and flanking-band (Moore and Schooneveldt, 1990). The envelope of the signal-band was delayed relative to the flanking-band envelope by 0, 5, 10, or 20 ms. CMR decreased for the 25 Hz wide maskers as the time-delay increased, but remained roughly constant for the 6.25 Hz wide maskers. No CMR was measured in any condition for the 100 Hz wide maskers. Envelope correlations calculated for the envelopes of the signal-bands and flanking-bands showed that the correlation between the envelopes remained above .9 as the delay increased to 20 ms for the 6.25 Hz wide maskers, but dropped to .36 at 20 ms for the 25 Hz wide maskers. These results are consistent with the idea that correlation between the flanking-band and signal-band envelopes is an important determinant of CMR.

Moore and Emmerich (1990) argue against the envelope correlation cue underlying CMR based on their finding that monaural envelope correlation perception becomes more difficult as the noise bandwidth decreases. They compared monaural envelope correlation for noise bandwidths of 25 and 100 Hz and durations of 100 and 500 ms. Correlation detection was evaluated as a function of the center frequency (350 and 2500 Hz) and the frequency separation between the two noise bands. They found that performance deteriorated at with decreasing bandwidth and decreasing duration. The finding that performance decreases with decreasing noise bandwidth is in the opposite direction of the improvement in CMR observed with decreasing noise bandwidth. They suggested that these findings support the idea that the number of fluctuations rather than the rate of fluctuation is important in monaural correlation perception.

Using a slightly different approach, Fantini (1991) varied the envelope phase disparity between the signal- and flanking-bands to study the relationship between envelope decorrelation and CMR. The pattern of changes in CMR with increasing phase disparity was different than the a pattern observed for envelope discrimination threshold. In addition, waveforms which were processed through an auditory model failed to produced envelope decorrelations sufficiently strong to account for the CMR results. In contrast, thresholds for discrimination of modulation depth compared favorably to changes in modulation depth which occurred with the addition of the signal in the CMR part of the experiment.

The results of these studies suggest that CMR is not determined by any single mechanism. It is likely that a variety of strategies are available and may contribute more or less to the magnitude of CMR depending on the conditions under which CMR is measured.

COMBINING SOURCES OF MASKING RELEASE

Several studies have investigated the effects of combining CMR and binaural masking level difference (BMLD) (Cohen and Schubert, 1985; Hall, Cokely, and Gross, 1988; Schooneveldt and Moore, 1989a). Given that both CMR and BMLD are thought to involve the use of temporal cues, it was thought that the processes involved in these two phenomena might not be independent. If CMR and BMLD involve similar processes, then it was suspected that CMR would not be observed in addition to BMLD as the cues provided by comodulation would be interdependent. Cohen and Schubert (1985) did not observed CMR in addition to BMLD, however the two latter

studies did report that CMR was present in addition to BMLD for some subjects (Hall *et al.*, 1988; Schooneveldt and Moore, 1989a). The magnitude of additional CMR at signal frequencies of 250, 1000 and 4000 Hz (when BMLD is already present) was largest at 250 Hz and smallest at 4000-Hz. The same frequency pattern was observed when BMLDs were obtained with CMR present. This frequency pattern is the same as the pattern observed for BMLD alone, but not for CMR alone.

The contribution of temporal and spectral cues to the release from informational masking has been investigated for detection of tones in noise (Gilkey, 1987). Thresholds for detection of 50 ms 500 Hz tones masked by white Gaussian noise were obtained in a "random" condition in which the overall level randomized within trials over a 40 dB range and in a "fixed" condition with overall level held constant across trials. For the fixed and random conditions, 300 ms wideband maskers (100-2000 Hz) were compared to 50 ms narrowband maskers (50 Hz wide) centered at 500 Hz. The difference between the duration of the signal and the noise was referred to as the "temporal fringe" and the difference in bandwidth between the narrow-band and wide-band maskers was referred to as the "spectral fringe". Thresholds in the "random" condition were negligibly worse (.4 dB) than the "fixed" condition for the wideband/long duration maskers, however they were approximately 4.4 dB worse with the narrow band/short duration maskers. Gilkey suggested that listeners may be using information in the spectral and temporal fringe of the wideband/long-duration maskers to overcome the effects of level uncertainty.

In the same study, masker bandwidth and duration were varied to examine the relative contributions of temporal and spectral masker fringe. When the masker duration was fixed at 56 ms and the masker bandwidth was varied from 50-2000 Hz, the effects of randomizing level decreased an average of approximately 3.7 dB. When the masker bandwidth was fixed at 50 Hz and the masker duration was varied from 56 to 700 ms, the difference between thresholds in the fixed and random conditions decreased an average of approximately 1.8 dB.

Eddins and Wright (1994) investigated the effects of providing more than one source of envelope rate information in a CMR paradigm. Narrow-band noise maskers (100-Hz bandwidth) were modulated with a 10-Hz sinusoid. This resulted in two simultaneous rates of fluctuation: the faster (average rate = 64 Hz), more irregular fluctuation associated with the noise carrier and the slower fluctuation associated with the 10-Hz modulator. The goal of the study was to determine if the combination of slow and fast rate information would produce greater CMR than the slow rate acting alone. By independently manipulating the phases of the 10-Hz modulator and the phase/amplitude combinations for the components of the noise, investigators were able to independently control the coherence of the modulation patterns between the signal-band and five flanking-bands. Comodulation masking release was observed when the fast fluctuations were comodulated without comodulation of the slow fluctuations. Conversely, there was CMR when the slow fluctuations were comodulated and the fast fluctuations were not. Finally, CMR was largest when both the fast and slow rates were comodulated, suggesting that subjects were able to use both sources of information simultaneously.

Fantini and Moore (1994) studied the effects of combining profile analysis cues and comodulation cues, both of which are presumed to require a comparison of information across frequency. Using SAM maskers, the use of CMR cues was restricted by using a modulation depth of 0% and the profile analysis cue was restricted by randomizing the level of each of the flanking bands from trial-to-trial. Results showed that CMR alone was 1-3 dB, profile analysis alone was 5-6 dB and when both cues were available, masking release was 6-9 dB. The investigators concluded that the two types of across-frequency cues appear to be roughly additive.

Results of the studies cited above show that CMR can be combined with at least one additional source of masking release to produce greater masking release than either single source acting alone. Some of these combinations appear to be additive (e.g. profile analysis cues and CMR), but, there are no reports of cues which appear to be identical to those responsible for CMR. One source of masking release which may rely on the same cues as CMR is frozen noise masking release (FNMR). Thusfar, the combination of FNMR and CMR has not been adequately studied. The current study investigates the effect of combining FNMR and CMR by examining the relative magnitude of CMR in frozen and randomly selected noise.

CHAPTER 3

EXPERIMENT 1

This experiment examined the effects of combining frozen noise masking release and comodulation masking release by comparing CMR using frozen noise and randomly-selected noise. It is hypothesized that if these two phenomena are dependent on the same cues, then CMR will be absent in frozen noise.

METHOD

Subjects.

Five normally hearing adults served as subjects. Subjects ranged in age from 31 to 38 years old with a mean age of 34. Each subject had pure-tone thresholds within 20 dB HL for 250-8000 Hz and normal tympanograms. All subjects have previous experience in psychoacoustic experiments and four of the five subjects had previous and similar experience in CMR studies.

Stimuli and stimulus generation

The signal was a 300 millisecond 1000 Hz tone with 20 millisecond raised cosine ramps. The single-band reference masker was 600 millisecond 20 Hz wide noise centered at 1000 Hz. Six 600 millisecond 20 Hz flanking-bands were centered at 400, 600, 800, 1200, 1400, and 1600 Hz. The onset of the maskers was 135 ms prior to the onset of the 300 ms 1000 Hz tone. These parameters were chosen with the goal of maximizing the magnitude of CMR. Specifically, largest CMR is observed

with very narrow band noise (Moore and Schooneveldt, 1990; Schooneveldt and Moore, 1987), multiple flanking bands (Hall et al., 1990; Hall and Grose, 1990), flanking bands in close proximity to the reference band (Cohen, 1991) and an asynchronous onset of the noise and tone (Fantini et al., 1993).

Stimuli were generated digitally with a sampling rate of 22050 Hz (half the conventional 44.1 kHz sampling rate used for CDs). Each noise band was an 11-component sinusoidal complex which was generated by adding 11 sinusoids spaced 2 Hz apart using custom written QuickBasic software. Amplitudes for each component were randomly chosen from a Rayleigh distribution and phase values for each component were randomly chosen from uniform angular distribution (0 to 2π radians). The same set of phase and amplitude values was used for each of the seven different center frequencies for a given noise sample. This resulted in seven comodulated bands of noise for each sample (i.e. each of the 20-Hz wide bands at the seven different center frequencies have identical envelopes). Eight different samples of noise were generated, each with seven comodulated bands. Phase and amplitude values for the sinusoidal components of each noise sample appear in Appendix A.

For each of the noise samples, the seven comodulated bands were summed to produce the seven-band comodulated noise using DaDisp software (1991). Waveforms of the 16 noise samples are shown in Appendix A together with both waveform and envelope spectrum analyses. A digital unit of 1 is equal to one step of the D/A converter. Throughout the dissertation amplitude characteristics of the noise samples will either be specified in either digitial units (amplitude) or in digital decibel units (dBD) which corresponds to 20log(digital amplitude).

Two of the eight noise samples were selected as the stimuli which would also be combined with the 1000 Hz tone. These two noise samples are referred to as noise samples "A" and "B", respectively. RMS values are essentially the same for the noise samples A and B in the portion of the noise that coincides with the tone, resulting in intensities that were within .1 dB of each other. The remaining six noise samples (noise alone) are referred to as noise sample "C", "D", "E", "F", "G", and "H", respectively.

The tone and noise were combined digitally and stored in twenty numbered stimulus files generated for each of the two noise samples. In each successive stimulus file, the level of the tone was decreased by 2 dB resulting in signal-to-noise ratios which ranged from 11.5 dB (file #20) to -26.5 dB (file #1). Two sets of stimulus files were generated for each of the two noise samples: one set for the single-band noise and one set for the seven-band noise, resulting in a total of four sets of twenty stimulus files (single and seven band noise X two noise samples). Table 3.1 lists the series of 20 stimulus files for noise samples A and B, together with the corresponding digital RMS amplitudes and signal-to-noise ratios of the single-band samples. The signal-to-noise ratios for the 7-band comodulated noise is expressed relative to the RMS of the 20-Hz center band. Therefore the S/N ratios in Table 3.1 also apply to these stimuli. Note that each band of the 7-band comodulated noise has the same RMS value as the single 20-Hz wide noise bands, thus the overall level of the comodulated noise is 8 dB higher than the single 20-Hz wide noise band. The RMS values for the noise samples were measured in the 300 millisecond portion of the waveform occurring simultaneously with the tone. After digitally combining the signal and noise, all signals were multiplied by a factor of 6972 to maximally fill the 16 bit D-

A board for the highest level stimulus (peak =4.67). Digital dB for these stimuli is within 1 dB of actual dB SPL measured through the earphones (after amplification).

A 600 millisecond 1000 Hz calibration tone was also digitally generated. This stimulus was identical to the 300 ms 1000-Hz experimental signal in every respect except duration. The experimental signal at its maximum level (prior to combining the noise) was identical to the level of the calibration tone.

Conditions

There were six masking conditions, consisting of four frozen-noise conditions (waveform identical for each presentation) and two random conditions in which noise samples were randomly selected for each presentation (within trial variations). During the random conditions, the tone always occurred in either noise sample A or B and the noise alone stimulus was randomly-selected from the remaining seven alternatives (one of which could be noise A or B). During a block of trials in the random condition, noise sample A or B could be chosen either as the noise that contains the tone or as the context noise (noise alone). However, a given noise sample never occurred twice in the same trial. The conditions of experiment 1 were as follows:

1) **Frozen single-band** :

a) Sample A: Single noise band (noise sample A) whose waveform was identical from trial-to-trial.

b) Sample B : Single noise band (noise sample B) whose waveform was identical from trial-to-trial.

2) **Randomly-selected single-band**: single noise band whose waveform was chosen at random from several alternatives for each presentation.

3) **Frozen seven-band** :

a) Sample A: Seven comodulated noise bands (noise sample A) whose waveform was identical from trial-to-trial.

b) Sample-B : Seven comodulated noise bands (noise sample B) whose waveform was identical from trial-to-trial.

4) **Randomly-selected seven-band**: Seven comodulated noise bands whose waveform was chosen at random from several alternatives for each presentation.

The magnitude of comodulation-masking-release (CMR) is defined as the difference between tone detection thresholds in the single-band randomly-selected noise conditions and tone thresholds in the 7-band (comodulated) randomly-selected noise conditions (i.e. CMR(R-C)). Comparisons are made between CMR measured in randomly-selected noise and CMR measured in frozen noise. The magnitude of

Table 3.1. Digital RMS and signal-to-noise ratios for 20 single-band "tone + noise" stimulus files for noise samples A and B. The additional six noise samples used as context (noise alone) stimuli are shown at the bottom. For each of the 600 millisecond noise samples, the RMS was measured for the 300 millisecond interval corresponding with the occurrence of the tone.

Samples A & B Tone + noise File names	**Sample A RMS noise alone**	**Sample B RMS noise alone**	**Samples A & B Tone RMS= 4720.81**	**Samples A & B Signal-to-noise ratio (dB)**
ST * .20	1260.60	1257.28	tone level/ 1.00	11.5
ST * . 19	1260.60	1257.28	tone level/ 1.26	9.5
ST * . 18	1260.60	1257.28	tone level/ 1.58	7.5
ST * . 17	1260.60	1257.28	tone level/ 2.00	5.5
ST * . 16	1260.60	1257.28	tone level/ 2.51	3.5
ST * . 15	1260.60	1257.28	tone level/ 3.16	1.5
ST * . 14	1260.60	1257.28	tone level/ 3.98	-0.5
ST * . 13	1260.60	1257.28	tone level/ 5.01	-2.5
ST * . 12	1260.60	1257.28	tone level/ 6.31	-4.5
ST * . 11	1260.60	1257.28	tone level/ 7.94	-6.5
ST * . 10	1260.60	1257.28	tone level/ 10.00	-8.5
ST * . 09	1260.60	1257.28	tone level/ 12.59	-10.5
ST * . 08	1260.60	1257.28	tone level/ 15.85	-12.5
ST * . 07	1260.60	1257.28	tone level/ 19.95	-14.5
ST * . 06	1260.60	1257.28	tone level/ 25.12	-16.5
ST * . 05	1260.60	1257.28	tone level/ 31.62	-18.5
ST * . 04	1260.60	1257.28	tone level/ 39.81	-20.5
ST * . 03	1260.60	1257.28	tone level/ 50.12	-22.5
ST * . 02	1260.60	1257.28	tone level/ 63.10	-24.5
ST * . 01	1260.60	1257.28	tone level/ 79.43	-26.5
ST *. 00	1260.60	1257.28	Noise alone	

Context sample Noise alone	**RMS noise alone**
Sample C	1440.50
Sample D	1300.87
Sample E	1147.60
Sample F	1214.22
Sample G	1318.51
Sample H	1359.94

frozen- noise- masking-release (FNMR) is defined as the difference between thresholds in randomly-selected single-band noise and frozen single-band noise.

Procedure

Stimuli were played through a 16-bit digital-to-analog converter (Pro-Audio Spectrum-16), passed through an antialiasing filter (cutoff 8 kHz), a custom amplifier and attenuator (SPS-6), and delivered to the subjects' right ears through Eartone-3A insert earphones. Stimulus presentation was controlled by a 486-based personal computer. Subjects were tested in a small single-walled sound treated booth.

Stimuli were calibrated using a B & K sound level meter type 2218 on fast setting with a B & K mic #4132 in a HA-1 2-cc coupler connected to Eartone-3A insert earphones. At the highest signal-to-noise ratio (+11.5 dB), the digital RMS level of the tone was 4720.81 (72 dB SPL for the playback system used). The level of each of the 20 Hz wide noise bands was 61 dB SPL. The level of each of the 7-band complexes was 69 dB SPL. A 600 ms 1000 Hz calibration tone was used to calibrate intensity levels prior to each test session.

A two-alternative forced-choice (one-up, three-down) procedure was used to estimate the 79.4% point on the psychometric function (Levitt, 1971). The signal-to-noise ratio was decreased following three correct responses and increased following an incorrect response. The use of a higher point on the psychometric function than the 70.9% point estimated by the one-up, two-down rule was expected to result in less intrasubject variability of the threshold estimates (Green, 1990).

An interleaving procedure was used for the randomly selected noise sample conditions i.e., two separate adaptive tracks were used to obtain concurrent independent threshold estimates for each of the two noise samples. During this

tracking procedure, noise samples are randomly selected, but subjects' responses and adjustments to the stimulus levels are made independently for the two target noise samples. This procedure was used to allow direct comparisons between thresholds obtained in the frozen and randomly-selected noise conditions for each of the two noise samples.

Stimuli were presented monaurally at an initial S/N ratio of 11.5 dB [20* (log signal RMS/ noise RMS)] . The S/N ratio was decreased in 8 dB steps, then increased in 6 dB steps after one reversal, and decreased in 4 dB steps following the second reversal. The minimum step size of 2 dB occurs after the third reversal. Each block was terminated following 6 reversals after the minimum step size is reached. Threshold estimates for each block were based on the mean of the last 6 reversals.

A minimum of sixteen estimates was obtained for each condition. Estimates were discarded based on two criteria: 1) if the standard deviation of the reversals within an estimate exceeded 5 dB or 2) if the z-score of an estimate, calculated from the entire set of estimates, exceeded 2.5 (Schiffler, 1988; Stevens, 1990). Mean threshold estimates for each condition were based on the last 10 estimates. A minimum of four additional estimates were obtained if practice effects were apparent from the last 10 estimates. The objective was to use estimates that represented a performance plateau. Linear regression analyses were performed on the last 10 estimates for each condition for each subject to establish that a plateau had been reached.

Subjects were tested in eight to nine sessions, each lasting approximately 90 minutes. Each session consisted of three to four blocks of four estimates each. Each block was separated by a short rest period.

A single subject design was used in this study because of large individual differences reported in the CMR literature, and the substantial individual differences

Table 3.2. Condition order for Experiment 1

Group 1	**RANDOMLY SELECTED**	**FROZEN**
S1	1R, 7R	1A, 7A, 1B, 7B
S5	1R, 7R	1B, 7B, 1A, 7A
Group 2	**FROZEN**	**RANDOMLY SELECTED**
S2	1A, 7A, 1B, 7B	1R, 7R
S3	1B, 7B, 1A, 7A	1R, 7R
S4	1A, 7A, 1B, 7B	1R, 7R

Legend:

1A = 1-band, frozen noise sample A

7A = 7-bands, frozen noise sample A

1B = 1-band, frozen noise sample B

7B = 7-bands, frozen noise sample B

1R = 1-band, randomly-selected noise samples

7R = 7-band, randomly-selected noise samples

observed in the two pilot studies conducted prior to these experiments. These individual differences occurred despite equivalent practice among subjects.

Each subject was randomly assigned to one of two groups. The first group completed the random conditions first and the second group completed the frozen-noise conditions first. Table 3.2 summarizes the condition order for each group. The subjects completed each condition before starting the next one. The objective of this group assignment was to ensure that all subjects did not complete all conditions in the same order. The number of subjects in each group is unequal. However, data for each individual were analyzed separately in keeping with the single-subject design of this study. Therefore, group assignment was not a major concern.

DATA ANALYSIS

Data analysis of the results consists of several components. These components are:

A) Analyses of time order effects

1) Linear regression analysis for each condition for each subject:

The goal of this analysis was to confirm that the last 10 replications used in data analysis were obtained from a performance plateau. This goal was an effort to reduce the influence of ongoing learning in the final data sets for each subject. Slopes which did not significantly differ from zero were considered evidence that performance had reached a plateau.

2) A t-test comparing the first half and last half of threshold estimates for each subject and condition:

This analysis was performed to further evaluate the influence of time order effects in the data for each condition.

B) Individual ANOVAS of threshold data

In keeping with the single-subject design of this study individual ANOVAs were

performed on threshold data for each of the five subjects. The raw data used in each of these analyses appears in Appendix B.

RESULTS

TIME ORDER ANALYSES

Linear regression analyses

Linear regression analyses were performed on the last 10 replications of each condition for each subject. Slopes of the functions and their associated significance levels for the regression analyses performed on the 40 data sets (eight conditions X five subjects) can be found in the Appendix C. By chance, one would expect that one or two of the 40 analyses would have reached significance. However, the 40 data sets did not have the same number of estimates preceding the ten estimates used in the analyses. This occurred because more testing was necessary for some subjects in some conditions in order to reach a plateau in performance.

These analyses failed to reveal any significant relationship between replication and threshold. There were no slopes that differed significantly from zero for any of these analyses, suggesting that the goal of obtaining data which reflect performance plateaus was achieved.

The entire data set (including practice estimates preceding the last 10 estimates) consisted of 725 data points for the five subjects. Five (0.7 %) of these data points were excluded because reversal standard deviations exceeded 5 dB and an additional five data points had z-scores which exceeded 2.5. Four of the ten

estimates excluded were from the last 10 estimates. These estimates were replaced by additional data points, therefore sensitivity was not compromised.

t-tests first half versus last half of threshold estimates

The t-tests comparing the first versus last five thresholds estimates for each condition were performed for each subject. Analyses failed to reveal any significant difference between the first and last 5 estimates for any condition for any subject. The t-values and corresponding significance levels can be found in Table C3 in Appendix C. These results provide further evidence that potential time order effects were sufficiently eliminated in the final data sets.

INDIVIDUAL ANALYSES OF VARIANCE OF THRESHOLD DATA

The factors for the individual ANOVAs are shown in Table 3.3 together with the corresponding levels for each factor.

Table 3.3. ANOVA factors and corresponding levels for analysis of individual threshold data.

Factor	Level 1	Level 2
Band number (B)	1 band	7 bands
Randomness (R)	Frozen	Randomly selected
Noise sample (S)	Sample A	Sample B

The band number effect reflects the magnitude of comodulation masking release (CMR) while the randomness effect reflects the magnitude of frozen noise

masking release (FNMR). Complete ANOVA and Tukey HSD post-hoc tables for each subject appear in Appendix C. A summary of the results of the individual ANOVA are shown in Table 3.4.

Table 3.4. Summary of Analyses of Variance for individual subject threshold data. F-ratios and significance levels are shown for each main effect and interaction.

EFFECT	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5
Band number (B)	F(1,9) = 25.00 p=.00074	F(1,9) = 29.50 p=.00041	F(1,9) = 92.49 p=.000005	F(1,9) = 187.35 p=.000000	F(1,9) = 3.23 p=.10594
Randomness (R)	F(1,9) = 34.57 p=.00024	F(1,9) = 13.04 p=.00565	F(1,9) = 30.41 p=.00037	F(1,9) = 2.05 p=.18583	F(1,9) = 3.65 p=.08842
Noise sample (S)	F(1,9) = 71.35 p=.00001	F(1,9) = 82.96 p=.00565	F(1,9) = 27.15 p=.00056	F(1,9) = 34.87 p=.00023	F(1,9) = 55.32 p=.00004
B x R	F(1,9) = 3.67 p=.08764	F(1,9) = 15.03 p=.00375	F(1,9) = 24.31 p=.00081	F(1,9) = .56 p=.47472	F(1,9) = 8.12 p=.01901
B x S	F(1,9) = 24.90 p=.00075	F(1,9) = 15.03 p=.00375	F(1,9) = 49.65 p=.00006	F(1,9) = 119.51 p=.000002	F(1,9) = 19.66 p=.00164
R x S	F(1,9) = 16.62 p=.00075	F(1,9) = 3.37 p=.09978	F(1,9) = .05 p=.82831	F(1,9) = .01 p=.91874	F(1,9) = 9.05 p=.01477
B x R x S	F(1,9) = 10.32 p=.01063	F(1,9) = 14.07 p=.00454	F(1,9) = .05 p=.82671	F(1,9) = 3.48 p=.09485	F(1,9) = 2.02 p=.18874

Main Effects

The main effect of band number was significant for four of the five subjects showing lower thresholds for 7-band than for 1-band noise (CMR). The subject (S5), who does not show a significant main effect of band number does show significant interactions involving band number for the other two factors (see below).

Thresholds for detection of tones in frozen noise are significantly lower than those for randomly-selected noise (randomness effect) for three of the five subjects (S1, S2, S3; $p < .01$). Although the main effect of randomness is not significant for subject S5, significant interactions involving randomness do appear (see below). Finally, for subject S4, there are no significant differences between thresholds for frozen and random noise under any conditions.

Thresholds for noise sample A are significantly lower than for noise sample B for all five subjects ($p<.01$).

Two-Way Interactions

Band number x randomness.

The interaction of band number and randomness directly relates to the hypothesis of this experiment. Based on the hypothesis that the envelope information provided by frozen noise and comodulated noise bands is essentially the same, it was expected that a significant interaction between band number and randomness would exist, revealing a significant band effect for the randomly selected noise condition, but not for the frozen noise condition.

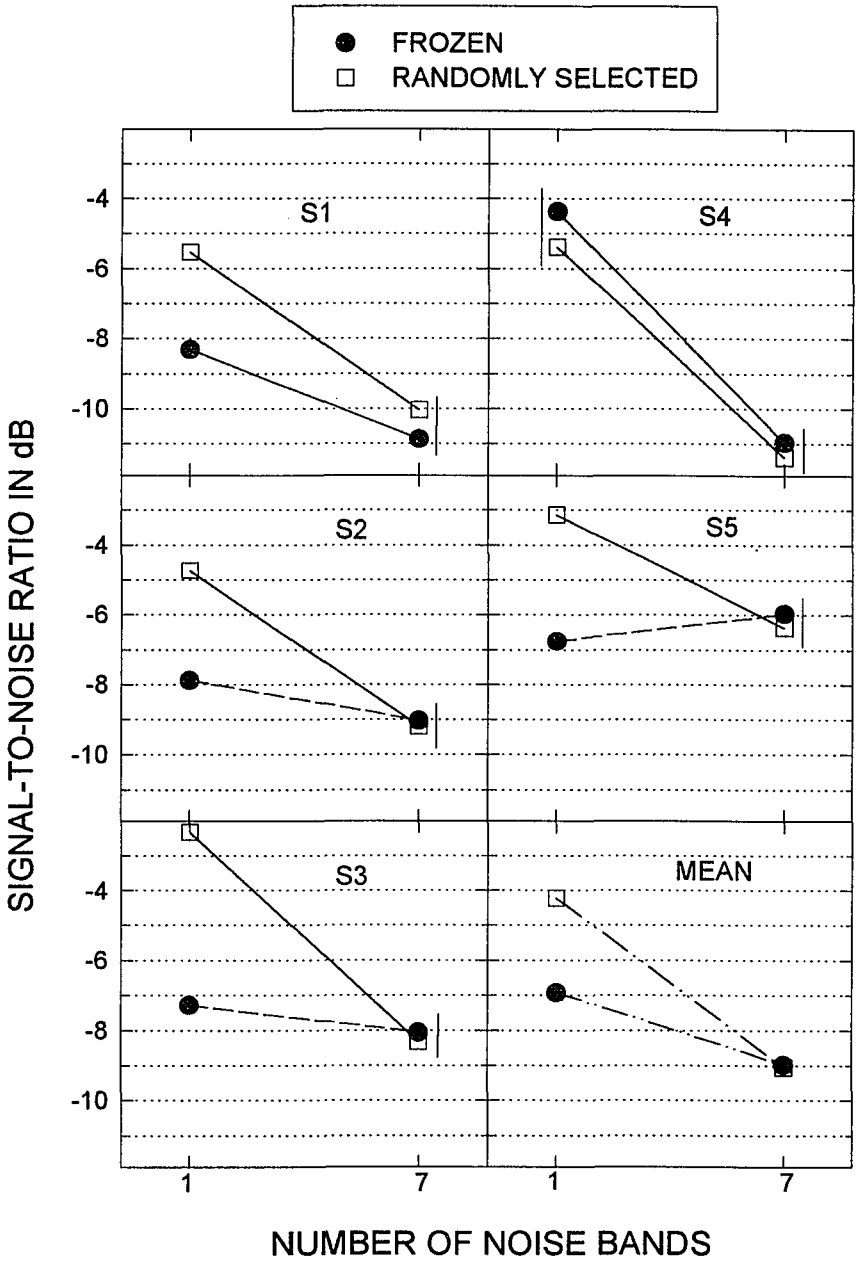

Figure 3.1. Individual and mean thresholds for frozen and randomly selected noise as a function of the number of noise bands (data collapsed across noise samples A and B). In individual subject panels, vertical lines indicate non-significant differences as determined by post-hoc analyses. Solid lines indicate significant differences between 1- and 7-band conditions (dashed lines denote non-significant differences).

Means for the four conditions in the band number/randomness interaction are shown in Figure 3.1 for all subjects. Data are collapsed across noise samples A and B. The predicted interactions are significant for subjects S2, S3, and S5 ($p<.02$), with a fourth subject (S1) showing a significant three-way interaction involving band number and randomness (discussed below).[1]

Post-hoc analyses using the Tukey Test of Honestly Significant Differences (HSD) was performed to examine two contrasts of interest: 1) the magnitude of CMR (B effect) measured in frozen vs. randomly selected noise and 2) frozen noise masking release (R effect). Results reveal a significant CMR (B effect) for randomly selected noise ($p< .05$ indicated by solid lines), but not for frozen noise ($p>.05$, dashed lines) for three of the five subjects (S2, S3, S5). Results for the remaining two subjects (S1, S4) show a significant CMR in both frozen and randomly selected noise (solid lines), however, as shown in Figure 3.1, the magnitude of the band number effect for Subject 1 appears smaller for the frozen noise. Analyses were performed on individual data only, therefore significance levels were not determined for the mean data which appears in the lower right panel of Figure 3.1.

The post-hoc analysis also shows significant frozen noise masking release (FNMR) for four of the five subjects (S1, S2, S3, S5) (indicated in Figure 3.1 differences between the single-band frozen and randomly-selected data points). The fifth subject (S4) does not show an effect of randomness for either condition (indicated by a vertical line next to the single-band data points). This subject's mean threshold in the single-band frozen condition (-4.37 dB SN) is substantially poorer

[1] Note: A t-test comparing CMR in frozen and randomly-selected noise was also done as a planned comparison, however significance levels were only slightly better than those reported for the ANOVA interaction and did not result in a change in outcome. Therefore, only ANOVA results are presented.

than the other four subjects (mean = -8.00 dB, range = -6.76 to -9.07 dB). However, it was similar to other subjects in the random condition. These data suggest that this subject may have been less able to use the envelope information present in the narrow-band frozen noise.

Band number x noise sample.

Means for the four conditions in the band number/noise sample interaction are shown in Figure 3.2. Note that in this interaction, data are collapsed across the frozen and randomly-selected noise conditions. Generally, the effect of band number (CMR) was smaller for noise sample A than for sample B. This was largely due to low sample A thresholds in the single-band condition. All five subjects showed a significant interaction between band number and sample ($p<.01$).

The Tukey HSD test of was used as a post-hoc analysis to further examine the interactions. The differences in the magnitude of CMR (B effect) for noise samples A and B are of particular interest. In the individual subject panels in Figure 3.2, solid lines indicate significant differences between 1- and 7-band conditions while broken lines indicate differences which were not significant. As shown in the figure, the band number effect (CMR) was significant for noise B, but not for noise A for four of the five subjects (S1, S2, S3, S5) and significant for both noise samples for the fifth subject (S4). This effect appears to be largely due to the significantly lower thresholds for noise sample A versus sample B in the single-band (reference) condition. The difference between noise samples A and B in the single band conditions was unexpected in light of the equal RMS levels for the two samples.

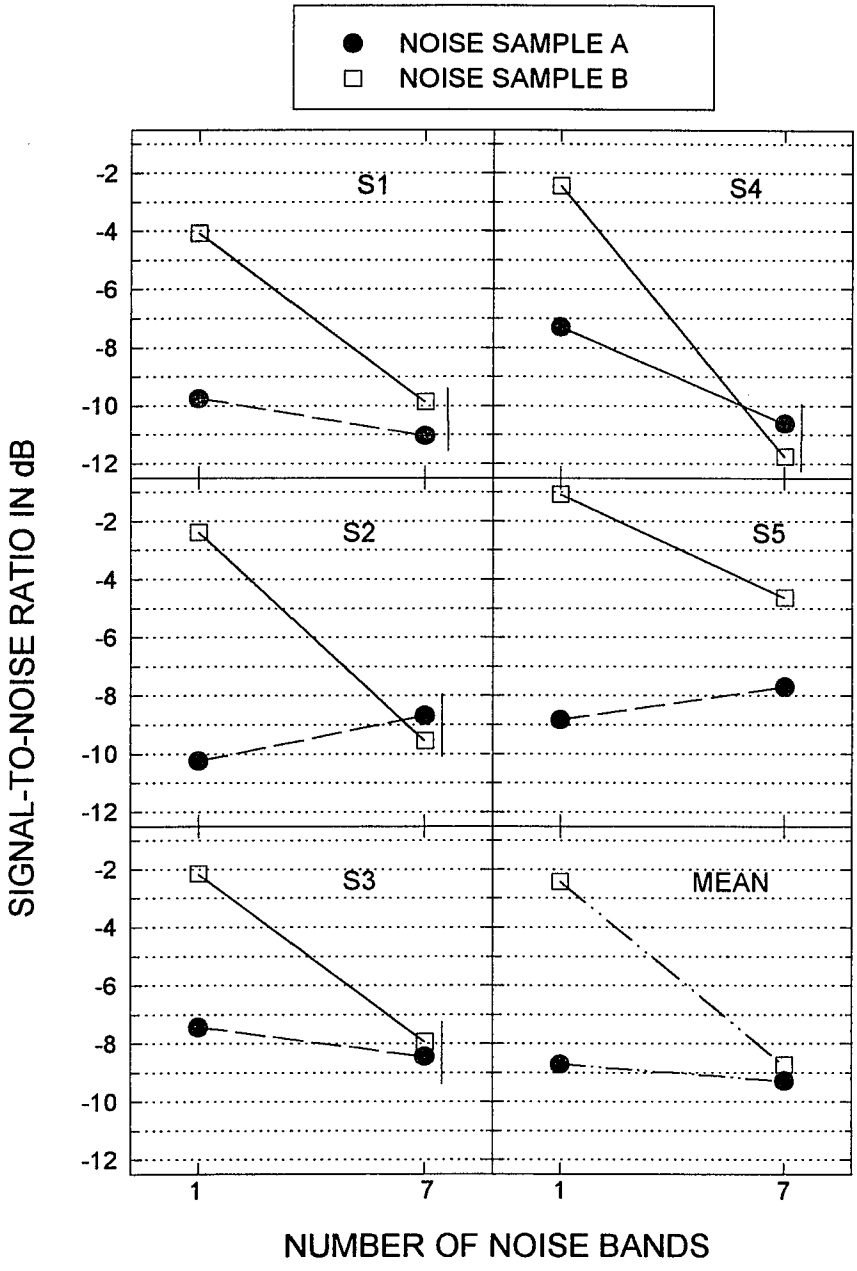

Figure 3.2. Individual and mean thresholds for noise samples A and B as a function of the number of noise bands(data collapsed across frozen and randomly-selected noise conditions). In individual subject panels, non-significant differences between noise samples A and B are indicated by vertical lines. Solid lines individual subjects panels indicate significant differences between 1- and 7-bands (dashed lines indicate non-significant differences).

Randomness x noise sample.

