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AN INVESTIGATION OF THE LOUDNESS CHANGES PRODUCED IN A PURE TONE BY CONTRALATERAL THERMAL NOISE

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CHAPTER I

INTRODUCTION

There are many psychophysical studies reported in the literature related to the effects of contralaterally-applied stimuli on the loudness of a stimulus applied to the test ear (1, 2, 4, 5, 7, 8, 24, 27, 28, 29, 35). Most of these studies have been motivated by a desire to measure the attenuation provided by the acoustic reflex. This reflex is bilateral, that is, presentation of a reflex-eliciting stimulus to one ear produces the reflex in both ears. Therefore, it was thought that measurement of the loudness reduction or the threshold increase produced in one ear by the presentation of an intense stimulus to the opposite ear would provide a measure of the attenuation provided by the reflex. Some studies (2, 4, 17, 28, 29) have shown the expected loudness decrease. However, the results of similar studies (7, 24, 27, 35) show loudness increases under the contralateral stimulus condition.

Some of the apparently conflicting results may be explained on the basis of the different conditions and procedures used in these studies. For example, in all of the studies showing loudness decreases in the presence of contralateral noise comparatively low-frequency test tones were used. This decrease is part of the evidence which supports the conclusion that the acoustic reflex has maximum effect on low-frequency tones and has a negligible effect on tones of 1000 Hz and higher (19).

Prather (24) and Vigran (35) included in their experiments conditions under which the level of the contralateral broad or narrow-band noise was held constant and frequencies both above and below 1000 Hz were used as test stimuli. Results showed loudness increases for the higher-frequency test tones and equal or decreased loudness when lower-frequency test tones were used.

A review of those studies using speech or tones of 1000 Hz and above as test stimuli (7, 24, 27, 35) suggests that the relationship between the intensity of the noise and the intensity of the test stimulus is a major factor in determining the extent of the loudness increase in the test stimulus.

Egan (7) obtained a maximum loudness increase of 6 dB at a speech sensation level (re. threshold of detectability) of 45 dB and a noise sensation level of 80 dB (i. e., approximately 90-dB SPL). Vigran (35) observed a maximum loudness increase of about 7. 5 dB for a 1100-Hz tone at a level of 70 dB SPL when a 1/3-octave band of contralaterally presented white noise was held constant at 100 dB SPL.

In another experiment in which the tone level was held constant at 80 dB SPL, Vigran found that the maximum loudness increase occurred at a noise level of 105 dB SPL.

Using a numerical magnitude balance procedure, Rowley (27) obtained the greatest increases in loudness at 1000-Hz tonal sensation levels of 42 and 56 dB in the presence of broad-band noise delivered at sensation levels of 80 and 100 dB, respectively.

Despite a number of procedural differences, the results of the foregoing studies all support the following generalizations:

(1) the perceived loudness of speech or tonal stimuli heard in one ear is, under certain conditions, increased by the presence of broad-band or narrow-band thermal noise presented to the opposite ear.

(2) the loudness increase is most apparent at frequencies 1000 Hz and above and for noise stimulus levels above 40 dB SL.

(3) the maximum loudness increase occurs when the contralateral noise stimulus is some 30 to 45 dB more intense than the test stimulus.

Rowley (27) obtained loudness functions of a 1000-Hz tone in quiet and also in the presence of four different levels of contralateral broad-band thermal noise. He suggested the generalization that maximum loudness increase may occur when the test stimulus is at a level which is equal to the spectrum level of the noise. An analysis of the results of Vigran's study (35) supports this generalization when both the test stimulus and noise level are expressed relative to a common reference. For example, Vigran's contralateral noise stimulus was a 1/3-octave band of thermal noise with a center frequency of 2500 Hz which did not overlap the frequency of any of the test tones. Yet the loudness increases of from 7- to 8-dB obtained in this study are similar in magnitude to those found under certain conditions in another study where the bandwidth of a contralateral noise encompassed the frequency of the test tone (24). The bandwidth of Vigran's 1/3-octave noise was 560 Hz, or approximately 27 dB. When this value is subtracted from the overall level of 105 dB it yields a level per cycle of 78 dB, which is very close to the 80-dB SPL tone level at which the maximum loudness increases were observed.

The results of Egan (7), who used a speech test stimulus, also seem to support Rowley's generalization but suggest for speech signals that the overall level of the test stimulus may be the determining factor instead of spectrum level. However, a lack of specification of signal reference levels make a detailed comparison hazardous.

The loudness increases produced in pure-tone test stimuli by contralateral noises require further study. The results of previous studies suggest that certain generalizations (listed above) might be reached, but, because of procedural differences, such generalizations are tenuous. The purpose of this investigation was to evaluate the loudness change produced in test tones by both a broad and a narrow-band noise when each was presented at one level which should elicit the acoustic reflex and at one level which should not. The test stimuli consisted of one tone (500 Hz) which should be affected by the reflex but which was below the narrow (one-octave) band in frequency, one tone (1000 Hz) which was at the center of the narrow band, and one tone (2000 Hz) which was higher in frequency than the narrow-band noise. Also, certain procedural variables were studied in order to determine the effect of these variables on the apparent loudness change.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

According to Stevens and Davis (33, P110), "loudness is an aspect of sensation obtained by listening directly to a sound." It is measured "by means of the discriminatory responses of a normal human observer." This general definition describes the very subjective nature of loudness measurements.

Indeed, the cumulative research to date has shown that in order to measure some aspect of loudness accurately an experimentor must carefully control not only the physical parameters of intensity, waveform, frequency, etc., but must also consider such physiological and psychological factors as the sensitivity of the sense organ and the attention, comfort, alertness, motivation, homogeneity and training of the listeners. In the design of any research study it is helpful to the experimentor to know as much about these conditions as possible--especially as they relate to the phenomenon (or phenomena) being investigated.

The phenomenon under investigation in the present study is the loudness change that occurs when one of two tones being delivered at supra-threshold levels to the same ear is paired with a contralateral noise. Only a few previous studies have been concerned with this auditory task (22, 27, 29, 35). Direct comparisons of the results of these studies are difficult, since different psychophysical procedures were used and the physical parameters used varied across the studies. However, certain relationships which do exist among these studies will be reviewed in this chapter. Attention will be given especially to the various frequency, intensity and spectral conditions which are associated with the magnitude and direction of the loudness change.

Some Basic Mechanisms Related to Loudness Changes in the Presence of Contralateral Noise

The loudness changes observed in the presence of noise described in this chapter appear to result from an interaction between any or all of three basic mechanisms of audition. These are binaural loudness summation, the acoustic reflex, and various types of masking. The first is usually identified with loudness increases experienced by subjects under certain listening conditions. The second and third are associated with loudness decreases. Each of these mechanisms has been the object of extensive research. The initial section of this chapter is included in order to provide a brief summary of the basic definitions and recognized characteristics of each of these mechanisms.

Binaural Summation of Loudness

During the past century several investigators have observed that identical tones heard simultaneously in the two ears sound louder than does one tone heard in one ear alone. This principle and these studies are reviewed by Hirsh (11) who suggests that "interaural summation" might be a more descriptive term, since it is based upon an interaction between the two ears. However, the more familiar term will be used in this study.

The monaural vs binaural loudness level relationship was quantified in 1933 by Fletcher and Munson (8) who concluded that a tone heard simultaneously in both ears is twice as loud as the same tone heard in one ear in quiet surroundings. These authors reasoned further that the loudness of a sound is probably dependent on the total number of impulses that reaches the brain per second along the auditory tract. Thus, stimulation reaching the cortex via the two auditory systems would present twice as many impulses per second as through one ear and, therefore, would sound twice as loud.

More recent works by Reynolds and Stevens (26) and others (9, 10, 27) show that the relationship mentioned above is not so simple as that suggested by Fletcher and Munson (8). Reynolds and Stevens determined loudness functions using five different kinds of psychophysical procedures and discovered that the binaural loudness of a 1000-Hz tone in quiet ranges from about 1.4 times as great as monaural loudness at sensation levels of 40 dB to 2.3 times as great at levels of about 100 dB SL. The dependence of the extent of the binaural summations on sensation level was also demonstrated by Causse and Chavasse (5) who used monaural-binaural loudness balances to discover that the 3-dB difference in favor of the binaurally-presented tone at threshold gradually became a 6-dB difference at levels of 35 to 65 dB.

The Acoustic Reflex

At high intensity levels the middle ear muscles, particularly the stapedius, contract and change the impedance properties of the middle ear mechanism in such a manner as to reduce the intensity of the sound reaching the inner ear (2, 4, 6, 14, 15, 16, 18, 19, 20, 24, 25, 36, 37, 38, 39). The literature on the acoustic reflex is extensive and has been summarized by Jepson (14) and others (20, 38). Thus, it is not reviewed thoroughly here. However, a few basic characteristics of the acoustic reflex that relate to the present study are reviewed.

First, the reflex is elicited only by relatively intense sounds. The reflex threshold in normal ears varies with frequency, ranging from 70 to 75 dB SL in the mid-frequency range to 90 to 95 dB SL at low and high frequencies (6, 14, 16, 19). The threshold has been found to vary widely among individuals at a given frequency (6, 14).

It has been known for nearly 100 years (23) that the contraction of the middle ear muscles in animals is bilateral--that is, the muscles on both sides will be activated by a tone presented to one ear only. The discovery by Luscher (18), in 1929, that this bilateral characteristic also pertains to man opened the door for many studies which used contralateral arousal stimuli to determine the effect of the acoustic reflex on various stimulus parameters presented to the test ear.

Other investigators (21, 25, 32) have discovered that the reflex can also be elicited voluntarily by certain individuals, producing threshold shifts ranging from 25 to 35 dB SL at the low frequencies to no shift at 2000 Hz and above. Loeb and Riopelle (17) suggested that this ability of some subjects to produce threshold shifts by voluntary contraction of the middle ear muscles might possibly confound certain results in reflex studies. Further attention is given this phenomenon in Chapter IV.

Pure tones, even at high levels, have been found to be relatively ineffective in producing sustained reflex activity (36). Ward (36) investigated the relative effectiveness of various bands of contralateral noise in arousing the acoustic reflex. Low-frequency noise bands produced more reflex activation than high-frequency bands. Varying the bandwidth of the arousal noise had very little effect on the acoustic reflex. An important variable was the lower cutoff frequency of the noise band. The noise band becomes more effective in altering thresholds as the low-frequency cut off is reduced toward 500 Hz. It was also found that a 500-Hz tone was attenuated more by the reflex than were tones of adjacent frequencies. This relationship held true for all bands of the remote arousal noise, all of which were above the frequency of the 500-Hz tone.

On the basis of this brief summary of the characteristics of the acoustic reflex one would expect the greatest attenuation caused by the acoustic reflex (1) to occur for a low (500-Hz) tone of high intensity, (2) to occur in the presence of a steady wide or narrow band of contralateral noise, the lower cutoff frequency of which either includes the 500 Hz tone or is close to it, and (3) to occur when the intensity of the noise is about 30 dB above the reflex threshold of 70 to 80 dB in the mid-frequency region.

Masking

Masking represents a change in the threshold of one sound due to the presence of a second sound. Several different types of masking are defined by Ward (37, P. 245) as follows:

> What is usually meant by "masking" is *ipsilateral direct masking*; this occurs when the masker and maskee are (a) in the same ear and (b) in the same frequency region. *Remote masking* describes threshold shifts in the same ear produced by a masker in a different frequency region from that of the maskee. *Transcranial masking* comes about because the ears cannot be completely *insulated* from each other *acoustically*: the masker leaks around the head and produces masking in the opposite ear. *Central masking*, similarly, arises because the two ears are not insulated *neurologically*; if the presence of a masker in

one ear at an intensity too low to produce transcranial masking nevertheless does raise the threshold in the other ear, this presumably occurs because some of the final common neural pathways usually available to the unmasked ear are preempted by the masking noise. Both transcranial and central masking are contralateral phenomena, in the sense that the masker is in one ear, the maskee in the other; they both may be either direct or remote, depending on the frequencies of the masker and maskee.

Loudness Change with Contralateral Noise

While investigating the effects of interaural phase on loudness measurements, Hirsh and Pollack (13), in 1948, found that the introduction of a thermal noise in the contralateral ear will increase the loudness of a suprathreshold tone mixed with noise in the test ear. No such enhancement of tonal loudness was observed when the tone was presented alone in the test ear along with the noise in the opposite ear. In fact, if the level of the noise in the opposite ear were very loud, the loudness of the tone in the test ear was reduced, presumably due to transcranial masking.

In 1948 Egan (7) reported a study on the effect of noise being presented to one ear on the subjective loudness of speech in the other. Using the method of adjustment, sixteen subjects varied the level of a noise in one ear while listening to a prosaic speech sample delivered at a constant level to the other. In the preliminary study 13 of the 16 subjects reported that speech sounded louder as the level of the contralateral thermal noise was progressively increased to a certain level, above which the speech began to sound fainter.

In a later study, using only two trained, normal-hearing listeners, Egan designed and carried out a more carefully controlled procedure in which each listener adjusted the level of one speech sample until it sounded equal in loudness to a similar prosaic speech sample that was being delivered alternately at a fixed intensity level in the same ear. The fixed levels were reported as 15, 25, 35, 45, and 55 dB SL.[1] Thermal noise ranging from 20 to 100 dB SL was presented to the opposite ear during alternate speech samples.

Egan's results fell into a consistent pattern which showed little or no loudness increase for speech in the presence of contralateral noise with noise levels lower than 40 dB SL. Then, as the noise level was increased above this value the speech with noise became louder until a maximum loudness increase was reached, after which the loudness of the speech seemed to decrease with increasing noise level. These maximum loudness increases occurred at different noise levels, depending on the fixed standard speech level. However, what was most interesting in the light of the present study was the tendency for the maximum loudness increase in noise to occur when the noise level was about 35 to 40 dB above the speech level. This effect was most pronounced at moderate speech levels. For example, the

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[1] Both the speech levels and noise levels given in this study are reported in sensation level units, i. e., levels above the subjects own threshold of detectability for speech or noise. Egan estimated that for these subjects 0 dB SL for speech would approximately equal 10 dB SPL, re .0002 dyne/cm^2.

maximum loudness increase for speech in noise (7 dB) was obtained when the speech level was 45-dB SL and the noise was delivered to the contralateral ear at 80-dB SL. Another generalization which can be made from these data is that there appears to be less loudness increase at high speech levels and at high noise levels. In some cases even loudness decreases were found at very high noise levels.

Egan offered two possible mechanisms to explain these results; The first was that when the intra-aural muscles (of animals) contract bilaterally in the presence of the noise they may, under certain conditions, produce an amplification effect. It wasn't stated as to how this might occur in humans. The second mechanism, offered by Egan as being more plausible, is as follows:

> The total impression of loudness in binaural stimulation is greater than for either ear alone. Thus the listener cannot 'hear out' the two components, one from the other, and then assess the loudness of each component. If the stimuli are markedly different, however, the loudness of one ear may not sum with the loudness from the other ear. Thus, if one pure tone is led to one ear and a pure tone of different frequency is led to the other, the amount of summation of loudness apparently depends upon the similarity in frequency between the two tones. It is probable, therefore, that a noise in one ear increases the loudness of speech heard in the other ear because of the similarity between the temporal and frequency characteristics of thermal noise and speech (7, p. 62).

Egan also reported another study which showed some variability due, (he thought), to procedural differences. Eight naive subjects made loudness matches for speech with the reference stimulus presented at a sensation level of 45 dB and with the noise presented at

70 dB SL. The average increase in the speech-with-noise signal was compensated for by a 3.7 dB change in the speech level when it was followed by the speech with noise. However, when the speech with noise was followed by the speech alone the speech level had to be increased by only 2.4 dB[2] in order to make a loudness match. This indicates that there may be a precedence effect involved. The relatively small increases found with both procedures when compared with Egan's first study are probably due to the fact that the speech and contralateral noise signals were separated by only 25 dB.