A significant interaction between randomness and noise sample can be interpreted to mean that the magnitude of frozen noise masking release (FNMR), as reflected by the randomness effect (frozen vs. randomly selected noise), is different for noise sample A and B. Means for the four conditions in the randomness/noise sample interaction are shown in Figure 3.3 for all subjects. Data are collapsed across the single-band and 7-band conditions. A significant interaction is present for two of the five subjects (S1 and S5) showing that thresholds are significantly better ($p<.02$) in frozen noise than randomly selected noise (FNMR) for noise B, but not for noise A.

A Tukey HSD post-hoc analysis was used to further examine the presence of FNMR in noise samples A and B for the five subjects. In Figure 3.3, non-significant differences are indicated by horizontal lines. The analysis reveals that three subjects show significant FNMR in noise B, but not noise A (S1, S2 and S5), one subject shows significant FNMR in both noise A and noise B (S3), and the remaining subject (S4) did not show FNMR for either noise sample. Thus, it appears that for the majority of subjects, both CMR and FNMR were affected by the noise sample in which they were measured.

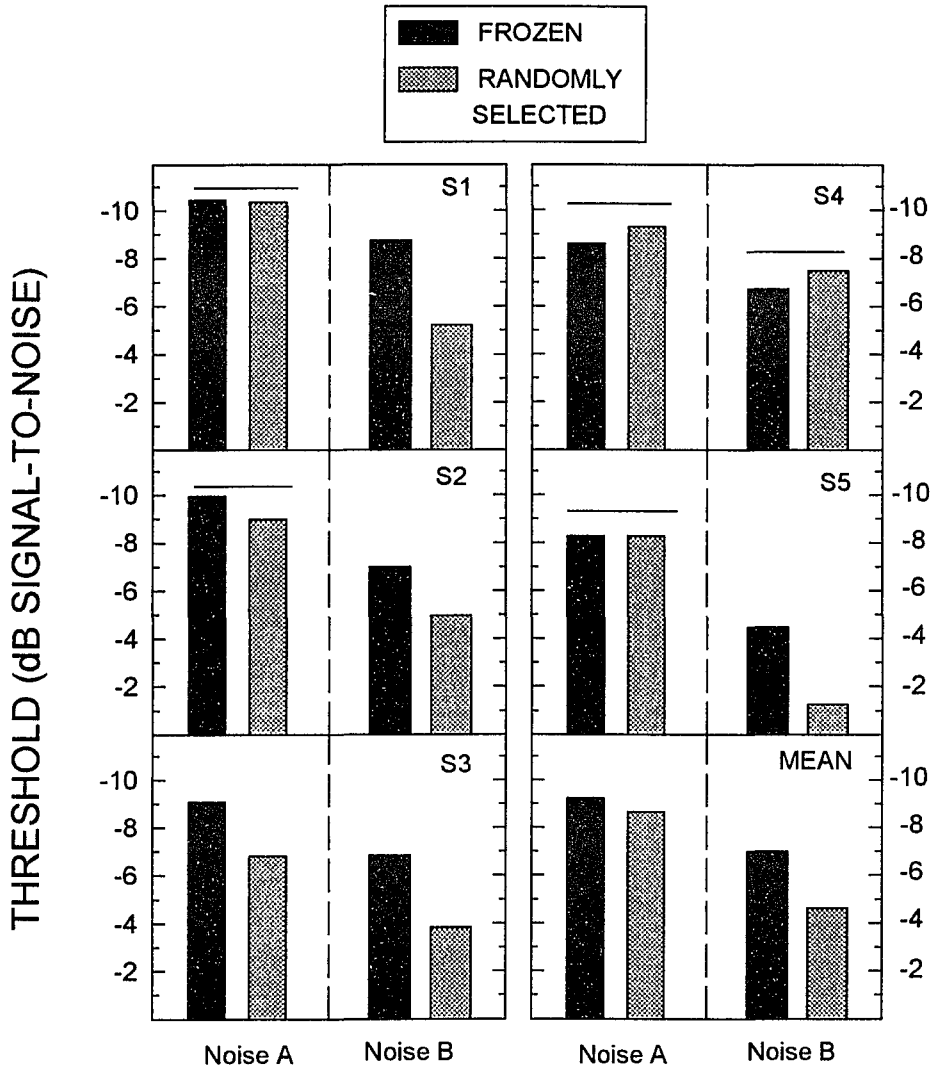

Figure 3.3. Thresholds for noise samples A and B in frozen and randomly-selected noise conditions (data collapsed across band number factor). Non-significant differences between frozen and randomly-selected noise are indicated by horizontal lines. Noise A thresholds were significantly lower than Noise B thresholds for four of the five subjects (excluding S5) for all conditions except frozen noise for S1.

THREE-WAY INTERACTION: Band number x randomness x sample

Means for the eight conditions in the three-way interaction are shown in Figure 3.4 for all subjects. The three-way interaction found for two subjects (S1 and S2) can be characterized by the differences between CMR and FNMR for noise samples A and B. Post-hoc analysis on the data of these subjects show that both FNMR (indicated by differences between the data points for randomly-selected and frozen noise) and CMR (indicated by solid lines connecting data points) is significant for noise sample B, however, neither is significant for noise sample A. Subjects 1, 2, 3, and 5 show similar patterns. Although the interaction for subject 3 was not significant the overall pattern is the same, except that frozen noise A show the same effect as frozen noise B.

Summary

For the majority of subjects (4/5), CMR was smaller for frozen noise than for randomly-selected noise and for two subjects CMR was absent in frozen noise. These findings partially support the hypothesis that cues involved in FNMR and CMR are similar.

Individual differences were apparent, however one subject in particular (S4), deviated substantially from the others, showing no FNMR for any condition and thus, no effect of frozen noise on the magnitude of CMR. It is suspected that this subject was unable to make use of envelope cues present in the narrow-band noise stimuli.

Unexpectedly, CMR was smaller for noise sample A than sample B, largely due to the low thresholds in the single-band reference condition for sample A. This occurred despite equal RMS levels for the two noise samples. It is possible that envelope cues in

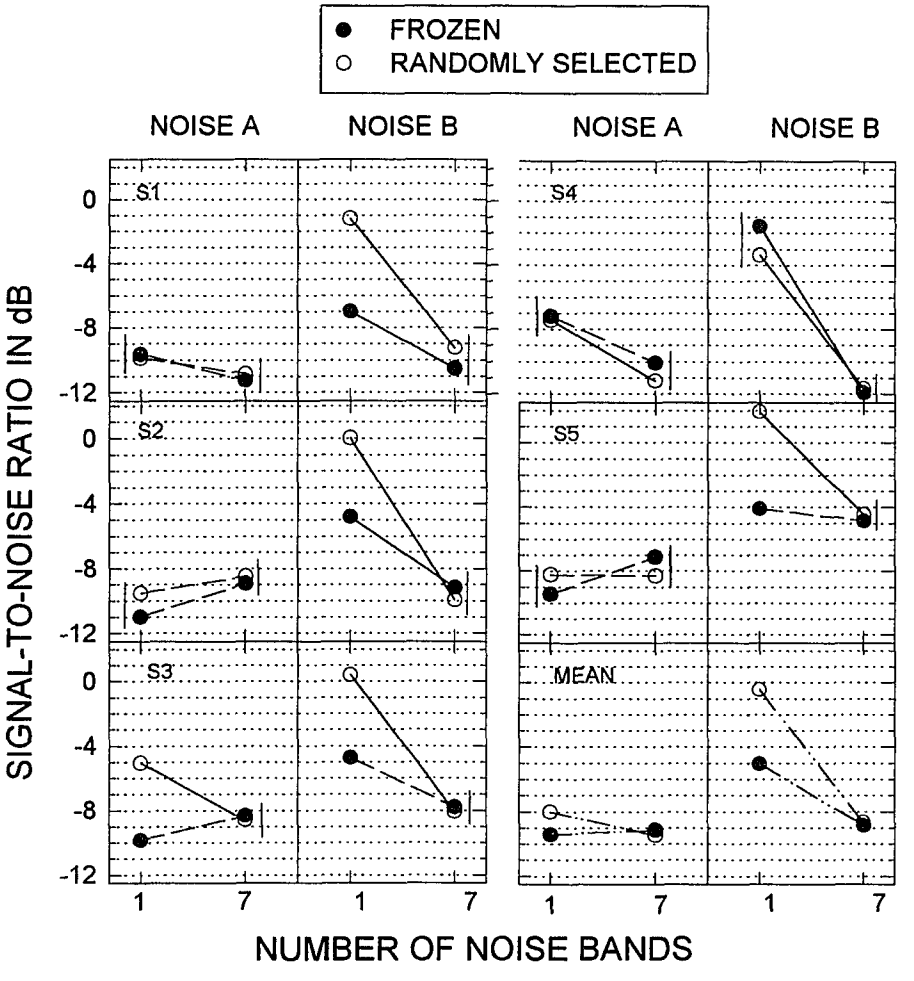

Figure 3.4. Individual and mean thresholds for noise samples A and B under frozen and randomly-selected conditions as a function of the number of noise bands. Vertical lines indicate non-significant differences, as determined by the post-hoc analyses. Solid lines indicate significant differences between 1- and 7-band conditions.

the noise stimuli are more available in noise sample A (lower threshold) than sample B. In the next section, the noise samples are analyzed in more detail to compare the availability of cues.

NOISE ANALYSES

An unexpected finding of Experiment 1 was the substantially lower thresholds for detection of tones in narrow-band noise A compared to thresholds in frozen noise B, despite equal overall levels in the tone portion of the two samples. These results suggest that even in narrow-band noise, subjects may be basing detection decisions on information other than overall signal-to-noise ratios. Previous work in this area has suggested that envelope cues present in noise waveforms can account for masked threshold differences observed for different noise samples (Kidd et al., 1993). Two possible cues which may distinguish noise samples A and B are 1) differences in short-term fluctuations of the maskers' envelopes and 2) cues associated with changes in the envelope power spectrum with the addition of the tone. Green et al. (1992) demonstrated a model based on envelope spectral cues was accurate in predicting subjects' detection of tones centered in narrow band noise.

The purpose of the analyses in this section is to investigate differences between the envelopes of two noise samples that could explain the threshold differences observed in Experiment 1. Analyses will explore the two possible explanations described above.

Envelope extraction.

The short-term RMS value of the waveform was used to estimate the waveform envelope. This was done using DADISP software (1991). The envelope was obtained

by first squaring the amplitudes of a waveform, obtaining a moving average over 111 points (5.03 ms), then obtaining the square root of the resulting average. In the analyses discussed below, the segment of interest was the 300 millisecond portion of the noise envelope which occurred simultaneously with the tone. This segment was extracted from the total 600 millisecond envelope.

Amplitude fluctuations.

Envelopes extracted from the two noise sample are shown in Figure 3.5. Vertical lines mark the portion of each envelope that occurs simultaneously with the tone. Although the envelope of sample A appears to have the largest peak, it also appears to have more periods of lower peaks than sample B. These periods of lower energy in sample A may provide an advantageous signal-to-noise ratio (S/N) over short time intervals.

In order to quantify this apparent difference between the short term fluctuations of the two envelopes, short-term signal-to-noise ratios were calculated in adjacent 20 millisecond windows across the 300 ms portion of the envelopes coincident with the tone. The results of this analysis are shown in Figure 3.6. These calculations were performed for an average signal-to-noise ratio of -4.5 dB, corresponding the mean detection threshold for the tone in frozen noise sample B. Although the average signal-to-noise ratio of both samples A and B are equal, sample B shows a slightly more favorable short-term signal-to-noise ratio than sample A in the initial portions of the envelope (between 40 and 140 ms). This slight advantage is considerably smaller than

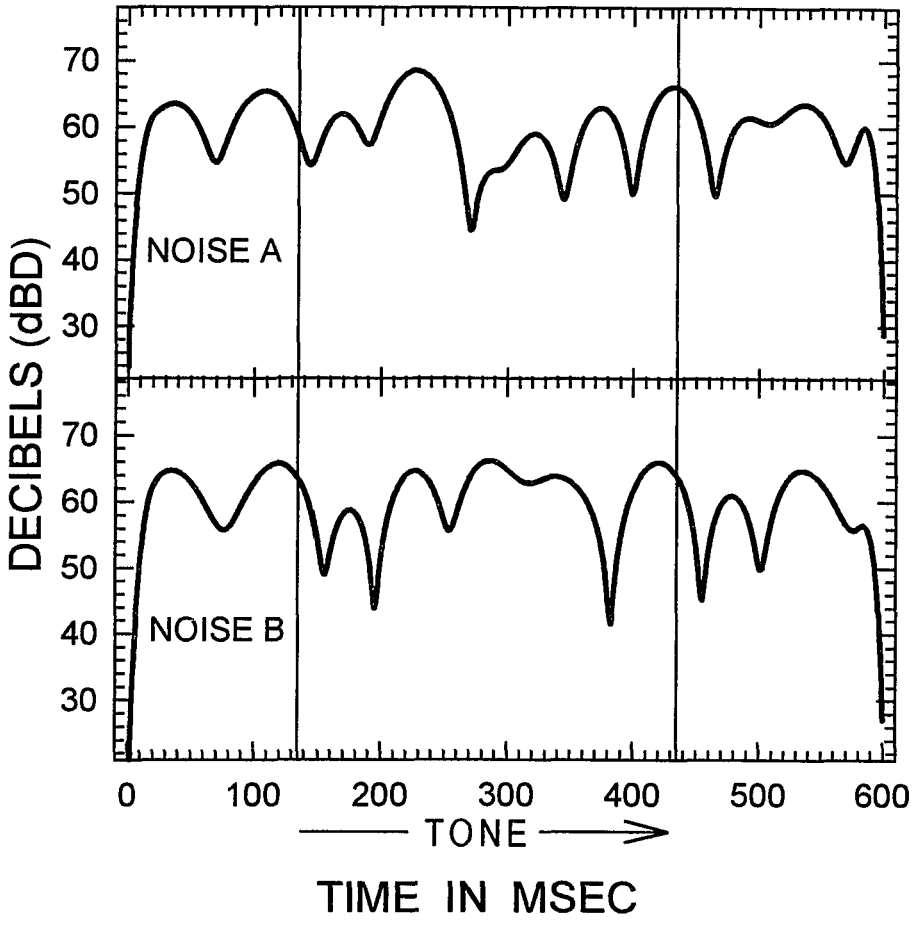

Figure 3.5. Envelopes of noise samples A and B.

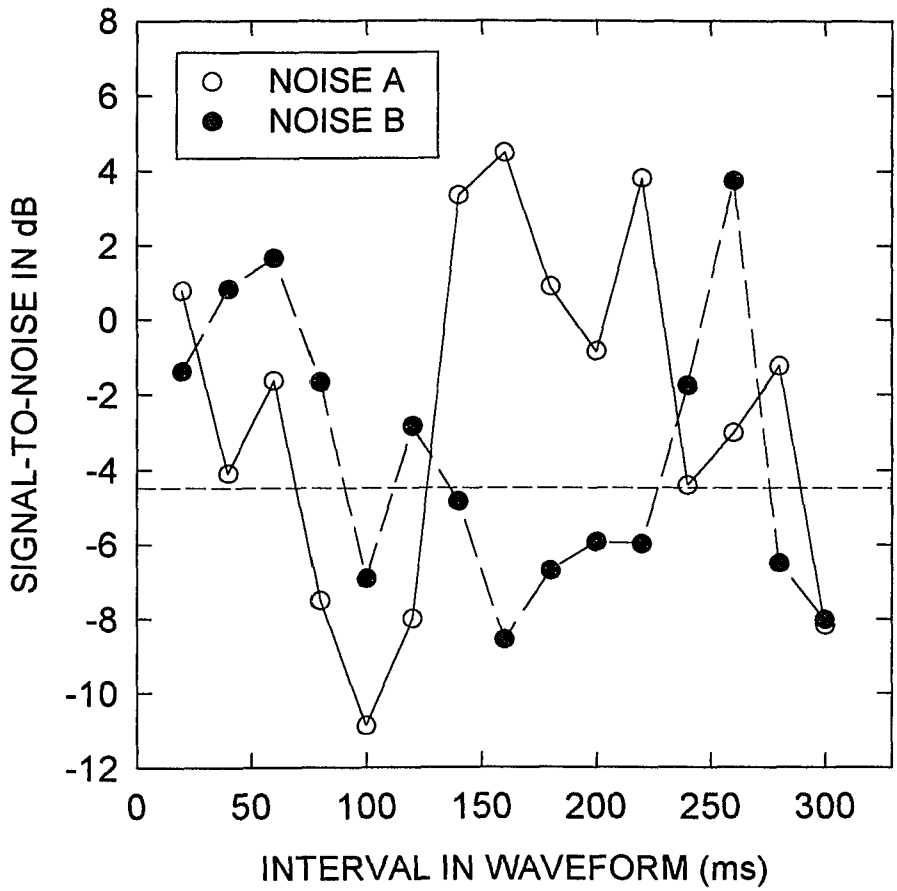

Figure 3.6. Signal-to-noise ratios over 20 ms windows across the duration of the tone for noise samples A and B. Average signal-to-noise ratios of sample A and B are equal (shown by horizontal line).

the short-term signal-to-noise advantage seen for sample A in the middle portion of the envelope (between 160 and 220 ms). It is possible that listeners who are selectively able to monitor this portion of the envelope would have lower masked thresholds for sample A than for sample B.

This figure depicts a commonly used method of examining fluctuations in S/N ratio based on calculations from separate measures of the short-term RMS for the noise and signal (20log signal RMS/noise RMS). The limitation of this type of analysis is that it fails to consider phase interactions between the noise and the signal. Therefore, the pattern of changes in short-term S/N depicted in Figure 3.6 may not be representative of the actual S/N changes that occur. The second analysis described below, which examined changes in the envelope power spectra when the tone was added, does consider the phase interactions between the signal and masker.

Envelope power spectrum.

Green et al. (1992) observed that changes in the envelope power spectrum occur when a tone is added to narrow-band Gaussian noise. These changes in envelope power spectrum may provide a cue for detection of tones in narrow-band noise.

Envelope power spectra for noise envelopes A and B were compared to determine if changes in the spectrum with the addition of the tone are greater for sample A than B. Greater changes with the addition of the tone could provide an additional advantage for detection.

The goal of this analysis was to answer two questions:

1) Is there a difference between the "noise alone" and "noise + tone" envelope power spectra near threshold that could provide a cue for detection?

2) Are the differences in the "noise alone" and "noise + tone" envelope power spectra larger for sample A than for sample B?

The signal-to-noise ratios chosen for analysis were -.5, -2.5, -4.5, -6.5, -8.5 and -10.5 dB. Mean behavioral thresholds for detection of tone in the frozen noise samples were -9.4 dB S/N and -5.2 dB S/N for samples A and B, respectively. Thus, the test stimuli with S/N ratios closest to that at which detection occured were stimulus files "st01.10" (S/N = -8.5 dB) for sample A and "st02.12" (S/N = - 4.5 dB) for sample B.

Although subject's thresholds varied substantially, they all fell either within or closest to the S/N ratios chosen for this analysis.

Envelopes of the two noise samples at the signal-to-noise ratios used in the envelope spectral analyses are shown in Figures 3.7 and 3.8 Note that envelope amplitude does not always vary monotonically with signal-to-noise ratio and level and temporal shifts in some of the peaks occur in some temporal locations. Phase interactions between the tone and components of the noise may be responsible for this.

The results of the envelope spectral analyses appear in Figure 3.9. The analysis of the envelope of noise sample A is shown on the left and the envelope of noise sample B is shown on the right. Values at 0-Hz reflect the DC shift which results from adding the tone to the noise. There is a substantial increase in the spectral power of envelope A between 3 and 10 Hz when the tone is added. This change is consistent

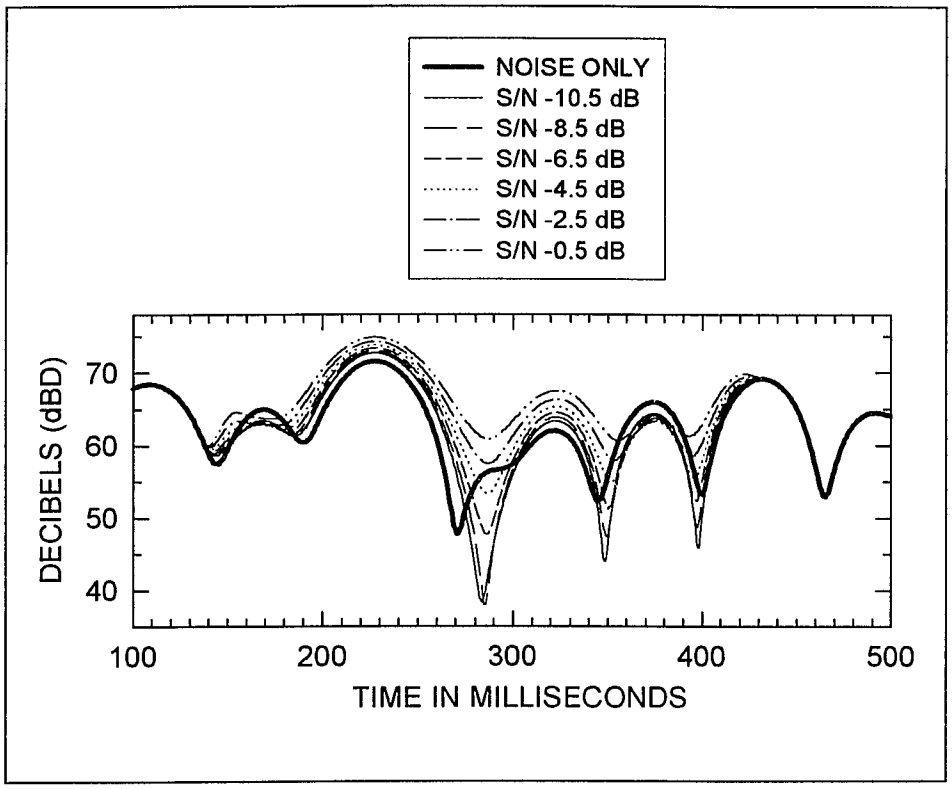

Figure 3.7. Envelopes of noise sample A for the noise-alone stimulus and tone+noise stimuli at the signal-to-noise ratios used in the envelope spectral analyses. Detection in frozen noise occurred at a signal-to-noise ratio of -9.4 dB.

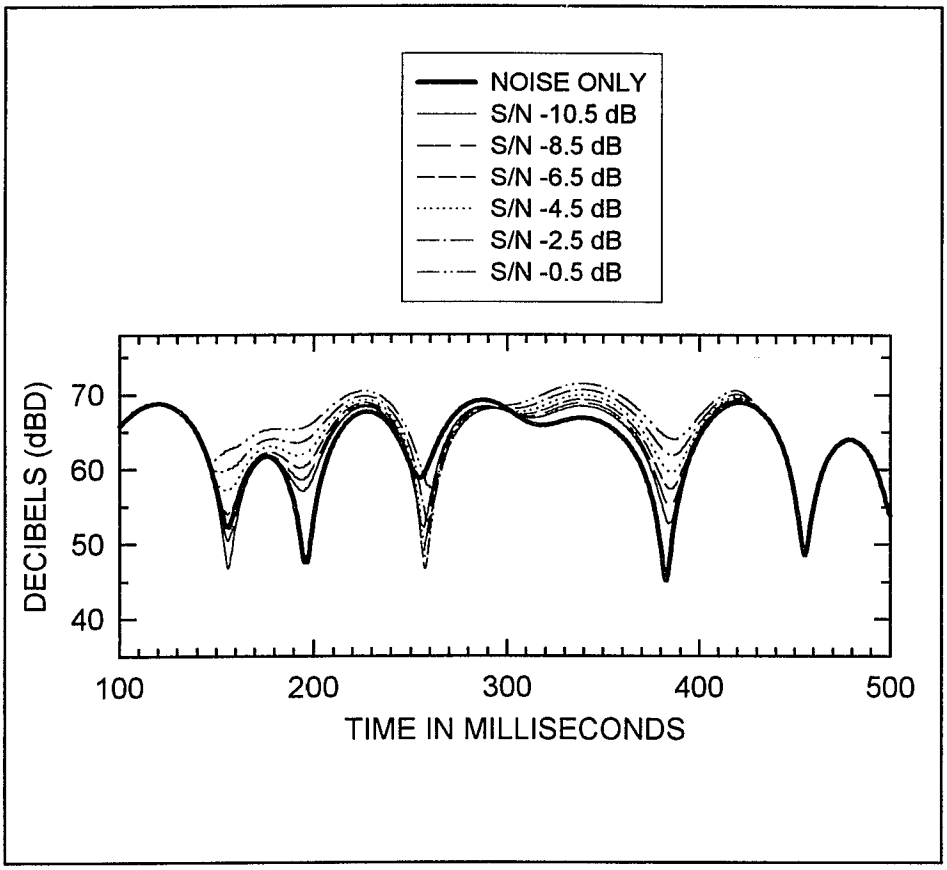

Figure 3.8. Envelopes of noise sample B for the noise-alone stimulus and tone+noise stimuli at the signal-to-noise ratios used in the envelope spectral analyses. Detection occurred at a signal-to-noise ratio of -5.2 dB.

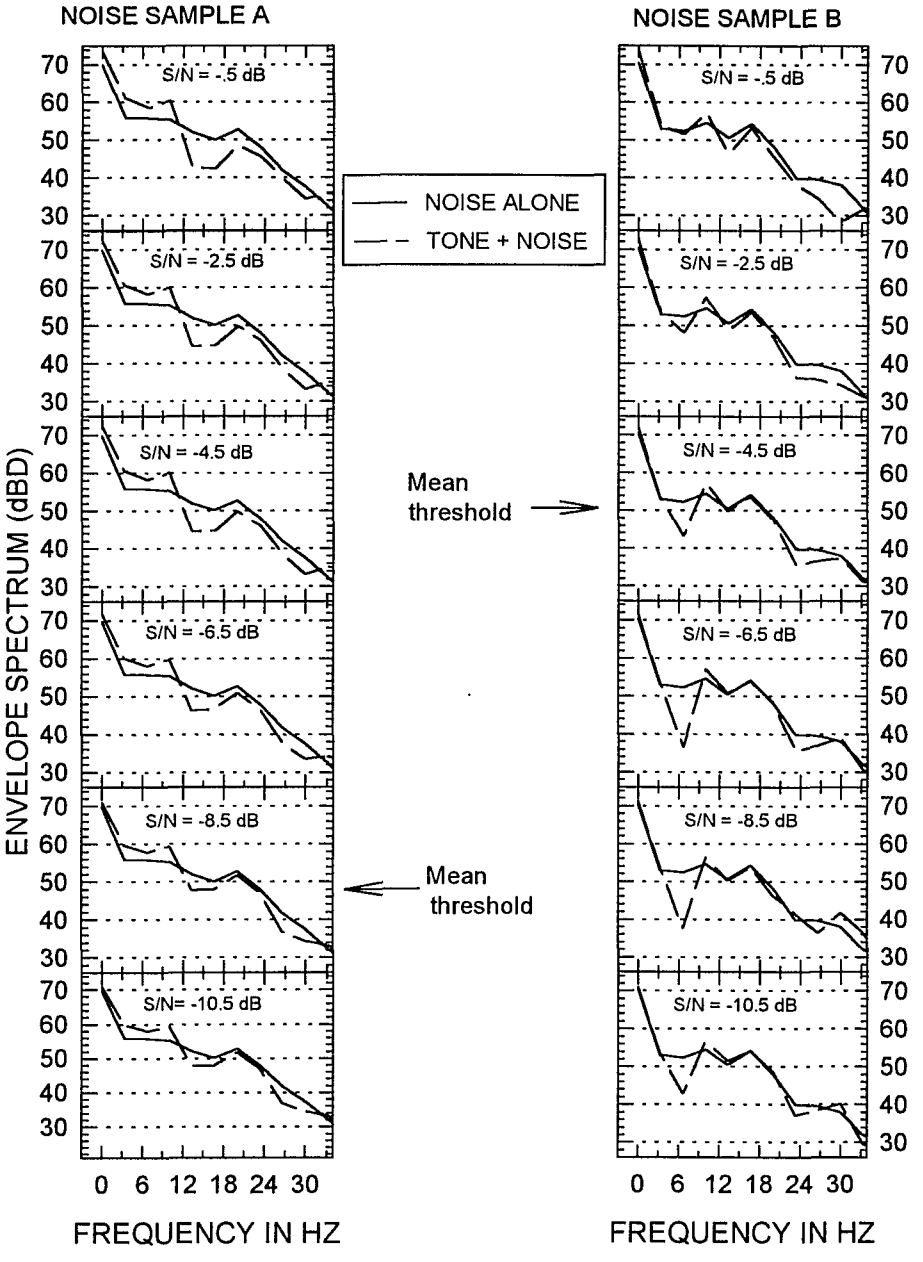

Figure 3.9. Envelope spectra (in dBD) for noise alone and tone + noise stimuli at different signal-to-noise ratios.

throughout the range of S/N ratios analyzed. Much smaller changes occur when tones are added to envelope B. It is clear from this analysis, that in frozen noise, the changes in envelope spectrum with the addition of a tone are substantially larger for noise A than for noise B.

One interesting finding from Experiment 1 was the absence of FNMR for noise A together with substantial FNMR for noise B for two of the subjects. For these subjects, detection deteriorated with the random selection of noise samples for noise B, but not for noise A. This implies, that the cue these subjects were using to detect tones in noise A must have been robust enough to resist the effects of randomizing envelopes on each presentation. If the envelope power spectrum were used as a primary cue in the single-band randomly-selected noise condition, the spectrum of the tone+noise envelope would have to distinguish it from any other envelope power spectrum without a tone. Figure 3.10 shows the envelope power spectrum for envelope A at -8.5 dB SN (the closest S/N to the mean threshold in the randomly selected condition) together with the envelope spectra for the remaining seven context (noise alone) stimuli. Although differences in the spectra are not as striking as with frozen noise, substantial differences between the tone+noise and noise alone stimuli persist for all envelopes at 3.3 Hz and for five of the seven envelopes at 6.6 Hz, suggesting that sufficient envelope spectrum information remains, even for the randomly selected condition. Figure 3.11 shows the same comparison for noise sample B at -.5 (the S/N ratio closest to the mean threshold in the randomly-selected condition). In contrast to noise sample A, the envelope spectrum for noise sample B is indistinguishable from the other seven noise samples that were presented during the randomly-selected noise condition.

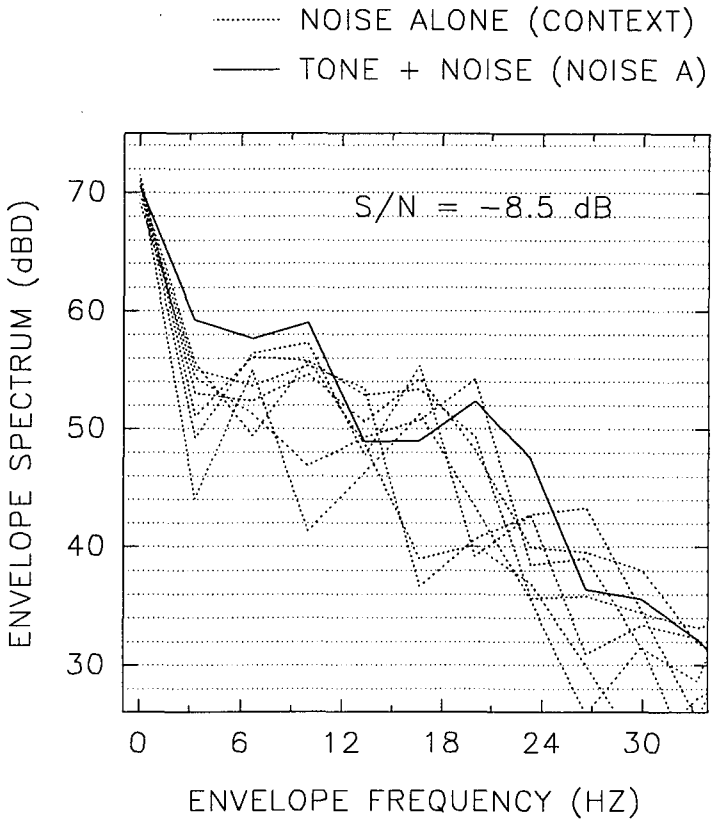

Figure 3.10. Envelope spectrum for tone + noise stimulus (sample A) at mean threshold obtained for randomly-selected condition. Also shown are envelope spectra for the pool of randomly-selected noise samples.

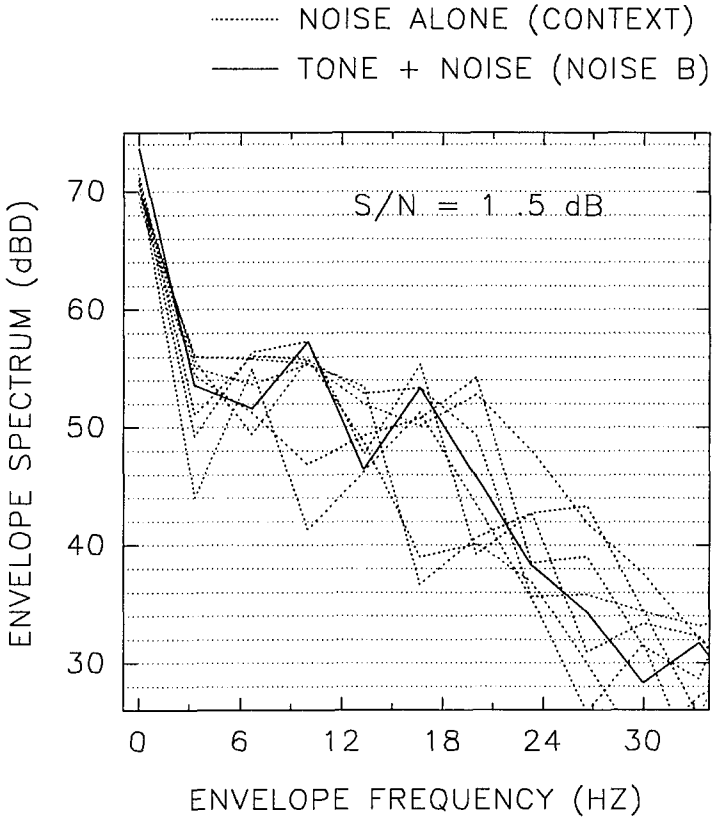

Figure 3.11. Envelope spectrum for tone + noise stimulus (sample B) at mean threshold obtained for randomly-selected condition. Also shown are envelope spectra for the pool of randomly-selected noise samples.

These analyses reveal two potential sources of cues which might explain the lower thresholds for tones masked by noise A. Unfortunately, demonstrating the existence of these sources of information falls short of revealing which, if either, of the cues subjects were actually using in their judgments. The goal of the next Experiment is to further explore this question.

CHAPTER 4

EXPERIMENT 2

One of the main findings of the Experiment 1 was the difference in thresholds for tones masked by narrow-band noise samples A and B. In the previous chapter, noise analyses confirmed the possibility that noise sample A contained two sources information that could possibly explain the lower thresholds found for detection: 1) the relatively large peak short term signal-to-noise ratios compared to sample B and 2) greater changes in envelope spectrum in the region of 3 Hz with the addition of the tone. While these analyses confirmed that the information was available, the question of whether these listeners took advantage of this information remains unanswered. One possible way to approach this question is to attempt to compare detection in these two narrow-band samples under conditions which may limit the use of envelope cues, one of the sources of information revealed by the noise analyses.