Some remarks were made in Egan's paper about some other experiments he had done pertaining to (1) the loudness of speech in the presence of contralateral masking pure tones of various frequencies, and (2) the effect of contralateral noise on the loudness of pure tones. With regard to the first, Egan reported no noticeable effect on the loudness of speech in the presence of high-level contralateral pure-tone masking, but there was a slight increase in the presence of low-level tone masking. Interestingly, in the second experiment no increase in the loudness of pure tones was observed in the presence of contralateral noise. There is no mention of the particular parameters

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[2] It has been found most convenient by Egan and by the authors of most of the other related studies to express loudness change--not in tones or loudness units--but in decibels signifying the intensity increases or decreases necessary to obtain equal subjective loudness between the stimuli being compared. This practice is adhered to in the present study.

used, however.

Among the earliest studies in which loudness changes in the presence of contralateral noise are reported are those designed to investigate the effect of the acoustic reflex. As early as 1941 Bekesy (2) observed that a low-frequency tone in one ear decreased in loudness when an intense high-frequency tone was presented to the other. A decade later Bekesy and Rosenblith (4) reported this same observation and added that the loudness decreases obtained in the unmasked ear were on the order of 5 to 10 dB, presumably due to the action of the acoustic reflex.

Shapley (28), in 1954, used a monaural loudness balance procedure similar to Egan's in an attempt to quantify the observed loudness change produced in pure tones as a result of the presence of contralaterally-presented noise as reported by 30 observers. Shapley describes his procedure as follows: "A 250 cycle tone at a 90 dB sensation level was introduced by phone into the right ear of each observer. Two seconds following the introduction of this tone a thermal noise was introduced by phone into the left ear, this also at a 90 dB sensation level. . . . The observers were given five seconds to note the reduced loudness of the tone while the noise was being delivered to the opposite ear. The noise stimulus was then terminated suddenly." During the 2- to 4-second period that followed the subject ". . . attenuated the tone in an attempt to maintain the loudness which seemed to him to be equal to the loudness observed during the presentation of the noise in the left ear. . . . The subject was then given a 15 second silent period before the cycle was repeated." (7, pp 419-420).

The results showed a mean decrease for the 30 observers of 15.1 dB in the loudness of the pure tone which was paired with the contralateral noise. However, the mean loudness decreases for each of the individual observers ranged from 7.4 dB to 26.8 dB SL, which indicates the existence of considerable intersubject variability even though each subject was reportedly consistent in his own responses. Shapley attributed this wide variability to (1) the possibility that the judgment of some subjects may have been influenced by subjective pitch changes which they reported (2) differences among subjects in the threshold of detectibility which would affect the sound pressure level of the 90-dB tone, or (3) differences among individuals in the ability of the acoustic reflex to attenuate the level of the tone.

Shapley did a second, more comprehensive study (29) which is unpublished but which has been reported in part by Prather (24) and Reger (25). Using a procedure essentially the same as that reported in his previous study (28) Shapley presented 250-Hz tones at levels ranging from 60 to 100 dB SL in 10-dB steps both in quiet and in the presence of four levels of contralateral noise. These noise levels were 60, 70, 80, and 90 dB SL. According to Reger (25) smaller reductions of loudness were obtained in this second study. For example, at 90 dB SL only a 6-dB mean loudness decrease was obtained as compared with the 15-dB decrease noted in the previous study. Reger also states that, in the course of experimentation with higher-frequency test tones, Shapley obtained loudness increases of about 4 dB in the presence of contralateral noise (25).

These results of Shapley's were statistically significant with respect to noise level and frequency, but he found little difference in loudness change as a function of tone level (29).

Prather (24) did a follow up study to determine if Shapley's results might have been different if the pitch shifts observed by Shapley's subjects were controlled. Ten subjects were trained to carry out monaural loudness balances between a tone appearing in quiet with a tone appearing in the presence of a 40-dB and a 100-dB SL thermal noise presented to the opposite ear. Only the tone levels of 20 dB and 80 dB SL were used. Five test-tone frequencies at one-octave intervals from 250 through 3000 Hz were used. Each of the 20 combinations of the three parameters was given under two conditions; (1) loudness match alone and (2) a match for both loudness and pitch. Prather describes the loudness-and-pitch match condition as follows: ". . . The subject was instructed to balance the two tones for both loudness and pitchby separate controls. . . . he adjusted the tone first for pitch, then for loudness, or vice versa, and then back and forth between pitch and loudness adjustments until he felt he had the best possible match for both." (24, p. 186).

The procedure for presenting the stimuli was similar to Shapley's but differed in that the two-second presentation of the standard tone-with-noise was followed by only a two-second silent period before the variable comparison tone was presented for two seconds, thus beginning a new six-second cycle.

The results showed both loudness increases and decreases, depending upon the stimulus parameters. Loudness increases were generally obtained at the 40-dB SL noise level and the 20-dB tone level, especially under the loudness-and-pitch match condition where loudness increases between 6 and 9 dB SL were obtained at all frequencies and at both noise levels. Loudness decreases were generally obtained for the 80-dB tones in the presence of the 100-dB noise. The exception was for the 500-Hz tone under the loudness-and-pitch match condition where large loudness increases were experienced under the high tone and high noise level conditions.

The within-subject variation was increased rather than decreased when the balances were made for pitch as well as loudness. Thus the wide variability between subjects observed in the Shapley study was not reduced by adjusting for changes in pitch.

Prather's results agree with those of other investigators (7, 27, 35) in showing that greater loudness decreases (or smaller increases) are obtained at high noise levels. He felt that the lack of loudness decrease at low noise levels and the decreases of up to 5 dB obtained at high noise levels added support for his "implicit" assumption that the binaural acoustic reflex is the mechanism that is responsible for the observed loudness changes. Prather explained his results as follows:

> Apparently if the noise is of sufficient intensity to activate the middle ear muscle reflex(es), it may well interact centrally with the pure tone stimulus in the opposite ear in such a way as to increase the loudness of the pure tone. Further, if one is willing to accept the model of Loeb and Riopelle as a reasonable one, a noise level of sufficient intensity to activate the middle ear muscles, such as the 100-dB SL white noise used in this study, may result in a greater binaural summation of loudness, greater in magnitude than the attenuation resulting from muscle contraction. Thus the over-all net effect, upon the loudness of a pure tone would be a facilitation effect, although perhaps not as great a facilitation as found in the 40-dB SL noise conditions. The 40-dB SL noise condition is one, of course, in which essentially no reflex activation would be expected and hence might be optimal for observation of loudness facilitation. (24, p. 190)

In agreement with the results of Shapley (29) and Loeb and Riopelle (17) Prather found significant interactions between loudness change and the frequency of the test tone. At increasingly higher frequencies greater loudness increases and smaller loudness decreases were obtained, although the magnitude of change became smaller at 2000 and 3000 Hz.

Loeb and Riopelle (17) reported a study designed to determine the effects of the acoustic reflex on both threshold sensitivity and loudness. In the loudness balance experiments fixed and variable tones of

500 Hz were alternately presented to the right ear of 11 sophisticated subjects at levels ranging from 70 to 105 dB in 5-dB steps. Presented with the fixed or standard tone, but overlapping it slightly, was an "activating" tone of 2200 Hz which was presented at a level of 105 dB in the opposite ear. Each observer was asked to state whether the comparison tone was fainter than, louder than, or equal in apparent loudness to the standard tone. Results indicated that the activating tone had no measurable effect at levels of 70 and 75 dB SL since the standard and comparison tones were generally reported as equal in loudness. However, at higher levels of the activating tone there were more reports that the comparison tone was louder than the standard tone that was presented with the noise. This would represent a loudness decrease.

In another experiment Loeb and Riopelle set the comparison tone attenuator so that this tone would be noticeably fainter or louder than the standard tone which was paired with the contralateral activating tone. Then each of the 14 subjects continued to make loudness judgments as the experimenter varied the comparison tone toward and beyond the "point of subjective equality." The results showed that a relatively louder comparison tone was required to match the level of the standard tone as the level of the standard tone was increased. The level of the contralateral activating tone in this experiment was held at 105-dB SL. The results of this second study are interesting in that only loudness decreases are reported in the presence of the activating tone. Some individual subjects showed no decrease in the loudness of the tone appearing with the activating tone until high levels of the test tone (which was overlapped by the activating tone) were reached. Unfortunately, on the basis of what appear to be preconceived ideas, the authors did not report results for stimulus conditions which might have shown loudness increases. The median loudness decreases shown were 7.2 dB at a standard tone level of 100 dB and 8.0 dB at a standard tone level of 105 dB SL.

The above results were interpreted as being supportive of the hypothesis that the acoustic reflex acts to attenuate intense sounds more than faint ones, thus it acts as an energy-limiting device rather than as a resistive attenuator. Loeb and Riopelle suggested a model which holds that the greater the excursion of the ossicles the greater is the counteracting force. Therefore, only the large excursions are attenuated by the decreased contracted middle ear muscles. However, they entertain another possibility that some of the subjects might have had voluntary control over their middle ear muscles and thus they may have "unintentionally inhibited the reflex to listen to the softer tones" (17, p. 609).

Vigran (35) reported a study concerning pure tone loudness changes produced by contralateral noise which was designed as a possible alternative approach for measuring the effect of the acoustic reflex. Three separate experiments were reported which were similar except that the variable parameter differed in each. In the first experiment the level of the tone was fixed at 80 dB SPL, and that of the noise at 100 dB SPL. The frequency of the tone was varied between 300 and 1500 Hz. In the second experiment the level of the tone was again fixed at 80 dB but the frequency was held constant at 1100 Hz. The noise level was varied between 75 and 105 dB SPL. In the third experiment the frequency was held constant at 1100 Hz, the noise level was maintained at 100 dB SPL, and the level of the tone was varied between 75 and 105 dB SPL. The contralateral noise stimulus was a 1/3-octave band of thermal noise centered at 2500 Hz, chosen because it would elicit the acoustic reflex at high levels without overlapping and possibly masking the test tones. A standard tone of one-second duration was presented one-half second before the comparison tone-with-noise combination which was also on for one second. A rest period of two and one-half seconds preceded the next cycle.

In the first experiment 16 normal-hearing subjects matched the loudness of the comparison tone-with-noise with the standard tone in quiet. The results showed that as the frequency of the tones was increased there was a corresponding loudness increase in the tone-with-noise, ranging from about 1 dB at 250 and 500 Hz to a maximum of about 7.5 dB at 1000 to 1500 Hz. This greater loudness increase as the tone approached the frequency of the noise band was attributed to binaural summation which cancels out the loudness reduction caused by the reflex action.

The results of the second experiment showed a gradual increase in the relative loudness of the 80-dB, 1100-Hz tone as it is paired with progressively higher levels of contralateral noise. A maximum increase of 7.0 dB was obtained with noise levels of 100 and 105 dB SPL.

The third experiment yielded results which suggest that the largest loudness increase occurs at tone levels which approximate the spectrum level of the noise. Maximum loudness increases of about 7.5 dB were obtained in the presence of the 100-dB SPL narrow-band, contralateral noise at tone levels of 70 and 80 dB SPL (the spectrum level of the noise was 78 dB). There was little difference in loudness increase at these two tone levels, but smaller loudness increases were shown at the 60-dB tone level.

Vigran attributed his observed loudness increases to "some sort of central interaction" rather than to the acoustic reflex although the reflex could not be ruled out altogether. He also concluded that the loudness balance procedure with contralateral noise was not an effective method for studying the effects of the acoustic reflex.

Vigran's results are at odds with those of Shapley (29) and Prather (22) who both found loudness decreases, especially for low-frequency tones of high intensity, when a tone was heard in the presence of a high-level contralateral noise. However, the disagreement between studies may be more apparent than real. In all three studies (22, 29, 35) there is agreement that smaller loudness increases or greater decreases are obtained (1) at lower frequencies, and (2) at high noise levels and high tone levels. Greater loudness increases are obtained also when the noise level is from 25 to 45 dB above the tone level.

Rowley (27) used the numerical magnitude balance method of Hellman and Zwislocki (10) to obtain loudness-intensity functions for a 1000-Hz tone. He used ten trained, normal-hearing subjects who made loudness judgments both in quiet and in the presence of four different sensation levels of contralaterally-presented thermal noise.

The 12 fixed tone levels used covered a range of from 8 to 100 dB SL in steps ranging from 4 to 10 dB. The range of the 12 tone levels varied somewhat with each noise level to allow for the masking effects of high-level noise on low-level tones. The broad-band noise levels were 40, 60, 80, and 100 dB SL.

Rowley's monaural loudness intensity function obtained in quiet agreed in shape and slope with those obtained by previous investigators (10, 26) who used the same psychophysical procedure. His results showing the effects of different levels of contralateral noise on the basic loudness-intensity function were also in general agreement with those obtained by Prather (24) and Vigran (35) for pure tones, and by Egan (7) for speech, despite the very different psychophysical procedures used in these studies. Rowley found that the rate of loudness levels is increased by the presence of the contralateral noise. He further reported that the ratio of increase in the loudness of the pure tone produced by the contralateral noise over the loudness of the tone in quiet grows with increasing levels of noise from about 1. 5 with 40 dB SL of noise to about 2. 6 with 100 dB SL of noise. Rowley also found that as the tone level is increased toward a given noise level the relatively greater loudness of the tone with contralateral noise is increased up to a pivotal intensity point, above which smaller loudness increases are noted. Rowley states that the "knee" or pivotal point of the loudness function curve usually occurs where the pure-tone level is approximately equal to the spectrum level of the noise. For example, Rowley's data show a maximum loudness increase of about 12 to 13 dB obtained under the tone-with-noise condition at a tone level of about 56 dB and a noise level of 100 dB SL. Rowley points out that under this condition, and under the 60-dB and 80-dB noise conditions as well, the point of maximum loudness increase occurred when the tone level approximated the spectrum level of the contralateral noise.

This tone level to noise spectrum level relationship can also be seen in Vigran's (35) results although he used a 1/3-octave noise with a center frequency well above that of any of the test-tone frequencies used. The spectrum level of Vigran's remote "arousal" noise, when delivered at a level of 105 dB SPL, was approximately 78 dB. This is very close to the 80-dB SPL tone level at which the maximum mean loudness increase of 7.5 dB was reached.

A comparable phenomenon can be seen in Egan's (7) results, although they cannot be compared directly because speech was used as a stimulus. Nevertheless, Egan's greatest increase in the loudness of the speech stimulus when presented with 80 dB SL of contralateral noise, occurred when the sensation level of the speech was about 42 dB. The magnitude of the increase was about 7.0 dB according to interpolation from Egan's curves. The maximum increase in the loudness of speech obtained in the presence of a given level of contralateral noise occurs over a fairly wide range of speech levels. A similar relationship was obtained at other noise levels. Thus, it appears that this relationship between speech level and noise spectrum level is similar to that observed by Rowley for pure tones.

Rowley's results also agree with those of Egan in showing very little increase in the loudness of test stimuli that are paired with contralateral noises as low as 40 dB SL, regardless of the level of those test stimuli. Rowley pointed out that the spectrum level of the 40-dB noise is approximately at threshold which may prevent complete summation under this condition.

With higher levels of contralateral noise, however, Rowley found loudness decreases as the tone level approached threshold.

Interpolating from Rowley's loudness function curve obtained at the 100-dB SL noise level, it would appear that the magnitude of this loudness decrease reaches about 14 dB for tone levels as low as 20 dB SL.

Rowley postulates the following mechanisms for his results:

> The form of the loudness function at low pure-tone levels is determined by transcranial conduction of the noise to the test ear producing ipsilateral masking or at lower noise levels by a 'central masking' effect. The noise thus produces an elevation in the threshold and a decrease in the loudness of the low level pure-tone stimulus. The loudness of the higher level pure-tone stimulus is not reduced producing the recruitment-like phenomenon long observed in noise masked ears.

Rowley further postulates that a summation effect, like that associated with binaural stimulation with similar stimuli, is responsible for the loudness increases at higher tone and noise levels. However, he states that "the reduced rate of loudness growth above the knee is not a result of the acoustic reflex but rather occurs because the optimal intensity relationship necessary to achieve maximum summation is not maintained as the pure-tone level is increased above the spectrum level of the noise."

A number of studies have been reviewed in this chapter which have shown changes in the perceived loudness of a sound produced in the presence of dissimilar contralateral stimuli. Differences in the magnitude and direction of these loudness changes observed by the various investigators appear to be related to a number of stimulus conditions such as (1) the frequency of the test tone stimulus (2) the bandwidth and center frequency of the contralateral stimulus and their frequency relation to the test tones (3) the level of the contralateral stimulus (4) the level of the test stimulus and (5) the relationship between the levels of the contralateral stimulus (noise) and the test stimulus. Other differences in results have been found depending upon whether or not subjects have been asked to consider in their judgments the changes in the pitch and quality of test tones that appear subjectively in the presence of contralateral noise (24, 29). Still other variations in loudness change seem to arise from procedural differences such as the order of presentation of the stimuli (7).

CHAPTER III

INSTRUMENTATION AND PROCEDURE

Introduction

In the studies reviewed in the previous chapters a number of relationships were shown to exist with respect to changes in the loudness of a tone in one ear when it was paired with a contralateral noise. The loudness increase produced in the test tone was shown to be of greater relative magnitude as the noise level was increased above the tone level until a noise level was reached at which either (a) the acoustic reflex was elicited (24, 29, 35) or (b) contralateral masking occurred due to the transcranial conduction of the noise to the test ear (27). Either of these conditions will result in a decrease (or a reduction of the increase) of the relative loudness of the tone sounded with the contralateral noise.

Conversely, as the tone level is increased with respect to a constant contralateral noise level the relative loudness of the tone increases until a certain level is reached. Above this tone level the loudness increase produced in the tone by the contralateral noise becomes smaller until finally, at high relative tone levels no loudness increase is observed.

Rowley (27) observed that the maximum summation or loudness increase in the presence of a contralateral broad-band thermal noise occurs in the intensity region where the level of the tone approximates the spectrum level of the noise. Inspection of Vigran's data (35) also shows maximum loudness increases occurring at tone levels which approximate the spectrum level of the noise. However, Vigran not only used a different psychophysical procedure but the frequency of his narrow-band noise was centered nearly one octave above the frequency of the highest tone used, which raises questions concerning the frequency relationships between tone and noise necessary to produce such loudness increases.

It seemed desirable to investigate further the frequency and intensity dependence of the loudness changes produced by a contralateral noise. Therefore, a study was designed to determine the amount of relative loudness change that occurs during monaural loudness balances of successively-presented, identical test tones when different bandwidths and levels of thermal noise are presented in the contralateral ear along with one of the tones.

A second study was carried out which differed from the first only in the experience, training, and instruction of the subjects. It was necessitated by the wide intersubject variability found in the first study, presumably as a function of the different listening criteria used by the subjects.

In the first study monaural loudness balance judgments were obtained from four normal-hearing, sophisticated adult listeners under 36 combinations of four stimulus parameters and two procedural variables. These are shown in Figure 1 and can be summarized as follows: (a) two noise conditions; broad-band and narrow-band (b) two noise levels; 75 and 95 dB SPL (c) tones of three frequencies; 500, 1000, and 2000 Hz and (d) three test tone levels, which varied according to the noise levels and noise bandwidths with which they were paired. For example, it can be seen in Figure 1 that under the broad-band noise condition tone levels of 30, 40, and 50 dB SPL are paired with the overall noise level of 75 dB SPL. Tone levels of 50, 60, and 70 dB SPL are paired with the 95-dB SPL noise level. The tone levels were selected so that the middle value approximated the spectrum level of the contralateral noise. Rowley's (27) and Vigran's (35) data suggest that this intensity relationship should produce relatively large effects.

The tone levels used to obtain balances under the narrow-band noise condition were all 10 dB higher when paired with a given noise level than those shown under the broad-band noise condition because the spectrum level of the narrow-band noise was approximately 10 dB higher at given overall levels than that of the broad-band noise. The tone levels overlapped in the two noise conditions permitting direct

SUBJECTS	SESSION	Noise Type	Noise Level and Variable Tone		Tone Levels	Tone Frequencies
No. 1	SESSION # 1	Broad-Band	95 dB	TA	50	500 1000 2000
					60	1000 2000 500
					70	2000 500 1000
			75 dB	TWN	40	1000 500 2000
					50	500 2000 1000
					30	2000 1000 500
	SESSION # 2	Narrow-Band	75 dB	TWN	50	2000 500 1000
					60	1000 500 2000
					40	500 2000 1000
			95 dB	TA	80	500 1000 200
					60	1000 2000 500
					70	2000 1000 500
No. 2	SESSION # 1	Narrow-Band	75 dB	TA	60	500 2000 1000
					40	2000 1000 500
					50	2000 500 1000
			95 dB	TWN	60	1000 500 2000
					70	500 1000 2000
					80	2000 1000 500
	SESSION # 2	Broad-Band	95 dB	TWN	60	1000 500 2000
					70	500 2000 1000
					50	2000 1000 500
			75 dB	TA	50	1000 2000 500
					30	2000 500 1000
					40	500 1000 2000
No. 3	SESSION # 1	Broad-Band	75 dB	TWN	50	1000 2000 500
					30	500 2000 1000
					40	2000 500 1000
			95 dB	TA	50	1000 500 2000
					60	500 1000 2000
					70	2000 1000 500
	SESSION # 2	Narrow-Band	95 dB	TA	60	2000 500 1000
					70	500 1000 2000
					80	1000 2000 500
			75 dB	TWN	50	1000 500 2000
					60	2000 1000 500
					40	500 2000 1000
No. 4	SESSION # 1	Narrow-Band	95 dB	TWN	70	2000 1000 500
					80	1000 2000 500
					60	500 1000 2000
			75 dB	TA	60	2000 500 1000
					40	1000 500 2000
					50	500 2000 1000
	SESSION # 2	Broad-Band	75 dB	TA	30	500 1000 2000
					40	2000 500 1000
					50	1000 500 2000
			95 dB	TWN	60	2000 1000 500
					70	500 2000 1000
					50	1000 2000 500

TIME →

Figure 1 - Order of presentation of variable combinations and conditions. All levels are in dB SPL and all frequencies are in Hz.

comparison between the noise conditions at two out of the three tone levels used.

The frequency parameters selected for this study were chosen in order to obtain evidence concerning the effect of the acoustic reflex on the apparent loudness summation. It has been demonstrated previously (18, 19, 32, 38, 39) that the acoustic reflex is effective at 500 Hz but has no appreciable attenuating effect at 2000 Hz. Another consideration was that no data were available concerning how much loudness increase one can expect as a result of contralateral noise stimulation when the test tone is higher in frequency than the upper frequency of the noise band.

The two noise levels of 75 and 95 dB SPL were selected in order to determine if this variable would have any differential effect on loudness increase. One of these noise levels is above the average normal threshold for the acoustic reflex while the other is below this threshold.

The two noise conditions were broad-band and narrow-band. The broad-band thermal noise was limited in spectrum width to about 7000 Hz, mainly by the frequency response of the earphone. The narrow-band noise had a nominal band width of 707 Hz (3 dB down) and was centered at 1000 Hz.

Two procedural variables were also investigated. The first was to have each subject vary both the tone alone and the tone presented with the noise under each combination of the above physical parameters in order to determine if this variable would have a significant effect on the apparent loudness change. It was observed that in some studies (24, 29) the tone appearing alone had been varied by the subject while in another study (35) the tone appearing with the noise had been the variable tone.

The second procedural variable investigated was the direction of the initial approach to the balanced condition. It had been observed during the pilot study preceding this investigation that under some noise conditions considerable differences may be seen between balances that are initially approached from below, (i. e., the up-down-up, etc., direction) and loudness balances that are approached initially from above (i. e., the down-up-down, etc., direction). All subjects were asked, therefore, to alternately approach the balanced condition from above and from below for each measure. That is, they would begin with the comparison tone set louder than the standard tone on the first match, adjust the attenuator until it was softer than the standard tone, reverse direction until it was again louder than the standard tone, etc., until a loudness balance was reached. Then the experimenter selected a new reference point by changing the level of his series-connected attenuator and asked the subject to balance the loudness of the two tones starting with the variable tone level below the level of the standard tone.

It should be remembered that the term standard tone will always refer to the tone which is held at a given level during a balance as determined by the examiner. The term comparison tone will always refer to the tone which is manipulated in level by the subject. The comparison tone may be either the tone heard alone (TA) or the tone heard with the noise (TWN) which is also true for the standard tone. The order of appearance and the coincident appearance of the factors was approximately balanced as will be shown in detail in a subsequent section.

A more detailed description of the subjects, apparatus, and experimental procedures is presented in the following sections.

Subjects

In the first study data were collected from four trained, normal-hearing male subjects, each of whom was a graduate student or employee at the University of Oklahoma Medical Center. No subject was included in the experiment who had a history of ear pathology or whose hearing thresholds in either ear exceeded a level of 15 dB (re. 1964-ISO Standard) at any frequency between 500 and 6000 Hz inclusive as determined by an audiometer threshold test.

In the second study the data were collected from four adult subjects who had no previous experience in psychophysical studies. Two subjects were male and two were female. Except for previous experience and training all of these subjects satisfied the criteria for selection as described in the preceding paragraph for the subjects in the first study.

The Test Environment

All data were collected in a sound-treated test suite at the Speech and Hearing Center at the University of Oklahoma Medical Center, Oklahoma City, Oklahoma. The test room was of double-walled, insulated construction with a glass window for maintaining visual contact between subject and experimenter. Auditory communications were maintained by means of a Talk-A-Phone intercommunication system.

Sound-level measurements made in the test room under experimental conditions showed an ambient room noise level of 48 dB SPL as determined by the random C-scale readings on an octave-band analyzer (General Radio Model 1558 AP).

Screening Apparatus

Hearing thresholds for all subjects in both studies were obtained by means of a portable Beltone Model 10-C audiometer in a sound-treated room similar in construction to the test room. The audiometer was calibrated prior to the tests relative to the 1964-ISO Standard.

Experimental Apparatus

The experimental apparatus used to deliver the test-tone pulses and contralateral noise levels is indicated by the block diagram shown in Figure 2.

The source of the standard and comparison tones was an audio oscillator (Hewlett-Packard Model 200 AB), the output of which was split and fed to channel A-2 of dual-channel electronic switch No. 2 (Grason-Stadler Model 829S) and to the single-channel electronic switch No. 1 (Grason-Stadler Model 829C).

The switches were triggered alternately by a timing network consisting of a waveform generator (Tektronix Type 162) and four pulse generators (Tektronix Type 161). The timing paradim is shown graphically in Figure 3. The waveform generator was set for a two-second period during which pulse generator No. 1 fired immediately and was turned off 400 msecs later by pulse generator No. 2. After a silent period of 600 msecs pulse generator No. 3 turned on both the tone and noise by triggering electronic switch No. 2, which pulse generator No. 4 turned off 400 msecs later. The rise and decay times for both the tone and noise pulses were 25 msec. According to Sergeant and Harris' (31) results this timing sequence should produce negligible cumulative loudness adaptation.

When the tone with noise (TWN) was used as the comparison tone it was fed from output A-2 of electronic switch No. 2 (ES-2)