While it may not be possible to limit envelope information entirely, it may be possible to reduce the contribution of envelope cues. Moore and Glasberg (1987) proposed that stimulus envelope information may be conveyed by changes in the pattern of phase locking of fibers tuned to the signal. In fluctuating narrow-band maskers, fibers may phase lock to the signal and masker in the minima of the envelope and primarily to the masker in the maxima of the envelope. They suggested that phase locking cues provide a potential explanation for the lower tone detection thresholds observed for narrow-band versus sinusoidal maskers when the signal is higher in frequency than the masker (Buus, 1985; Moore and Glasberg, 1987). To evaluate this hypothesis, Moore and Glasberg (1987) compared the magnitude of

masking release at different frequencies (defined as the threshold difference for detection of tones using narrow-band vs. sinusoidal maskers). The magnitude of masking release was substantially smaller for frequencies above 5 kHz (where phase locking does not occur), than for mid-frequency signals. These findings support the idea that phase locking may provide a useful cue for the detection of tones in fluctuating maskers.

If phase locking serves as an input mechanism for the envelope cues present in the stimuli in Experiment 1, then it may be possible to reduce the threshold differences observed for the two noise samples by transposing the envelopes of these noise samples to 6 kHz, a frequency above which phase locking generally occurs (Javel, 1986). In addition, to the extent that subjects are using envelope information in the frozen noise samples, thresholds for detection in frozen noise may increase if envelope information is limited at high frequencies. This, in turn, would be expected to decrease the magnitude of frozen-noise masking release.

Another explanation for the threshold differences between samples A and B in Experiment 1 is the greater signal-to-noise advantage observed for sample A in the mid-temporal portion of the envelope (see Figure 3.6, previous chapter). This cue would not be expected to be affected by changes in frequency.

Two specific goals of this experiment were as follows:

1) The first goal was to compare detection of 6000 Hz tones masked by two different frozen narrow-band noise (samples A and B) whose envelopes are identical to the envelopes of noise samples A and B in Experiment 1.

2) The second goal was to compare the magnitude of frozen-noise masking release (FNMR) at 1000 and 6000 Hz.

It was hypothesized that the substantial threshold differences observed for detection of the 1000 Hz tones in noise samples A and B in Experiment 1 would not be present for 6000 Hz tones in Experiment 2. A substantial reduction in threshold differences would be interpreted as evidence that envelope cues were largely responsible for the threshold differences observed in Experiment 1. Reduction in the magnitude of FNMR would be interpreted as further evidence that envelope cues are more limited at 6 kHz than at 1 kHz.

METHOD

Subjects.

The same five adults served as subjects in Experiments 1 and 2. Because Experiment 2 was conceived as a follow-up study to Experiment 1, all subjects completed Experiment 1 first.

Stimuli .

The signal was a 300-millisecond 6000-Hz tone with 20 millisecond raised cosine ramps. The single band reference masker was 600-millisecond 20-Hz wide noise centered at 6000 Hz. As in Experiment 1, the onset of the maskers was 135 ms prior to the onset of the 300-ms 6000-Hz tone.

The method of stimulus generation was identical to the method used in Experiment 1. Each noise band was an 11-component sinusoidal complex which was generated by adding 11 sinusoids spaced 2 Hz apart. The amplitude and phase values for each component of the eight noise samples were identical to the values used for the components of the eight noise samples in Experiment 1. Noise samples in the two experiments differed only in their component frequencies.

As in Experiment 1, the tone and noise were combined digitally in twenty numbered stimulus files generated for each of two noise samples (A and B). Each stimulus file corresponds to a different signal-to-noise ratio ranging from -26.5 dB to 11.5 dB in 2 dB steps. In file # 20, the tone was added to the noise without any rediction in level resulting in a signal-to-noise level of 11.5 dB. In each subsequent file (#19 to #1), the tone was rediced in level by 2 dB compared to the previous file. This reduced amplitude tone was then added to the noise.

Conditions

There were three masking conditions: two frozen-noise conditions (noise samples A and B in which the waveform identical for each presentation) and one random condition in which noise samples were randomly-selected for each presentation using the same method used in Experiment 1. During the random conditions, the tone always occurred in either noise sample A or B and the noise alone stimulus was randomly-selected from the remaining seven alternatives (one of which could be noise A or B). During a block of trials, one of the target noise samples might randomly be chosen as a context stimulus (noise alone), however a given target noise never occurred twice in the same trial.

Procedure

Stimuli were played through a 16-bit digital-to-analog converter (Pro-Audio Spectrum-16), passed through an antialiasing filter (cutoff 8 kHz), a custom amplifier and attenuator (SPS-6), and delivered to the subjects' right ears through Eartone-3A insert earphones. Stimulus presentation was controlled by a 486-based personal computer. Subjects were tested in a small single-walled sound treated booth.

Stimuli were calibrated using a B & K sound level meter type 2218 on fast setting with a B & K mic #4132 in a HA-1 2-cc coupler connected to Eartone-3A insert earphones. The level of the tone was 72 dB. The overall level of each of the 20-Hz wide noise bands was constant at 61 dB SPL. These levels are equal to the levels of the stimuli used in Experiment 1. A 600 ms 6-kHz calibration tone was used to calibrate intensity levels prior to each test session.

As in Experiment 1, a two-alternative forced-choice (one-up, three-down) procedure was used to estimate the 79.4% point on the psychometric function. Stimuli were presented monaurally at an initial S/N ratio of 11.5 dB. The S/N ratio was decreased in 8 dB steps, then in 6 dB steps after one reversal, and 4 dB steps following the second reversal. The minimum step size of 2 dB occurred after the third reversal. Each block is terminated following 6 reversals after the minimum step size is reached. Threshold estimates for each block were based on the mean of the last 6 reversals. The interleaving procedure used for the randomly-selected noise conditions was the same procedure used in Experiment 1.

A minimum of twelve estimates were obtained for each condition. The number of estimates was reduced from the sixteen minimum used in Experiment 1 because

little evidence of practice was observed for the single-band conditions. Runs were discarded based on the same criteria used in Experiment 1. Mean threshold estimates for each condition were based on the last 10 estimates. A minimum of four additional estimates were obtained if practice effects were apparent from in data from the last 10 estimates. As before, the objective was to use estimates that represented a performance plateau. Linear regression analysis were performed on the last 10 estimates for each condition for each subject to establish that a plateau had been reached.

Subjects were tested in four to five sessions, each lasting approximately 90 minutes. Each session consisted of two to three blocks of four estimates each. Each block was separated by a short rest period.

The order of conditions was determined for each subject using a Latin-square design. This was done to ensure that all subjects did not complete all conditions in the same order. The subjects completed each condition before starting the next one.

DATA ANALYSIS

As in Experiment 1, linear regression functions were fitted to the last 10 estimates for each condition and subject in order to test whether a plateau in performance had been reached. In addition, t-tests were performed on the first half vs. last half of threshold estimates for each subject and condition as a further test of time order effects.

Single-band thresholds for 1000 and 6000 Hz for frozen and randomly-selected noise samples A and B were used in the ANOVAs performed the individual data [Frequency (1-kHz, 6-kHz) X Randomness (frozen, randomly selected) X Noise sample (A, B)].

RESULTS

The entire data set (including practices estimates preceding the last 10 estimates) consisted of 240 data points for the five subjects. Two (.8 %) of these data points were excluded due to reversal standard deviations exceeding 5 dB. There were no estimates whose z-scores exceeded 2.5. The estimates whose reversal standard deviations exceeded 5 dB were replaced by additional data points, therefore sensitivity was not compromised.

TIME ORDER ANALYSES

Linear regression analyses performed on the last 10 replications of the four data sets for each subject failed to reveal any significant relationship between replication and threshold. There were no slopes that differed significantly from zero for any of these analyses, suggesting that the goal of obtaining data which reflect performance plateaus was achieved. Slopes of the functions and their associated significance levels for the 10 regression analyses can be found in the Appendix C.

The t-tests failed to reveal any significant difference between the first and last 5 estimates for any condition for any subject. The t-values and corresponding

significance levels can be found in Appendix C. These results provide further evidence that time order effects, if any, were not significant in the final data sets.

INDIVIDUAL ANALYSES OF VARIANCE OF THRESHOLD DATA

Main effects

Table 4.1 shows a summary of the individual ANOVAs. Complete ANOVA tables and Tukey HSD post-hoc tables for each subject appear in Appendix C. Main effects of frequency and noise sample were significant for all subjects showing lower thresholds for 1000 Hz and for noise sample A. The main effect of randomness was significant for four of the five subject (S1, S2, S3, S5) showing lower thresholds for tones masked by frozen noise.

Two-Way Interactions

Frequency x noise sample (FS).

Individual and mean thresholds for the four conditions in this interaction are shown in Figure 4.1. Data are collapsed across frozen and randomly-selected conditions. As predicted, differences between noise samples A and B are generally greater at 1-kHz than at 6-kHz.

A Tukey HSD post-hoc analysis was used to further examine the interaction. The results of this analysis is also shown in Figure 4.1. Vertical lines in the individual subject panels indicate no significant differences between noise samples A and B at a given frequency. Data points connected by solid lines indicate significant differences between 1 kHz and 6 kHz for a given noise sample and broken lines denote

Table 4.1. Summary of Analyses of Variance for individual subject threshold data for Experiment 2. F-ratios and significance levels are shown for each main effect and interaction.

EFFECT	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5
Frequency (F)	F(1,9) = 153.16 p=.000001	F(1,9) = 81.13 p=.000008	F(1,9) = 268.11 p=.000000	F(1,9) = 73.24 p=.00001	F(1,9) = 260.78 p=.000000
Randomness (R)	F(1,9) = 23.81 p=.000871	F(1,9) = 9.93 p=.01172	F(1,9) = 29.70 p=.00041	F(1,9) = .39 p=.54807	F(1,9) = 31.28 p=.00034
Noise sample (S)	F(1,9) = 55.15 p=.00004	F(1,9) = 91.70 p=.000005	F(1,9) = 77.02 p=.00001	F(1,9) = 88.80 p=.000006	F(1,9) = 75.11 p=.00001
F x R	F(1,9) = 4.76 p=.05700	F(1,9) = 6.72 p=.02914	F(1,9) = 12.32 p=.000663	F(1,9) = 4.49 p=.06319	F(1,9) = 20.09 p=.00153
F x S	F(1,9) = 46.24 p=.00008	F(1,9) = 31.38 p=.00033	F(1,9) = 13.38 p=.000525	F(1,9) = 12.91 p=.00581	F(1,9) = 25.24 p=.00072
R x S	F(1,9) = 19.26 p=.00018	F(1,9) = 5.88 p=.03829	F(1,9) = 2.97 p=..11920	F(1,9) = 2.49 p=.14935	F(1,9) = 1.65 p=.23050
F x R x S	F(1,9) = 10.32 p=.01062	F(1,9) = .77 p=.40244	F(1,9) = 1.23 p= .29491	F(1,9) = .14 p=.72211	F(1,9) = 16.08 p=.00306

no significant differences. Analyses were performed on individual data only, therefore significance levels were not determined for the mean data which appears in the lower right panel of Figure 4.1. Of particular interest are the differences between noise samples A and B. For four of the five subjects (S1, S2, S3, S4), the significant differences between noise samples A and B at 1 kHz disappeared at 6 kHz.

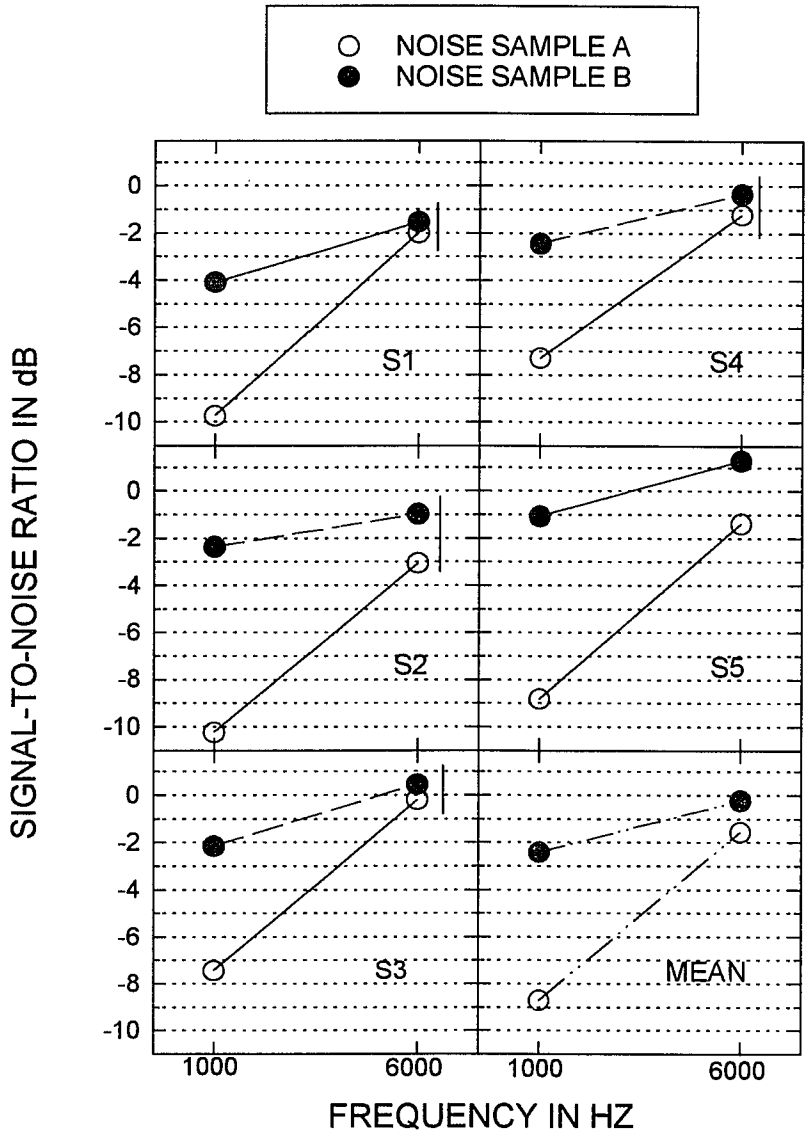

Figure 4.1. Individual and mean thresholds for noise samples A and B as a function of frequency (collapsed across frozen and randomly-selected noise conditions). In individual subject panels, vertical lines denote non-significant differences between noise samples A and B. Solid lines in individual subjects panels indicate significant differences between 1k and 6k Hz. Significant differences ($p<.05$) were determined by Tukey HSD post-hoc analyses.

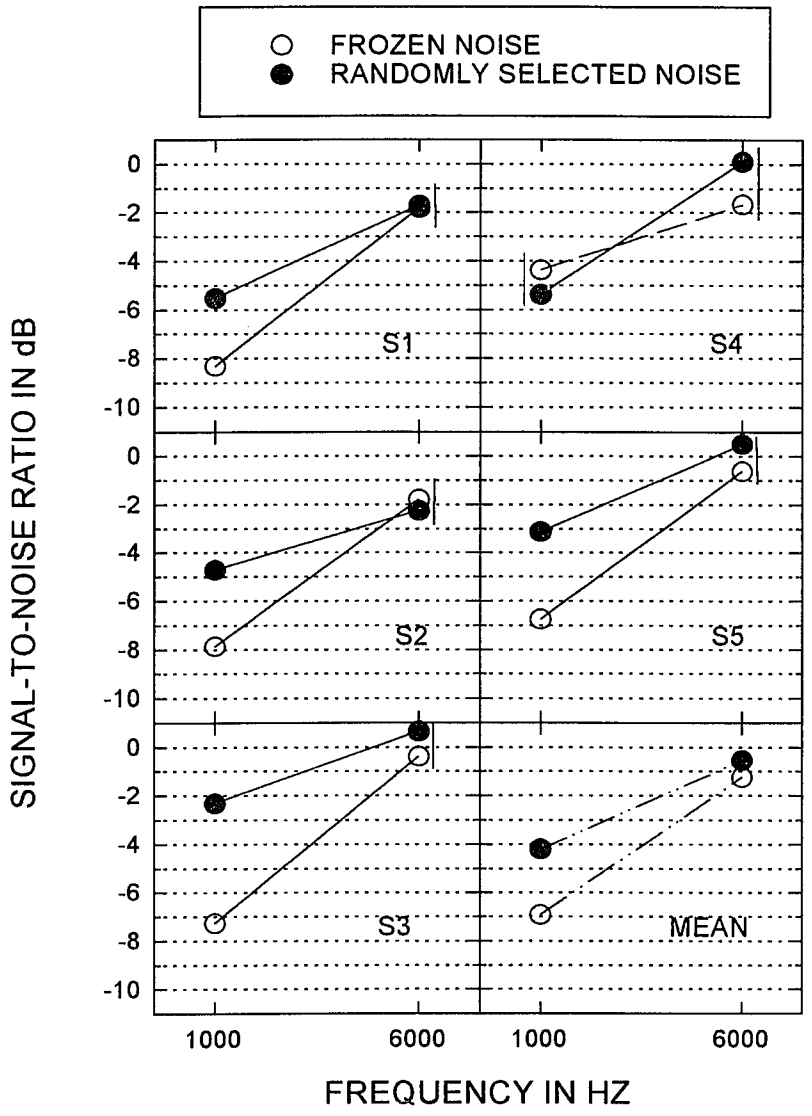

Figure 4.2. Individual and mean thresholds for frozen and randomly-selected noise as a function of frequency (collapsed across noise samples A and B). In individual subject panels, vertical lines indicate non-significant differences between frozen and randomly-selected noise conditions. Solid lines indicate significant differences between 1k and 6k Hz.

The fifth subject (S5) showed lower thresholds in noise sample A than in sample B for both 1- and 6-kHz, although differences between the noise samples appear to be smaller at 6-kHz than at 1-kHz.

Frequency x randomness (FR).

Individual and mean thresholds for the four conditions in this interaction are shown in Figure 4.2. Data are collapsed across noise sample. Frozen noise masking release (FNMR) is represented by differences between frozen and randomly selected noise. As predicted, FNMR is generally greater at 1-kHz than at 6-kHz.

A Tukey HSD post-hoc analysis was used to further examine the interaction. Frozen noise masking release as a function of frequency was the contrast of interest. The asterisks in Figure 4.2 indicate significant differences between frozen and randomly selected noise (FNMR) at a given frequency, while vertical lines reflect non-significant differences. Data points connected by solid lines indicate significant differences between 1 kHz and 6 kHz for a given noise condition and broken lines denote non-significant differences. Analyses were performed on individual data only, therefore significance levels were not determined for the mean data which appears in the lower right panel of Figure 4.2. Four of the five subjects (S1, S2, S3, S5) showed significant FNMR at 1-kHz with no significant FNMR at 6-kHz. The remaining subject (S4) did not show FNMR at either frequency. These findings are consistent with the hypothesis that envelope cues are more limited at 6-kHz than at 1-kHz.

Randomness x Noise sample (RS).

Means for the four conditions in the randomness/noise sample interaction are shown in Figure 4.3 for all subjects. As in Experiment 1, this interaction reveals

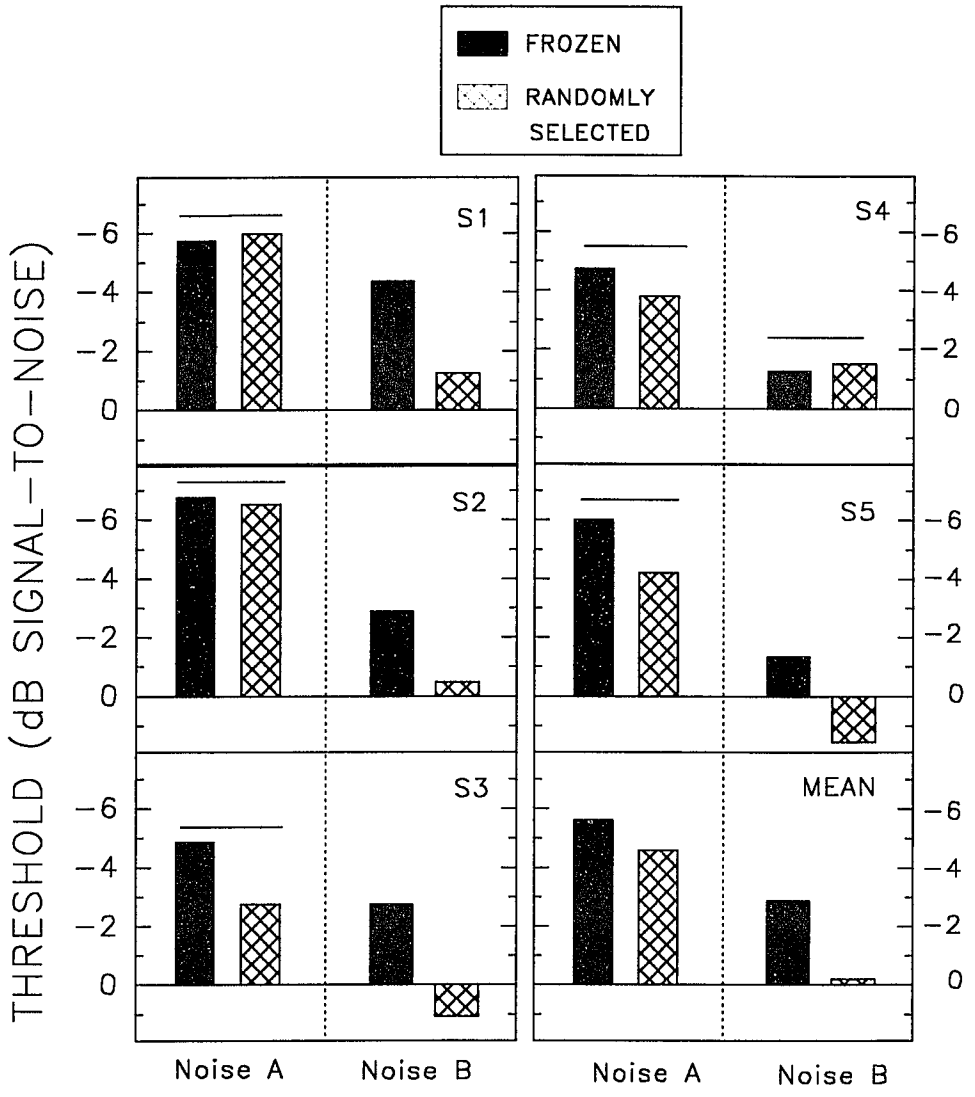

Figure 4.3. Individual and mean thresholds for single-band noise samples A and B in the frozen and randomly-selected noise conditions collapsed across frequency (1k-, 6k-Hz). Horizontal lines in individual subject panels indicate non-significant differences between frozen and randomly-selected noise conditions ($p<.05$ as determined by Tukey HSD post-hoc analyses). Differences between noise samples A and B were significant in both the frozen and random conditions with the exception of frozen noise conditions for subjects S1 and S3.

information about the magnitude of frozen noise masking release for noise samples A and B (cf. Figure 3.3, Chapter 3). In this experiment, data are collapsed across frequency, whereas Experiment 1 data for this interaction are collapsed across single- and seven-band conditions. Non-significant FNMR, as determined by Tukey HSD post-hoc analyses, is indicated by horizontal lines. Analyses were performed on individual data only, therefore significance levels were not determined for the mean data which appears in the lower right panel of Figure 4.3.

Results of the post-hoc analyses reveal that four of the five subjects (S1, S2, S3, S5) had significant frozen noise masking release for noise sample B, but not for noise sample A. The remaining subject (S4) did not show FNMR for either noise sample.

THREE-WAY INTERACTION

Frequency x randomness x Noise sample (FRS).

Results for all eight conditions are shown in Figure 4.4. A significant three-way interaction is seen for two subjects (S1, S5) which is characterized by a contrasting pattern of differences between frozen noise masking release for noise samples A and B at the two frequencies. Post-hoc analyses using the Tukey HSD test show that, for these two subjects, there is no frozen noise masking release at 6-kHz for either noise sample (non-significant differences indicated by vertical lines). In contrast, at 1-kHz, significant FNMR (indicated by the asterisks) is present for noise sample B, but not for noise sample A. Analyses were performed on individual data only, therefore

significance levels were not determined for the mean data which appears in the lower right panel of Figure 4.4.

Thresholds for 6-kHz tones are generally greater than those for 1-kHz tones, particularly for noise sample A. A reduction in the contribution of envelope cues at 6-kHz may explain this finding.

SUMMARY

Results of Experiment 2 show that frozen noise masking release present at 1-kHz is not present at 6-kHz. The substantially higher thresholds in frozen noise at 6-kHz may be responsible for this finding. These results are consistent with the idea that envelope cues are less accessible at 6-kHz.

For the majority of subjects, significant differences between thresholds in noise samples A and B observed at 1-kHz were not present at 6-kHz. This supports the idea that for the majority of subjects, envelope cues contributed to the low frozen noise thresholds at 1-kHz. One subject, however, continued to show significant differences between noise samples A and B at 6-kHz. It is possible that this subject was using a different cue, such as the relatively large short-term S/N ratio for noise sample A.

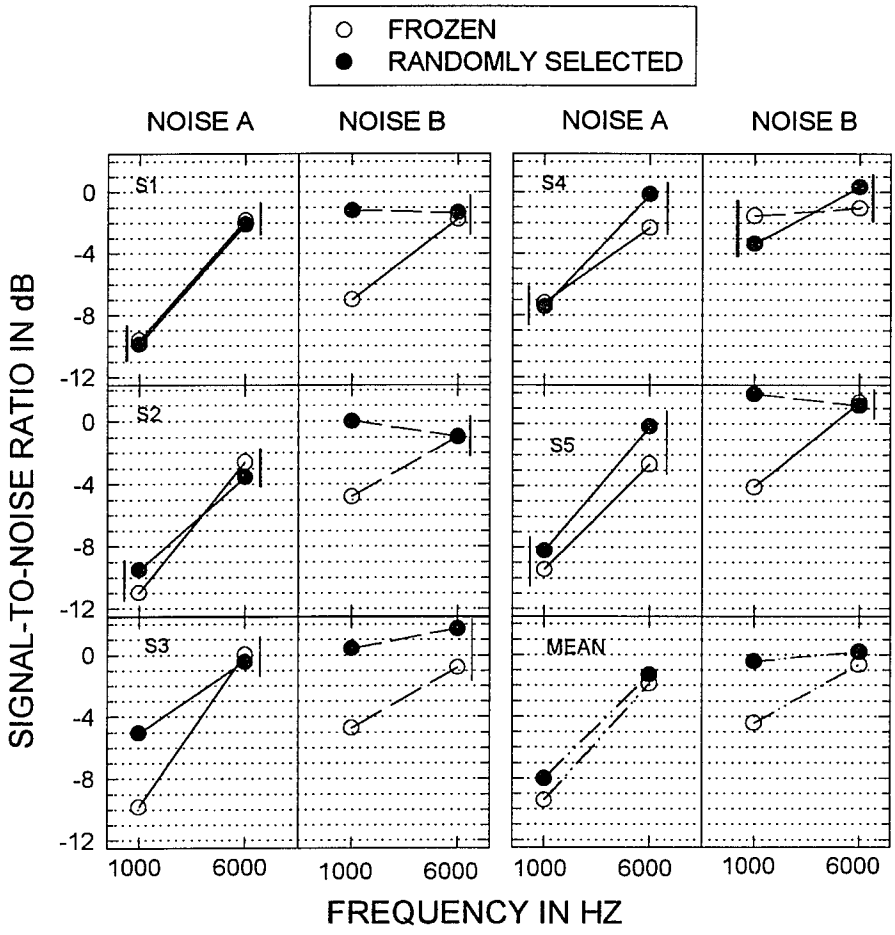

Figure 4.4. Individual and mean thresholds for noise samples A and B under frozen and randomly-selected conditions as a function of frequency. Vertical lines in the individual subject panels denote non-significant difference between frozen and randomly-selected noise conditions. Solid lines indicate significant differences between 1- and 6-kHz.

CHAPTER 5

DISCUSSION

The purpose of Experiment 1 was to examine the effects of combining frozen noise masking release (FNMR) and comodulation masking release (CMR). The experiment was designed to test the hypothesis that cues underlying CMR and FNMR are the same. This hypothesis was tested by comparing the magnitude of comodulation masking release using frozen and randomly-selected noise samples. It was predicted that if these two phenomena are dependent on same envelope cues, then CMR will not be present with frozen noise.

A single-subject experimental design was used to collect and analyze data for five subjects. Subjects were tested using two noise samples (noise samples A and B) under four different masking conditions: single-band frozen noise, single-band randomly-selected noise, seven-band (comodulated) frozen noise and seven-band (comodulated) randomly-selected noise. Under the frozen noise conditions, the same noise sample was used on each presentation. Under the randomly-selected conditions, the tone was masked by either noise samples A or B and the "noise-alone" sample was randomly chosen from the remaining seven alternatives.

The main findings of Experiment 1 were:

1) There were significant differences between results for the two noise samples.

2) Comodulation masking release was smaller in frozen noise than in randomly-selected noise for the majority of subjects.

3) There were substantial intersubject differences.

Unexpectedly, results were significantly different for the two noise samples for all subjects. The effect of noise sample was observed both in absolute threshold differences as well as the magnitude of both FNMR and CMR.

Thresholds for tones masked by noise sample A were significantly lower than for noise sample B (mean difference = 5.6 dB), although the average RMS level was the same for the two noises. Several other investigators have reported differences in thresholds for tones masked by different samples of narrow-band noise that could not be explained by level differences between the noise samples (Gilkey and Robinson, 1986; Hartmann and Pumplin, 1988; Kidd et al., 1993; Pfafflin 1968; Richards, 1992). Kidd et al. (1993) reported differences between thresholds for 12 equal-intensity narrow-band noise samples (20-Hz-wide) that ranged up to 15 dB (0-15 dB). Hartmann and Pumplin (1988) found an average difference of 5.5 dB between thresholds for tones in equal amplitude random phase narrow-band noise and noise whose phase values were specially chosen to reduce the amplitude fluctuation ("low-noise noise"). Threshold differences were attributed to the larger power fluctuations present in the random phase noise. Threshold differences between noise samples A

and B in the current study ranged between 2.6 dB and 6.2 dB, which is compatible with findings of other investigators.

Noise sample also had an unexpected influence on both frozen noise masking release and comodulation masking release. Only one subject showed frozen-noise masking release for noise sample A, whereas four subjects showed FNMR for noise sample B (see Figure 3.4, previous chapter). Comodulation masking release was observed for three of the five subjects for noise sample A and for all subjects for noise sample B. The magnitude of CMR in noise sample A was considerably smaller than in noise sample B for the two subjects who did show CMR in sample A.

The reduction or absence of FNMR and CMR for noise sample A may be due to the low thresholds in the reference condition (single-band randomly-selected noise). Thresholds obtained in noise sample A in the reference condition were generally as low as both frozen noise thresholds and thresholds in the comodulated noise. It is possible that these low reference thresholds represent the minimum thresholds for these subjects. If minimum thresholds were reached in the reference condition, then additional information provided by either frozen or comodulated noise would not be expected to improve detection. The cues used to detect tones in noise sample A may be the same cues used in both FNMR and CMR.

These findings suggest that the cues in noise sample A that occur with the addition of the tone, are different and/or stronger than those available in noise sample B. In order for thresholds to remain low in noise sample A under the randomly-

selected condition, cues would have to be robust enough to overcome the effects of randomly-selecting the noise on each presentation. In contrast, the substantial FNMR observed for the majority of subjects in noise sample B, suggests that the cues used by the subjects to detect tones in frozen noise B may be difficult to recognize in the randomly-selected noise conditions.

The absence of FNMR and CMR in noise sample A makes it unfeasible to evaluate the hypothesis for this noise sample, therefore the discussion of the hypothesis will be limited to results obtained with noise sample B. Most relevant to the hypothesis was the finding that the majority of subjects show smaller CMR in frozen than randomly-selected multi-band noise, suggesting that cues available in frozen noise are at least partially interdependent with cues important for CMR. These cues appeared to be identical for two subjects who showed no significant CMR in frozen noise. For the other three subjects, it appears that other cues present in the comodulated bands supplemented the information used by these subjects in the frozen noise, possibly because the subjects were not making full use of the cues available in frozen narrow-band noise.

The above interpretation of the results has focused on the additional contribution made by comodulation after frozen noise cues have been provided. An alternative way to evaluate the hypothesis is to determine the additional contribution of frozen noise cues after the comodulation cues have been provided. The difference between thresholds in 7-band randomly-selected noise and 7-band frozen noises

provide an estimate of the contribution of frozen noises cues after comodulation cues have been provided. The data showed no further improvement in thresholds for any subject. In other words, comodulated cues added after frozen noise cues result in further improvement in thresholds, but combining cues in the reverse order does not. It may be that comodulation cues are more easily recognized than cues in frozen noise; i.e. both sets of cues may rely on the same underlying mechanism, but CMR cues may be more salient than cues in frozen noise. Real life experience listening of comodulation present in speech may contribute to listeners' abilities to readily use these cues in these non-speech stimuli. In contrast, listeners generally have less experience memorizing temporal details in a frozen waveform. It is possible that thresholds in frozen noise would drop further with practice as subjects learn to use the cues in the frozen noise.

Several investigators have shown that learning patterns in psychophysical experiments can have a long and irregular course (Leek and Watson, 1984; McFadden and Wright, 1992). McFadden and Wright (1992) raised this issue of learning within the context of psychophysical experimentation and point out that investigators must decide if the goal of the study is to examine the limits of human performance (whereby extensive practice is a crucial factor) or to examine the nature of relatively untrained perception that may more closely reflect the way in which individuals process sound and information in the real world. The priority of the present study was the latter perspective of attempting to reveal individual differences that may

reflect differences in perception or perceptual strategies in the real world environment, while attempting to avoid the effects of early learning.

There were substantial individual differences apparent in the results. Reports of large individual differences are numerous in psychoacoustics studies involving the perception of complex sounds (Kidd, 1993; McFadden and Wright, 1990, 1992; Moore et al., 1990a; Moore et al., 1990b; Neff, Dethlef, Jesteadt, 1990).

The individual differences in the current study may partially reflect differential weighting of information present in the stimuli. The stimuli used in this study contain multiple sources of information, including two sources of envelope information: 1) frozen noise which contains information within the critical band of the signal in the form of envelope reproducibility across time and 2) comodulated noise which contains information in several critical bands in the form of envelope reproducibility across frequency. In addition, frozen noise may contain other cues such as the short-term fluctuations in RMS. Although all subjects were exposed to the same stimuli, hence the same information, it appears that some subjects reach their minimum thresholds in different ways. Some rely more heavily on information in frozen narrow-band noise while others rely more on information in the comodulated bands. Evidence that individuals weight multiple sources of stimulus information differently is present in several studies (Ahumada and Lovell, 1971; Berg, Nguyen, and Green, 1992; Gilkey and Robinson, 1986; Richards, Heller, and Green, 1991; Southworth and Berg, 1994).

In the current study, one subject in particular (S4) deviated substantially from the other four. The small number of subjects used in this study precludes knowing whether this subject is part of a subset of an otherwise unsampled population, or whether she truly would be an outlier on a larger scale study. The results for this subject were characterized by substantially higher frozen noise thresholds than other subjects, together with the absence of frozen noise masking release for either noise sample. These results suggest that she had difficulty using information in frozen noise. In light of the findings that cues involved in FNMR and CMR appear to be at least partially interdependent, one might expect that this subject would also have difficulty using cues available for CMR, however this was not the case. Rather, she showed the largest magnitude of CMR of all the subjects.

There are several possible explanations for this. It is possible that this subject assigns more weight to across-channel information present in the comodulated bands than the within-channel cues present in the frozen noise samples. It is also possible that this subject required more exposure to the frozen noise in order to used the available information. Given sufficient practice, could this subject learn to use the information in frozen noise? If so, would frozen noise masking release then become apparent?

Another possible explanation may lie in potential differences in sensory memory coding for the comodulated and frozen noise conditions. While both phenomena most likely involve a comparison of the signal and non-signal intervals, the actual envelope reproducibility occurs across time in the case of frozen narrow-band

noise and across frequency in the case of CMR. Taking advantage of the frozen noise reproducibility across time may require successive comparisons that involve encoding a representation of the signal in short-term memory ("sensory-trace mode" (Durlach and Braida, 1969)), whereas information obtained with simultaneous comparisons (comodulation across frequency) may be reduced to a more gross categorization (signal vs. non-signal) which could be stored in long-term memory ("context-coding mode" (Durlach and Braida, 1969)).

Evidence for context coding of complex non-speech stimuli appears in the literature on profile analysis, another phenomenon believed to involve a comparison of information across critical bands (Green, Kidd and Picardi, 1983; Kidd, Mason and Hanna, 1988). They showed that profile analysis (in which simultaneous comparisons were possible) was unaffected by increased interstimulus interval (ISI), whereas traditional intensity discrimination of a single tone, (requiring successive comparisons) deteriorated as the ISI increased. Perhaps similar differences between the nature of memory coding for the frozen and comodulated conditions exist in the present study. If so, it is possible that subject 4 was unable to adequately store the sequential information in short-term memory.

The pervasive influence of noise sample on the results led to a more detailed analysis of the noise samples used. Although equal in terms of RMS level, the two noise samples have distinctly different envelopes. Noise sample A peaks at a higher level than sample B. The latter, however, appears to have relatively longer periods of

low energy (see Figure 3.5, Chapter 3). The noise analyses examined two possible sources of information that could explain the lower thresholds found for tones masked by noise sample A. The first of these is the distribution of energy across the noise envelope. This was examined by measuring the short-term signal-to-noise ratio across 20-ms segments of each noise sample. An advantageous signal-to-noise ratio was found for noise sample A in the mid-temporal portion of the envelope. This analysis should be interpreted with caution, however, due to probable phase interactions between the signal and masker.

The distribution of short-term energy across time is also related to the crest factor (peak/RMS) of the noise. Noise with a high crest factor is associated with greater fluctuations in short-term energy over time; i.e. by a high peak in short-term energy followed by periods of low short-term energy.

There is physiological evidence that noise with high crest factors may provide less masking than noise with low crest factors (Mott, McDonald and Sinex, 1990). These investigators found a group of neurons whose thresholds were generally higher for 1.5 kHz probes masked by the noise with the low crest factor (2.4) than with the high crest factor (3.3) noise. The results of the physiological study (Mott et al., 1990) are compatible with the lower thresholds found for noise sample A in the current study in that the crest factor for noise sample A was higher (2.96) than for noise sample B (2.32).

In contrast to these findings are psychophysical results that showed that thresholds for tones masked by narrow band noise with a small crest factor were lower

than thresholds masked by high crest factor noise (Hartmann and Pumplin, 1988). Although the Mott et al., (1990) used the same algorithm (developed by Pumplin, 1985) to generate the low crest factor noise, the difference between the crest factors of their high- and low-crest factor noise samples was only .8 compared to the difference of 1.75 in the Hartmann and Pumplin study. Hartmann and Pumplin failed to find any difference in the thresholds for two noise samples whose crest factors differed by 0.6. Although both investigators discussed crest factor as a characteristic that distinguished the noise samples, there may be some other acoustic feature of the noise sample (e.g. envelope spectrum) that would explain the differences in results. Due to the disparity between the results of the physiological and psychophysical studies described above, the importance of the crest factor of the noise samples used in the current study is unclear.

The second noise analysis was a comparison between changes in the envelope power spectra with the addition of the tone for noise samples A and B. Results showed a pronounced shift in envelope power spectra toward the lower frequencies for noise sample A, with much smaller changes occurring for noise sample B.

There is evidence to suggest that the ear is particularly sensitive to envelope frequencies in the region of 3 Hz (Riesz, 1928). For noise sample A, the largest changes in the envelope power spectrum with the addition of the tone occur at this frequency. In contrast, no change is apparent at this frequency for noise sample B.

This difference may account for the threshold differences observed for these two narrow-band noise samples.

This shift in envelope power spectra toward the low frequencies agrees qualitatively with the findings of Green et al., (1992). Thresholds for tones masked by 20-Hz wide narrow-band noise in their study were approximately 3 dB lower than would be predicted by critical band theory and were 2 dB higher than the values predicted by a model incorporating envelope power spectral information as a detection cue.

A quantitative comparison with the results obtained by Green et al. (1992) is precluded because of differences in procedure (fixed overall level vs. 20 dB roving in level) and stimuli (fixed phase/amplitudes vs. random phase/amplitudes). In addition, Green's measures were based on an average of 1000 noise samples. However, it is possible to compare the magnitude of change in the envelope power spectrum corresponding to threshold for detection in the two studies. In the current study, the envelope power spectrum of noise sample A increased (2.9 dB) in the low frequency region (between 3-10-Hz) at the S/N ratio closest to the mean threshold. This is compatible with the 2.0 dB increase in the low frequency region of the envelope power spectrum required for detection in the Green et al. (1992) study.

Changes in envelope power spectra for noise sample A and B were also compared to the envelope power spectra for the other seven noise samples used in the randomly-selected noise conditions. The objective was to find acoustic evidence

that could explain why frozen noise masking release was present for noise sample B but not for noise sample A for the majority of subjects. This analysis showed that even in the randomly-selected noise condition, the energy of the envelope power spectrum at 3 Hz for noise A at threshold (tone+noise) was greater than for any of the other seven (noise alone) noise samples (see Figure 3.9, Chapter 3). This finding supports the idea that the robustness of cues in noise sample A underlies the similar thresholds observed in the randomly-selected and frozen noise conditions. In contrast, changes in the envelope power spectrum for noise sample B at threshold did not distinguish it from any other of the seven noise samples.

The above analysis suggests that subjects did not use changes in the envelope power spectrum as a detection cue for tones masked by noise B. There are no changes at 3-Hz and the changes that occur at other frequencies are not monotonically related to S/N ratio (perhaps due to phase interactions). Furthermore, the largest changes in noise sample B occur at a S/N ratio well below the mean threshold. Therefore, it would seem likely that if subjects were using these cues for detection, thresholds would correspond to the lower S/N ratios with the larger envelope power spectral changes.

If subjects did not use changes in the envelope power spectrum as a detection cue in noise sample B then some other frozen noise cue must be responsible for the existence of frozen noise masking release for this noise sample. A possible alternate cue for detection in frozen noise sample B is the decrease in the correlation of the noise alone and tone + noise envelope when the tone is added.

Richards (1987) showed that for simultaneously presented envelopes (for narrow-band noise at different center frequencies), listeners were able to detect changes in correlation of about 0.15 from perfectly correlated envelopes. Although envelope decorrelation is not necessarily different from a change in envelope power spectrum, it is possible for phase interactions between the tone and masker to alter (and therefore decorrelate) the envelope without having a large effect on the envelope power spectrum. The change in envelope correlation with the addition of a tone to noise sample B at threshold exceeded the 0.15 change in correlation required for decorrelation detection in Richard's study, but did not exceed 0.15 for noise sample A.

In addition to possible differences between the cues involved in detection of tones in the two noise samples, it is interesting to consider possible differences in the detection process itself. Is more learning required to take advantage of the cues in noise sample B than in noise sample A? The use of a cue such as decorrelation of a waveform would more likely require some "learning" of the waveform. Changes in the envelope power spectrum have been associated with the subjective quality of "smoothness" (Green et al., 1992; Southworth and Berg, 1994) which may immediately result in greater detectability, without the subjects having to "learn" the noise waveform.

Experiment 2 further examined differences between noise samples A and B. Noise analyses confirmed that the lower thresholds observed for noise sample A could be explained by the greater accessibility to envelope cues and/or greater short-term

S/N ratios present in noise sample A, however it was unclear whether subjects took advantage of this information.

The goal of Experiment 2 was to limit accessibility to envelope information by comparing thresholds for the two noise samples at 6000 Hz, a frequency at which phase locking is not expected to occur. This goal was based on evidence from other investigators suggesting that envelope information may be reflected by the pattern of phase locking of neurons tuned to the signal (Moore and Glasberg, 1987). It was hypothesized that both the differences between the two noise samples and the magnitude of frozen noise masking release would be reduced at 6000 Hz.

Thresholds for 6000 Hz tones masked by noise samples A and B transposed to a higher frequency region were obtained in frozen and randomly-selected noise. Envelopes of the noise samples were identical to the corresponding samples used in Experiment 1.

The fact that all subjects completed Experiment 1 before Experiment 2 raises the issue of possible practice effects should the 6000 Hz thresholds (collected last) be lower than 1000 Hz. This was not of concern for two reasons: 1) differences between noise samples A and B within a frequency was the primary contrast of interest not threshold differences across frequency and 2) data for Experiment 2 showed higher thresholds for 6000 Hz, therefore threshold improvement attributable to test order (i.e. 1-kHz before 6-kHz) is unlikely.

As predicted, differences between thresholds measured in noise samples A and B were reduced at 6-kHz. At 6-kHz, there were no significant differences between

thresholds in noise samples A and B for four of the five subjects. One of the four subjects (S5) continued to show significantly better thresholds for noise sample A, however differences were smaller than at 1-kHz. One possible explanation for the persistent difference between thresholds in noise samples A and B may lie in the favorable short-term S/N ratio present in noise sample A, which may not be affected by inaccessibility to envelope information. A second possibility is that some envelope information may still have been accessible.

No subjects showed significant frozen-noise masking release (FNMR) at 6-kHz, however four of the subjects showed FNMR at 1-kHz. This supports the idea that cues underlying FNMR at 1-kHz become inaccessible at 6-kHz. Parallel to this finding are the reports of other investigators that comodulation masking release is substantially reduced or absent at 6-k and 8-kHz (Schooneveldt and Moore, 1987; Fantini, et al., 1993).

Thresholds obtained at 6-kHz were higher than those obtained at 1-kHz for both frozen noise samples. In contrast, for the randomly-selected noise conditions, thresholds were lower at 1-kHz than at 6-kHz for noise sample A, but similar at the two frequencies for noise sample B. One possible explanation for this finding is that for noise sample B, subjects may be forced to rely on level cues (due to an inaccessibility of envelope cues) in randomly-selected noise at both frequencies. In contrast, the robust nature of envelope cues in noise sample A may have permitted listens to rely on this information even in randomly-selected noise at 1-kHz, whereas at 6-kHz inaccessibility to envelope cues may have forced subjects to rely on level cues.

Generally, thresholds obtained at 6-kHz are in agreement with thresholds obtained in random noise of the same bandwidth, falling within the range of prediction based on critical band theory (Bos and de Boer, 1966). This lends further support for the idea that detection was based primarily on the comparison of energy in the signal and non-signal intervals at this frequency.

Experiment 2 supports the idea that envelope information at least partially underlies the differences between detection of tones in narrow-band noise samples A and B. It is clear from noise analyses that envelope cues in noise A are more accessible to the auditory system. The robust envelope information present in noise sample A may explain the finding that both FNMR and CMR are reduced for this noise sample. For some subjects, these envelope cues may be interdependent with cues for both FNMR and CMR.

It is worth considering possible physiological mechanisms that may underlie the apparent reduced accessibility of envelope cues at 6-kHz compared to 1-kHz. Physiological studies have shown that noise envelope information is represented in the auditory system by both the pattern of phase locking (Javel, 1980; Khanna and Teich, 1989) and changes in firing rates corresponding to peaks and dips in the noise (Mott et al., 1990).

Results of physiologic studies show that at high carrier frequencies (e.g. 12-kHz) modulated at a slow rate, there is no phase locking to neurons at the carrier frequency. However, envelope information is preserved in the phase locking patterns

of neurons to the modulation frequency (Javel, 1980; Khanna and Teich, 1989). It is possible that additional envelope information is carried by slight temporal alterations of the fine structure of the waveform imposed by the modulation envelope. In this case, the absence of phase locking to the component frequencies of the noise could result in a loss of envelope information that may be important for perception.

Subjective responses of the subjects also support the perception of loss of envelope information at 6-kHz. Subjects report a perception of "modulation" in response to the 1-kHz narrow band stimuli, but report only a perception of "roughness" in response to the 6-kHz stimuli.

The results reported here suggest that subjects are sensitive to envelope cues both within (FNMR) and across critical bands (CMR). Envelope spectra of the eight noise samples show the largest concentration of energy below 10 Hz (see Appendix A). It is not surprising that subjects would be sensitive to these slow modulation rates in these stimuli given the vast auditory experience human subjects gain in listening to speech that has a modulation rate of approximately 3-4 Hz. Auditory experience of slow rates of modulation in speech may also explain the sensitivity to 3-Hz modulation rates observed for non-speech stimuli (Riesz, 1928). The importance of envelope cues to the perception of speech has been demonstrated several investigators (Remez and Rubin, 1990; Van Tasell et al, 1992).

Sound encountered in our real world environment is exquisitely complex. We are consistently confronted by multiple sources of information and required to make

perceptual decision regarding this input. The results of the studies in this dissertation as well as other studies (see Bregman, 1990 for review) suggest that individuals make use of sensory information in different ways. Bregman (1990) observes that in experiments which pit one source of information against another, individuals tend to use the information in distinctly different ways. He suggests that these individual "perceptual maps" may reflect differences in the way individuals process sound in natural listening environments.

Within the audiology and hearing science disciplines, the auditory masking literature has historically emphasized the question of how sound is represented in the auditory system, rather than how the auditory system organizes or uses sound. The question of perceptual organization has largely been ignored in the field of audiology. A better understanding of differences in perceptual organization of information for an individual may eventually contribute to our treatment of hearing impaired patients. It is possible that some of the individual perceptual differences seen in the hearing impaired may be attributable to differences in the organization of auditory information. Further exploration of this possibility could have implications for the design and fitting of hearing aids for individual patients.

IMPLICATIONS FOR FUTURE RESEARCH

The results of this study have several implications for future research. One implication relates to the substantial differences between results for the two noise samples. Although the noise analyses helped explain these differences, it is unknown how representative these noise samples are of narrow-band frozen noise. Both noise samples produced unusual results in some respect. The absence of FNMR and CMR in noise sample A for the majority of subjects was unusual considering the presence of FNMR and CMR in noise sample B and the substantial documentation of these phenomena in other studies. Noise sample B failed to produced an increase the low frequency region of the envelope power spectrum, which was shown for noise sample A and has been documented previously by Green et al. (1992). Further examination of FNMR and CMR using a larger pool of noise samples may contribute to our understanding of what characteristics are important for detection of tones in frozen noise as well as what characteristics are responsible for FNMR.

Results of Experiment 1 showed that thresholds improved for some subjects when CMR cues were added after frozen-noise cues. These subjects, however, failed to show threshold improvement when frozen-noise cues were provided in addition to CMR cues. This suggests that for the stimuli used in this study, CMR cues were more salient. Re-examination of this pattern under conditions which may be less favorable to CMR and more conducive to the use of frozen noise cues added after CMR (e.g. fewer flanking bands) may further our understanding of the relationship between these two phenomena.

The individual differences apparent in the results suggest that individuals in this study used cues differently. Some appeared to rely more on cues in frozen noise and others relied more heavily on CMR cues. It is possible that these results reflect differences in how individual subjects use of sequential (e.g. frozen-noise) and simultaneous (e.g. comodulation) cues. Comparison of the performance of these subjects on other tasks which encompass competition between simultaneous and sequential cues (e.g. Bregman and Tougas, 1989) might be helpful in understanding factors that underlie these individual differences.

CONCLUSIONS

1) Results for two of the five subjects who showed no CMR in frozen noise are consistent with the interpretation that the same cues underlie both CMR and FNMR. For both subjects, the addition of comodulated bands to the frozen narrow-band noise did not result in any further release from masking.

2) Results for two of the five subjects who showed smaller CMR in frozen noise than randomly-selected noise, results are compatible with two interpretations:

a) cues in frozen narrow-band noise were used inefficiently or

b) different cues were partially responsible for CMR

3) Results for one subject who did not show FNMR, are consistent with the interpretation the she was unable to use the envelope cues for FNMR.

4) Differences in the acoustic characteristics of noise samples A and B help to explain the threshold differences observed for the two noises and identify envelope cues which might be used (e.g. low frequency changes in the envelope power spectrum).

5) The absence of FNMR and the decrease in differences between the thresholds for the two noise samples at 6000 Hz provide additional support for the interpretation that envelope cues are responsible for both FNMR and the threshold differences between the noise samples.

APPENDIX A

CHARACTERISTICS OF THE NOISE SAMPLES

Table A1. Phase and amplitude values for the individual components of the eight noise samples and the 1000 Hz tone. Amplitudes are shown in parentheses.

						Center					
Component:	1	2	3	4	5	6	7	8	9	10	11
Noise A	65 (1.8)	196 (3.5)	98 (1.5)	295 (2.7)	33 (1.0)	327 (2.3)	164 (2.0)	360 (1.3)	131 (0.5)	262 (3.0)	229 (4.5)
Noise B	196 (3.0)	327 (1.5)	229 (2.3)	98 (2.0)	164 (2.7)	262 (2.7)	295 (0.5)	33 (1.0)	65 (1.8)	131 (4.5)	360 (1.3)
Noise C	360 (1.5)	196 (2.0)	131 (0.5)	229 (1.8)	65 (1.3)	33 (2.7)	262 (3.5)	98 (3.0)	164 (1.0)	327 (4.5)	295 (2.3)
Noise D	327 (0.5)	262 (3.0)	65 (2.3)	196 (1.3)	164 (3.5)	229 (1.0)	33 (1.8)	131 (2.0)	98 (2.7)	295 (1.5)	360 (4.5)
Noise E	327 (2.7)	196 (1.5)	360 (4.5)	65 (2.3)	262 (3.0)	229 (1.8)	164 (2.0)	295 (1.0)	33 (1.3)	98 (0.5)	131 (3.5)
Noise F	65 (1.3)	196 (1.5)	295 (2.3)	262 (3.5)	131 (4.5)	98 (3.0)	327 (2.7)	164 (2.0)	360 (1.8)	229 (1.0)	33 (0.5)
Noise G	164 (3.0)	327 (1.0)	229 (0.5)	65 (1.3)	360 (1.8)	295 (2.3)	196 (1.5)	98 (2.7)	131 (3.5)	33 (2.0)	262 (4.5)
Noise H	295 (1.5)	229 (1.0)	262 (2.7)	327 (4.5)	196 (2.3)	360 (1.3)	131 (2.0)	98 (1.8)	33 (0.5)	164 3.5)	65 (3.0)
1000 Hz tone	0 (1.0)										

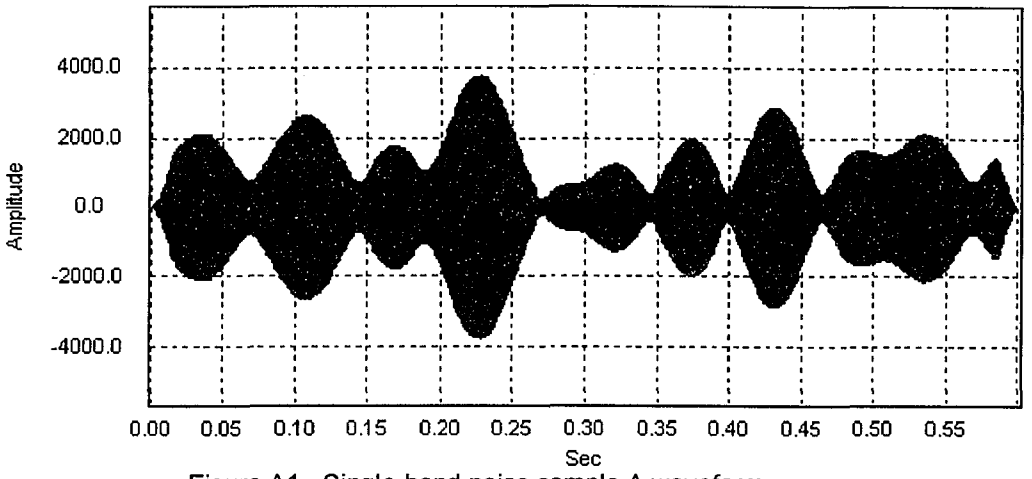

Figure A1. Single-band noise sample A waveform.

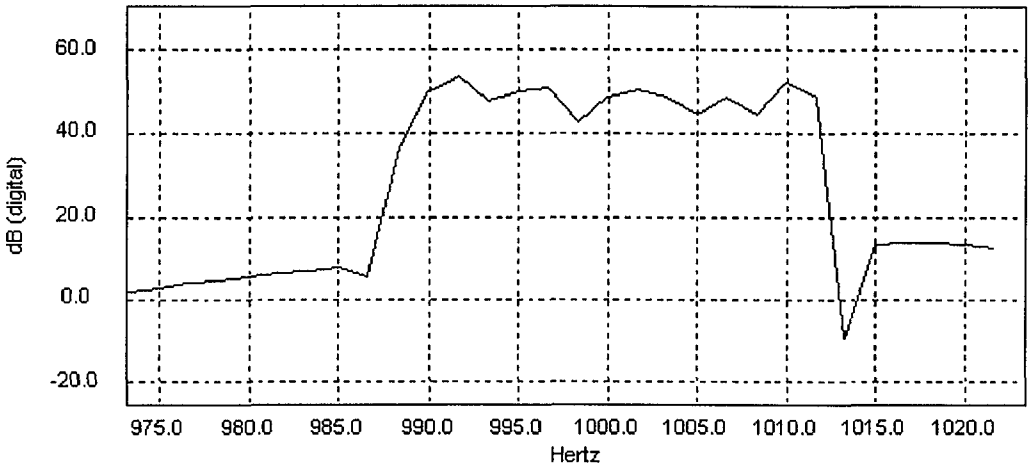

Figure A2. Spectrum of single-band noise sample A.

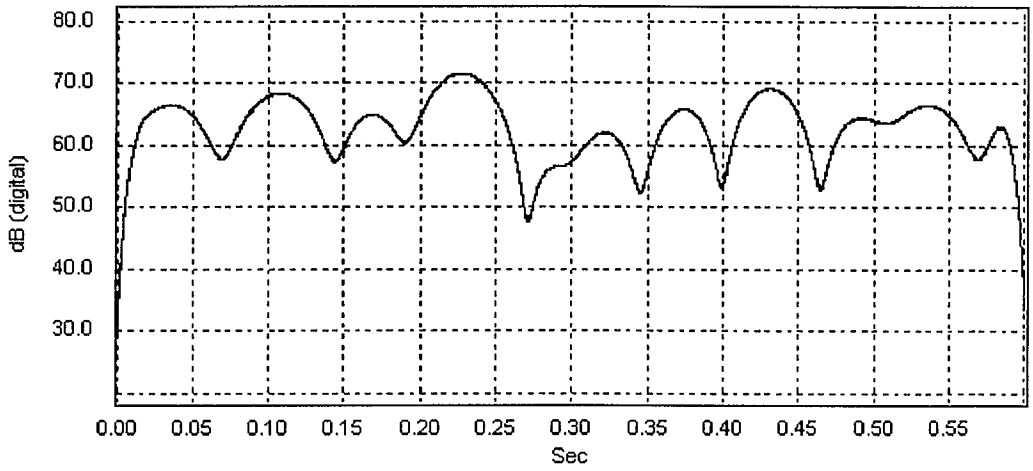

Figure A3. Envelope of single-band noise sample A.

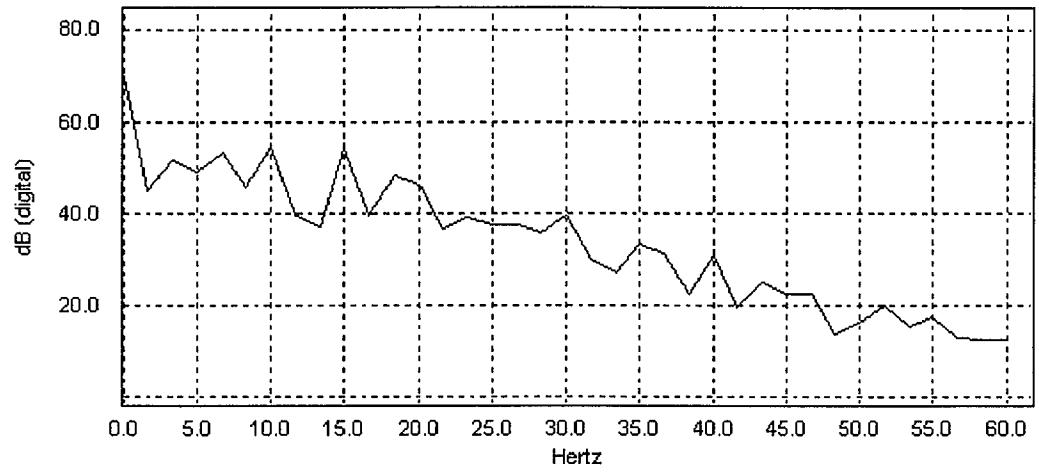

Figure A4. Envelope spectrum of single-band noise sample A.

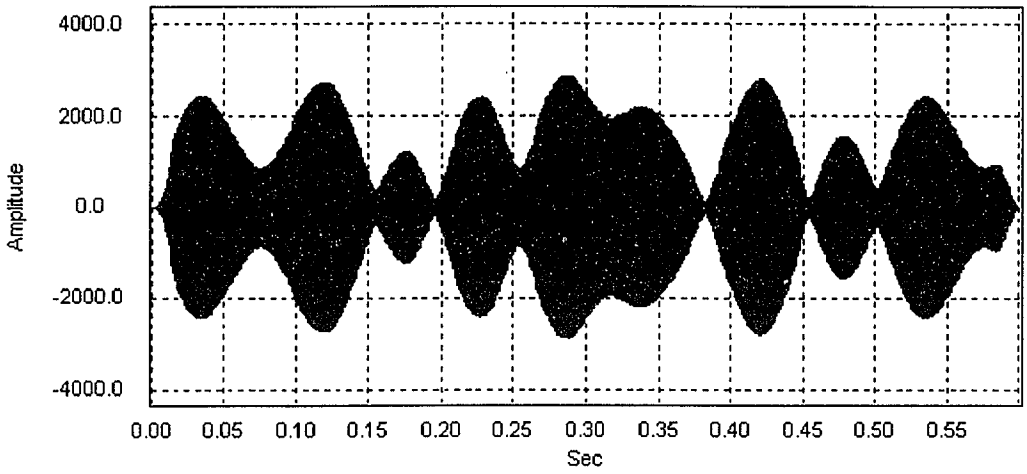

Figure A5. Single-band noise sample B waveform.

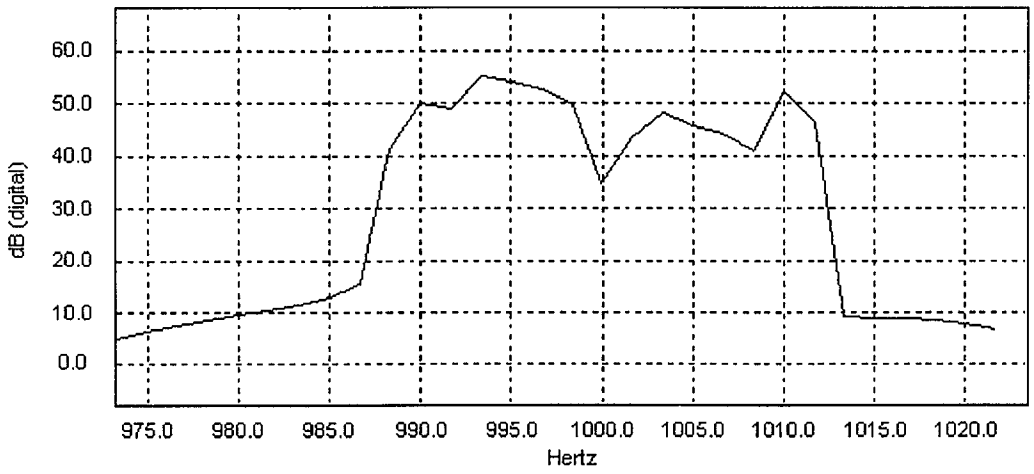

Figure A6. Spectrum of single-band noise sample B.

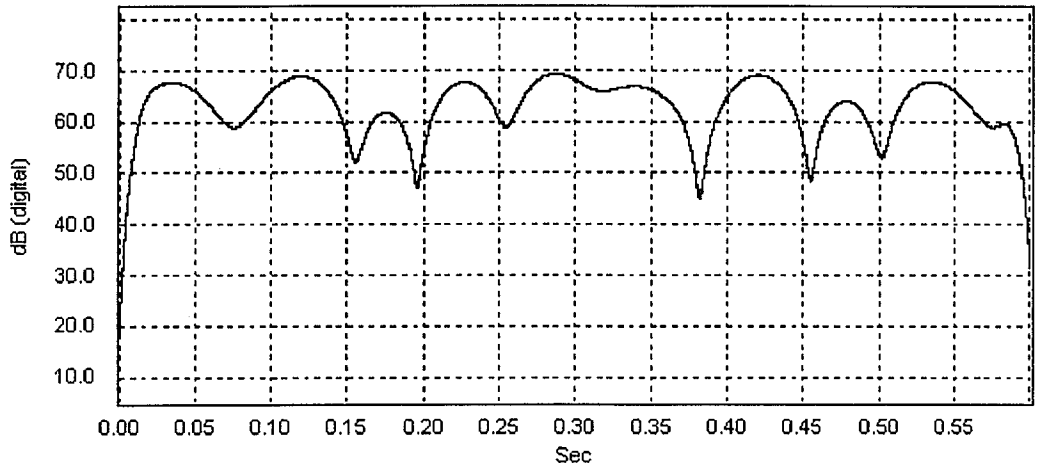

Figure A7. Envelope of single-band noise sample B.

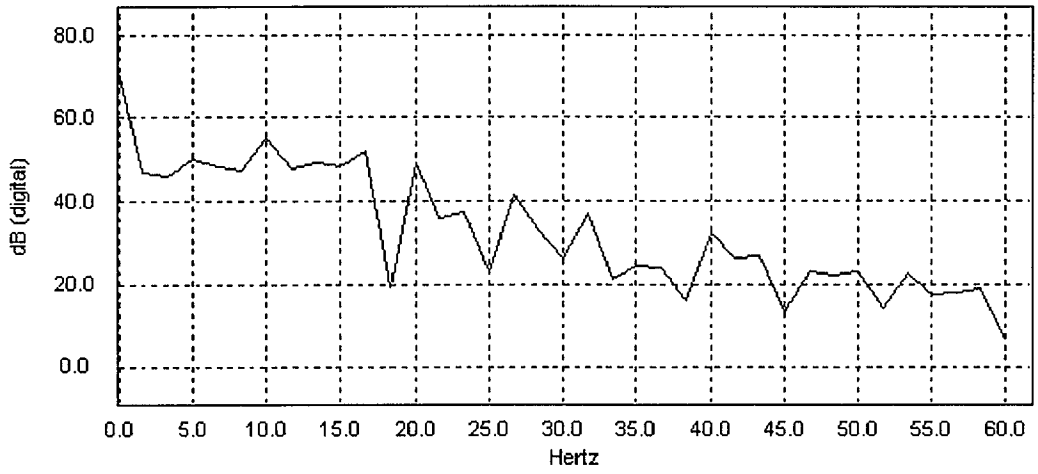

Figure A8. Envelope spectrum of single-band noise sample B.

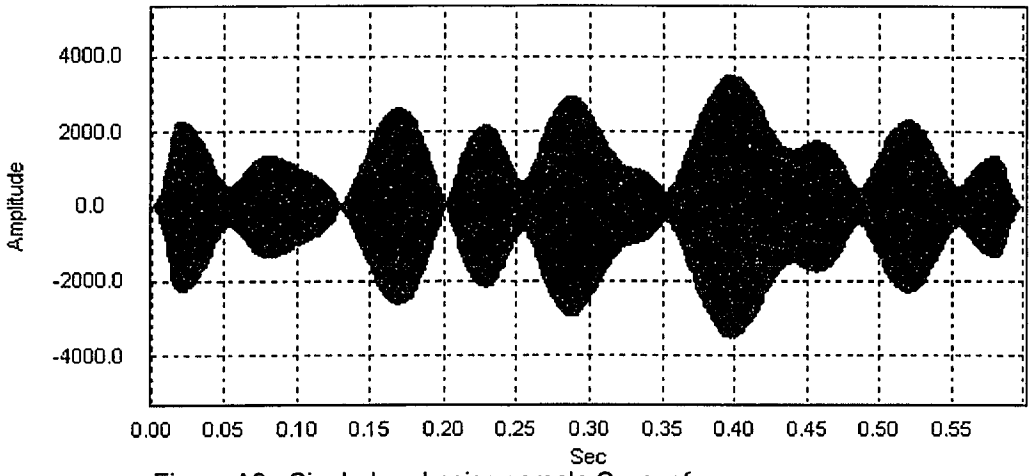

Figure A9. Single-band noise sample C waveform.

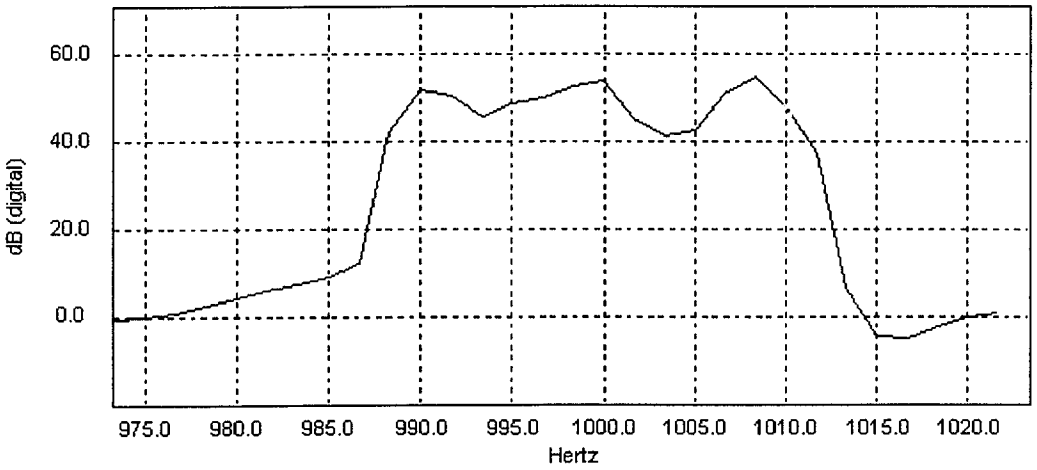

Figure A10. Spectrum of single-band noise sample C.

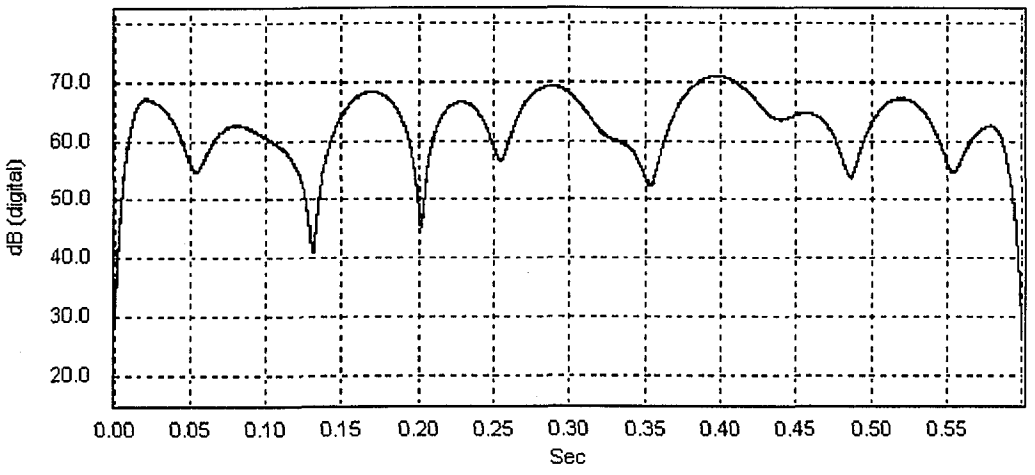

Figure A11. Envelope of single-band noise sample C.