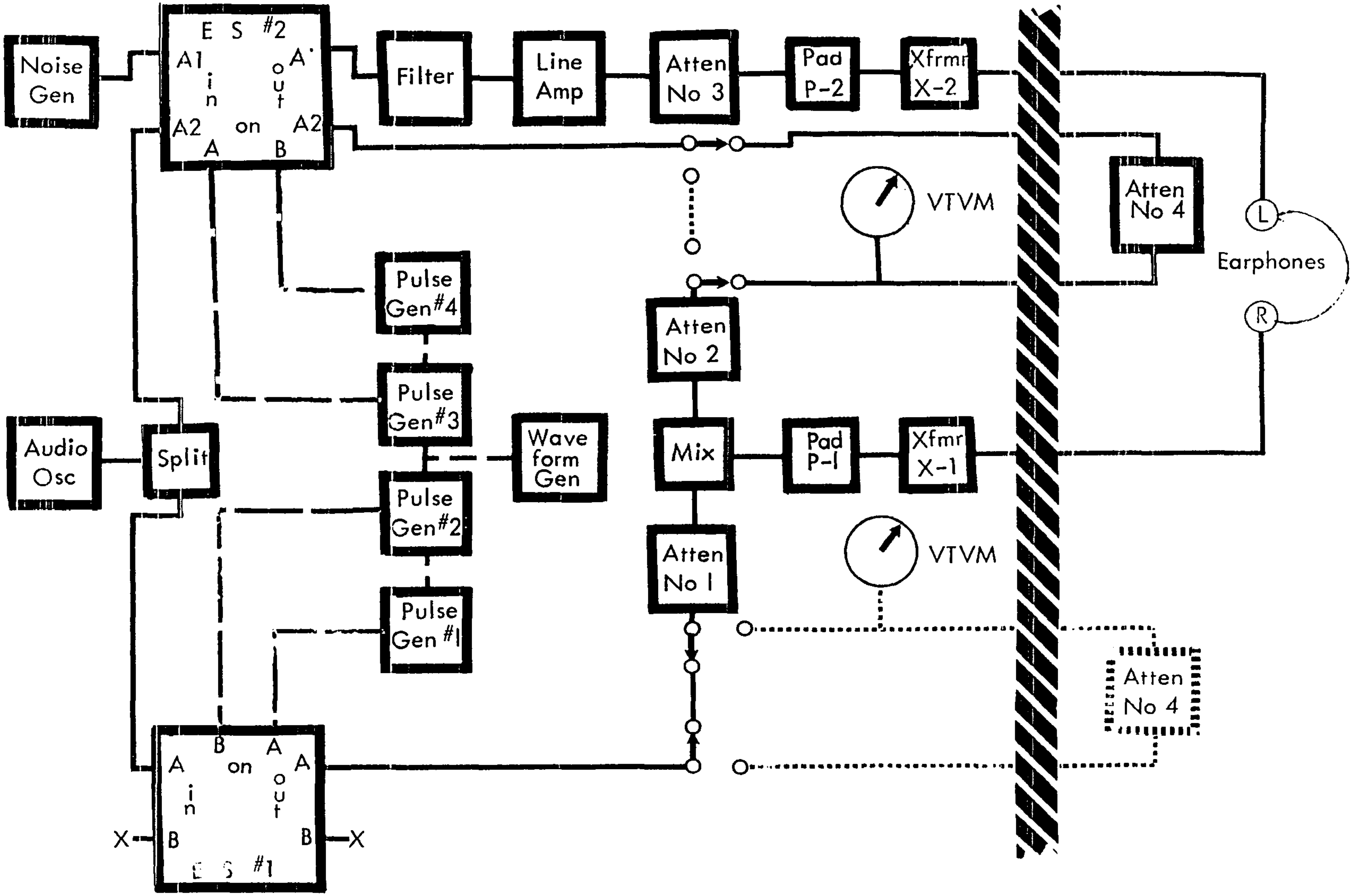

Figure 2 - Experimental Apparatus

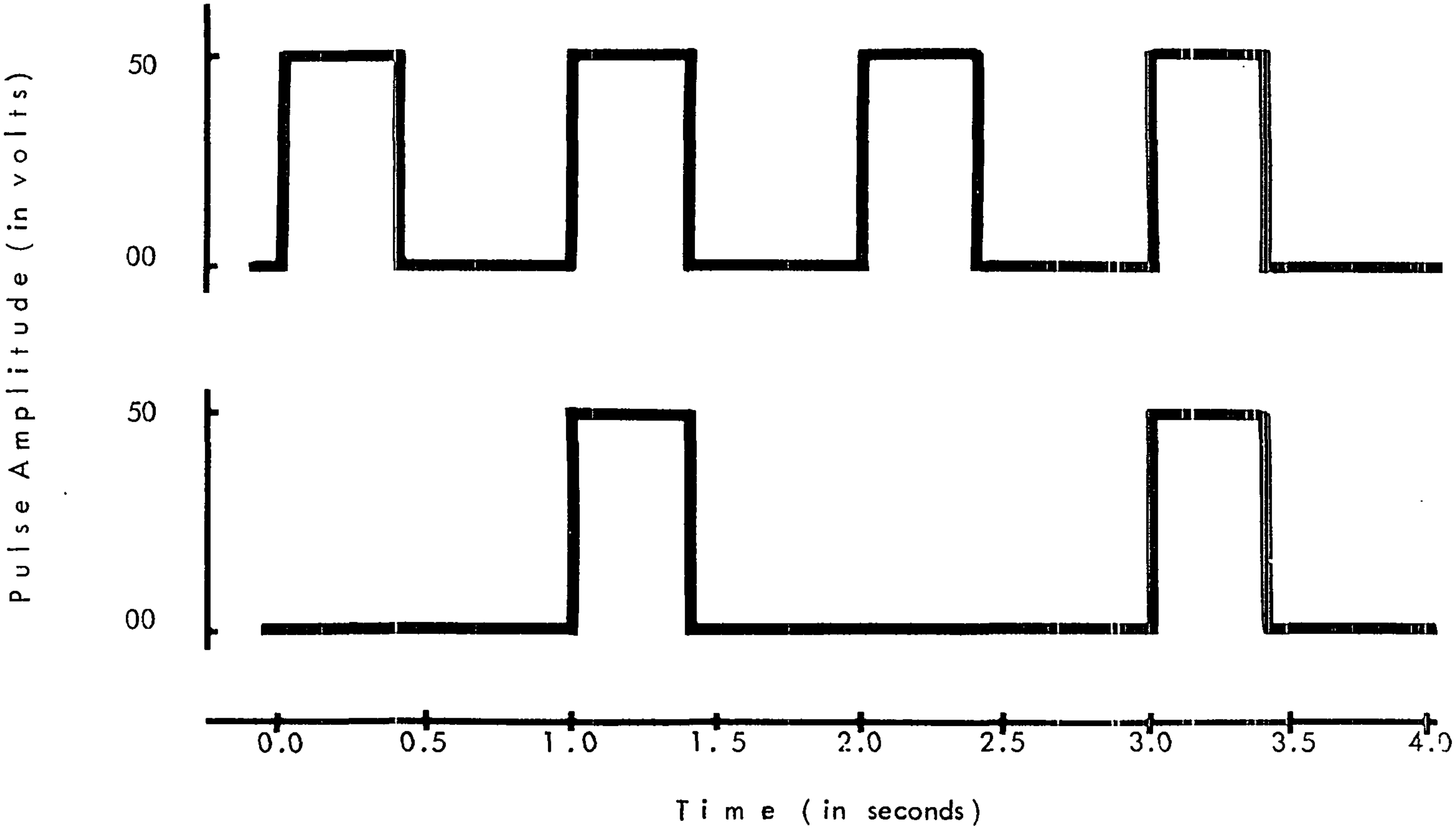

Figure 3 - Time sequence used for presentation of signals

directly to the subject's attenuator (No. 4) (Clarostat 500 ohm variable T pad with logarithmic taper) in the test room. This attenuator had no detents no visible scale and was continuously variable over a range of about 45 dB. A voltmeter (Ballentine Model 300) was connected to the attenuator output where it re-entered the control room, enabling the experimenter to read out directly in decibels the amount of relative increase or decrease in the magnitude of the signal before it entered control attenuator No. 2 (Hewlett-Packard Model 350 AR). This tandem arrangement enabled either the subject or the experimenter to control the level of the comparison tone before it reached the mixer, matching pad, transformer, and then the TDH-39 earphone in the test room.

The dotted lines shown in Figure 2 indicate the circuit modifications required when the tone alone (TA) served as the comparison tone and the TWN remained at the fixed level set by the experimenter. Under this condition the TA was fed directly to the subject's attenuator (No. 4) in the test room, then back into the control room where its output was monitored on the voltmeter and passed through attenuator No. 1 before it was fed to the mixer, matching pad, transformer, and then into the test room to the TDH-39 earphone. The TWN signal was then fed directly to control attenuator No. 2 and then alternated with the TA in passing through the mixer, matching pad, transformer and to the same TDH-39 receiver as the TA.

The noise was produced by a noise generator (Grason-Stadler Model 455C). It was fed to channel A-1 of dual-channelled electronic switch No. 2 where it was pulsed and synchronized to appear with the TWN. Under the narrow-band noise condition the pulsed output was passed through the band-pass filter (comprised of high and low-pass components of Allison Model 2-B). The filtered output was then amplified by a line amplifier (Altec-Lansing Model 436C Compressor Amplifier) before it passed through attenuator No. 3 (Hewlett-Packard Model 350 AR) which enabled the experimenter to control the level of the noise. The noise signal was then fed through an isolation pad and transformer X-2 to the TDH-39 earphone opposite to the one receiving the tones. Both earphones were mounted in type MX 41A/R cushions and held in a standard headband.

The frequency and duration of the test signals were checked for accuracy with a counter-timer (Transistor Specialties Inc. Model 361). The rise and decay patterns were checked with an oscilloscope (Tektronix Model 561).

The characteristics of the filter were verified with a graphic level recorder (General Radio Model 1521B) driven by a beat-frequency oscillator (General Radio Type 1304B). The octave-band filter exhibited an attenuation rate of 29 dB per octave.

Prior to the data collection the linearity of the attenuators was evaluated using a calibrating unit (Allison Model 300). The results showed that the control attenuators for the tone were accurate within 0.1 dB from step to step and had a cumulative error of no more than ± 0.5 dB over a range of 40 dB. The noise attenuator was accurate within ± 0.1 dB over a 50-dB range.

The intensity calibration of the tone and noise signals delivered to the TDH-39 earphones was checked prior to each experimental session using a condenser microphone (Western Electric Model 640AA) and condenser microphone complement (Western Electric Model 100 D/E). The earphones were mounted on an NBS type 9A coupler.

Procedures

The psychophysical procedure utilized in this study was the method of adjustment. Each subject was asked to adjust the level of the comparison tone until it was equal in loudness to an alternately-presented standard tone of identical frequency but fixed intensity. The comparison tone was the tone appearing alone one-half of the time and the tone appearing with the noise the other half of the time. A balance was initially approached from a level above that of the standard tone one-half of the time and from below one-half of the time. The subject used an unmarked, detentless attenuator to make his adjustments. A secondary attenuator controlled by the experimenter prevented the subject from obtaining positional clues from his attenuator in arriving at a balance.

Subject Training

In the first study a preliminary training period was required of each subject in order (1) to familiarize him with the loudness balance task under the various tone and noise conditions and (2) to help him establish a reliable criterion for a loudness match. Satisfactory subject sophistication for the task was evidenced by (1) his ability to repeat a loudness match within plus or minus two decibels of the level of the original balance in the presence of a just detectable contralateral noise and (2) a lack of further improvement in performance of the loudness-matching task regardless of the contralateral noise condition. One subject satisfied these criteria during the second practice session, but the others required three or four practice sessions in order to be satisfactorily consistent in their loudness matches under the various tone and noise conditions.

These preliminary sessions also served to further familiarize the experimenter with the apparatus and the order of presentation of the various combinations of stimulus parameters. The final training session and the first experimental session were separated by at least one day.

The subjects in the second study were trained differently than those in the first study. Instead of receiving a long training period, each was given only two trial loudness balances in quiet at each frequency, one starting from above, and one from below the balanced condition. They were also given one trial balance in the presence of a low-level noise while varying the tone alone (TA) and another trial balance in which they varied the tone-with noise (TWN). Following these trial balances they immediately began the experimental procedure as described below. The only modifications in the procedure from that followed by the subjects of Study I were that (1) one trial balance was given prior to each new tone and/or noise condition and (2) instructions were repeated if the subject had a question or seemed to be making bizarre or inconsistent responses.

Experimental Procedure

For both studies the experimental data were collected from each subject in two listening sessions of approximately two hours each. Precautions were taken to insure that each subject was rested and alert prior to each session. In addition, he was given a rest period halfway through each session. The right ear of each subject received the tones and the left ear received the noise.

The 36 combinations of the four parameters plus the two procedural effects investigated were presented to the four subjects in as nearly a balanced order as was possible. The balanced temporal order of test-tone levels and frequencies was sacrificed to some extent in order to reduce associations between particular test-tone levels, frequency orders, and noise variables. The temporal sequencing and the coincidence of the parameter values are shown in Figure 1 (p. 33).

The blocks representing each listening session show the noise conditions at the top and the tone levels at the bottom. The subjects are identified along the ordinate and the temporal order is shown from left to right. For example, it is seen that in the first session Subject #1 first varied the intensity of a 500-Hz tone to equal loudness with a fixed-level, 500-Hz tone set at 50 dB. A high-level (95 dB) broad-band noise was presented to the opposite ear concurrently with the fixed-level tone. Balances were then obtained for 1000- and 2000-Hz tones under the same set of conditions.

The procedure was then repeated at the middle tone level (60 dB). the order of frequency presentations was altered under this condition so that the 1000-Hz tone appeared first, the 2000-Hz tone second, and the 500-Hz tone appeared third. Then, with the noise parameters unaltered, the experimenter switched to the high-level tone and the subject completed loudness balances for the 2000-, 500-, and 1000-Hz tones respectively. The subject was then allowed a ten-minute rest period while the experimenter adjusted the equipment to make the tone-with-noise (TWN) the comparison tone and the tone alone (TA) the fixed tone.

When testing was resumed Subject #1 first balanced the loudness of the 1000-Hz tone (TWN) appearing in the presence of the low-level (75 dB) broad-band noise with that of the standard tone which was delivered to the ear at the 40-dB (or middle) tone level. The procedure was then repeated successively at 500 and 2000 Hz, etc.

In the second session, which followed the first after a period of from one to four days, the order of presentation of the noise conditions and of all tonal combinations were varied with respect to session one as shown in the right-hand half of Figure 1. It can also be seen in Figure 1 that the order of presentation of the noise parameters was reversed from subject to subject and that the tone conditions are approximately balanced for temporal order and coincidence across subjects.

Instructions to Subjects

Prior to each training session each subject in Study I was informed verbally of the purpose of the study and the procedures to be followed. In addition he was given a card containing printed instructions as follows:

> You are about to participate in a psychophysical study on loudness. Your specific task is to change the intensity level of a variable tone heard in your right ear until it sounds equal in loudness to an identical tone of fixed intensity which you will hear alternately also in the right ear. The variable attenuator on the table to your right is for this purpose.
>
> You will note that as you turn the attenuator knob in a clockwise direction the variable tone will get louder. As you turn the knob counter-clockwise the tone will get softer.
>
> Appearing with one of the tones but in the left earphone

> will be either a broad-band or a narrow-band noise. You will learn to disregard the noise and listen only to the comparative loudness of the two tones. At first the contralateral noise will be just loud enough to help you differentiate between the two tones. With the noise at this level you will make two balance judgments. First you will begin with the variable tone being much louder than the fixed tone and you will decrease it until it is softer than the fixed tone. Then increase the level of the variable tone until it sounds equally loud as the standard or fixed tone. Nod your head affirmatively when you feel that the two tones are equally loud. Do not move your attenuator until I nod affirmatively that your level has been recorded.
>
> Now repeat the above procedure. This time approach the loudness balance from below. Begin with your attenuator in a counter-clockwise position so that the variable tone is softer than the fixed or standard tone. Increase the level until the variable tone sounds louder, return to where it is softer, and then increase the level until it sounds as loud as the standard tone. When the experiment begins you will see a card appearing in the window to remind you whether to approach the balance from above or below.
>
> Remember that during half of each listening session you will be varying the level of the tone with the noise (TWN). During the other half you will balance the loudness by varying the level of the tone alone (TA).
>
> Are there any questions?

Following the preliminary practice balances further instructions were presented to each subject in Study I. These same instructions were also seen and heard by the subjects in Study II.

> Now you will hear the three paired tones appear at each of three different intensity levels. Appearing with one of the tones will be either a low-level or a high-level noise in the left ear. Under these conditions your balancing task may be more difficult. You must resist the tendency to change your criterion of judgment if the pitch, quality, or laterality of the tone with the noise seems to change. Your judgment must be based solely upon magnitude or loudness, regardless of any other differences between the tones--either real or fancied. You should require no more than one minute to complete a loudness balance, although you may take as much time as you need to insure accuracy.
>
> After completing the first series of balances you will take

> a ten-minute break before completing the last series under a similar set of variables. The same procedures will be followed during your second and final session.
>
> Remember that (1) all judgments are to be made entirely on the basis of the relative magnitudes or loudness of the two tones and (2) once a loudness balance has been completed do not move the attenuator knob until the result has been recorded as evidenced by the examiner's signal.

The subjects in Study II also were given additional verbal instructions regarding the listening criteria they were to use. Specifically, they were asked to balance the loudness of the two tones as requested in the above instructions, but were cautioned that there might be quality or localization changes in the tone which was presented with the noise. They were told not to try to block out the noisiness surrounding the tone but to consider the tone and its associated noisiness as a total complex, the loudness of which they were to compare with the loudness of the tone appearing alone. They were also cautioned that there might be more than one point on their attenuator at which the two tonal signals would seem to balance depending on the criterion applied. However, they were to try to hold to the requested listening criterion. Occasionally these instructions were repeated if a subject seemed to be having difficulty in following the instructions or in holding to the requested listening criterion.

The Processing of the Data

The data for both studies were processed using an analysis of variance designed for multi-factor experiments having repeated measures (40, p. 300). The main effects treated were noise type, noise level, tone frequency, tone level and the two procedural variables of (1) which tone was varied and (2) whether the initial approach was from a level above or below that of the fixed-level tone. The interactions between these main effects were also tested.

The data for Study I were also analyzed by comparing the results of Subjects #1 and #3 (Group #1) with those of Subjects #2 and #4 (Group #2). This separate treatment was necessitated by the wide differences in the data obtained from the two pairs of subjects.

It was realized, of course, that this "after-the-fact" categorization violates a basic tenent of the statistical decision-making process. But, after Study II was completed and showed no such wide differences between subjects, it was hoped that such treatment of the data from Study I might offer an impression of the magnitude of the differences between subjects, whatever their cause. Also such an analysis improved the evaluation of the other main effects. The data from Study II were analyzed using the four subjects as a single group. The processing of the data was carried out by the use of an IBM 360 computer (Model 50).

CHAPTER IV

RESULTS

Introduction

Two studies are reported which are identical in most respects but which differ in the criteria the subjects were asked to use in evaluating relative loudness. The purpose of both studies was to investigate the loudness change that occurs during monaural loudness balances of identical pure tones when one of the tones is paired with contralaterally-presented thermal noises of different bandwidths and levels.

The main effects investigated were noise type, noise level, tone frequency, and tone level. Specifically, a broad-band noise and an octave-band noise were each presented to the left ears of four subjects at one level which should have elicited the acoustic reflex and at another level which should not have done so. The test stimuli which were presented to the right ear included a 500-Hz tone which should have been affected by the reflex but which is below the octave-band noise in frequency, a 1000-Hz tone which is at the center of the octave-band noise, and a 2000-Hz tone which is higher in frequency than the octave-band noise. Each tone was presented at three levels which varied with each different noise type and noise level so that the middle tone level would always approximate the spectrum level of the contralateral noise. Also studied were two procedural effects: (1) whether the tone heard with the noise or the tone which was heard alone was varied by the subject, and (2) whether the subject's initial approach to the balanced condition was from a tone level above or below the intensity producing a judgment of loudness equality.

In the first study four highly-trained, normal-hearing adults--sophisticated in psychophysical procedures--used the method of adjustment to obtain monaural loudness balances under the conditions described above. The order of presentation of the experimental conditions was systematically balanced in order to reduce the effects of any temporally-related biases. Prior to gathering the data each subject participated in several training sessions during which he practiced the experimental task until reliable measures were obtained. During the training sessions the subjects were instructed to disregard the contralateral noise and to concentrate on matching only the loudness of the two tones appearing alternately in the test ear.

The results of the first study did not readily lend themselves to a meaningful statistical analysis when the data from all the subjects were grouped because two of the four subjects obtained loudness increases in the presence of the contralateral noise while the other two obtained loudness decreases of approximately the same magnitude.