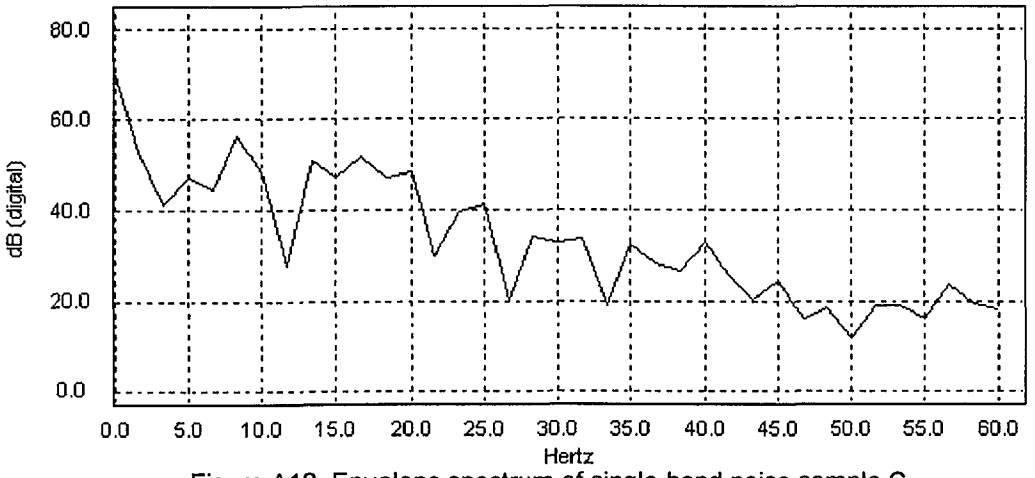

Figure A12. Envelope spectrum of single-band noise sample C.

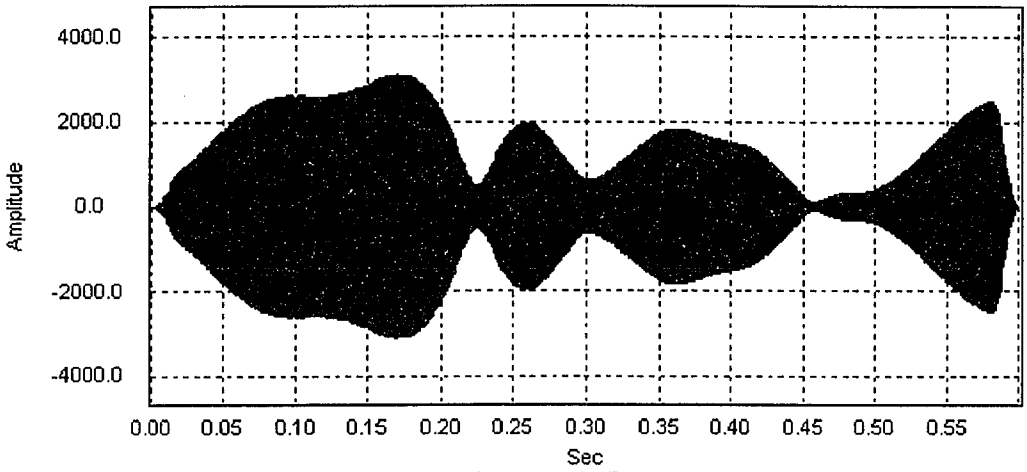

Figure A13. Single-band noise sample D waveform.

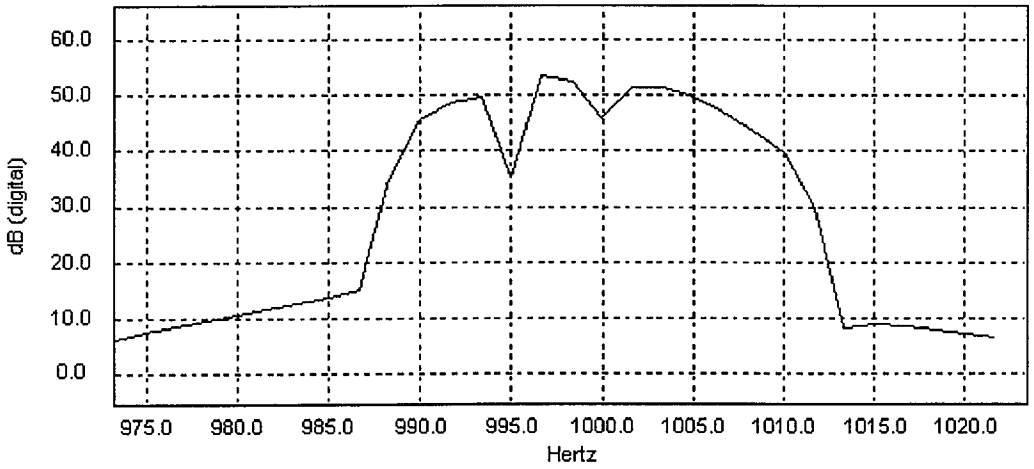

Figure A14. Spectrum of single-band noise sample D.

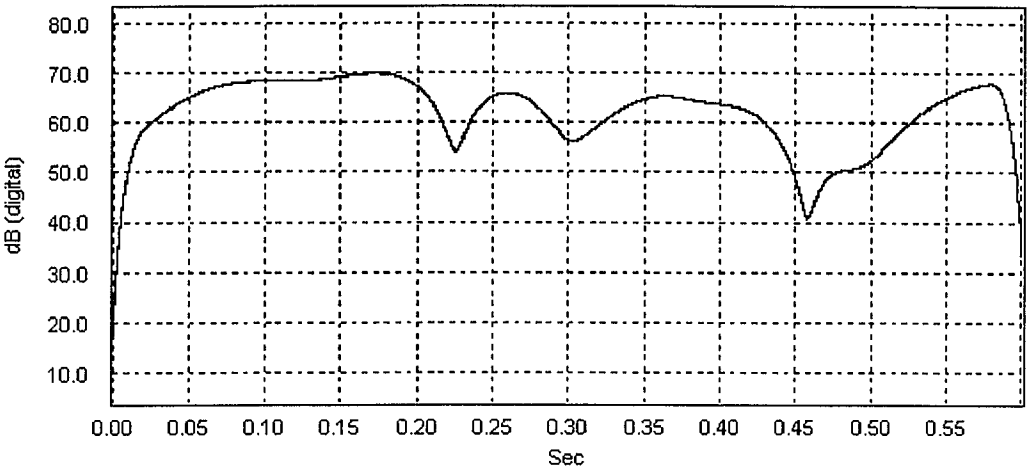

Figure A15. Envelope of single-band noise sample D.

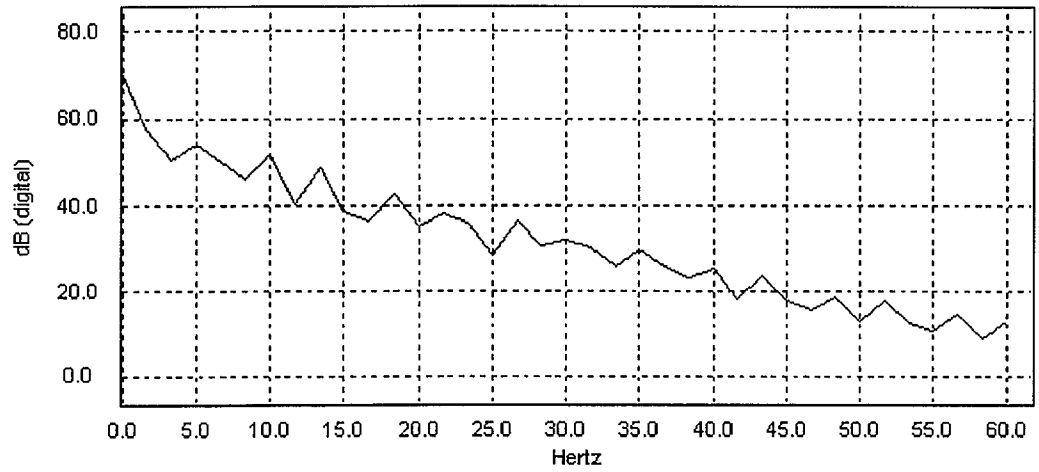

Figure A16. Envelope spectrum of single-band noise sample D.

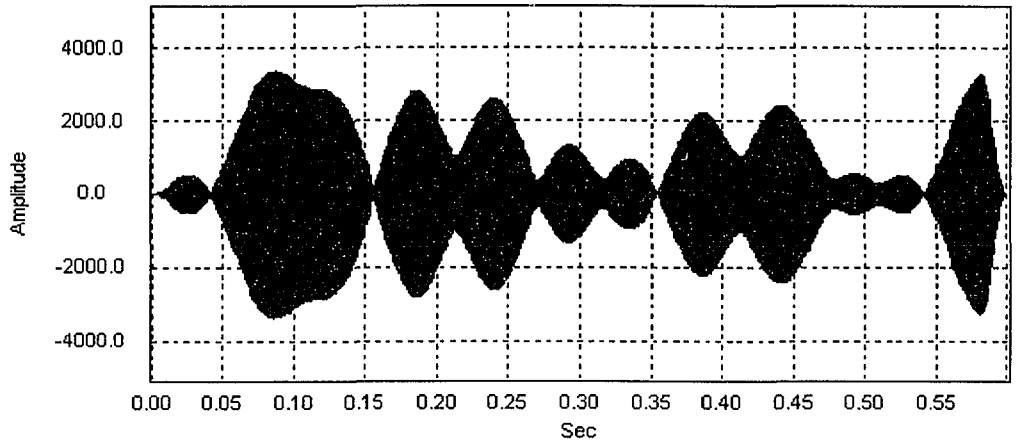

Figure A17. Single-band noise sample E waveform.

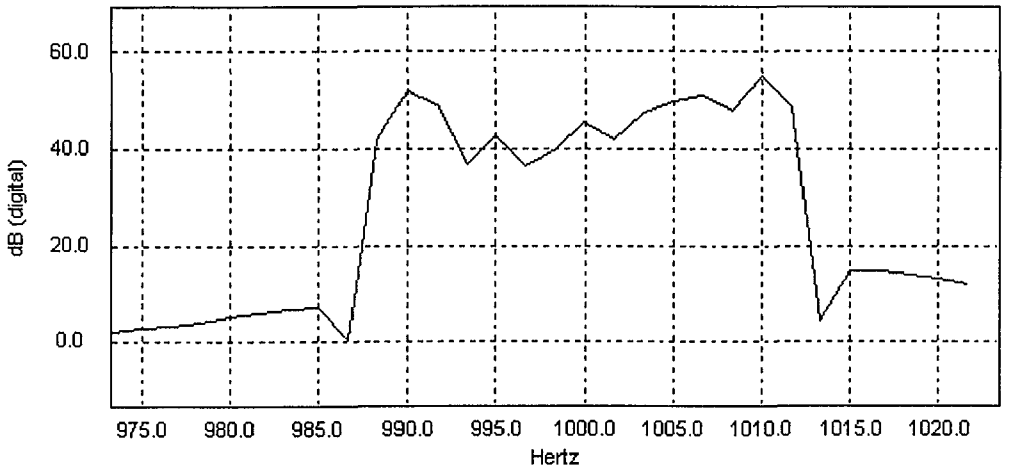

Figure A18. Spectrum of single-band noise sample E.

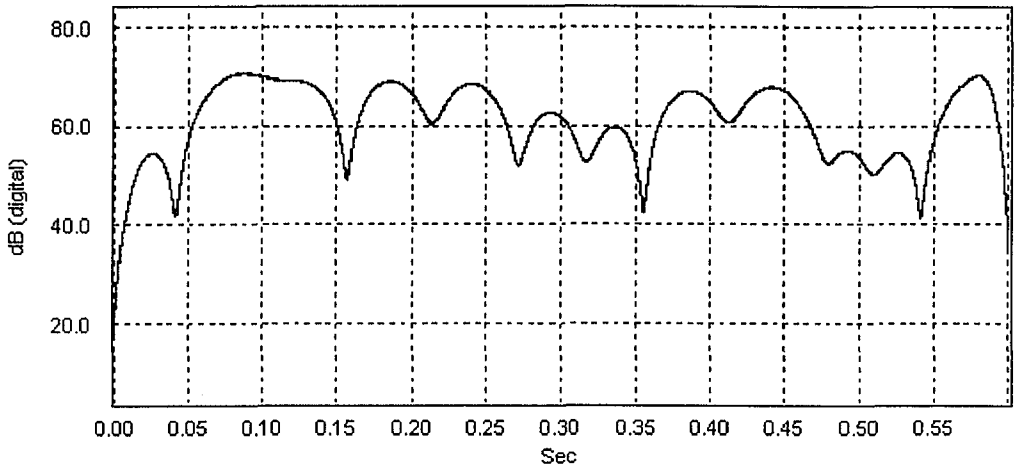

Figure A19. Envelope of single-band noise sample E in dBD.

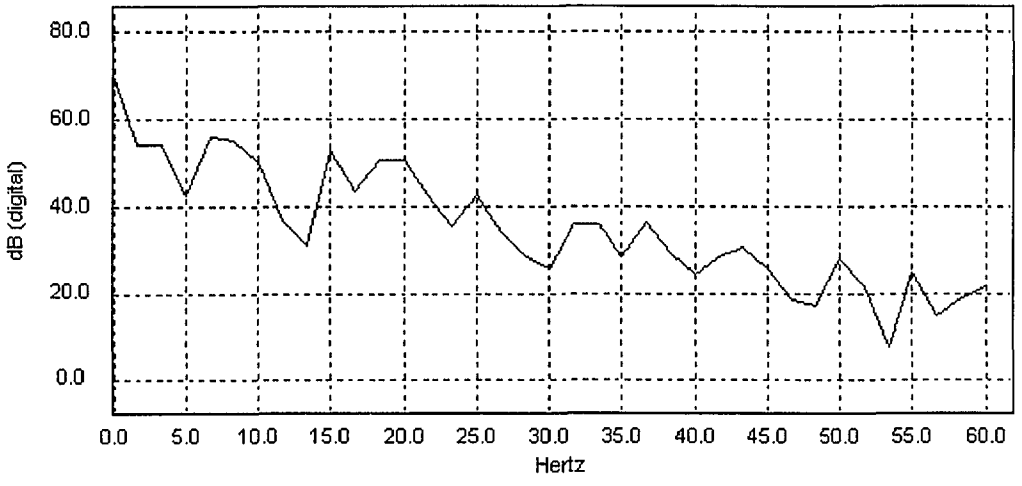

Figure A20. Envelope spectrum of single-band noise sample E.

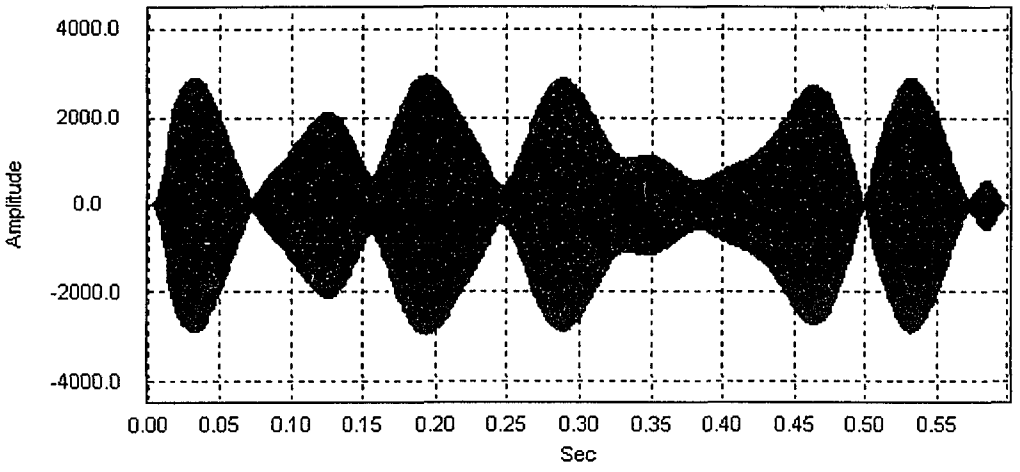

Figure A21. Single-band noise sample F waveform.

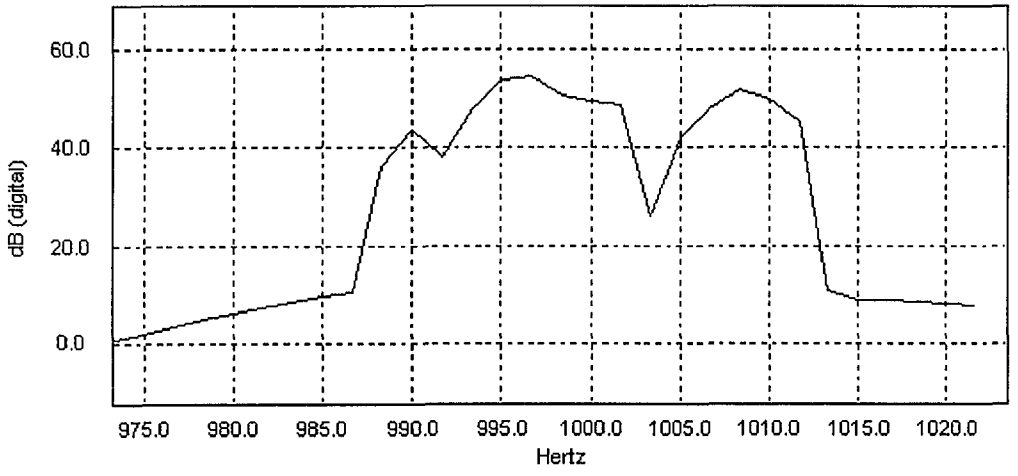

Figure A22. Spectrum of single-band noise sample F.

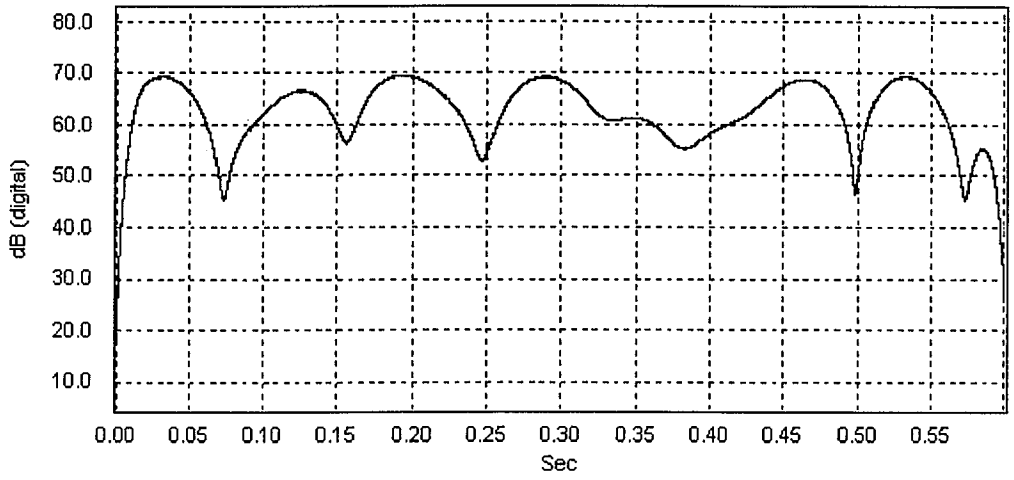

Figure A23. Envelope of single-band noise sample F in dBD.

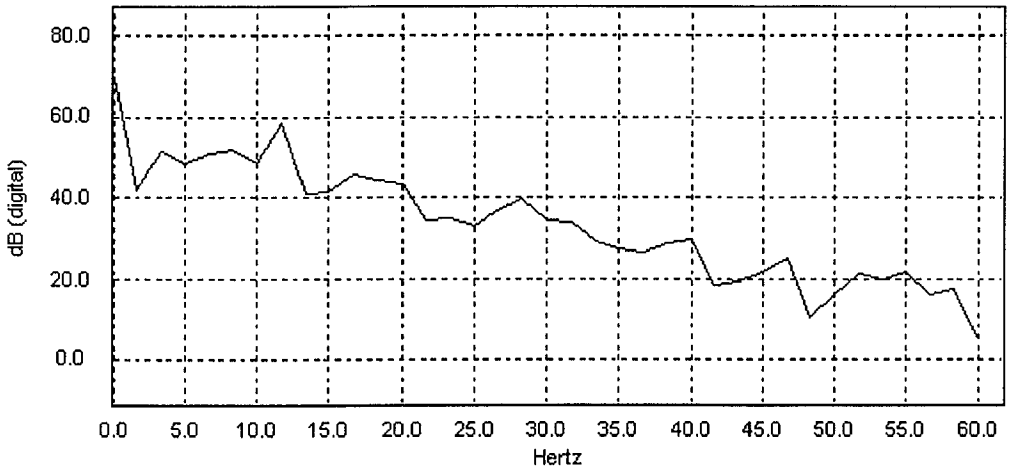

Figure A24. Envelope spectrum of single-band noise sample F.

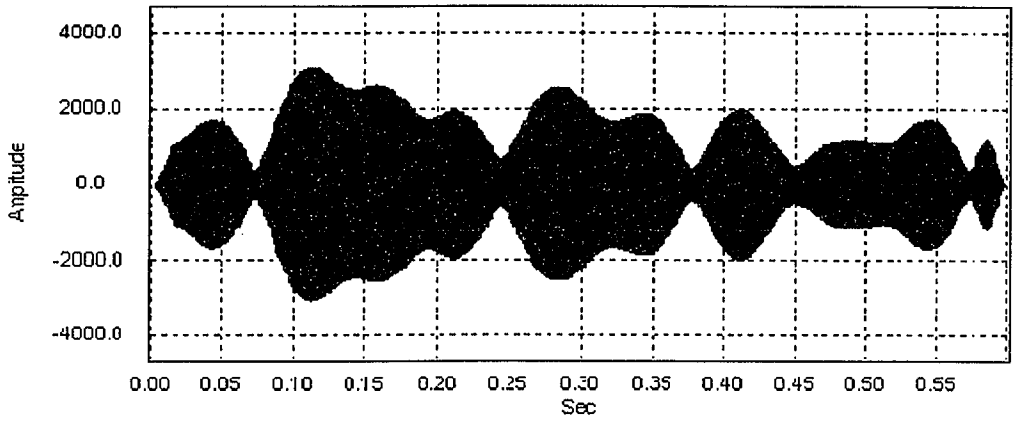

Figure A25. Single-band noise sample G waveform.

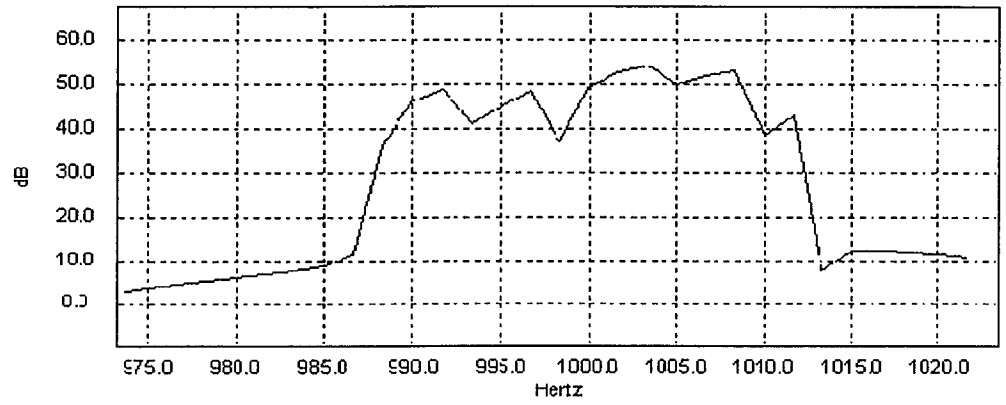

Figure A26. Spectrum of single-band noise sample G.

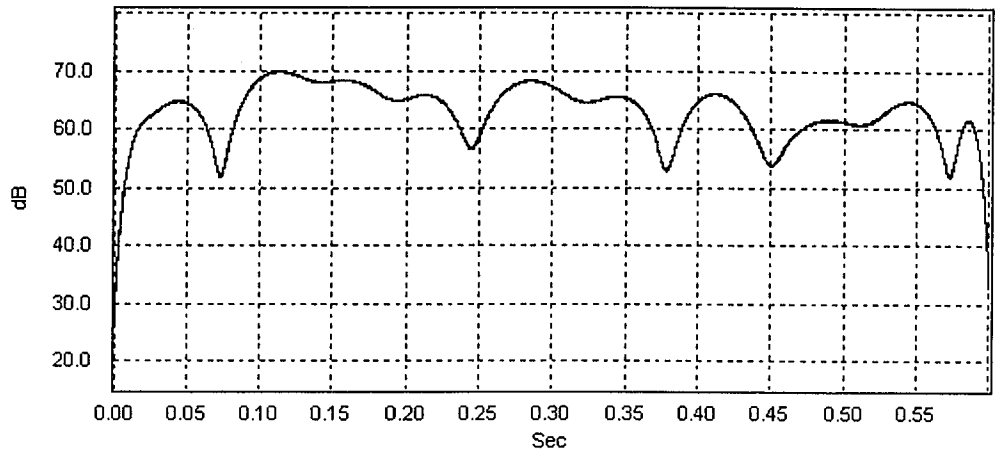

Figure A27. Envelope of single-band noise sample G in dBD.

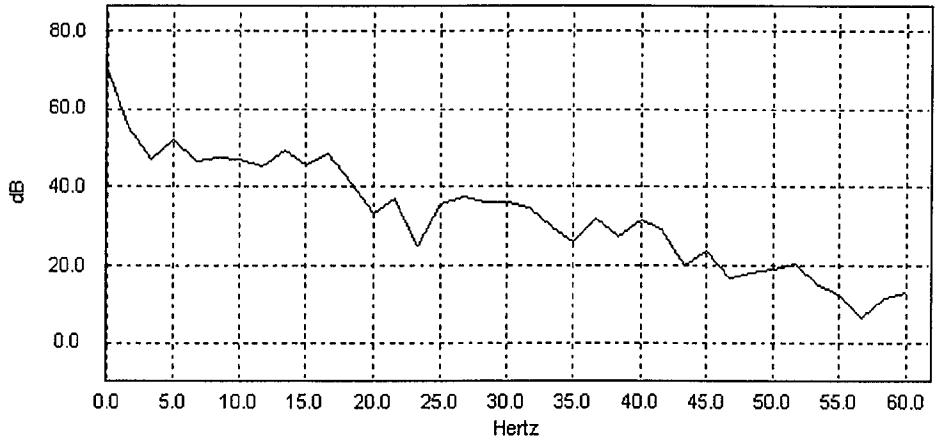

Figure A28. Envelope spectrum of single-band noise sample G in dBD (digital).

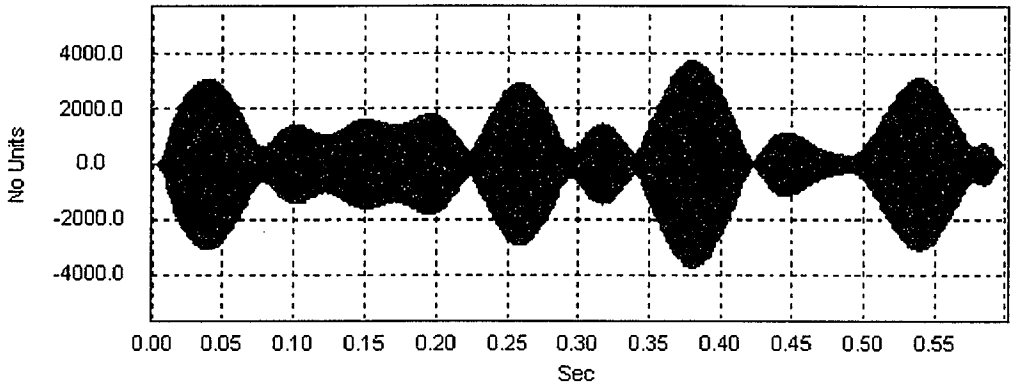

Figure A29. Single-band noise sample H waveform.

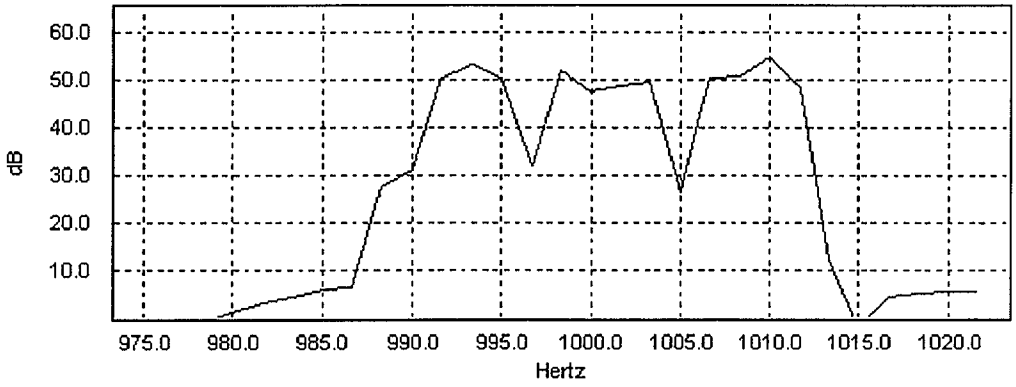

Figure A30. Spectrum of single-band noise sample H.

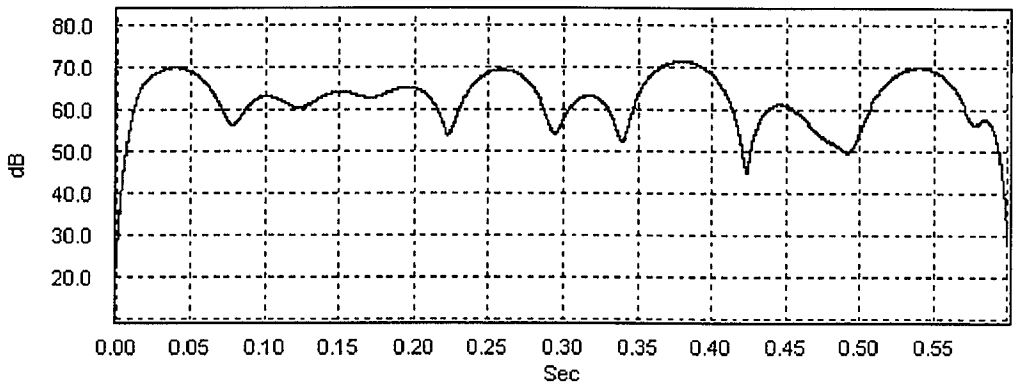

Figure A31. Envelope of single-band noise sample H.

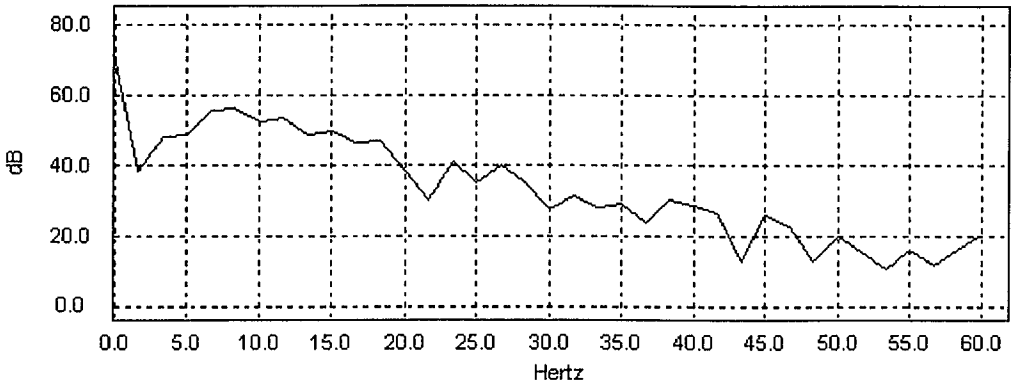

Figure A32. Envelope spectrum of single-band noise sample H.

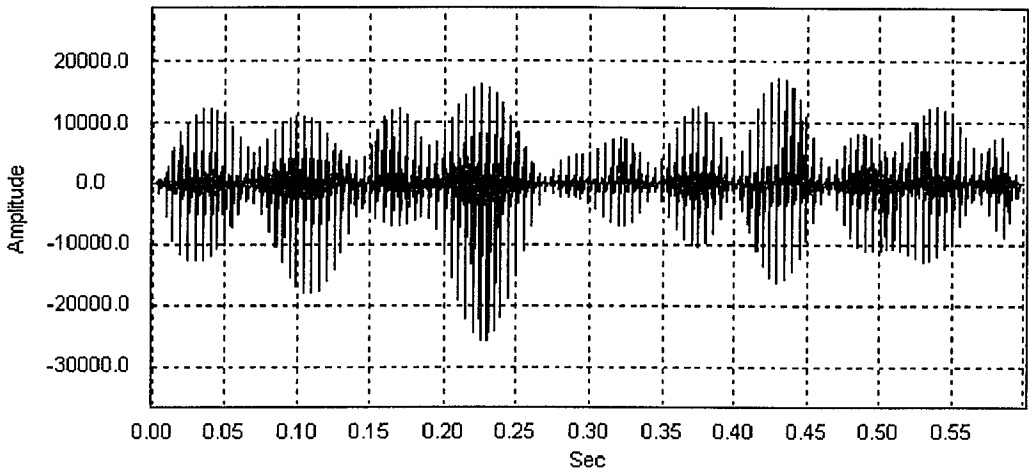

Figure A33. Seven-band noise sample A waveform.

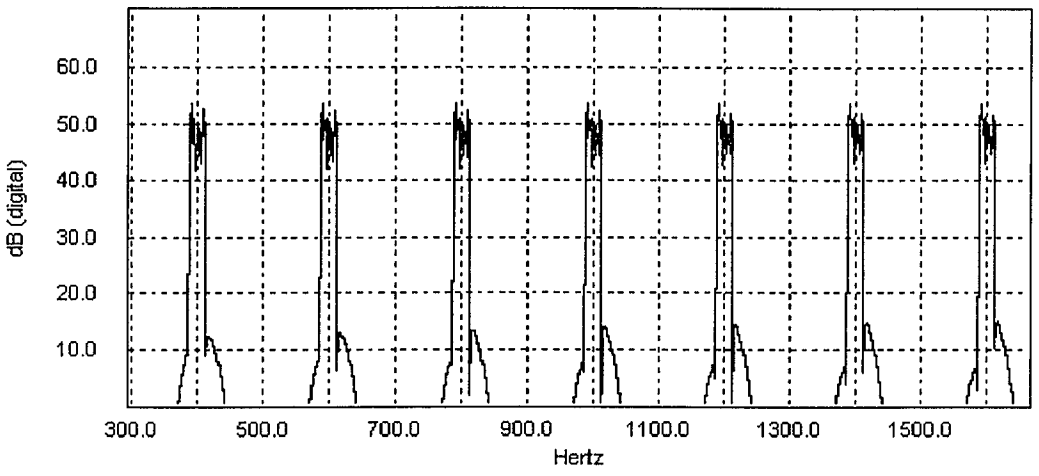

Figure A34. Spectrum of seven-band noise sample A.

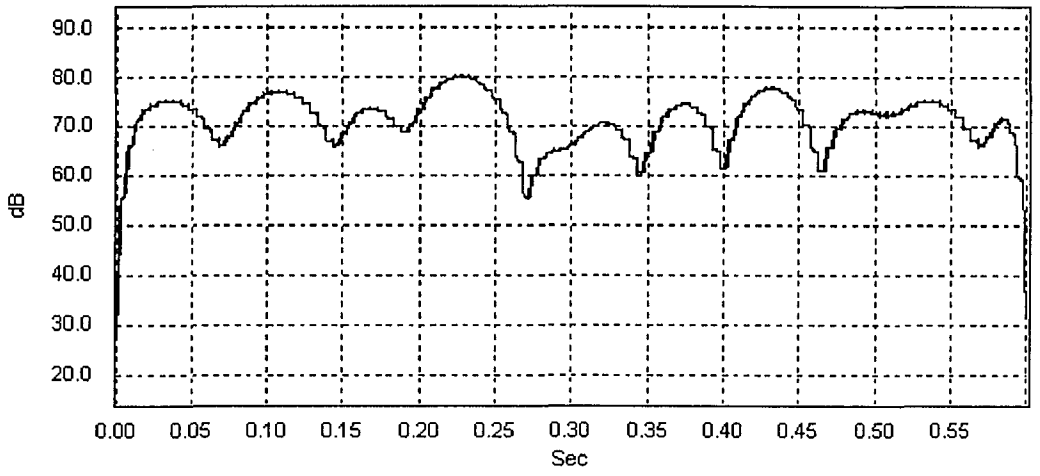

Figure A35. Envelope of seven-band noise sample A.

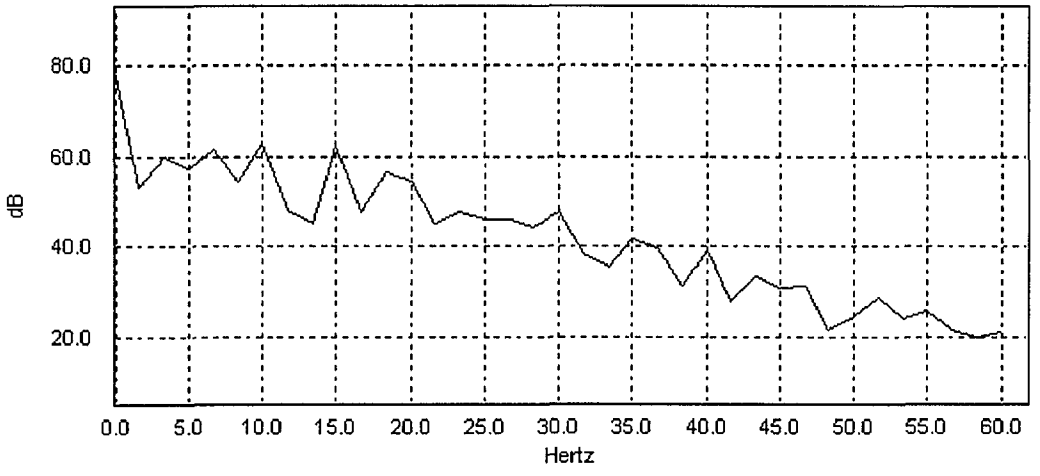

Figure A36. Envelope spectrum of seven-band noise sample A.

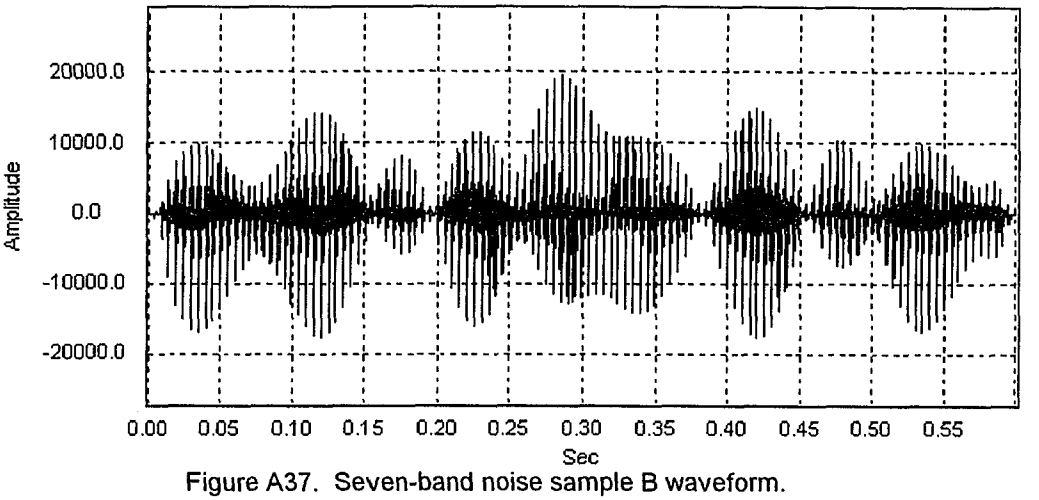

Figure A37. Seven-band noise sample B waveform.

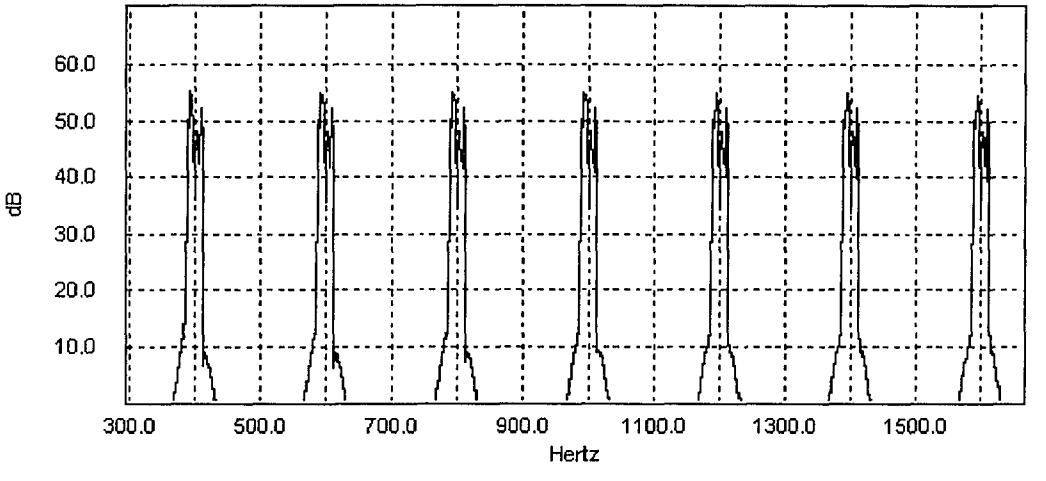

Figure A38. Spectrum of seven-band noise sample B.

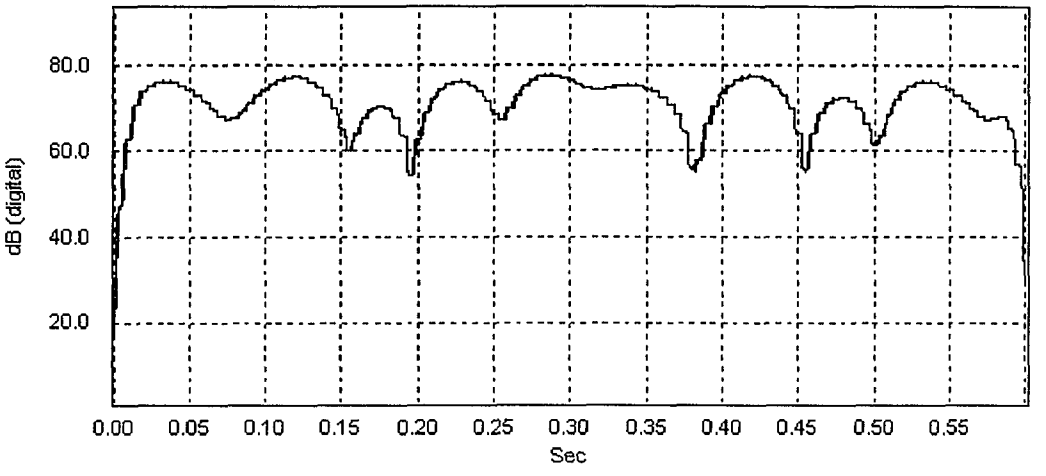

Figure A39. Envelope of seven-band noise sample B.

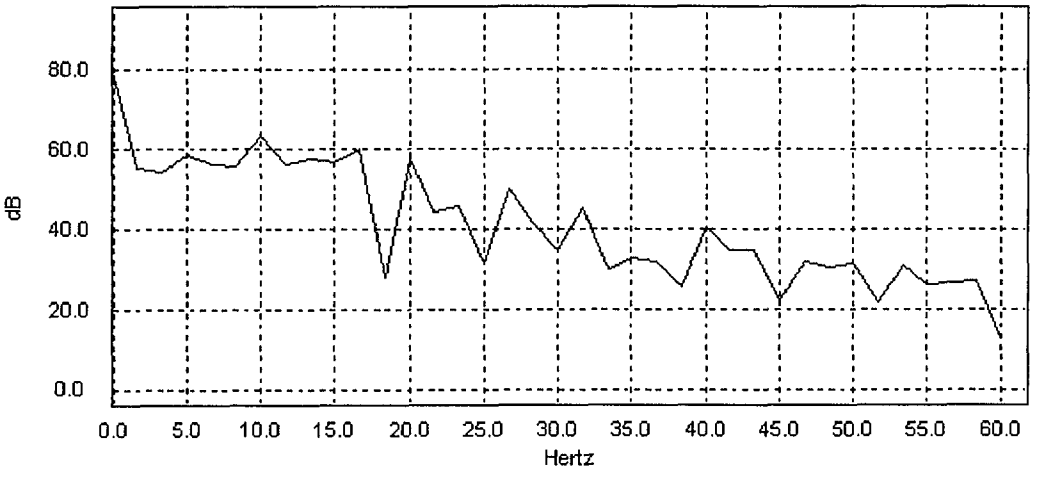

Figure A40. Envelope spectrum of seven-band noise sample B.

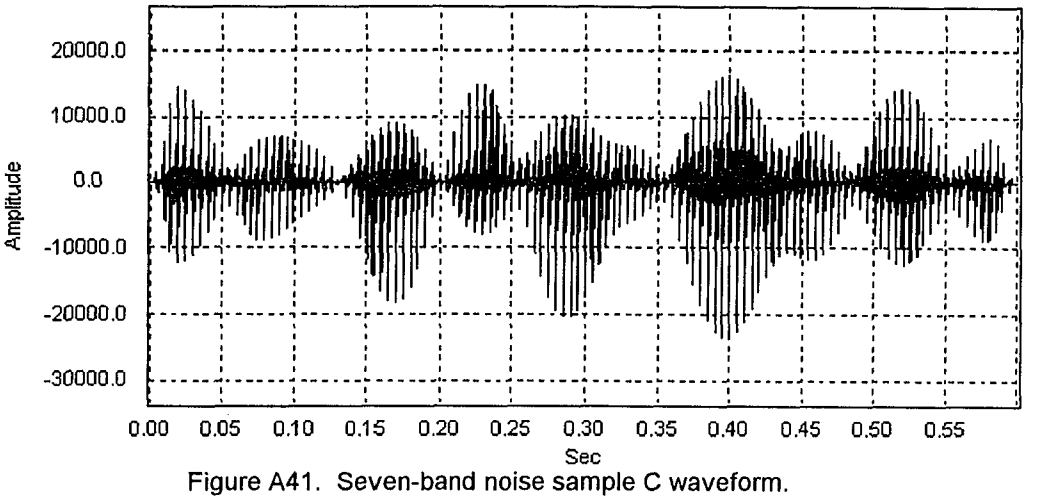

Figure A41. Seven-band noise sample C waveform.

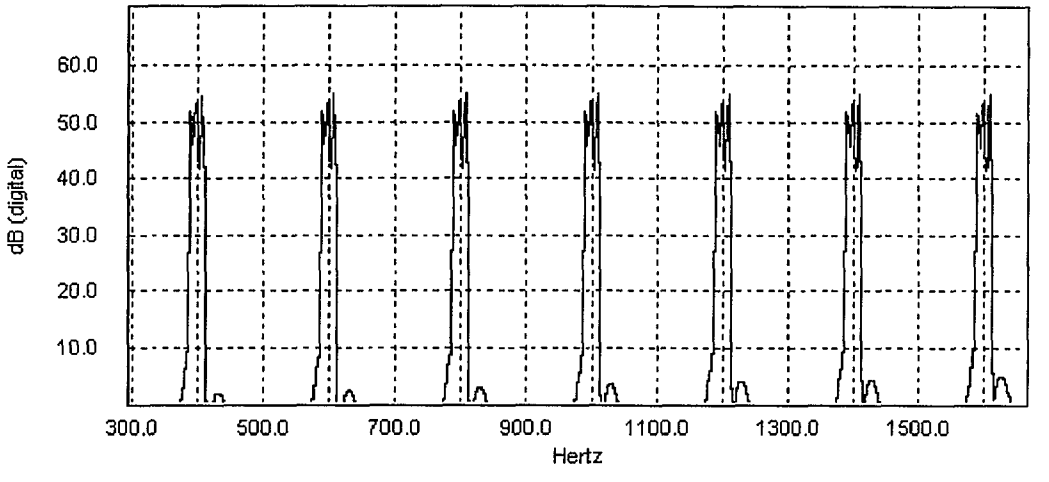

Figure A42. Spectrum of seven-band noise sample C.

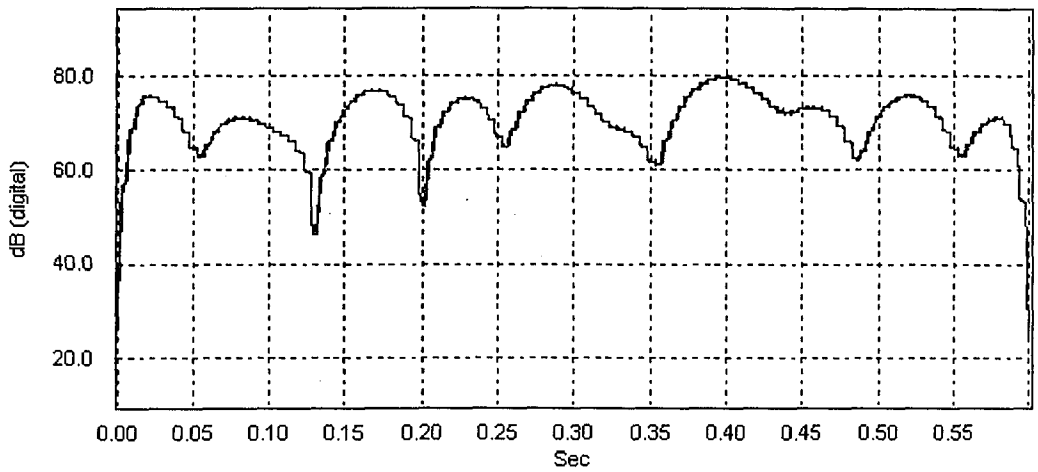

Figure A43. Envelope of seven-band noise sample C.

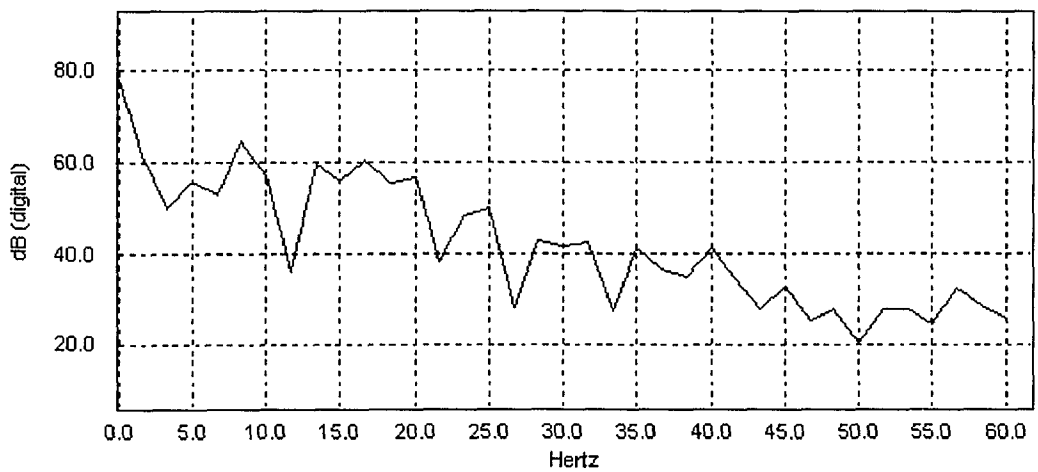

Figure A44. Envelope spectrum of seven-band noise sample C.

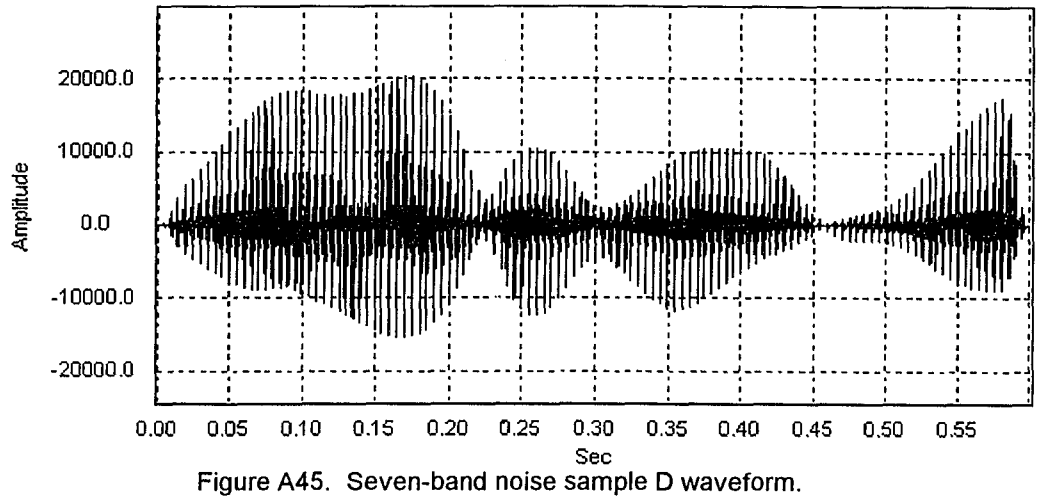

Figure A45. Seven-band noise sample D waveform.

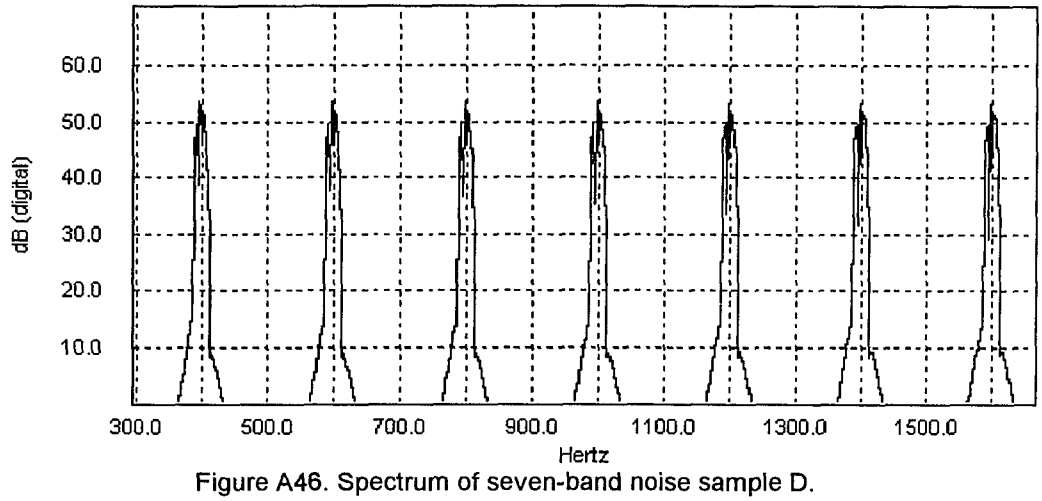

Figure A46. Spectrum of seven-band noise sample D.

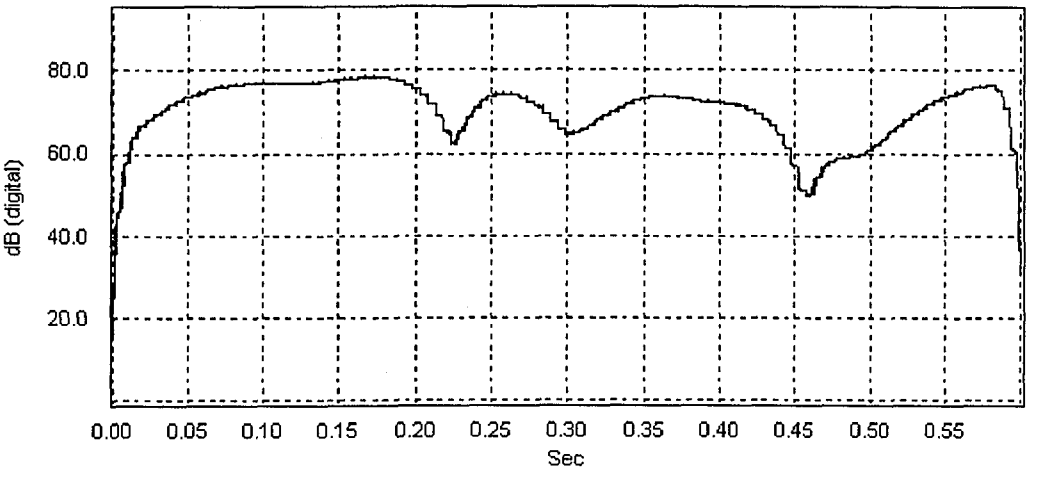

Figure A47. Envelope of seven-band noise sample D.

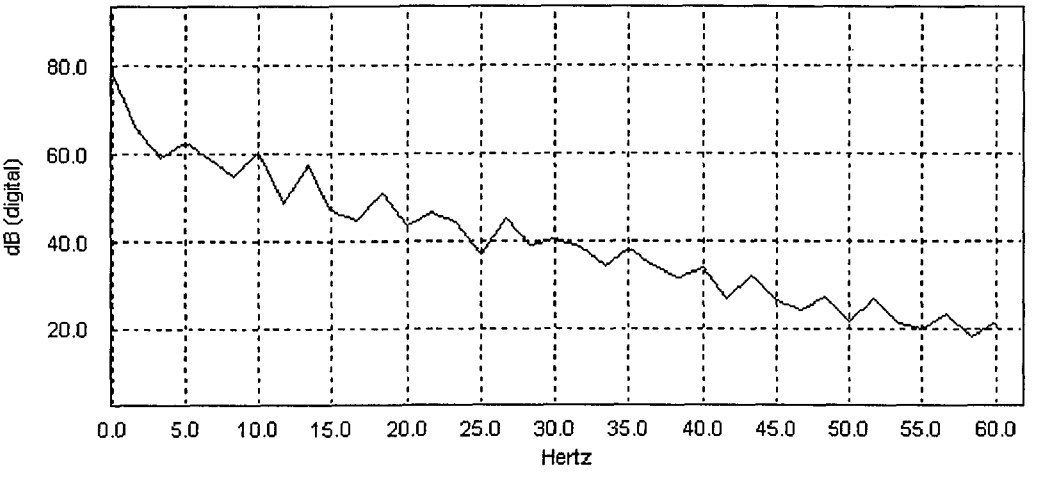

Figure A48. Envelope spectrum of seven-band noise sample D.

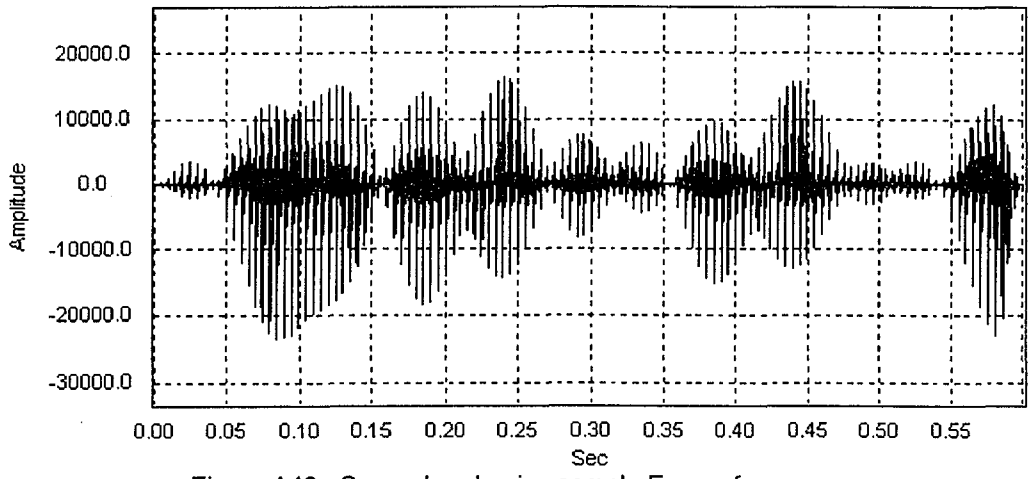

Figure A49. Seven-band noise sample E waveform.

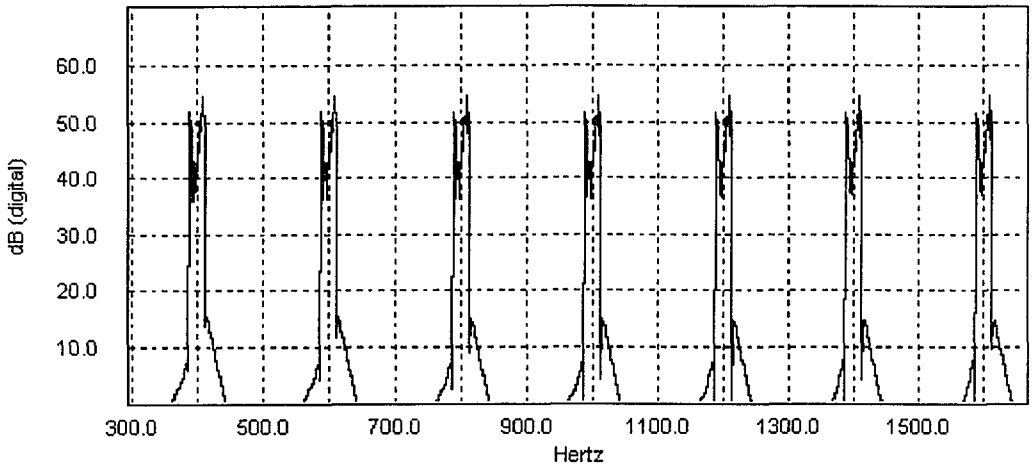

Figure A50. Spectrum of seven-band noise sample E.

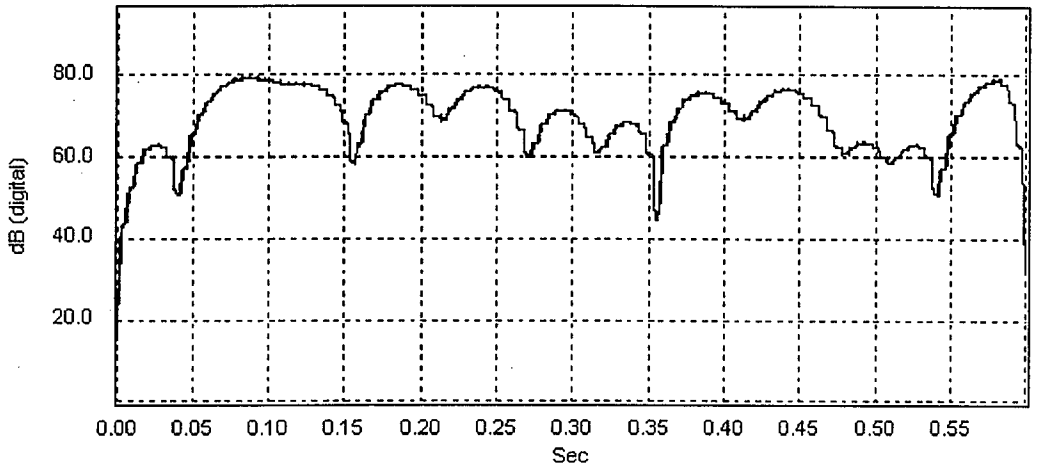

Figure A51. Envelope of seven-band noise sample E.

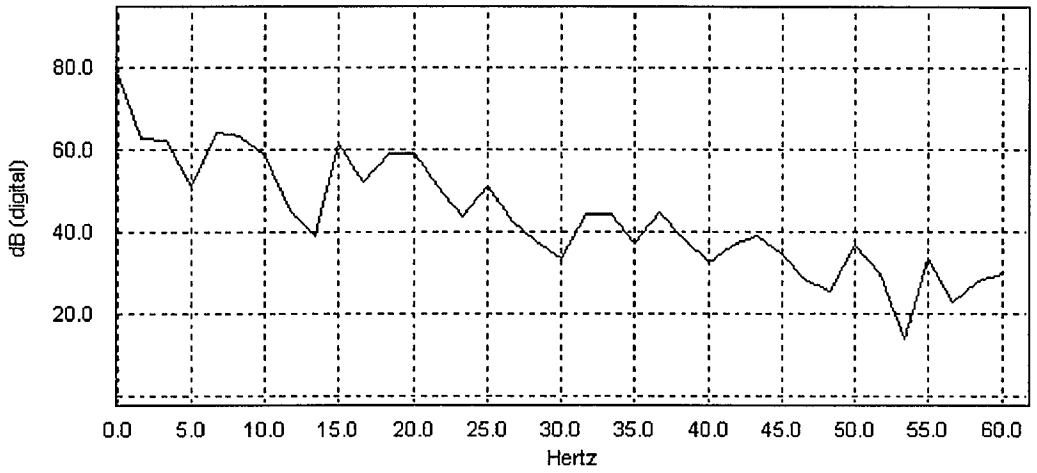

Figure A52. Envelope spectrum of seven-band noise sample E.

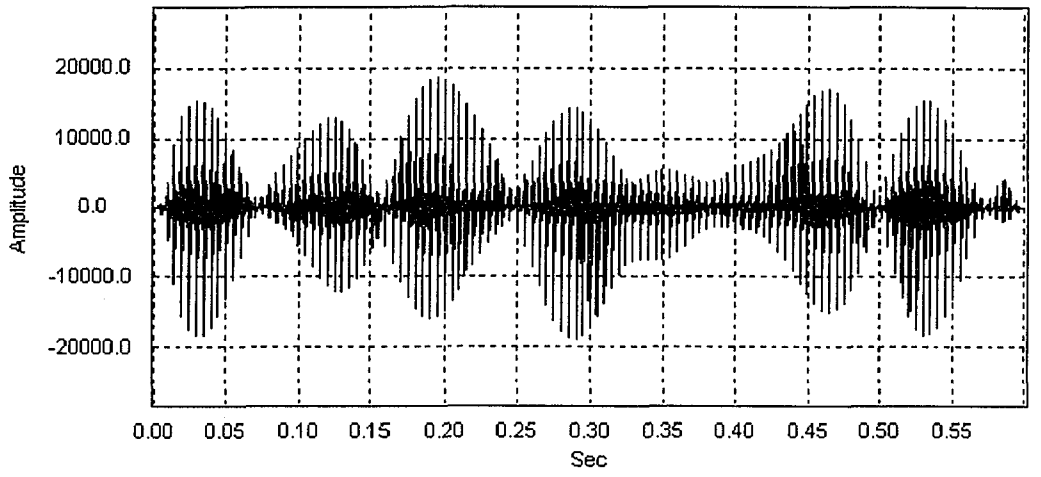

Figure A53. Seven-band noise sample F waveform.

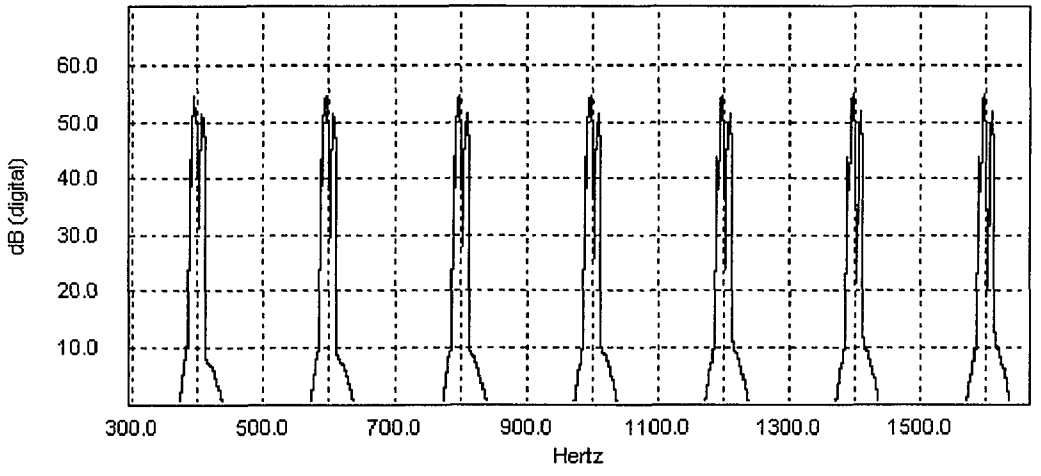

Figure A54. Spectrum of seven-band noise sample F.

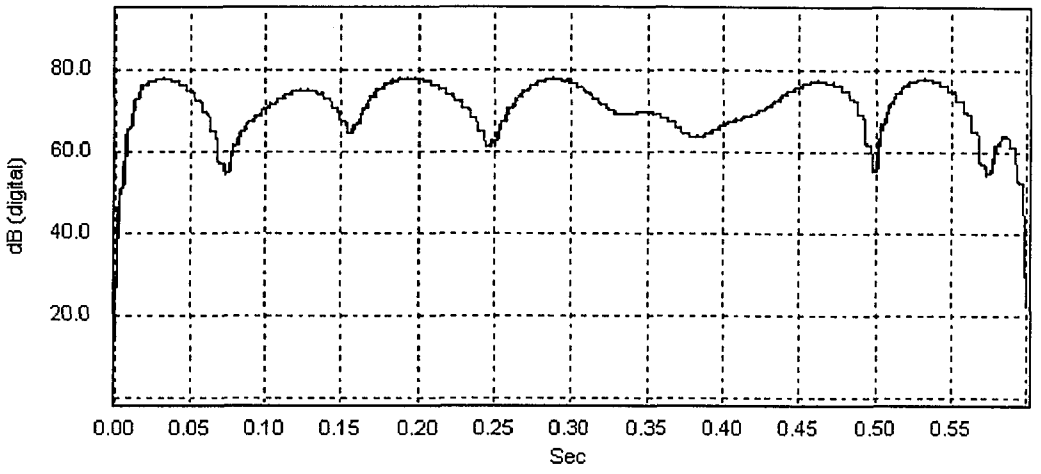

Figure A55. Envelope of seven-band noise sample F.