As a part of a re-evaluation of the experimental procedures the four subjects were questioned regarding their listening criteria. All subjects expressed difficulty in maintaining a criterion for equal loudness for the two tones under all conditions because of various quality and localization changes associated with the tone during the different noise conditions in the contralateral ear. Under some conditions the tone presented with the noise appeared to lateralize toward the opposite ear and blend with the noise. At other times the tone-with-noise seemed to get "fuzzy" which made its recognition difficult. Subjects #2 and #4 (those that produced the loudness decreases) reported that they had mentally tried to suppress or block out the noise, both that heard contralaterally and that associated with and surrounding the tone sounded with the noise in the opposite ear. Instead, they had tried to concentrate on only the tone itself which appeared in the midst of the noise complex. With this criterion the noise associated with the tone presumably represented an interference which decreased the apparent loudness of the tone occurring with the noise.

The other two subjects (#1 and #3) reported that they considered the tone, and its associated noisiness, as a form of combined, complex, tonal-like signal to which it was easier for them to match the criterion tone occurring alone. The use of this criterion apparently resulted in loudness increases. It was apparent from these comments that either loudness decreases or increases could be obtained depending upon whether a subject used only the pure tone element of the complex or whether he included the fringe area noisiness which accompanied the tone as well in his judgment of equal loudness.

In order to assess this effect further the second study was carried out. Four normal-hearing, previously-inexperienced subjects were used. The procedures were essentially the same as in the first study. However, these subjects were not given the instructions that were associated with the training sessions in the first study, but only those instructions that preceded the experimental sessions. In addition, each subject was cautioned that there might be more than one point on his attenuator at which the two tones might sound equally loud. He was asked to try to hold to the same criterion for balance which had resulted in loudness increases in the previous study; namely, to consider the noisiness associated with the tone in the presence of the contralateral noise as a part of the signal to be balanced with the tone heard alone.

The data from both studies were processed using an analysis of variance designed for multi-factor experiments having repeated measures (40).

Results of Study I

Inspection of the data from Study I revealed immediately the almost equal but opposite loudness changes produced by the two pairs of subjects. It is apparent that simple means averaged across all four subjects would produce near 0.0 dB loudness level change indications. For example, the mean loudness level increase in the presence of noise across all conditions for all subjects is slightly less than 0.3 dB. Because of this virtual cancellation of effects and because of the great inter-subject variability it was decided at this point to carry out the second study. Nevertheless, it seemed worthwhile to evaluate the results of the first study by treating subjects #1 and #3 and subjects #2 and #4 as two separate groups. This after-the-fact categorization violates, of course, a basic tenent of the statistical decision-making process. However, it was hoped that an impression of the magnitude of the differences, whatever their cause, and an evaluation of other main effects could be obtained thereby. With these precautions in mind, the outcomes are presented in the following sections.

Listening Criteria

Group #1 (Subjects #1 and #3) produced an overall mean loudness increase of 2.4 dB. Group #2 (Subjects #2 and #4) produced an overall mean loudness decrease of 1.8 dB. The difference between these two group means was significant at the .05 level. The error term was quite large reflecting the large differences between the subjects even after subdivision into two groups.

Noise Type

Another variable which was shown to be significant at the

.05 level was noise type. There were no significant interactions between noise type and other conditions. Neither were there significant differences among individuals treated alike, which indicated that this effect was similar for all subjects. This is shown in Figure 4 which presents the mean loudness increases for each subject across all other conditions as a function of noise type. It is seen that greater loudness increases (or smaller decreases) were obtained by all subjects under the narrow-band noise condition. This figure also illustrates the wide separation between the two groups of subjects.

Procedural Variables

There was a significant interaction between the procedural variable of tone-with-noise vs. tone alone (TWN-TA) and tone level. When the TA was varied by the subject smaller mean loudness increases were shown at low and high levels while larger increases were shown at medium tone levels. When the TWN was used as the comparison tone (see Figure 5), the greatest loudness increase occurred at the low tone level and progressively smaller increases were obtained at medium and high tone levels. These differences are small, generally on the order of 0.5 dB at each tone level. Yet, the variance among subjects was small also as was indicated by the lack of a significant error term. There is no immediate explanation for these differences except that at low tone levels some subjects reported that it

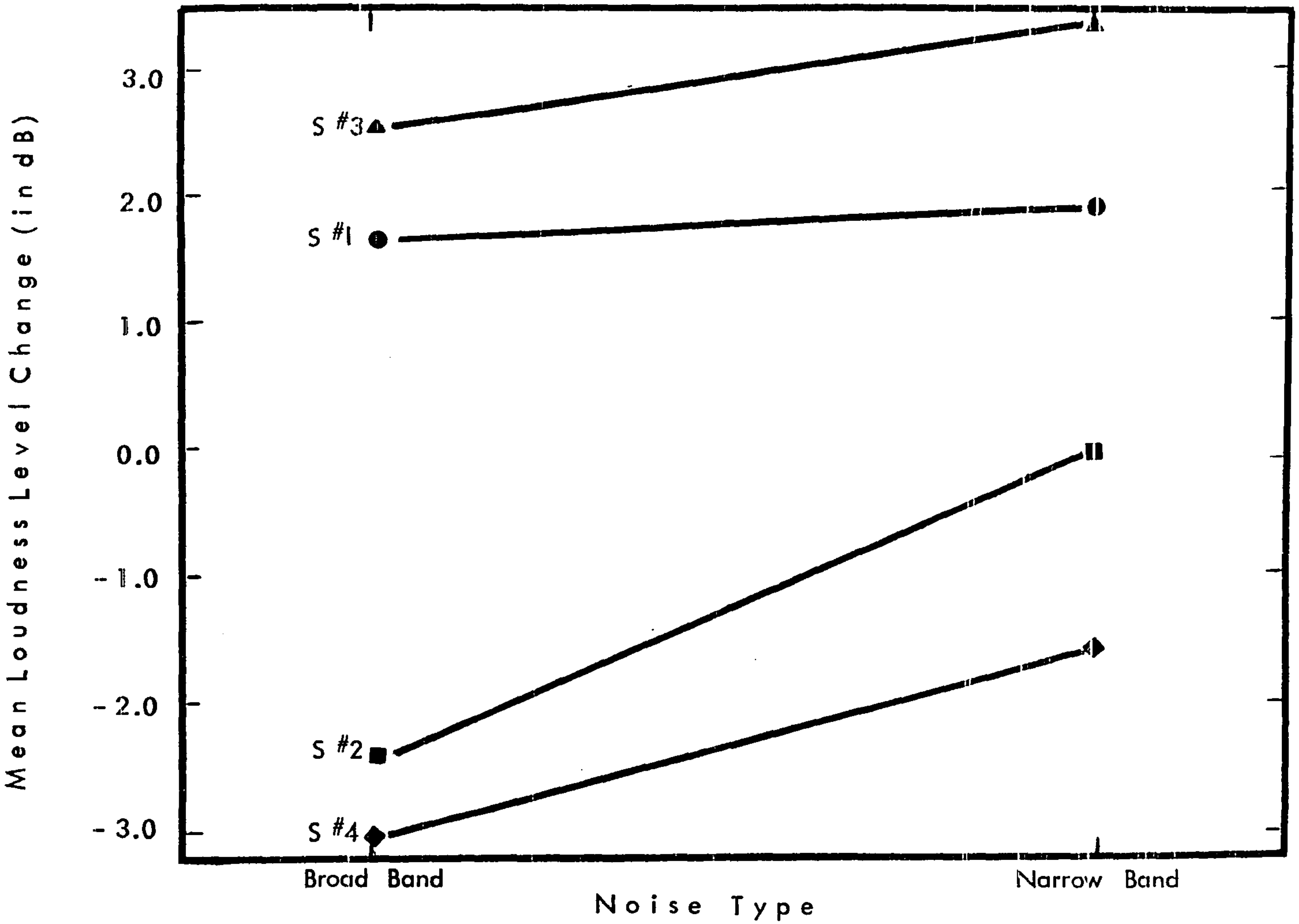

Figure 4 - Mean loudness level changes for each subject across stimulus conditions shown as a function of noise type

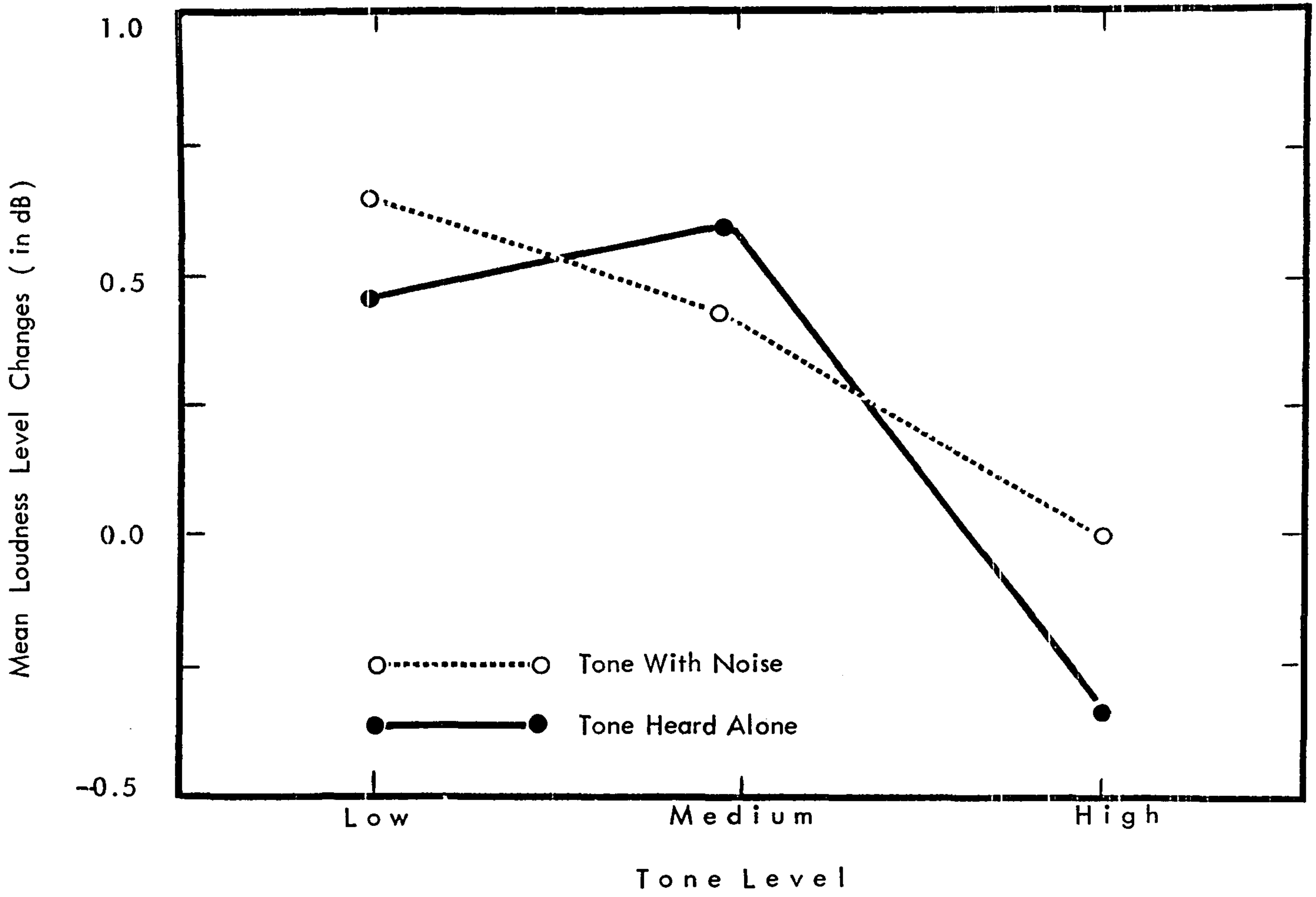

Figure 5 – Mean loudness level change shown as a function of tone level with the running parameter showing the effect of whether the subject varied the tone heard alone or whether he adjusted the tone heard in the presence of the contralateral noise during his balance judgments

was more difficult to identify and vary the tone-with-noise because the tone was very difficult to hear.

Other Effects

No other main effects (tone frequency, tone level, noise level, TWN-TA and direction of initial approach) or interactions were significant. Possibly the results were confounded by the large intersubject variability and the small sample size imposed by the division of the subjects into two groups.

Discussion of the Results of Study I

Clearly the most striking factor to emerge from Study I is the importance of each subject's listening criterion in determining the results he will produce. It seems that even highly trained and internally consistent subjects may be trained to different criteria if safeguards against different interpretations of the instructions or the task are not specifically built into the instructions. Conversely, it is shown in Study II that even inexperienced subjects, although more internally inconsistent in their judgments because of lack of training, can perform the same difficult psychophysical task with less variation in results when the instructions are more specific and include such safeguards.

The question arises as to what extent differences in the way subjects interpret instructions of the assigned task may have contributed to the wide intersubject variability that is reported in many of the similar studies reviewed in Chapter II. For example, the 5.3 dB range in individual mean loudness level shifts in the presence of contralateral noise obtained by the subjects in Study I seems small compared with the range of 19 dB in mean loudness shifts reported by Shapley (29) for his subjects in a similar experiment. Shapley also stated that each of his subjects had been fairly consistent in his own judgments. He attributed the large intersubject variability partly to small differences among subjects' thresholds of detectability but mostly to the subjective observations on the part of some subjects that the tonal characteristics seemed to change in the presence of contralateral noise. He also felt that different results would have been obtained if compensation for the observed "pitch shifts" had been made prior to the loudness matches.

Prather (24) investigated this subjective characteristic of loudness balance measurements in a similar study by having his subjects make balances for both loudness and pitch, using separate controls for each and alternating back and forth until the subjects felt they had made the best balance for both. He found significant differences under certain conditions, depending on whether his subjects balanced for both pitch and loudness or for loudness alone. These differences were found at low frequencies and at either (1) low tone and high noise levels (2) low noise and high tone levels, or (3) high tone and high noise levels. Under these conditions consistently greater loudness increases were obtained when adjustments were made for pitch as well as for loudness differences.

In a recent article Scharf (30) reported large variability in measurements of dichotic loudness balances between pure tones and two-tone complexes varying in bandwidth. His subjects matched the loudness of the dichotic complex to that of a binaural tone (same frequency in both ears which was set at the center frequency of the complex (500, 1000, or 2000 Hz). Dichotic and binaural stimuli alternated so that the subject would first hear the same (comparison) tone in both ears and then different tones in each ear. The difference between the setting of each dichotic component when matched by itself to the binaural tone and when matched together with the tonal component in the other ear was considered to be a measure of overall dichotic loudness summation.

Scharf attributed the wide variability between subjects to the differential ability of certain subjects to mentally split the auditory image into two distinct parts which correspond to the components of the complex. He stated: "Under dichotic stimulation a subject can usually make two different loudness judgments, one of overall loudness and the other of the component loudness. . . . Following instructions the listener can often attend to one component of a complex or to the whole complex."

The component loudness-matching ability of the subjects was investigated further by presenting the comparison tone monaurally "to the same ear and at the same frequency as the dichotic complex that was being judged." Scharf described the procedure as follows:

> When he clearly split the complex the subject heard a pure tone in one ear on every presentation; on every other presentation this tone was accompanied by a tone of a different frequency in the other ear. The subject was told to ignore the tone in the other ear and match the repeating tone to itself. He first adjusted the unaccompanied monaural tone to make it as loud as the dichotic component. Later the monaural tone was set to a level chosen by the subject and he adjusted the level of the whole complex until the loudness of the appropriate component equalled that of the monaural tone.

The results of these experiments indicated that when subjects were making overall loudness judgments the intersubject variability increased as the frequency separation between the tones in the dichotic complex increased, because it became more difficult to combine the component tones into a single sound image. However, when subjects balanced the loudness of each component tone in the complex with the monaural comparison tone the task became easier as the frequency between the tones in the dichotic complex increased.