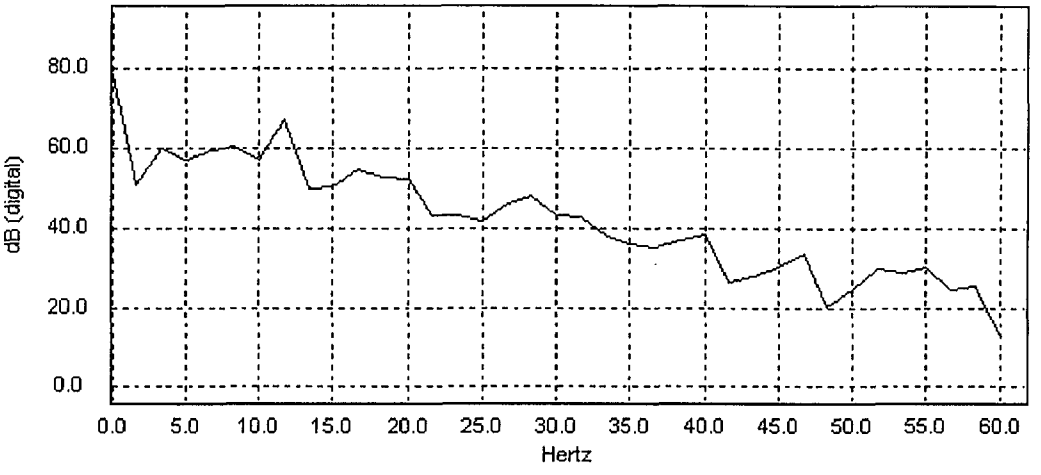

Figure A56. Envelope spectrum of seven-band noise sample F.

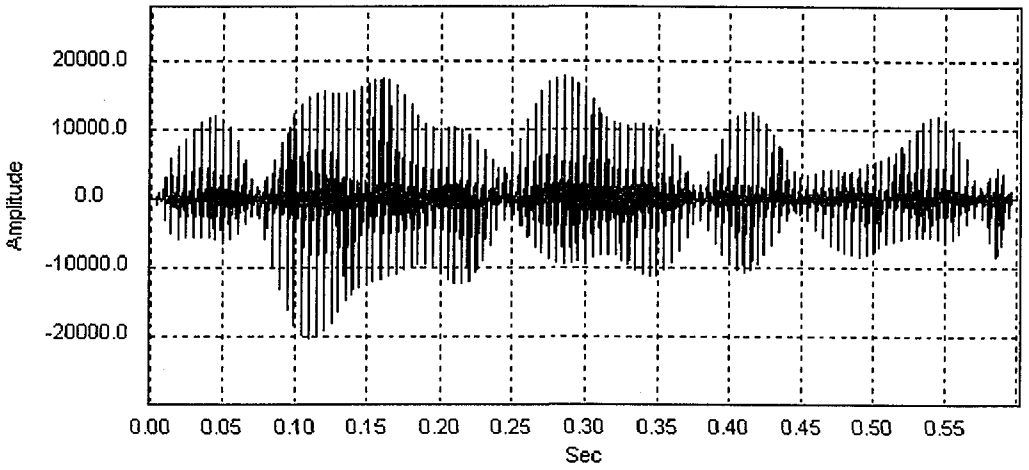

Figure A57. Seven-band noise sample G waveform.

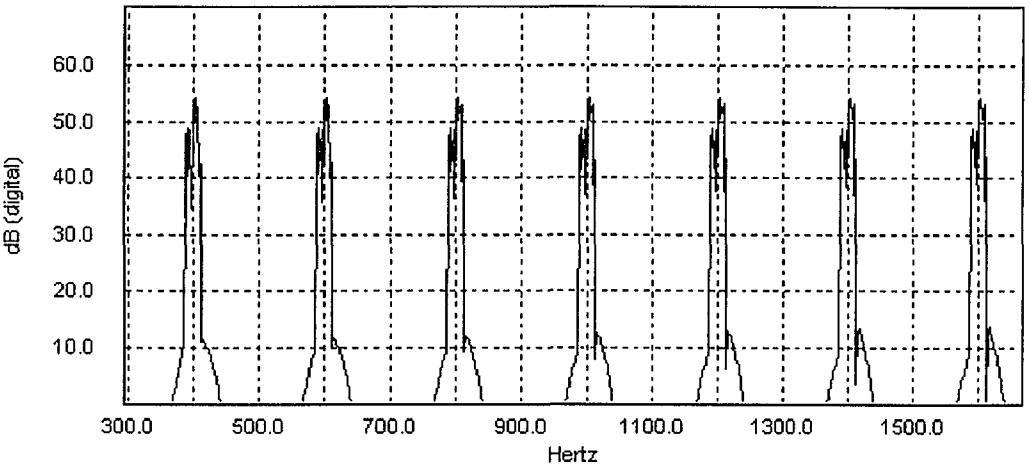

Figure A58. Spectrum of seven-band noise sample G.

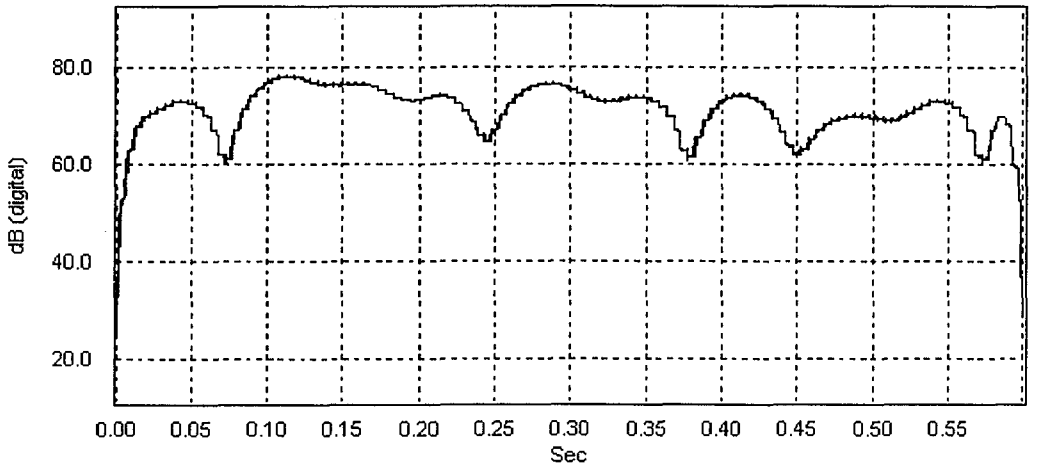

Figure A59. Envelope of seven-band noise sample G.

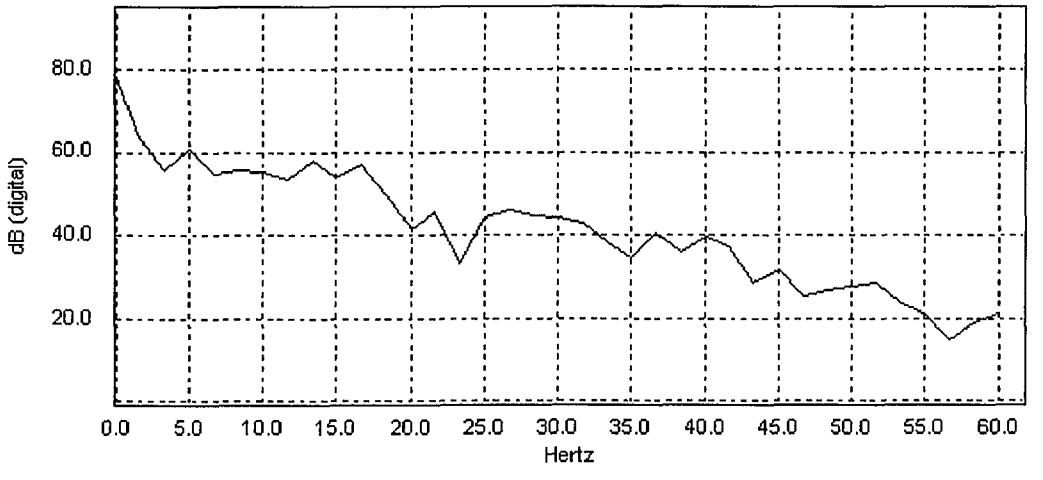

Figure A60. Envelope spectrum of seven-band noise sample G.

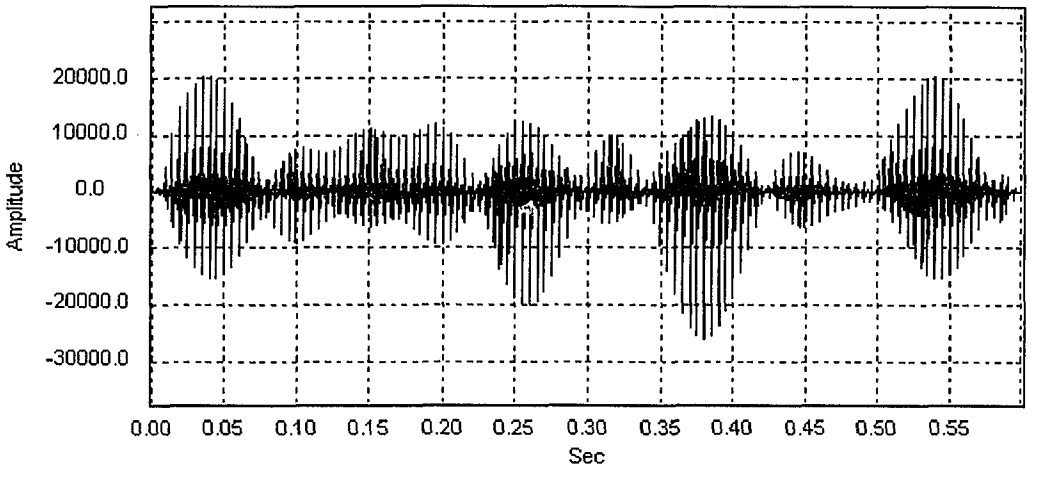

Figure A61. Seven-band noise sample H waveform.

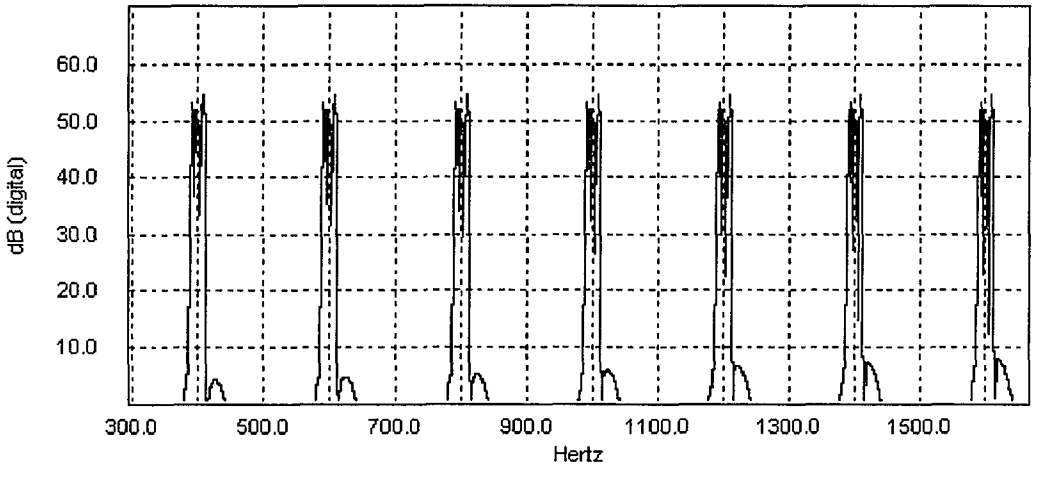

Figure A62. Spectrum of seven-band noise sample H.

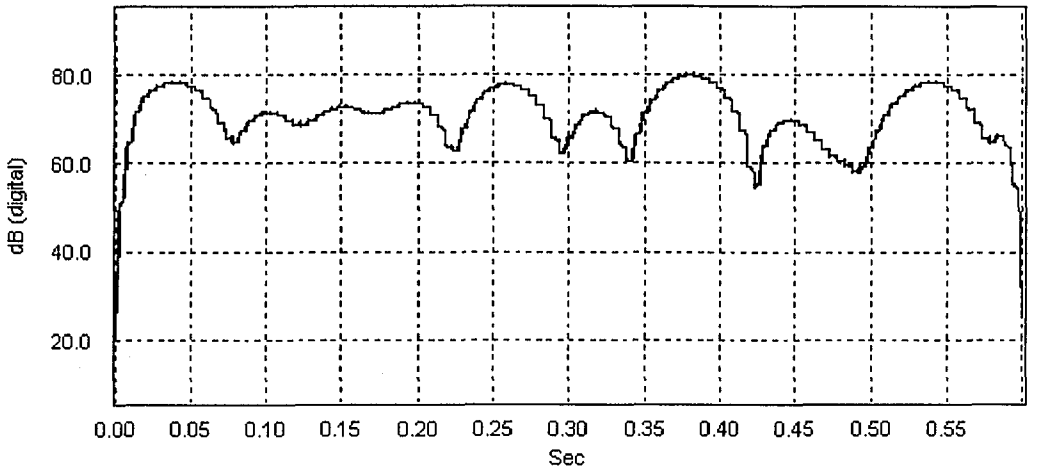

Figure A63. Envelope of seven-band noise sample H.

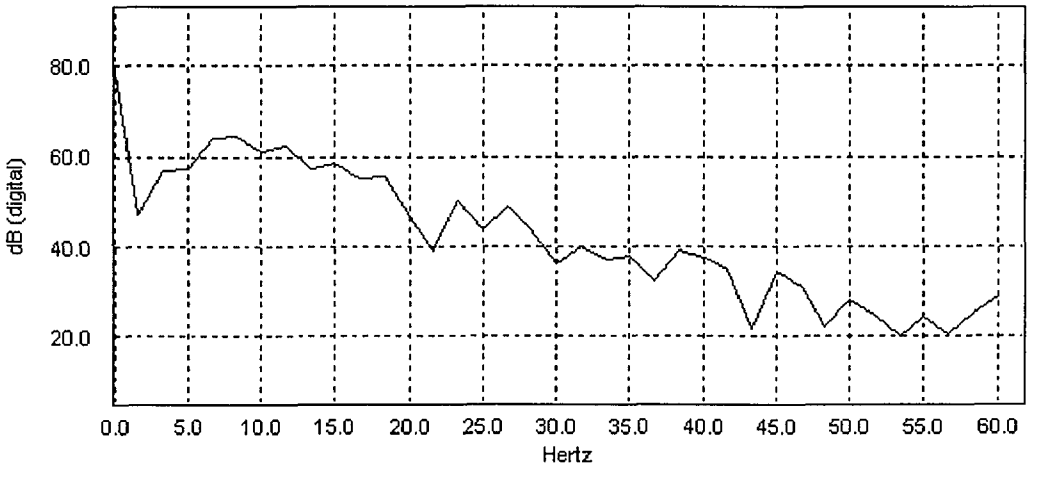

Figure A64. Envelope spectrum of seven-band noise sample H.

APPENDIX B

THRESHOLD DATA FOR EXPERIMENTS 1 AND 2

Table B1. Experiment 1 threshold data for subject S1.

Rep	Froz 1A	Froz 1B	Rand 1A	Rand 1B	Froz 7A	Froz 7B	Rand 7A	Rand 7B
1	-10.62	-6.24	-6.68	-0.50	-11.50	-10.74	-11.00	-9.00
2	-7.74	-7.12	-8.50	0.66	-10.38	-8.50	-8.68	-4.34
3	-5.74	-6.24	-11.50	-1.34	-12.74	-12.50	-10.84	-8.84
4	-8.26	-5.00	-6.66	-3.34	-10.24	-10.12	-11.00	-10.18
5	-17.24	-8.62	-13.84	-1.66	-11.38	-9.88	-10.34	-13.16
6	-5.74	-7.74	-7.50	0.16	-12.50	-10.88	-12.34	-13.66
7	-8.74	-6.74	-13.66	-2.00	-9.62	-10.12	-9.18	-3.84
8	-8.50	-7.74	-15.50	-1.66	-13.00	-10.88	-11.00	-8.68
9	-11.12	-8.38	-5.84	-0.34	-11.38	-10.24	-13.16	-11.16
10	-12.62	-6.12	-9.00	-1.84	-9.74	-11.14	-10.84	-9.50

Table B2. Experiment 1 threshold data for subject S2.

Rep	Froz 1A	Froz 1B	Rand 1A	Rand 1B	Froz 7A	Froz 7B	Rand 7A	Rand 7B
1	-9.50	-4.50	-9.00	0.66	-9.00	-9.24	-11.00	-10.00
2	-11.26	-5.38	-10.84	2.84	-9.80	-9.38	-8.34	-8.68
3	-11.50	-1.50	-12.68	-1.34	-8.00	-10.74	-8.00	-10.68
4	-9.74	-6.50	-9.50	-2.68	-7.64	-7.50	-5.34	-9.68
5	-13.50	-5.24	-14.44	1.50	-9.12	-9.00	-7.00	-9.16
6	-10.38	-2.64	-8.18	-0.66	-7.74	-10.00	-7.50	-9.84
7	-10.74	-5.60	-2.84	1.84	-10.24	-9.74	-10.34	-10.50
8	-13.12	-4.50	-5.68	2.00	-9.14	-8.38	-8.44	-10.34
9	-8.88	-8.00	-10.16	-2.34	-10.38	-8.88	-10.50	-10.50
10	-11.14	-4.00	-11.68	-1.50	-8.12	-8.74	-8.18	-10.00

Table B3. Experiment 1 threshold data for subject S3.

Rep	Froz 1A	Froz 1B	Rand 1A	Rand 1B	Froz 7A	Froz 7B	Rand 7A	Rand 7B
1	-10.88	-5.12	-1.50	0.84	-7.38	-7.74	-7.00	-8.34
2	-7.74	-3.38	-8.34	0.84	-6.38	-7.62	-9.50	-5.50
3	-6.88	-3.74	-6.66	0.00	-10.12	-8.00	-9.84	-6.00
4	-13.74	-4.88	-8.34	-0.34	-8.88	-8.12	-11.00	-8.50
5	-9.88	-10.00	-3.00	2.00	-7.50	-7.38	-6.84	-9.68
6	-5.00	-5.12	-5.50	-0.34	-9.38	-6.62	-5.50	-9.34
7	-8.74	-5.62	-4.00	0.34	-7.74	-11.00	-6.34	-6.50
8	-10.50	-3.50	-2.84	0.50	-10.00	-6.50	-10.16	-6.50
9	-11.50	-3.64	-2.66	1.16	-7.62	-9.24	-11.16	-11.16
10	-13.38	-2.38	-7.66	-0.84	-8.24	-5.74	-8.50	-9.16

Table B4. Experiment 1 threshold data for subject S4.

Rep	Froz 1A	Froz 1B	Rand 1A	Rand 1B	Froz 7A	Froz 7B	Rand 7A	Rand 7B
1	-5.88	-1.12	-8.16	-1.34	-9.74	-10.74	-9.66	-14.66
2	-8.00	-2.74	-5.84	-4.84	-9.38	-13.00	-9.16	-11.66
3	-9.00	-1.74	-4.84	-2.68	-10.00	-10.74	-12.00	-10.00
4	-8.50	0.00	-7.00	-2.66	-10.62	-12.00	-9.84	-11.50
5	-8.88	-2.38	-8.00	-2.66	-12.12	-11.88	-10.50	-9.34
6	-3.50	-2.88	-11.50	-3.84	-9.74	-11.88	-15.32	-11.84
7	-6.24	-0.38	-3.84	-2.16	-9.50	-12.00	-15.84	-15.00
8	-5.74	-3.00	-9.18	-2.16	-8.88	-13.12	-9.16	-10.34
9	-5.62	-0.24	-9.34	-3.84	-9.30	-10.24	-11.18	-10.68
10	-10.50	-1.00	-6.50	-7.50	-11.30	-13.25	-9.00	-11.18

Table B5. Experiment 1 threshold data for subject S5.

Rep	Froz 1A	Froz 1B	Rand 1A	Rand 1B	Froz 7A	Froz 7B	Rand 7A	Rand 7B
1	-10.00	-2.38	-9.84	4.34	-7.50	-7.00	-7.66	1.00
2	-14.88	-4.12	-10.84	-0.16	-6.88	-5.74	-12.16	-3.34
3	-11.38	-2.12	-6.66	2.16	-9.24	-8.88	-6.00	0.16
4	-7.50	-4.62	-7.50	-1.00	-8.62	-2.12	-4.50	-8.66
5	-8.24	-4.88	-9.00	1.66	-6.62	-6.00	-17.00	-17.84
6	-6.24	-5.74	-4.50	3.84	-7.24	-3.00	-6.00	0.66
7	-12.00	-3.00	-10.50	4.66	-5.24	-4.62	-11.50	-3.34
8	-6.88	-5.88	-5.16	0.34	-7.50	-2.50	-3.50	-0.84
9	-8.88	-4.12	-11.16	1.84	-6.88	-3.00	-9.16	-2.16
10	-8.38	-4.00	-7.00	1.66	-5.38	-5.50	-5.50	-10.00

Table B6. Experiment 2 threshold data for subject S1.

Rep	1-kHz Frozen A	1-kHz Frozen B	1-kHz Random A	1-kHz Random B	6-kHz Frozen A	6-kHz Frozen B	6-kHz Random A	6-kHz Random B
1	-10.62	-6.24	-6.68	-0.50	-0.62	0.88	-3.18	-2.16
2	-7.74	-7.12	-8.50	0.66	-1.74	0.00	-4.00	-1.50
3	-5.74	-6.24	-11.50	-1.34	-2.88	-3.24	-1.68	-0.68
4	-8.26	-5.00	-6.66	-3.34	-2.62	-2.24	0.66	-0.84
5	-17.24	-8.62	-13.84	-1.66	-2.50	-3.38	-2.84	-3.34
6	-5.74	-7.74	-7.50	0.16	0.12	-0.38	-1.18	-1.18
7	-8.74	-6.74	-13.66	-2.00	-1.50	-2.00	-0.16	0.00
8	-8.50	-7.74	-15.50	-1.66	-3.62	-0.62	-2.16	-0.50
9	-11.12	-8.38	-5.84	-0.34	-0.74	-3.62	-4.00	-2.50
10	-12.62	-6.12	-9.00	-1.84	-2.50	-2.88	-2.50	-0.68

Table B7. Experiment 2 threshold data for subject S2.

Rep	1-kHz Frozen A	1-kHz Frozen B	1-kHz Random A	1-kHz Random B	6-kHz Frozen A	6-kHz Frozen B	6-kHz Random A	6-kHz Random B
1	-9.50	-4.50	-9.00	0.66	-1.88	-1.24	-2.18	-0.18
2	-11.26	-5.38	-10.84	2.84	-0.38	3.26	-3.16	-0.66
3	-11.50	-1.50	-12.68	-1.34	-5.24	-3.00	-3.00	0.00
4	-9.74	-6.50	-9.50	-2.68	-1.74	2.74	-2.84	-3.68
5	-13.50	-5.24	-14.44	1.50	-3.26	-0.64	-5.50	-0.16
6	-10.38	-2.64	-8.18	-0.66	-2.50	-3.12	-7.50	1.32
7	-10.74	-5.60	-2.84	1.84	1.86	-1.38	-9.30	0.70
8	-13.12	-4.50	-5.68	2.00	-4.12	-4.14	-0.34	-3.84
9	-8.88	-8.00	-10.16	-2.34	-6.64	0.50	-2.18	-2.68
10	-11.14	-4.00	-11.68	-1.50	-2.00	-2.88	0.50	-0.50

Table B8. Experiment 2 threshold data for subject S3.

Rep	1-kHz Frozen A	1-kHz Frozen B	1-kHz Random A	1-kHz Random B	6-kHz Frozen A	6-kHz Frozen B	6-kHz Random A	6-kHz Random B
1	-10.88	-5.12	-1.50	0.84	1.26	3.00	1.66	2.00
2	-7.74	-3.38	-8.34	0.84	-2.50	0.62	-1.50	0.84
3	-6.88	-3.74	-6.66	0.00	0.00	0.50	-4.00	0.50
4	-13.74	-4.88	-8.34	-0.34	2.38	-10.00	0.66	2.50
5	-9.88	-10.00	-3.00	2.00	1.12	-1.00	-3.66	1.50
6	-5.00	-5.12	-5.50	-0.34	-4.12	0.88	1.66	0.66
7	-8.74	-5.62	-4.00	0.34	1.76	0.76	0.16	2.16
8	-10.50	-3.50	-2.84	0.50	-1.88	-1.12	1.00	3.16
9	-11.50	-3.64	-2.66	1.16	1.62	-1.12	1.00	4.00
10	-13.38	-2.38	-7.66	-0.84	0.76	-0.50	-1.32	-0.16

Table B9. Experiment 2 threshold data for subject S4.

Rep	1-kHz Frozen A	1-kHz Frozen B	1-kHz Random A	1-kHz Random B	6-kHz Frozen A	6-kHz Frozen B	6-kHz Random A	6-kHz Random B
1	-5.88	-1.12	-8.16	-1.34	0.50	1.12	-1.84	-3.68
2	-8.00	-2.74	-5.84	-4.84	-3.38	0.00	-1.50	1.50
3	-9.00	-1.74	-4.84	-2.68	0.70	-0.74	0.50	-1.84
4	-8.50	0.00	-7.00	-2.66	-6.38	-0.88	-0.34	0.56
5	-8.88	-2.38	-8.00	-2.66	-4.00	-4.64	5.32	1.16
6	-3.50	-2.88	-11.50	-3.84	-2.88	2.76	3.34	1.66
7	-6.24	-0.38	-3.84	-2.16	-3.50	0.62	-7.00	0.00
8	-5.74	-3.00	-9.18	-2.16	-0.74	-1.12	-0.16	0.66
9	-5.62	-0.24	-9.34	-3.84	-2.00	-4.88	2.00	3.00
10	-10.50	-1.00	-6.50	-7.50	-1.38	-2.62	-1.68	0.34

Table B10. Experiment 2 threshold data for subject S5.

Rep	1-kHz Frozen A	1-kHz Frozen B	1-kHz Random A	1-kHz Random B	6-kHz Frozen A	6-kHz Frozen B	6-kHz Random A	6-kHz Random B
1	-10.00	-2.38	-9.84	4.34	-1.62	1.88	2.66	1.66
2	-14.88	-4.12	-10.84	-0.16	-3.00	-0.12	-2.50	1.34
3	-11.38	-2.12	-6.66	2.16	-3.38	0.62	-1.00	3.34
4	-7.50	-4.62	-7.50	-1.00	-2.74	3.00	1.66	-6.00
5	-8.24	-4.88	-9.00	1.66	-3.00	1.00	-4.50	1.34
6	-6.24	-5.74	-4.50	3.84	-1.74	3.00	-0.16	0.16
7	-12.00	-3.00	-10.50	4.66	-3.24	-1.74	-0.34	4.00
8	-6.88	-5.88	-5.16	0.34	-2.88	2.26	0.66	2.84
9	-8.88	-4.12	-11.16	1.84	-2.62	3.00	-0.16	1.66
10	-8.38	-4.00	-7.00	1.66	-1.88	0.76	2.00	1.34

APPENDIX C

DATA ANALYSES FOR EXPERIMENTS 1 AND 2

Table C1. Slopes and significance levels for the regression analyses performed on the thresholds for each condition in Experiment 1. The independent variable was replication number. Significance levels are shown in parentheses.

Condition	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Single-band frozen					
Noise A	-0.28 (.50)	-.04 (.84)	-0.29 (.38)	0.02 (.93)	0.41 (.17)
Noise B	-0.12 (.37)	-.14 (.52)	0.16 (.52)	0.06 (.64)	-0.18 (.23)
Single-band random					
Noise A	-0.63 (.10)	.25 (.53)	0.08 (.78)	-0.15 (.58)	0.16 (.58)
Noise B	-0.16 (.23)	-0.17 (.47)	-0.06 (.51)	0.09 (.58)	0 (1.0)
Seven-band frozen					
Noise A	0.05 (.73)	-0.05 (.68)	-0.09 (.56)	-0.01 (.91)	0.23 (.10)
Noise B	-0.05 (.67)	0.07 (.49)	0.03 (.83)	-0.09 (.46)	0.36 (.14)
Seven-band random					
Noise A	-0.17 (.28)	-0.04 (.82)	-0.07 (.78)	-0.1 (.74)	0.26 (.60)
Noise B	-0.20 (.60)	-0.09 (.24)	-0.26 (.22)	-0.14 (.52)	-.37 (.61)

Table C2. Slopes and significance levels for the regression analyses performed on the thresholds for each condition in Experiment 2. The independent variable was replication number. Significance levels are shown in parentheses.

Condition	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Frozen 6-kHz					
Noise A	0.04 (.74)	-0.17 (.56)	0.05 (.85)	-0.02 (.91)	0.02 (.84)
Noise B	-0.26 (.16)	-0.33 (.25)	-0.11 (.80)	-0.44 (.10)	0.05 (.80)
Random 6-kHz					
Noise A	0.02 (.92)	0.14 (.70)	0.12 (.64)	-0.00 (.99)	0.10 (.69)
Noise B	-0.07 (.56)	-0.13 (.54)	0.09 (.58)	-0.35 (.09)	.15 (.64)

Table C3. Results of t-tests comparing thresholds for the first half versus last half of each group of 10 replications for each condition in Experiment 1. The 2-tailed t-values appear in each cell, followed by significance levels (shown in parentheses).

Condition	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
	t-value (p-level)	t-value (p-level)	t-value (p-level)	t-value (p-level)	t-value (p-level)
Single-band frozen					
Noise A	.25 (.81)	-.25 (.81)	0 (.00)	-1.35 (.21)	-1.17 (.28)
Noise B	.97 (.36)	-.26 (.80)	-1.03 (.33)	-0.12 (.90)	1.16 (.28)
Single-band random					
Noise A	1.51 (.17)	1.91 (.09)	-0.61 (.56)	0.89 (.40)	-0.71 (.50)
Noise B	.38 (.71)	-0.25 (.81)	0.95 (.37)	0.95 (.37)	-0.88 (.41)
Seven-band frozen					
Noise A	0.00 (1.00)	.62 (.55)	0.68 (.52)	-0.99 (.35)	-1.91 (.09)
Noise B	.45 (.67)	-.04 (.97)	0.05 (.96)	0.62 (.55)	-1.79 (.11)
Seven-band random					
Noise A	1.15 (.28)	.96 (.37)	-0.37 (.72)	1.20 (.26)	-0.87 (.41)
Noise B	.12 (.91)	1.61 (.15)	0.77 (.46)	0.30 (.77)	-0.66 (.53)

Table C4. Results of t-tests comparing thresholds for the first half versus last half of each group of 10 replications for each condition in Experiment 2. The 2-tailed t-values appear in each cell, followed by significance levels (shown in parentheses).

Condition	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
	t-value (p-level)	t-value (p-level)	t-value (p-level)	t-value (p-level)	t-value (p-level)
Frozen 6-kHz					
Noise A	-0.55 (.60)	0.11 (.91)	0.58 (.58)	-0.28 (.78)	-0.66 (.53)
Noise B	0.28 (.78)	1.68 (.13)	0.50 (.63)	-0.01 (.99)	-0.17 (.87)
Random 6-kHz					
Noise A	0.20 (.85)	0.21 (.84)	1.50 (.17)	1.51 (.62)	-0.92 (.44)
Noise B	-1.13 (.29)	0.05 (.96)	-0.58 (.58)	-1.41 (.20)	-0.95 (.37)

Table C5. Experiment 1 : Three-Way Analysis of Variance for Subject 1 Number Of Bands (1 vs. 7) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-BAND#, 2-RANDOMN, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	249.9952	9	9.995938	25.00968	.000738
*2	1	65.6307	9	1.898734	34.56548	.000235
*3	1	233.5861	9	3.273703	71.35227	.000014
12	1	18.9930	9	5.174449	3.67054	.087635
*13	1	100.5761	9	4.039858	24.89595	.000750
*23	1	59.4780	9	3.578827	16.61941	.002772
*123	1	33.6701	9	3.263992	10.31563	.010628

Table C6. Experiment 1: Tukey post-hoc analysis for band X randomness interaction for subject 1.

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
BAND#	RANDOMN	SAMPLE	{1} -8.31300	{2} -5.52700	{3} -10.8740
1	1	•••• {1}		.016443	.026015
1	2	•••• {2}	.016443		.000371
2	1	•••• {3}	.026015	.000371	
2	2	•••• {4}	.147245	.000850	.662665

Table C6 continued...

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
BAND#	RANDOMN	SAMPLE	{4} -10.0370
1	1	•••• {1}	.147245
1	2	•••• {2}	.000850
2	1	•••• {3}	.662665
2	2	•••• {4}	

Table C7. Experiment 1: Tukey post-hoc analysis for band X sample interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
BAND#	RANDOMN	SAMPLE		{1} -9.75000	{2} -4.09000	{3} -11.0430
1	••••	1	{1}		.000242	.245127
1	••••	2	{2}	.000242		.000212
2	••••	1	{3}	.245127	.000212	
2	••••	2	{4}	.997621	.000238	.313358

Table C7 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3
BAND#	RANDOMN	SAMPLE		{4} -9.86800
1	••••	1	{1}	.997621
1	••••	2	{2}	.000238
2	••••	1	{3}	.313358
2	••••	2	{4}	

Table C8. Experiment 1: Tukey post-hoc analysis for randomness X sample interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -10.4400	{2} -8.74700	{3} -10.3530
••••	1	1	{1}		.077606	.998872
••••	1	2	{2}	.077606		.096426
••••	2	1	{3}	.998872	.096426	
••••	2	2	{4}	.000248	.001211	.000254

Table C8 continued....

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
BAND#	RANDOMN	SAMPLE		{4} -5.21100
••••	1	1	{1}	.000248
••••	1	2	{2}	.001211
••••	2	1	{3}	.000254
••••	2	2	{4}	

Table C9. Experiment 1: Tukey post-hoc analysis for band X randomness X sample interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -9.63200	{2} -6.99400	{3} -9.86800
1	1	1	{1}		.110574	.999982
1	1	2	{2}	.110574		.074024
1	2	1	{3}	.999982	.074024	
1	2	2	{4}	.000234	.000957	.000230
2	1	1	{5}	.528136	.007659	.684611
2	1	2	{6}	.947592	.025410	.990055
2	2	1	{7}	.794947	.014604	.912959
2	2	2	{8}	.999427	.213213	.990055

Table C9 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
BAND#	RANDOMN	SAMPLE		{7} -10.8380	{8} -9.23600
1	1	1	{1}	.794947	.999427
1	1	2	{2}	.014604	.213213
1	2	1	{3}	.912959	.990055
1	2	2	{4}	.000220	.000248
2	1	1	{5}	.999284	.305539
2	1	2	{6}	.999795	.759605
2	2	1	{7}		.537188
2	2	2	{8}	.537188	

Table C9 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
				{4}	{5}	{6}
BAND#	RANDOMN	SAMPLE		-1.18600	-11.2480	-10.5000
1	1	1	{1}	.000234	.528136	.947592
1	1	2	{2}	.000957	.007659	.025410
1	2	1	{3}	.000230	.684611	.990055
1	2	2	{4}		.000219	.000222
2	1	1	{5}	.000219		.975088
2	1	2	{6}	.000222	.975088	
2	2	1	{7}	.000220	.999284	.999795
2	2	2	{8}	.000248	.305539	.759605

Table C10. Experiment 1 : Three-Way Analysis of Variance for Subject 2: Number Of Bands (1 vs. 7) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-BAND#, 2-RANDOMN, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	158.2031	9	5.363581	29.49580	.000416
*2	1	44.5511	9	3.417514	13.03612	.005654
*3	1	245.2101	9	2.955812	82.95862	.000008
*12	1	54.7474	9	3.643394	15.02649	.003752
*13	1	380.1048	9	5.146749	73.85337	.000012
23	1	5.5651	9	1.653669	3.36532	.099783
*123	1	26.1519	9	1.858167	14.07400	.004544

*Marked effects significant at p_.0500

Table C11. Experiment 1: Tukey post-hoc analysis for band x randomness interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
BAND#	RANDOMN	SAMPLE		{1} -7.88100	{2} -4.73400	{3} -9.03900
1	1	••••	{1}		.002678	.286187
1	2	••••	{2}	.002678		.000436
2	1	••••	{3}	.286187	.000436	
2	2	••••	{4}	.198591	.000377	.992835

Table C11 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
BAND#	RANDOMN	SAMPLE		{4} -9.20100
1	1	••••	{1}	.198591
1	2	••••	{2}	.000377
2	1	••••	{3}	.992835
2	2	••••	{4}	

Table C12. Experiment 1: Tukey post-hoc analysis for band X sample interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
BAND#	RANDOMN	SAMPLE		{1} -10.2380	{2} -2.37700	{3} -8.69100
1	••••	1	{1}		.000212	.207232
1	••••	2	{2}	.000212		.000246
2	••••	1	{3}	.207232	.000246	
2	••••	2	{4}	.774415	.000225	.644285

Table C12 continued...