A similar condition was found in the present study. Subjects #1 and #3 (who balanced the overall tone-with-noise signal with the tone heard alone) reported that the task was easier when balancing the 1000-Hz tones in the presence of the narrow-band contralateral noise (in which the tone was centered). Subjects #2 and #4 who tried to mentally block out the contralateral noise and concentrate on the tonal component during loudness judgments) reported that the loudness-balance task was more difficult under the above condition but was easier when the tone frequency and the center-frequency of the narrow-band noise were different.

Scharf (30) attributed the lack of agreement between certain results of his study and those of a similar study by von Bekesy (3) to differences in instructions. Whereas Scharf's data showed that the judgment of overall loudness is independent of the frequency separation of the dichotic tonal complex and that component loudness judgments produced loudness increases with increased separation of the tones in the dichotic complex, von Bekesy's results showed that dichotic loudness decreases as the frequency separation (ΔF) increases (3, 1960, pp 223-227). Scharf explains this discrepancy as follows:

> Although von Bekesy apparently intended to measure over-all loudness his procedure and instructions seemed to lead the subject to judge primarily the component loudness. Von Bekesy tried 'to fix the attention of the subject in such a way that he regarded the variable frequency in the other ear as a disturbance that might alter the loudness of the base tone of constant frequency. . . . In following this instruction, his subjects would be expected to judge the over-all loudness only at the narrowest ΔF's; as soon as the dichotic complex begins to split up (which occurs at very narrow ΔF's when a silent interval is omitted), more attention would be paid to the component loudness which however, would be enhanced by the contralateral tone. I was probably unable to obtain von Bekesy's results because, in my replication, I asked the subjects to ignore the tone in the other ear. Rather than enhance the loudness of the ipsilateral component, the contralateral component interfered with it. (30, p. 1203)

Scharf concluded that ". . . . judgements of the loudness of a dichotic complex depend very much on instructions and procedure. Probably the most meaningful measure of overall loudness is the one based upon instructions that implicitely ask the subject to judge overall loudness and a procedure that facilitates this task. "

The above observation seems to hold true also for the task of monaural loudness balances in the presence of contralateral noise. It may be seen in the results of Study II that, in response to more specific instructions, even inexperienced listeners showed less variation across subjects, even though they all had a tendency, at times, to shift to a different listening criterion.

The importance of instructions has been emphasized in other psychophysical areas of auditory research. A case in point is Pollack's study (22) which reported differences in threshold sensitivity of up to 7 dB depending on whether the subject was asked to respond when he first heard the "tone" or to respond when he first heard a sound of any type or quality.

In a study designed in part to determine the importance of instructions to subjects in loudness adaptation experiments Stokinger (34) found a difference of 28. 5 dB between the mean values of adaptation obtained on 10 trained subjects depending upon whether the subject was asked to make judgments on the basis of equal loudness balances or on the basis of localizing a fused sound image at the midline of the head under identical simultaneously-presented stimulus conditions.

Several of Stokinger's subjects reported considerable difficulty in making localization judgments, since the 80-dB adapting tone 'appeared fuzzy' or lost much of its tonality or clearness by the time the judgments were made, especially when the comparison tone was introduced. Similar comments by subjects in the present study, along with other remarks about the tone being presented with the contralateral noise seeming to cross over and blend with the noise, may relate to a mechanism by which common elements in the noise may summate with the tone in such a manner as to change the quality of the tone and produce a localization effect.

Despite the evidence cited above that the nearly equal and opposite results obtained by Groups #1 and #2 in Study I resulted from differences in listening criteria, other possible explanations must be entertained. It is known, for example, that some individuals can voluntarily contract the middle ear muscles (21, 25, 32). It is possible that Subjects #2 and #4 in this study were unwittingly eliciting the acoustic reflex in order to shut out the contralateral noise during some of the loudness judgments. Reger (25) reports "The writer learned that individuals who can contract their intra tympanic muscles can produce a marked subjective transmission loss by contracting these muscles while exposed to uncomfortably loud low frequency sounds."

The observation that subjects #2 and #4 did not show a greater frequency dependance in their results than the other two subjects fails to support this hypothesis.

It is interesting to note that Subject #2 in the present study is also, by coincidence, the same individual who was Subject #2 in Stokinger's study where his results were so deviant as to require a special processing of the data both with and without this subject's results included. Under conditions in which all other subjects experienced considerable loudness adaptation, this subject experienced no such adaptation and even showed loudness increases in some cases. One possible explanation for this is that he was voluntarily although perhaps unwittingly contracting his middle ear muscles in response to the annoyance of the 50-dB adapting tone.

It could also be argued, in the case of Stokinger's study, that the deviant results of Subject #2 could be attributed to a different listening criterion. That a difference in subjective listening criterion existed is reflected in Stokinger's notation of this subject's remarkable internal consistency in loudness and localization judgments when compared with the others; "All except Subject #2 reported either a change in the pitch of the adapting tone or a change in its quality or both. The quality change was described by most subjects as a 'fuzz' or 'noise' accompanying the tone. Subject #2 reported neither change. Thus, apparently, he was able to balance two stimuli which appeared to him to be identical in pitch and quality. Loudness balances are more reliable when the pitches of the stimuli are the same, thus the lack of clarity or the change in pitch of the adapting tone noted by all subjects except Subject #2 may have contributed to the larger variability of their responses" (34).

In an attempt to find reasons for the divergent results found in Study I a second study was carried out in which instructions were carefully reworded in an effort to have all subjects use the same criterion. A report of this study follows.

Results of Study II

In this study all subjects were requested to maintain the same listening criterion as that described for Group #1 (Subjects #1 and #3) in the first study (see page 53). Their ability to maintain this criterion is indicated by the overall mean loudness increase of 2.8 dB, obtained for all subjects across conditions. This value compares favorably with the mean of 2.4 dB obtained by Group #1 of Study I across the same conditions. The overall means for each subject ranged from 2.0 dB for Subject #4 to 3.8 dB for Subject #1. This range of only 1.8 dB suggests that these previously inexperienced subjects were using essentially the same listening criterion. There were no mean loudness decreases obtained in the present study under any condition.

The analysis of variance based upon the data produced by the four inexperienced subjects under each of the conditions investigated is presented in Table 1. Only the main effects are recorded. Highly significant differences are indicated for tone frequency. Significant differences are also shown with respect to tone level. The procedural effect of down-up was significant at the .05 level.

There were no significant interactions between any of the main variables investigated. This, in part, may be related to the relatively large size of the error terms for these measures. The analysis of variance results for these interactions is tabulated separately in the appendix.

In the following sections the main effects are discussed individually, followed by a discussion of their interrelationships and of their relationships to the results of other studies.

Noise Type

The results of this study show no significant differences as a function of noise type.

Although the mean loudness increases obtained across conditions were 0.9 dB higher under the narrow-band noise condition the difference did not reach statistical significance, whereas an overall mean difference of 1.4 dB in the same direction obtained in the first study was significant at the 0.5 level. Two factors may be responsible

TABLE 1

SUMMARY OF THE ANALYSIS OF VARIANCE OF STUDY II -- MAIN EFFECTS ONLY

Source	Degrees of Freedom	Mean Square	F
Subjects	3	110.62	0.86
Noise Type	1	121.91	0.95
Noise Type X Subject (Error)	3	128.05	39.47[b]
Noise Level	1	0.99	0.08
Noise Level X Subjects (Error)	3	12.42	3.83[b]
Tone Frequency	2	39.59	13.21[b]
Tone Frequency X Subject (Error)	6	2.99	0.92
Tone Level	2	85.26	5.22[a]
Tone Level X Subjects (Error)	6	16.32	5.03[b]
Procedural Variable TWN-TA	1	1.77	2.45
TWN-TA X Subject (Error)	3	0.72	0.22
Procedural Variable DOWN-UP	1	129.39	19.57[a]
DOWN-UP X Subjects (Error)	3	6.61	2.04
Within Cell	436	3.24	

[a] Significant at the .05 level of confidence.

[b] Significant at the .01 level of confidence.

for this discrepancy. The first is that the sample size is not large enough to produce consistently significant differences at the 0. 5 level with real differences in the neighborhood of 0. 9 to 1. 4 dB.

The second possibility is that the significant difference in noise type in Study I was influenced primarily by the differences in loudness change experienced by Subjects #2 and #4 (the loudness decrease subjects). Subjects #1 and #3 in Study I produced results very similar to those seen in Figure 6 for Subjects #1, #3 and #4 in Study II. It is noted also that the responses of only one subject (#2) are largely responsible for the greater loudness increase for the narrow-band noise condition and also for the large error term. Thus, of the six subjects showing loudness increases in the two studies only one appears to perform differently with respect to the two noise types.

Noise Level

The mean loudness level increase with the low level noise was 2. 8 dB and the mean loudness level increase with the high level noise was 2. 9 dB, a difference of only 0. 1 dB which, of course, was not significant at the . 05 level. There was considerable variation among subjects. Two subjects obtained greater loudness increase under the high noise condition; the other two showed the opposite effect. Similar results were obtained in the first study. The lack of a significant interaction between noise level and test tone frequency indicates

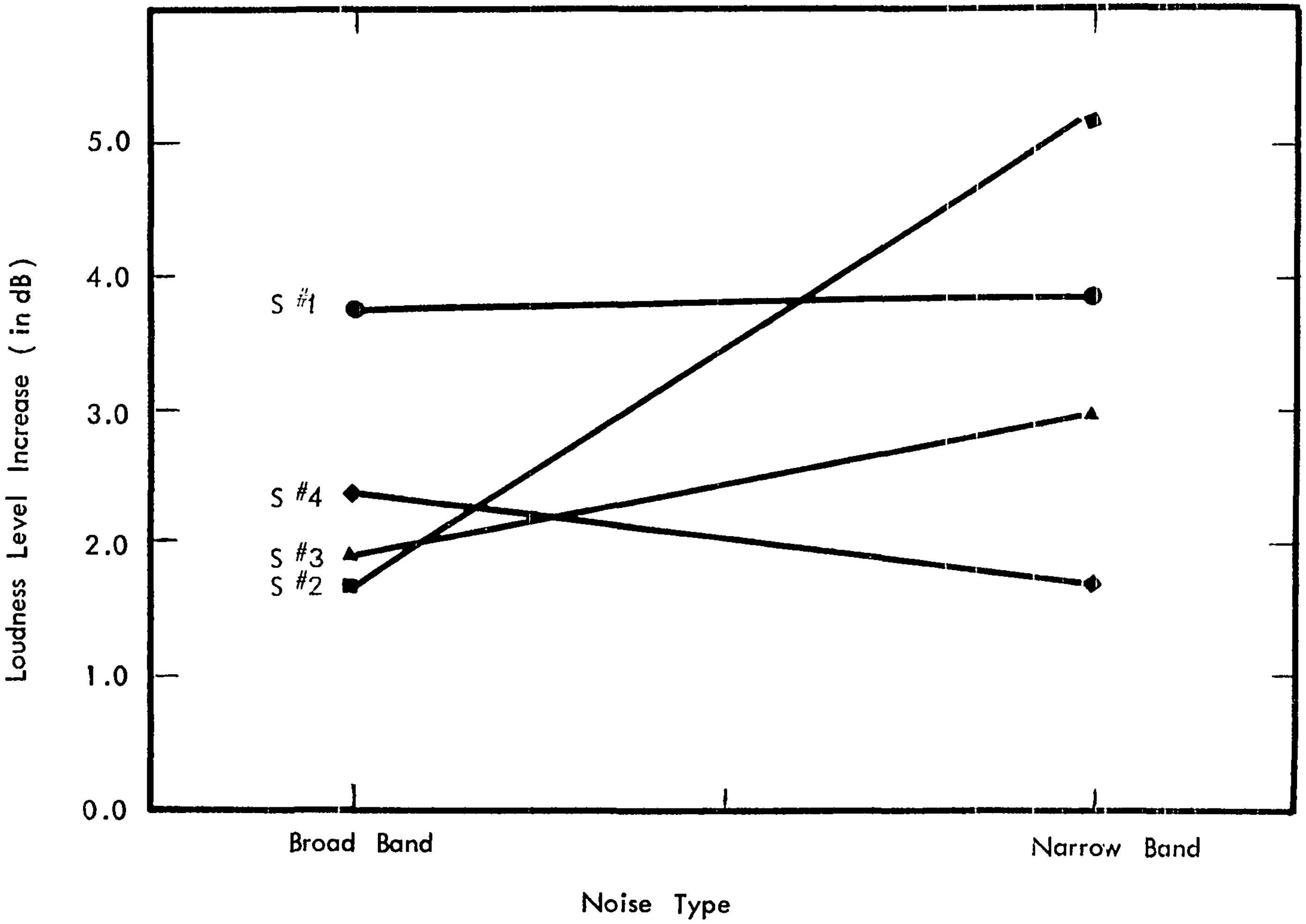

Figure 6 - Mean loudness level increase plotted for each subject as a function of noise type

that the lack of the significance of the noise level factor is common to all test tone frequencies.

Tone Frequency

Figure 7 shows the mean loudness level increase obtained in noise as a function of tone frequency. The tone-frequency factor was significant at the .01 level. The greatest loudness increase of 3.3 dB is seen at 1000 Hz, while the smallest increase of 2.4 dB is shown at 500 Hz. Although the relative differences in loudness increase shown between frequencies is small all subjects followed a similar pattern in their responses producing the significant effect. A further breakdown of the data by subjects is shown in Figure 8, which illustrates not only the consistent response patterns at the various frequencies but also the small range of variability across subjects which is reflected in a small error term (see Table 1).

Similar results were obtained in the first study with respect to the pattern of response, but they were not significant apparently due to the greater intersubject variability in that study.

The test tone frequency effect has also been found to be a significant variable in other similar studies (24, 29, 35).

Tone Level

Significant differences in loudness increase across conditions as a function of tone level are presented in Figure 9. The greatest

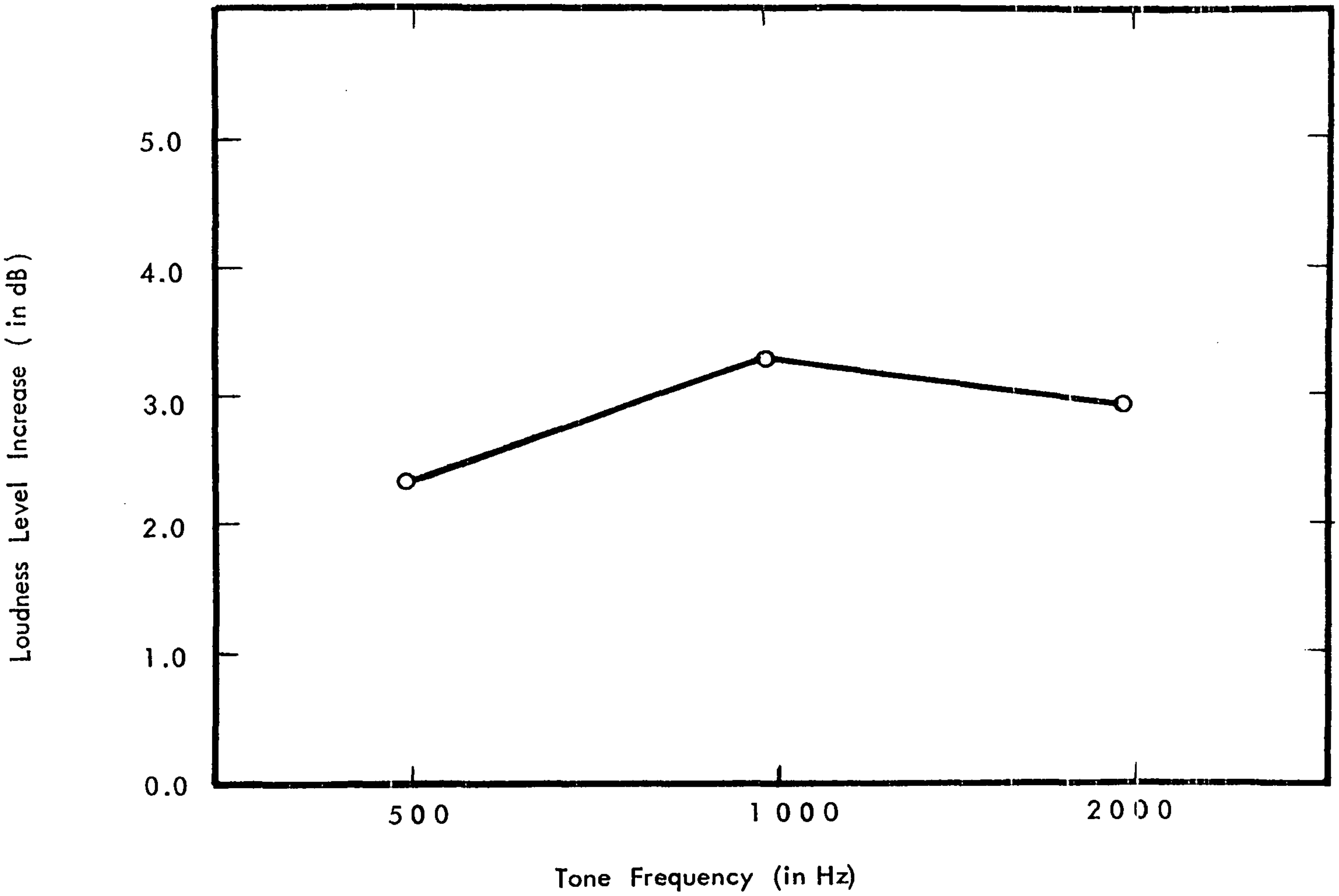

Figure 7 - Mean loudness level increase for all subjects combined across all other conditions plotted as a function of tone frequency