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3	
		{4}
BAND#	RANDOMN SAMPLE	-9.54900
1	•••• 1 {1}	.774415
1	•••• 2 {2}	.000225
2	•••• 1 {3}	.644285
2	•••• 2 {4}	

Table C13. Experiment 1: Tukey post-hoc analysis for randomness X sample interaction for subject 2.

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3			
		{1}	{2}	{3}
BAND#	RANDOMN SAMPLE	-9.94700	-6.97300	-8.98200
••••	1 1 {1}		.000394	.152358
••••	1 2 {2}	.000394		.003777
••••	2 1 {3}	.152358	.003777	
••••	2 2 {4}	.000210	.003649	.000225

Table C13 continued...

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3	
		{4}
BAND#	RANDOMN SAMPLE	-4.95300
••••	1 1 {1}	.000210
••••	1 2 {2}	.003649
••••	2 1 {3}	.000225
••••	2 2 {4}	

Table C14. Experiment 1: Tukey post-hoc analysis for band X randomness X sample interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -10.9760	{2} -4.78600	{3} -9.50000
1	1	1	{1}		.000242	.332115
1	1	2	{2}	.000242		.000614
1	2	1	{3}	.332115	.000614	
1	2	2	{4}	.000218	.000546	.000218
2	1	1	{5}	.094992	.001401	.970786
2	1	2	{6}	.162898	.000968	.998700
2	2	1	{7}	.034164	.003080	.689202
2	2	2	{8}	.687447	.000399	.993909

Table C14 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{4} .0320000	{5} -8.91800	{6} -9.16000
1	1	1	{1}	.000218	.094992	.162898
1	1	2	{2}	.000546	.001401	.000968
1	2	1	{3}	.000218	.970786	.998700
1	2	2	{4}		.000218	.000218
2	1	1	{5}	.000218		.999855
2	1	2	{6}	.000218	.999855	
2	2	1	{7}	.000218	.992501	.930424
2	2	2	{8}	.000218	.703175	.887162

Table C14 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
BAND#	RANDOMN	SAMPLE		{7} -8.46400	{8} -9.93800
1	1	1	{1}	.034164	.687447
1	1	2	{2}	.003080	.000399
1	2	1	{3}	.689202	.993909
1	2	2	{4}	.000218	.000218
2	1	1	{5}	.992501	.703175
2	1	2	{6}	.930424	.887162
2	2	1	{7}		.333419
2	2	2	{8}	.333419	

Table C15. Experiment 1 : Three-Way Analysis of Variance for Subject 3: Number Of Bands (1 vs. 7) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-BAND#, 2-RANDOMN, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	230.3847	9	2.491053	92.48486	.000005
*2	1	110.3560	9	3.628776	30.41137	.000373
*3	1	168.0840	9	6.191775	27.14634	.000556
*12	1	136.7645	9	5.624567	24.31556	.000812
*13	1	113.0026	9	2.276180	49.64571	.000060
23	1	.1693	9	3.395747	.04985	.828309
123	1	.1921	9	3.780791	.05080	.826705

*Marked effects significant at p_.0500

Table C16. Experiment 1: Tukey post-hoc analysis for band x randomness interaction for subject 3.

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
BAND#	RANDOMN	SAMPLE	{1} -7.28100	{2} -2.31700	{3} -8.06000
1	1	•••• {1}		.000627	.732414
1	2	•••• {2}	.000627		.000336
2	1	•••• {3}	.732414	.000336	
2	2	•••• {4}	.533309	.000297	.983777

Table C16 continued...

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
BAND#	RANDOMN	SAMPLE	{4} -8.32600
1	1	•••• {1}	.533309
1	2	•••• {2}	.000297
2	1	•••• {3}	.983777
2	2	•••• {4}	

Table C17. Experiment 1: Tukey post-hoc analysis for band X sample interaction for subject 3.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
BAND#	RANDOMN	SAMPLE		{1} -7.43700	{2} -2.16100	{3} -8.45400
1	••••	1	{1}		.000211	.214487
1	••••	2	{2}	.000211		.000210
2	••••	1	{3}	.214487	.000210	
2	••••	2	{4}	.733056	.000210	.701752

Table C17 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3
BAND#	RANDOMN	SAMPLE		{4} -7.93200
1	••••	1	{1}	.733056
1	••••	2	{2}	.000210
2	••••	1	{3}	.701752
2	••••	2	{4}	

Table C18. Experiment 1: Tukey post-hoc analysis for randomness X sample interaction for subject 3.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -9.07400	{2} -6.26700	{3} -6.81700
••••	1	1	{1}		.004431	.016440
••••	1	2	{2}	.004431		.783047
••••	2	1	{3}	.016440	.783047	
••••	2	2	{4}	.000240	.010464	.002959

Table C18 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
BAND#	RANDOMN	SAMPLE		{4} -3.82600
••••	1	1	{1}	.000240
••••	1	2	{2}	.010464
••••	2	1	{3}	.002959
••••	2	2	{4}	

Table C19. Experiment 1: Tukey post-hoc analysis for band X randomness X sample interaction for subject 3.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -9.82400	{2} -4.73800	{3} -5.05000
1	1	1	{1}		.003807	.005820
1	1	2	{2}	.003807		.999926
1	2	1	{3}	.005820	.999926	
1	2	2	{4}	.000221	.003475	.002336
2	1	1	{5}	.675508	.034014	.055585
2	1	2	{6}	.368843	.078277	.127986
2	2	1	{7}	.825910	.022719	.036897
2	2	2	{8}	.517928	.050875	.083391

Table C19 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{4} .4160000	{5} -8.32400	{6} -7.79600
1	1	1	{1}	.000221	.675508	.368843
1	1	2	{2}	.003475	.034014	.078277
1	2	1	{3}	.002336	.055585	.127986
1	2	2	{4}		.000245	.000274
2	1	1	{5}	.000245		.997799
2	1	2	{6}	.000274	.997799	
2	2	1	{7}	.000237	.999978	.977746
2	2	2	{8}	.000256	.999980	.999971

Table C19 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{7} -8.58400	{8} -8.06800	
1	1	1	{1}	.825910	.517928	
1	1	2	{2}	.022719	.050875	
1	2	1	{3}	.036897	.083391	
1	2	2	{4}	.000237	.000256	
2	1	1	{5}	.999978	.999980	
2	1	2	{6}	.977746	.999971	
2	2	1	{7}		.998090	
2	2	2	{8}	.998090		

Table C20. Experiment 1 : Three-Way Analysis of Variance for Subject 4: Number Of Bands (1 vs. 7) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-BAND#, 2-RANDOMN, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	794.2411	9	4.239273	187.3532	.000000
2	1	10.4908	9	5.112950	2.0518	.185829
*3	1	68.6166	9	1.967612	34.8730	.000228
12	1	1.8332	9	3.294207	.5565	.474716
*13	1	179.1311	9	1.498907	119.5078	.000002
23	1	.0567	9	5.151855	.0110	.918741
123	1	10.9446	9	3.142057	3.4833	.094849

*Marked effects significant at p_.0500

Table C21. Experiment 1: Tukey post-hoc analysis for band x randomness interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
BAND#	RANDOMN	SAMPLE		{1} -4.36700	{2} -5.39400	{3} -10.9715
1	1	••••	{1}		.337899	.000211
1	2	••••	{2}	.337899		.000227
2	1	••••	{3}	.000211	.000227	
2	2	••••	{4}	.000210	.000213	.880982

Table C21 continued...

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2

BAND#	RANDOMN	SAMPLE		{4} -11.3930
1	1	••••	{1}	.000210
1	2	••••	{2}	.000213
2	1	••••	{3}	.880982
2	2	••••	{4}	

Table C22. Experiment 1: Tukey post-hoc analysis for band X sample interaction for subject 4.

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3

BAND#	RANDOMN	SAMPLE		{1} -7.30300	{2} -2.45800	{3} -10.6120
1	••••	1	{1}		.000210	.000256
1	••••	2	{2}	.000210		.000210
2	••••	1	{3}	.000256	.000210	
2	••••	2	{4}	.000211	.000210	.065239

Table C22 continued...

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3

BAND#	RANDOMN	SAMPLE		{4} -11.7525
1	••••	1	{1}	.000211
1	••••	2	{2}	.000210
2	••••	1	{3}	.065239
2	••••	2	{4}	

Table C23. Experiment 1: Tukey post-hoc analysis for randomness X sample interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -8.62200	{2} -6.71650	{3} -9.29300
••••	1	1	{1}		.100788	.787682
••••	1	2	{2}	.100788		.024908
••••	2	1	{3}	.787682	.024908	
••••	2	2	{4}	.439277	.707829	.125499

Table C23 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
BAND#	RANDOMN	SAMPLE		{4} -7.49400
••••	1	1	{1}	.439277
••••	1	2	{2}	.707829
••••	2	1	{3}	.125499
••••	2	2	{4}	

Table C24. Experiment 1: Tukey post-hoc analysis for band X randomness X sample interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{1} -7.18600	{2} -1.54800	{3} -7.42000
1	1	1	{1}		.001023	.999980
1	1	2	{2}	.001023		.000789
1	2	1	{3}	.999980	.000789	
1	2	2	{4}	.013533	.384716	.009277
2	1	1	{5}	.067606	.000230	.101473
2	1	2	{6}	.003473	.000218	.004903
2	2	1	{7}	.010409	.000220	.015229
2	2	2	{8}	.005135	.000219	.007353

Table C24 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDOMN	SAMPLE		{4} -3.36800	{5} -10.0580	{6} -11.8850
1	1	1	{1}	.013533	.067606	.003473
1	1	2	{2}	.384716	.000230	.000218
1	2	1	{3}	.009277	.101473	.004903
1	2	2	{4}		.000402	.000230
2	1	1	{5}	.000402		.380846
2	1	2	{6}	.000230	.380846	
2	2	1	{7}	.000253	.838414	.977641
2	2	2	{8}	.000235	.543675	.999954

Table C24 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
BAND#	RANDOMN	SAMPLE		{7} -11.1660	{8} -11.6200
1	1	1	{1}	.010409	.005135
1	1	2	{2}	.000220	.000219
1	2	1	{3}	.015229	.007353
1	2	2	{4}	.000253	.000235
2	1	1	{5}	.838414	.543675
2	1	2	{6}	.977641	.999954
2	2	1	{7}		.998466
2	2	2	{8}	.998466	

Table C25. Experiment 1 : Three-Way Analysis of Variance for Subject 5: Number Of Bands (1 vs. 7) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-BAND#, 2-RANDOMNESS, 3-NOISE SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	29.6949	9	9.19868	3.22816	.105941
2	1	52.0677	9	14.26803	3.64925	.088419
*3	1	585.2538	9	10.58017	55.31610	.000039
*12	1	80.6011	9	9.92016	8.12498	.019076
*13	1	109.6524	9	5.57857	19.65602	.001639
*23	1	50.9763	9	5.63483	9.04663	.014769
123	1	12.8801	9	6.36954	2.02215	.188737

*Marked effects significant at p_.0500

Table C26. Tukey post-hoc analysis for band x randomness interaction for subject 5.

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
BAND#	RANDMN.	SAMPLE	{1} -6.76200	{2} -3.14100	{3} -5.97300
1	1	•••• {1}		.023276	.856357
1	2	•••• {2}	.023276		.076069
2	1	•••• {3}	.856357	.076069	
2	2	•••• {4}	.977661	.042023	.977822

Table 26 continued...

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
BAND#	RANDMN.	SAMPLE	{4} -6.36700
1	1	•••• {1}	.977661
1	2	•••• {2}	.042023
2	1	•••• {3}	.977822
2	2	•••• {4}	

Table C27. Tukey post-hoc analysis for band X sample interaction for subject 5.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
BAND#	RANDMN.	SAMPLE		{1} -8.82700	{2} -1.07600	{3} -7.70400
1	••••	1	{1}		.000214	.474153
1	••••	2	{2}	.000214		.000243
2	••••	1	{3}	.474153	.000243	
2	••••	2	{4}	.001682	.004735	.011743

Table 27 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3
BAND#	RANDMN.	SAMPLE		{4} -4.63600
1	••••	1	{1}	.001682
1	••••	2	{2}	.004735
2	••••	1	{3}	.011743
2	••••	2	{4}	

Table C28. Tukey post-hoc analysis for randomness X sample interaction for subject 5.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
BAND#	RANDMN.	SAMPLE		{1} -8.27400	{2} -4.46100	{3} -8.25700
••••	1	1	{1}		.003162	.999996
••••	1	2	{2}	.003162		.003253
••••	2	1	{3}	.999996	.003253	
••••	2	2	{4}	.000232	.009259	.000232

Table 28 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
BAND#	RANDMN.	SAMPLE		{4} -1.25100
••••	1	1	{1}	.000232
••••	1	2	{2}	.009259
••••	2	1	{3}	.000232
••••	2	2	{4}	

Table C29. Tukey post-hoc analysis for band X randomness X sample interaction for subject 5.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDMN.	SAMPLE		{1} -9.43800	{2} -4.08600	{3} -8.21600
1	1	1	{1}		.014908	.945614
1	1	2	{2}	.014908		.064313
1	2	1	{3}	.945614	.064313	
1	2	2	{4}	.000244	.007039	.000311
2	1	1	{5}	.495749	.241256	.966640
2	1	2	{6}	.036235	.996169	.159504
2	2	1	{7}	.961176	.058187	1.000000
2	2	2	{8}	.022451	.999972	.098554

Table 29 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
BAND#	RANDMN.	SAMPLE		{4} 1.934000	{5} -7.11000	{6} -4.83600
1	1	1	{1}	.000244	.495749	.036235
1	1	2	{2}	.007039	.241256	.996169
1	2	1	{3}	.000311	.966640	.159504
1	2	2	{4}		.000509	.003204
2	1	1	{5}	.000509		.520327
2	1	2	{6}	.003204	.520327	
2	2	1	{7}	.000304	.952484	.144671
2	2	2	{8}	.004837	.353253	.999932

Table 29 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
BAND#	RANDMN.	SAMPLE		{7} -8.29800	{8} -4.43600
1	1	1	{1}	.961176	.022451
1	1	2	{2}	.058187	.999972
1	2	1	{3}	1.000000	.098554
1	2	2	{4}	.000304	.004837
2	1	1	{5}	.952484	.353253
2	1	2	{6}	.144671	.999932
2	2	1	{7}		.089197
2	2	2	{8}	.089197	

Table C30. Experiment 2 : Three-Way Analysis of Variance for Subject 1 Frequency (1-kHz vs. 6-kHz) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-freeq, 2-random, 3-sample					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	531.9962	9	3.473492	153.1589	.000001
*2	1	41.1558	9	1.728194	23.8143	.000871
*3	1	185.9890	9	3.372749	55.1446	.000040
12	1	36.5310	9	7.673256	4.7608	.056995
*13	1	136.2942	9	2.947283	46.2440	.000079
*23	1	56.0790	9	2.911549	19.2609	.001749
*123	1	36.3151	9	3.519581	10.3180	.010622

*Marked effects significant at p<.0500

Table C31. Experiment 2: Tukey post-hoc analysis for frequency X randomness interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
freeq	random	sample		{1} -8.31300	{2} -5.52700	{3} -1.80400
1	1	••••	{1}		.045872	.000371
1	2	••••	{2}	.045872		.009603
2	1	••••	{3}	.000371	.009603	
2	2	••••	{4}	.000355	.008409	.999694

Table C31 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
freeq	random	sample		{4} -1.72100
1	1	••••	{1}	.000355
1	2	••••	{2}	.008409
2	1	••••	{3}	.999694
2	2	••••	{4}	

Table C32. Experiment 2: Tukey post-hoc analysis for frequency X sample interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
freeq	random	sample		{1} -9.75000	{2} -4.09000	{3} -1.98200
1	••••	1	{1}		.000214	.000210
1	••••	2	{2}	.000214		.016208
2	••••	1	{3}	.000210	.016208	
2	••••	2	{4}	.000210	.005229	.848967

Table C32 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3
freeq	random	sample		{4} -1.54300
1	••••	1	{1}	.000210
1	••••	2	{2}	.005229
2	••••	1	{3}	.848967
2	••••	2	{4}	

Table C33. Experiment 2: Tukey post-hoc analysis for randomness X sample interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
				{1}	{2}	{3}
freeq	random	sample		-5.74600	-4.37100	-5.98600
••••	1	1	{1}		.118023	.969070
••••	1	2	{2}	.118023		.060778
••••	2	1	{3}	.969070	.060778	
••••	2	2	{4}	.000276	.001423	.000247

Table C33 continued....

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
				{4}
freeq	random	sample		-1.26200
••••	1	1	{1}	.000276
••••	1	2	{2}	.001423
••••	2	1	{3}	.000247
••••	2	2	{4}	

Table C34. Experiment 2: Tukey post-hoc analysis for frequency X randomness X sample interaction for subject 1.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
				{1}	{2}	{3}
freeq	random	sample		-9.63200	-6.99400	-9.86800
1	1	1	{1}		.130376	.999986
1	1	2	{2}	.130376		.088732
1	2	1	{3}	.999986	.088732	
1	2	2	{4}	.000244	.001217	.000237
2	1	1	{5}	.000286	.002799	.000267
2	1	2	{6}	.000277	.002420	.000260
2	2	1	{7}	.000319	.003898	.000287
2	2	2	{8}	.000251	.001452	.000241

Table C34 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
freeq	random	sample		{4} -1.18600	{5} -1.86000	{6} -1.74800
1	1	1	{1}	.000244	.000286	.000277
1	1	2	{2}	.001217	.002799	.002420
1	2	1	{3}	.000237	.000267	.000260
1	2	2	{4}		.988448	.995981
2	1	1	{5}	.988448		1.000000
2	1	2	{6}	.995981	1.000000	
2	2	1	{7}	.942843	.999982	.999775
2	2	2	{8}	.999999	.997431	.999438

Table C34 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
freeq	random	sample		{7} -2.10400	{8} -1.33800
1	1	1	{1}	.000319	.000251
1	1	2	{2}	.003898	.001452
1	2	1	{3}	.000287	.000241
1	2	2	{4}	.942843	.999999
2	1	1	{5}	.999982	.997431
2	1	2	{6}	.999775	.999438
2	2	1	{7}		.976844
2	2	2	{8}	.976844	

Table C35. Experiment 2 : Three-Way Analysis of Variance for Subject 2 Frequency (1-kHz vs. 6-kHz) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-FREQ, 2-RANDOMNESS, 3-NOISE SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	366.8818	9	4.521914	81.13419	.000008
*2	1	35.8584	9	3.611776	9.92820	.011720
*3	1	495.2115	9	5.400631	91.69512	.000005
*12	1	65.3773	9	9.734791	6.71584	.029142
*13	1	166.4645	9	5.304833	31.37978	.000334
*23	1	23.3712	9	3.973798	5.88133	.038286
123	1	6.9620	9	9.017844	.77202	.402440

*Marked effects significant at p_.0500

Table C36. Experiment 2: Tukey post-hoc analysis for frequency X randomness interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
FREQ	RANDOMN.	SAMPLE		{1} -7.88100	{2} -4.73400	{3} -1.79000
1	1	••••	{1}		.045250	.000930
1	2	••••	{2}	.045250		.061622
2	1	••••	{3}	.000930	.061622	
2	2	••••	{4}	.001529	.125115	.962722

Table C36 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
FREQ	RANDOMN.	SAMPLE		{4} -2.25900
1	1	••••	{1}	.001529
1	2	••••	{2}	.125115
2	1	••••	{3}	.962722
2	2	••••	{4}	

Table C37. Experiment 2: Tukey post-hoc analysis for frequency X sample interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
FREQ	RANDOMN.	SAMPLE		{1} -10.2380	{2} -2.37700	{3} -3.07000
1	••••	1	{1}		.000212	.000226
1	••••	2	{2}	.000212		.779075
2	••••	1	{3}	.000226	.779075	
2	••••	2	{4}	.000210	.285829	.072996

Table C37 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3
FREQ	RANDOMN.	SAMPLE		{4} -.979000
1	••••	1	{1}	.000210
1	••••	2	{2}	.285829
2	••••	1	{3}	.072996
2	••••	2	{4}	

Table C38. Experiment 2: Tukey post-hoc analysis for randomness X sample interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
FREQ	RANDOMN.	SAMPLE		{1} -6.78300	{2} -2.88800	{3} -6.52500
••••	1	1	{1}		.000925	.975569
••••	1	2	{2}	.000925		.001405
••••	2	1	{3}	.975569	.001405	
••••	2	2	{4}	.000224	.017276	.000228

Table C38 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
FREQ	RANDOMN.	SAMPLE		{4} -.468000
••••	1	1	{1}	.000224
••••	1	2	{2}	.017276
••••	2	1	{3}	.000228
••••	2	2	{4}	

Table C39. Experiment 2: Tukey post-hoc analysis for frequency X randomness X sample interaction for subject 2.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN.	SAMPLE		{1} -10.9760	{2} -4.78600	{3} -9.50000
1	1	1	{1}		.017741	.941635
1	1	2	{2}	.017741		.078984
1	2	1	{3}	.941635	.078984	
1	2	2	{4}	.000456	.070983	.001037
2	1	1	{5}	.002442	.723201	.008892
2	1	2	{6}	.000771	.199306	.002208
2	2	1	{7}	.005545	.975848	.022489
2	2	2	{8}	.000761	.195068	.002170

Table C39 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN.	SAMPLE		{4} .0320000	{5} -2.59000	{6} -.990000
1	1	1	{1}	.000456	.002442	.000771
1	1	2	{2}	.070983	.723201	.199306
1	2	1	{3}	.001037	.008892	.002208
1	2	2	{4}		.553189	.991511
2	1	1	{5}	.553189		.915834
2	1	2	{6}	.991511	.915834	
2	2	1	{7}	.244982	.994087	.577760
2	2	2	{8}	.992507	.910660	1.000000

Table C39 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN.	SAMPLE		{7} -3.55000	{8} -.968000	
1	1	1	{1}	.005545	.000761	
1	1	2	{2}	.975848	.195068	
1	2	1	{3}	.022489	.002170	
1	2	2	{4}	.244982	.992507	
2	1	1	{5}	.994087	.910660	
2	1	2	{6}	.577760	1.000000	
2	2	1	{7}		.569010	
2	2	2	{8}	.569010		

Table C40. Experiment 2 : Three-Way Analysis of Variance for Subject 3 Frequency (1-kHz vs. 6-kHz) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-FREQ, 2-RANDOMN, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	486.0980	9	1.813067	268.1082	.000000
*2	1	179.0413	9	6.028347	29.6999	.000406
*3	1	175.9431	9	2.284431	77.0184	.000010
*12	1	77.7757	9	6.315125	12.3158	.006625
*13	1	106.7220	9	7.977067	13.3786	.005254
23	1	14.1793	9	4.782525	2.9648	.119197
123	1	8.5021	9	6.874236	1.2368	.294911

*Marked effects significant at p_.0500

Table C41. Experiment 2: Tukey post-hoc analysis for frequency X randomness interaction for subject 3.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
FREQ	RANDOMN	SAMPLE		{1} -7.28100	{2} -2.31700	{3} -.379000
1	1	••••	{1}		.000869	.000250
1	2	••••	{2}	.000869		.138526
2	1	••••	{3}	.000250	.138526	
2	2	••••	{4}	.000225	.020490	.594623

Table C41 continued...

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2	
			{4}	
FREQ	RANDOMN	SAMPLE	.6410000	
1	1	•••• {1}	.000225	
1	2	•••• {2}	.020490	
2	1	•••• {3}	.594623	
2	2	•••• {4}		

Table C42. Experiment 2: Tukey post-hoc analysis for frequency X sample interaction for subject 3.

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3			
			{1}	{2}	{3}	
FREQ	RANDOMN	SAMPLE	-7.43700	-2.16100	-.197000	
1	••••	1 {1}		.001216	.000289	
1	••••	2 {2}	.001216		.195246	
2	••••	1 {3}	.000289	.195246		
2	••••	2 {4}	.000245	.066462	.880941	

Table C42 continued...

css/3: general manova			Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3	
			{4}	
FREQ	RANDOMN	SAMPLE	.4590000	
1	••••	1 {1}	.000245	
1	••••	2 {2}	.066462	
2	••••	1 {3}	.880941	
2	••••	2 {4}		

Table C43. Experiment 2: Tukey post-hoc analysis for randomness X sample interaction for subject 3.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
FREQ	RANDOMN	SAMPLE		{1} -4.89200	{2} -2.76800	{3} -2.74200
••••	1	1	{1}		.054036	.051071
••••	1	2	{2}	.054036		.999981
••••	2	1	{3}	.051071	.999981	
••••	2	2	{4}	.000253	.001814	.001894

Table C43 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
FREQ	RANDOMN	SAMPLE		{4} 1.066000
••••	1	1	{1}	.000253
••••	1	2	{2}	.001814
••••	2	1	{3}	.001894
••••	2	2	{4}	

Table C44. Experiment 2: Tukey post-hoc analysis for frequency X randomness X sample interaction for subject 3.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN	SAMPLE		{1} -9.82400	{2} -4.73800	{3} -5.05000
1	1	1	{1}		.025470	.036525
1	1	2	{2}	.025470		.999990
1	2	1	{3}	.036525	.999990	
1	2	2	{4}	.000353	.023564	.016556
2	1	1	{5}	.000407	.036356	.025353
2	1	2	{6}	.000630	.097055	.067293
2	2	1	{7}	.000510	.063301	.043907
2	2	2	{8}	.000253	.005721	.004168

Table C44 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN	SAMPLE		{4} .4160000	{5} .0400000	{6} -.798000
1	1	1	{1}	.000353	.000407	.000630
1	1	2	{2}	.023564	.036356	.097055
1	2	1	{3}	.016556	.025353	.067293
1	2	2	{4}		.999965	.956141
2	1	1	{5}	.999965		.994094
2	1	2	{6}	.956141	.994094	
2	2	1	{7}	.993584	.999837	.999972
2	2	2	{8}	.939206	.824385	.455179

Table C44 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
FREQ	RANDOMN	SAMPLE		{7} -.434000	{8} 1.716000
1	1	1	{1}	.000510	.000253
1	1	2	{2}	.063301	.005721
1	2	1	{3}	.043907	.004168
1	2	2	{4}	.993584	.939206
2	1	1	{5}	.999837	.824385
2	1	2	{6}	.999972	.455179
2	2	1	{7}		.616841
2	2	2	{8}	.616841	

Table C45. Experiment 2 : Three-Way Analysis of Variance for Subject 4 Frequency (1-kHz vs. 6-kHz) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-FREQ, 2-RANDOMN, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	335.2986	9	5.100783	65.73473	.000020
2	1	2.7751	9	5.849747	.47440	.508334
*3	1	163.3061	9	2.519036	64.82881	.000021
12	1	39.1720	9	9.245382	4.23693	.069663
*13	1	79.0031	9	5.072081	15.57608	.003372
23	1	7.0924	9	2.775094	2.55574	.144359
123	1	.7801	9	7.245303	.10767	.750314

*Marked effects significant at p_.0500

Table C46. Experiment 2: Tukey post-hoc analysis for frequency X randomness interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
FREQ	RANDOMN	SAMPLE		{1} -4.36700	{2} -5.39400	{3} -1.67200
1	1	••••	{1}		.716231	.080830
1	2	••••	{2}	.716231		.016493
2	1	••••	{3}	.080830	.016493	
2	2	••••	{4}	.005559	.001503	.315680

Table C46 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2
FREQ	RANDOMN	SAMPLE		{4} .1000000
1	1	••••	{1}	.005559
1	2	••••	{2}	.001503
2	1	••••	{3}	.315680
2	2	••••	{4}	

Table C47. Experiment 2: Tukey post-hoc analysis for frequency X sample interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3		
FREQ	RANDOMN	SAMPLE		{1} -7.30300	{2} -2.45800	{3} -1.22100
1	••••	1	{1}		.000546	.000256
1	••••	2	{2}	.000546		.360715
2	••••	1	{3}	.000256	.360715	
2	••••	2	{4}	.000227	.064010	.629726

Table C47 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3
FREQ	RANDOMN	SAMPLE		{4} -.351000
1	••••	1	{1}	.000227
1	••••	2	{2}	.064010
2	••••	1	{3}	.629726
2	••••	2	{4}	

Table C48. Experiment 2: Tukey post-hoc analysis for randomness X sample interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
FREQ	RANDOMN	SAMPLE		{1} -4.74600	{2} -1.29300	{3} -3.77800
••••	1	1	{1}		.000660	.317854
••••	1	2	{2}	.000660		.005053
••••	2	1	{3}	.317854	.005053	
••••	2	2	{4}	.000968	.973103	.009035

Table C48 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3	
FREQ	RANDOMN	SAMPLE		{4} -1.51600	
••••	1	1	{1}	.000968	
••••	1	2	{2}	.973103	
••••	2	1	{3}	.009035	
••••	2	2	{4}		

Table C49. Experiment 2: Tukey post-hoc analysis for frequency X randomness X sample interaction for subject 4.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN	SAMPLE		{1} -7.18600	{2} -1.54800	{3} -7.42000
1	1	1	{1}		.016086	.999999
1	1	2	{2}	.016086		.012497
1	2	1	{3}	.999999	.012497	
1	2	2	{4}	.125603	.785646	.096277
2	1	1	{5}	.037410	.997236	.028732
2	1	2	{6}	.009327	.999777	.007321
2	2	1	{7}	.003774	.921431	.003020
2	2	2	{8}	.002430	.759278	.001974

Table C49 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMN	SAMPLE		{4} -3.36800	{5} -2.30600	{6} -1.03800
1	1	1	{1}	.125603	.037410	.009327
1	1	2	{2}	.785646	.997236	.999777
1	2	1	{3}	.096277	.028732	.007321
1	2	2	{4}		.980702	.562099
2	1	1	{5}	.980702		.952310
2	1	2	{6}	.562099	.952310	
2	2	1	{7}	.239521	.633588	.992231
2	2	2	{8}	.142793	.430850	.930503

Table C49 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
FREQ	RANDOMN	SAMPLE		{7} -.136000	{8} .3360000
1	1	1	{1}	.003774	.002430
1	1	2	{2}	.921431	.759278
1	2	1	{3}	.003020	.001974
1	2	2	{4}	.239521	.142793
2	1	1	{5}	.633588	.430850
2	1	2	{6}	.992231	.930503
2	2	1	{7}		.999866
2	2	2	{8}	.999866	

Table C50. Experiment 2 : Three-Way Analysis of Variance for Subject 5 Frequency (1-kHz vs. 6-kHz) x Randomness (Frozen vs. Randomly Selected) x Sample (A vs. B)

css/3: general manova	Summary of all Effects; design: 1-FREQ, 2-RANDOMNE, 3-SAMPLE					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
*1	1	478.3398	9	1.834238	260.7839	.000000
*2	1	112.4802	9	3.596323	31.2765	.000337
*3	1	541.5283	9	7.209167	75.1166	.000012
*12	1	31.2250	9	1.554238	20.0902	.001528
*13	1	129.7951	9	5.142314	25.2406	.000715
23	1	5.8212	9	3.519283	1.6541	.230503
*123	1	69.1548	9	4.300927	16.0791	.003064

*Marked effects significant at p_.0500

Table C51. Experiment 2: Tukey post-hoc analysis for frequency X randomness interaction for subject 5.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2		
FREQ	RANDOMNE	SAMPLE		{1} -6.76200	{2} -3.14100	{3} -.622000
1	1	••••	{1}		.000235	.000210
1	2	••••	{2}	.000235		.000759
2	1	••••	{3}	.000210	.000759	
2	2	••••	{4}	.000210	.000234	.075771

Table C51 continued...

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2	
FREQ RANDOMNE SAMPLE		{4} .5000000
1 1 ••••	{1}	.000210
1 2 ••••	{2}	.000234
2 1 ••••	{3}	.075771
2 2 ••••	{4}	

Table C52. Experiment 2: Tukey post-hoc analysis for frequency X sample interaction for subject 5.

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3			
FREQ RANDOMNE SAMPLE		{1} -8.82700	{2} -1.07600	{3} -1.38900
1 •••• 1	{1}		.000212	.000214
1 •••• 2	{2}	.000212		.970668
2 •••• 1	{3}	.000214	.970668	
2 •••• 2	{4}	.000210	.040275	.021052

Table C52 continued...

css/3: general manova	Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 3	
FREQ RANDOMNE SAMPLE		{4} 1.267000
1 •••• 1	{1}	.000210
1 •••• 2	{2}	.040275
2 •••• 1	{3}	.021052
2 •••• 2	{4}	

Table C53. Experiment 2: Tukey post-hoc analysis for randomness X sample interaction for subject 5.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3		
FREQ	RANDOMNE	SAMPLE		{1} -6.02400	{2} -1.36000	{3} -4.19200
••••	1	1	{1}		.000312	.052689
••••	1	2	{2}	.000312		.004689
••••	2	1	{3}	.052689	.004689	
••••	2	2	{4}	.000210	.003942	.000228

Table C53 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 2 x 3
FREQ	RANDOMNE	SAMPLE		{4} 1.551000
••••	1	1	{1}	.000210
••••	1	2	{2}	.003942
••••	2	1	{3}	.000228
••••	2	2	{4}	

Table C54. Experiment 2: Tukey post-hoc analysis for frequency X randomness X sample interaction for subject 5.

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
FREQ	RANDOMNE	SAMPLE		{1} -9.43800	{2} -4.08600	{3} -8.21600
1	1	1	{1}		.004167	.871533
1	1	2	{2}	.004167		.021823
1	2	1	{3}	.871533	.021823	
1	2	2	{4}	.000220	.001876	.000227
2	1	1	{5}	.000819	.745860	.003042
2	1	2	{6}	.000222	.003681	.000237
2	2	1	{7}	.000247	.029675	.000361
2	2	2	{8}	.000223	.004718	.000243

Table C54 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3		
				{4}	{5}	{6}
FREQ	RANDOMNE	SAMPLE		1.934000	-2.61000	1.366000
1	1	1	{1}	.000220	.000819	.000222
1	1	2	{2}	.001876	.745860	.003681
1	2	1	{3}	.000227	.003042	.000237
1	2	2	{4}		.012158	.997674
2	1	1	{5}	.012158		.027268
2	1	2	{6}	.997674	.027268	
2	2	1	{7}	.397826	.255853	.713332
2	2	2	{8}	.986521	.036427	.999998

Table C54 continued...

css/3: general manova				Tukey HSD test; variable Var.1 Probabilities for Post-Hoc Tests INTERACTION: 1 x 2 x 3	
				{7}	{8}
FREQ	RANDOMNE	SAMPLE		-.168000	1.168000
1	1	1	{1}	.000247	.000223
1	1	2	{2}	.029675	.004718
1	2	1	{3}	.000361	.000243
1	2	2	{4}	.397826	.986521
2	1	1	{5}	.255853	.036427
2	1	2	{6}	.713332	.999998
2	2	1	{7}		.819345
2	2	2	{8}	.819345	

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