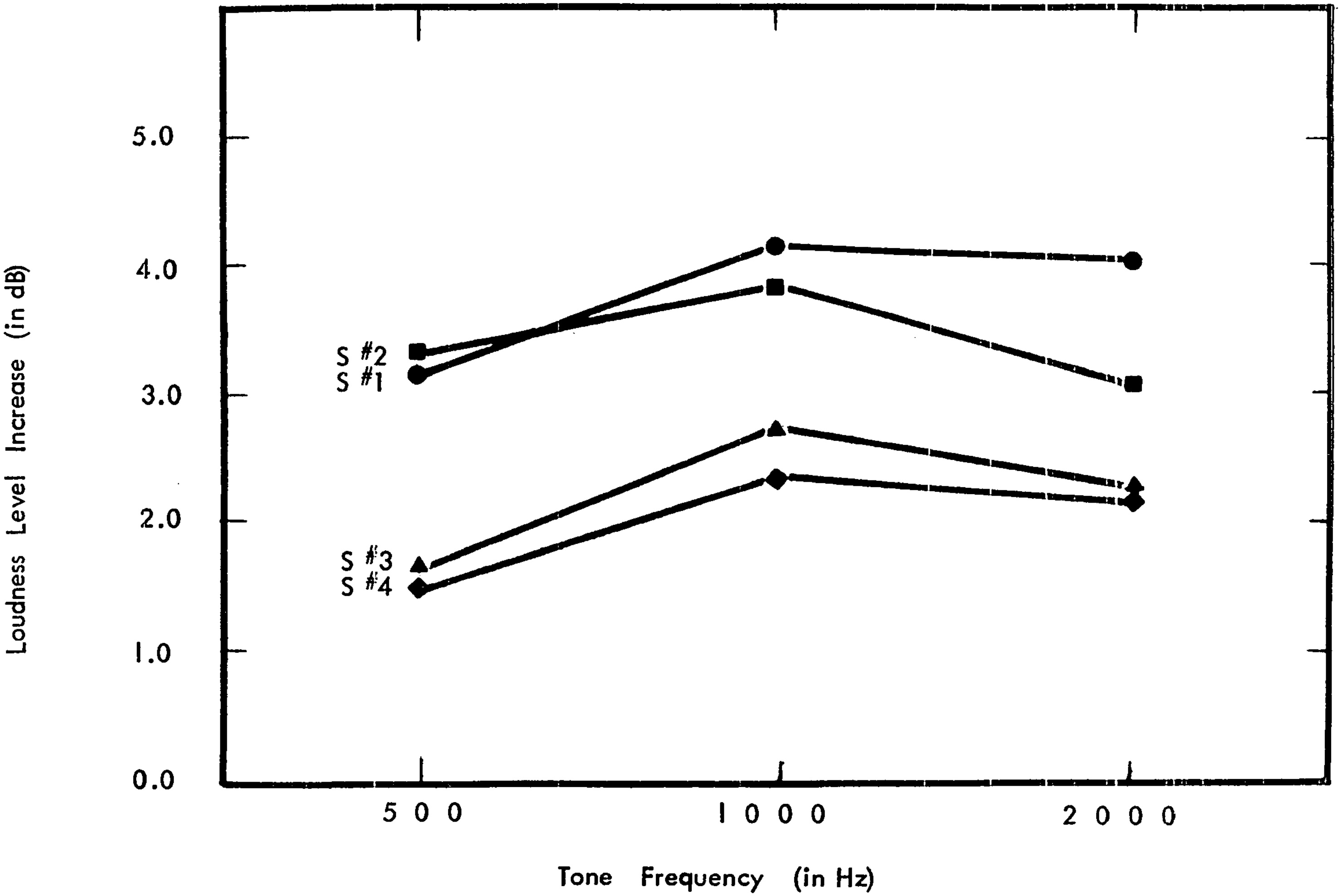

Figure 8--Mean loudness level increase in the presence of contralateral noise shown for each subject as a function of tone frequency

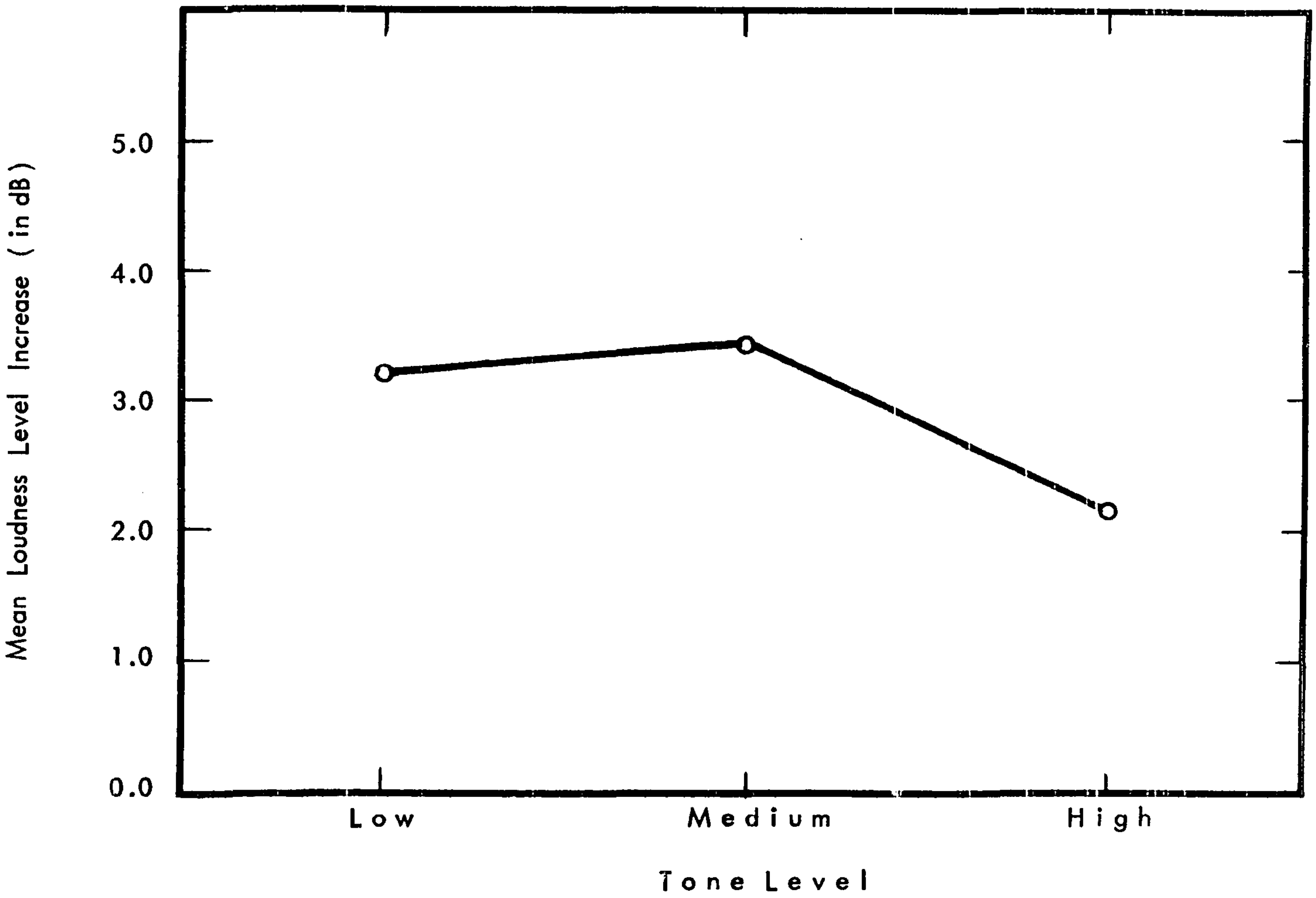

Figure 9 - Mean loudness level increase for all subjects combined across all other conditions plotted as a function of tone level

loudness increases were generally obtained at the medium tone levels, while the smallest increases always appear at the high tone levels. This is true for all subjects except Subject #3 who obtained the greatest loudness increases at low tone levels. The tone-level effect is significant in spite of the relatively large intersubject variation as shown in Figure 10.

The significant tone level effect found in this study agrees with the results obtained in the studies of Loeb and Riopelle (17), Prather (24) and Vigran (35), but differs with the non-significant result found by Shapley (29).

Procedural Variables

There were no significant differences or interactions with regard to whether a subject varied the tone heard alone or the one which was presented with the contralateral noise. This finding is notable in view of the complaint by most of the subjects that a loudness balance was more difficult to achieve when the tone they were required to vary was presented with the noise, especially at high noise and low tone levels. This result is also in contrast with the significant interaction observed between TWN-TA and tone level in Study I.

There was also a small error term shown for the subjects in the present study indicating that the responses of individual subjects were fairly homogeneous with respect to whether the tone alone or

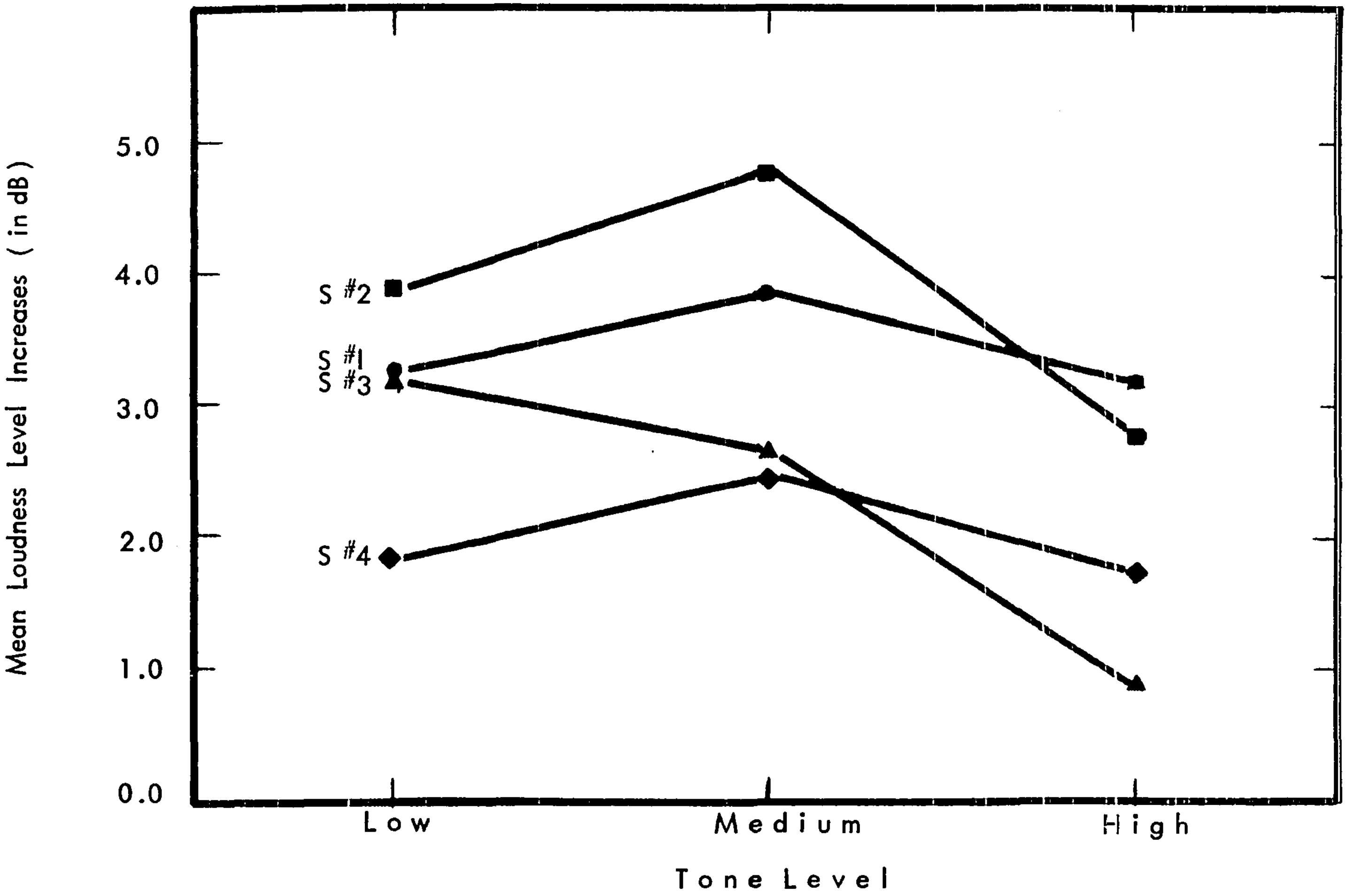

Figure 10 - Mean loudness level increase across all other conditions plotted for each subject as a function of tone level

tone-with-noise was adjusted.

There was a significant difference in the magnitude of loudness increase as a function of whether the subject made an initial approach to the balanced condition from a tone level below or above the final balance intensity. This finding was significant at the .05 level of confidence.

A greater mean loudness increase of approximately 1.0 dB was obtained when the initial approach to the balanced condition was from below. It was noted that the magnitude of this difference was considerably greater under the broad-band noise condition; however, the interaction between the direction of approach and noise type was not statistically significant. The small error term indicates very little intersubject variability for this procedural variable.

Relationships Between Stimulus Parameters And Comparison with Other Studies

A more detailed breakdown of the data obtained in this study is shown in Figures 11 a, b, c, and d. Figures 11 a and b show loudness increases as a function of tone level, with frequency as the running parameter, at low and high levels of broad-band noise. Figures 11 c and d show the same relationships obtained under the narrow-band noise condition.

Each point represents a mean of 16 observations, which includes four measures with differing procedural variables (TWN-TA,

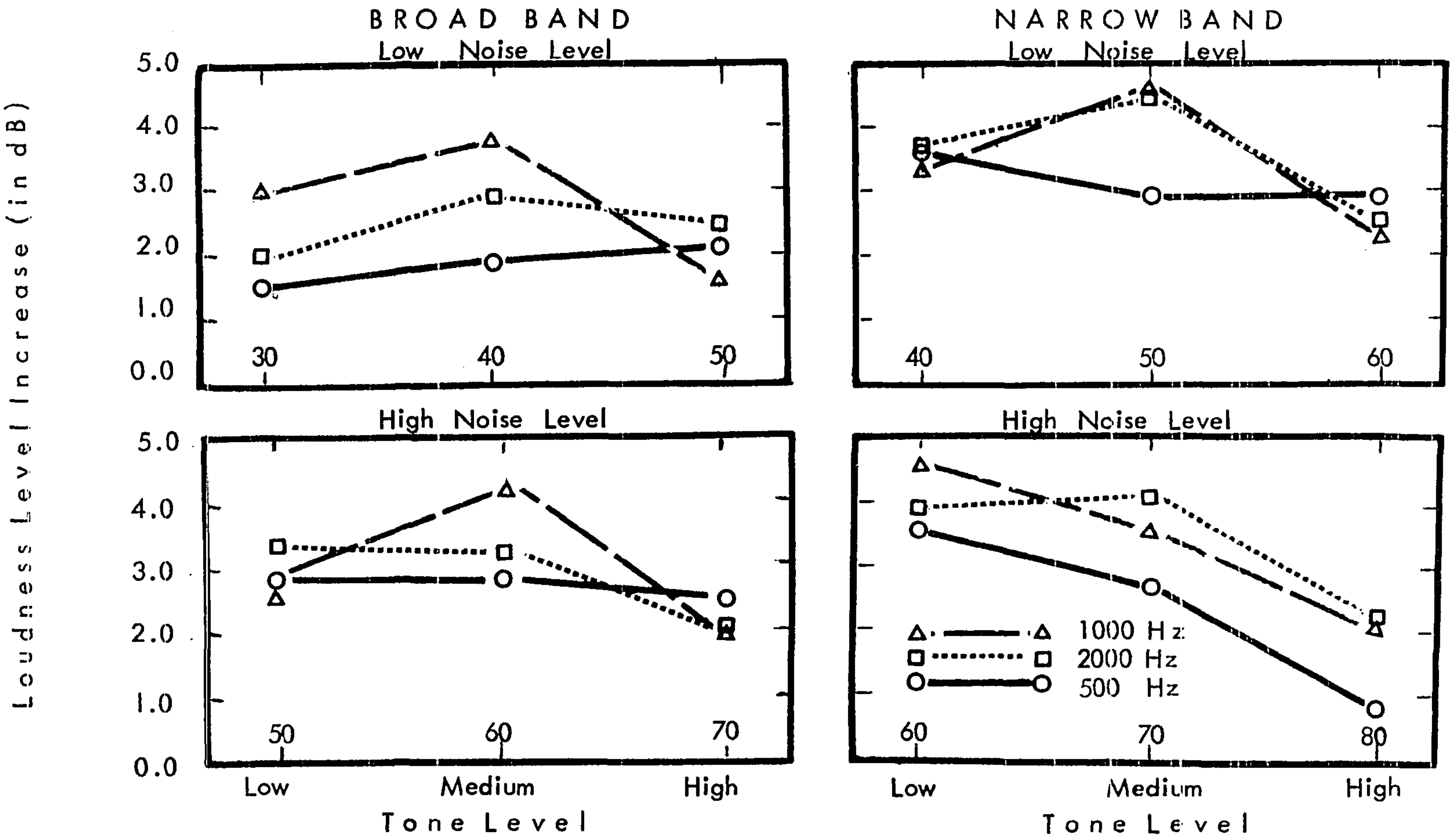

Figure II a, b, c and d - Loudness level increases at 500-, 1000- and 2000-Hz tones (parameter) at low, medium and high tone levels produced by the presence of low and high levels of contralateral noise of broad and narrow bandwidth down-up) for each of the four subjects.

Tone Level and Noise Relationships at 1000 Hz

With one exception the greatest loudness increases obtained for the 1000-Hz tone in the presence of contralateral noise were found at medium tone levels regardless of the noise type or noise level. It will be recalled that the medium tone levels used in this study were selected to approximate the spectrum level of the noise regardless of noise type or noise level. These results then support Rowley's (27) observation that the greatest loudness increases obtained for a 1000-Hz tone heard in the presence of a broad-band contralateral noise will occur at tone levels which approximate the spectrum level of the noise and that if the tone level is above or below the noise spectrum level progressively smaller loudness increases will be obtained. The exception mentioned above occurred at the high noise level under the narrow-band noise condition. There, the greater loudness increase is found at the low tone level with smaller increases occurring at medium and high tone levels in an almost linear relationship. Without exception, however, the smallest loudness increases for the 1000-Hz tone are found at the high tone levels.

The absence of a significant interaction between tone level and noise level for the 1000-Hz tone in the overall analysis coupled with the fact that the medium tone level always approximated the spectrum of the noise indicates that the observed deviations from this generalization are not statistically significant.

Nevertheless, at the high narrow-band noise level there is a deviation from this basic pattern (Figure 11d). The greatest loudness increase occurs not at the medium tone level (which approximates the spectrum level of the noise) but at the low tone level which is about 8 dB lower than the spectrum level of the narrow-band noise. Rowley's generalization does not seem to hold under this noise condition. But Rowley observed this same discrepancy under similar conditions. He stated (27, p. 128) that "the knee (or point of maximum loudness increase) of the loudness function with 100 dB of contralateral noise falls slightly below, rather than above, the (broad-band) noise spectrum level."

Vigran found maximum loudness increases at the tone level that was 9 dB below the spectrum level of a 100-dB, narrow-band, noise. However, he also observed relatively large summation effects (only 0.3 dB less than the maximum increase observed) at a tone level that was within 1 dB of the spectrum level of the noise. These results are similar to those found in the present study under the high-level, narrow-band noise condition.

The low, medium and high tone levels used in this study under each noise condition actually represent different intensities, although there is considerable overlap of tone levels across conditions. It is possible to observe the effects of the different noise types and levels on the loudness increase obtained at a given tonal intensity level. The overall noise intensity levels are the same for both broad and narrow-band noises. These are 75 and 95 dB for low and high noise levels, respectively.

Figure 12 shows the effects of high- and low-level, broad- and narrow-band contralateral noises on the loudness of the 1000-Hz tone when plotted as a function of the actual tone intensity levels used. The marked peakedness of three of the curves obviously reflects the greater increases at the medium tone levels. It is seen that there is very little difference in the mean loudness level increases obtained at the standard tone level of 40 dB under the broad- and narrow-band noise conditions, both of which were presented at the low (75-dB SPL) level. However, marked noise type effects are seen at the 50-dB tone level where 3.0 dB greater loudness increases were obtained under the narrow-band noise condition than under the broad-band noise condition. This is notable since the overall noise levels were the same for both broad- and narrow-band noise conditions but the spectrum levels differed by 10 dB. Only slightly greater loudness increases (0.3 dB) were obtained for the 60-dB tone level under the narrow-band noise condition than under the broad-band noise condition when both were presented at 95 dB SPL. At the 70-dB tone level the mean loudness increases obtained under the narrow-band noise condition were

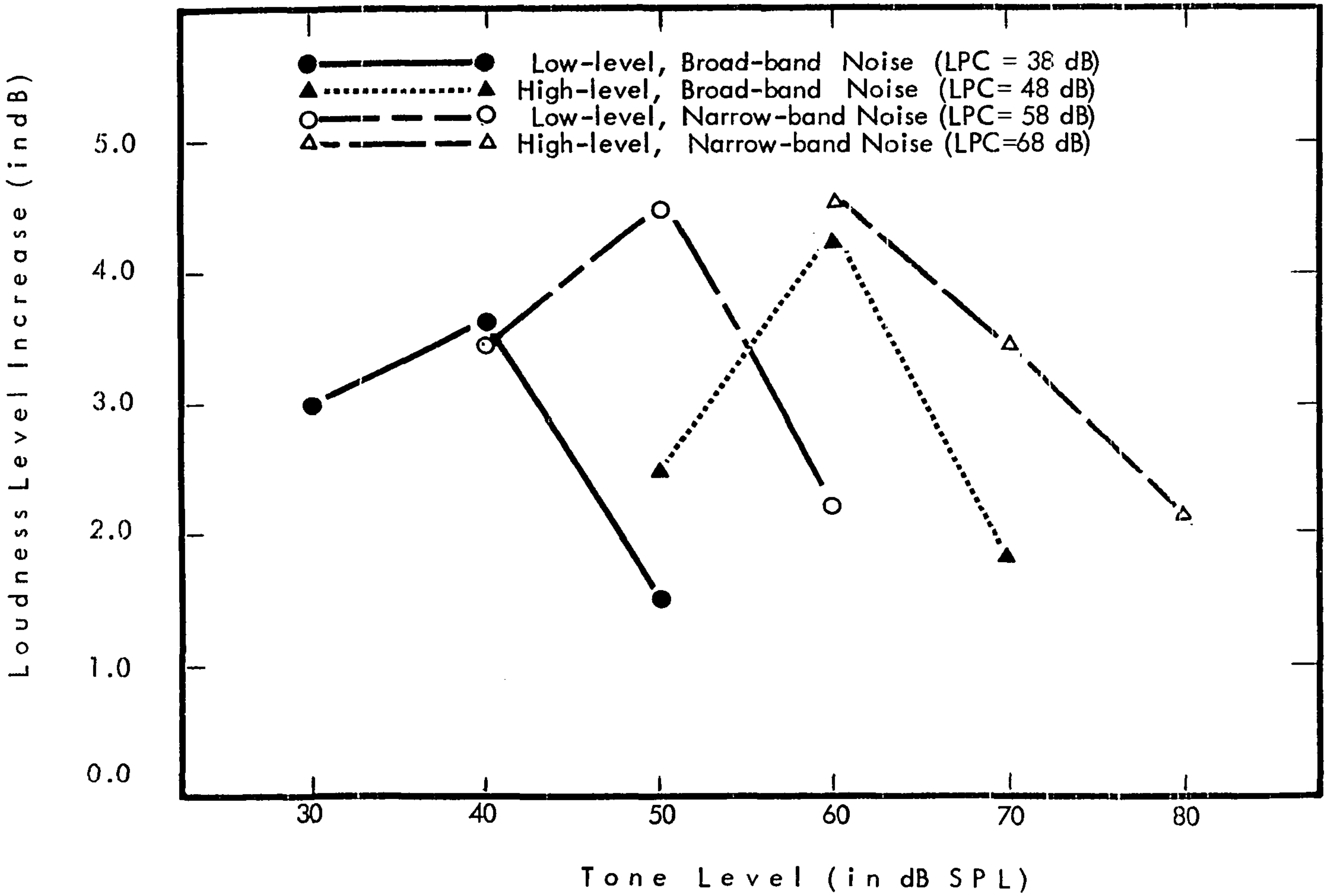

Figure 12 - Effects of noise level and noise type (parameter) on the loudness levels of a 1000 Hz standard tone presented at six different intensity levels (re. SPL)

about 1.7 dB greater than those obtained under the broad-band condition when both noises were presented at 95 dB SPL.

In summary, it would appear that the results of this study, at 1000 Hz at least, support the generalizations that the maximum loudness increase occurs when the tone level approximately equals the spectrum level of the noise, that the summation is reduced more sharply when tone levels are above this level than when they are below, and that at high noise levels, tone levels that are somewhat below the noise spectrum level may produce equal or greater summation effects.

Tone Level and Noise Relationships by Frequency of the Test Tone

Figure 13 reveals that the 500-Hz tone curve interacts little with tone level. In particular, the larger loudness increase at the medium tone level is not present at this frequency. While the results for 500 Hz show less loudness increase under nearly all conditions and while the acoustic reflex might be responsible, the data do not clearly suggest this or any other factor as an explanation. The fact that the greater increase at the medium tone level is absent at 500 Hz suggests that this effect may occur only when the test tone is within or above the noise band or it may suggest that the effect is simply absent at 500 Hz. The data as shown in Figures 11 a, b, c, and d suggest that the results are essentially the same for either noise type which supports the latter of these two generalizations. The nonsignificant

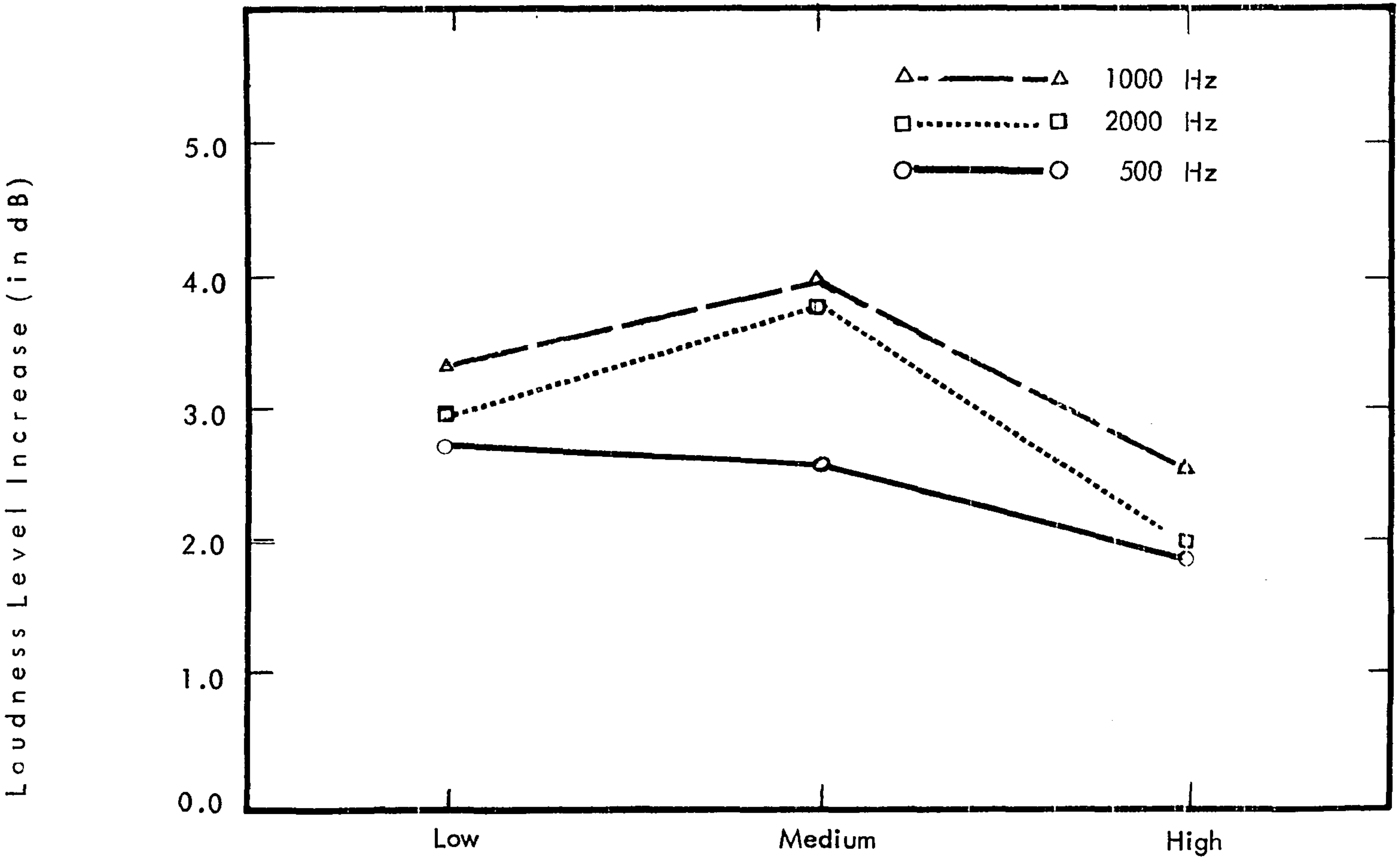

Figure 13 - Mean loudness level increases obtained across conditions for all subjects plotted as a function of tone level

noise type by tone frequency interaction further emphasizes that this effect is not related to the bandwidth or center frequency of the noise band but depends only upon the frequency of the test tone.

Only under the high-level, narrow-band noise condition does the curve for the 500 Hz tone drop sharply at the high tone levels, showing about 1. 5 dB smaller loudness increases than were shown for either the 1000-Hz or 2000-Hz tones. This indicates that under this condition there was either less loudness summation present, a greater counteracting force (which could be attributed, at least in part, to the acoustic reflex), or a combination of these factors.

The shape of the overall 500-Hz curve could be interpreted as reflecting an energy-limiting effect similar to that observed by Loeb and Riopelle (17) in that there appears to be greater counteracting force as greater tonal energy is presented. The results at other frequencies suggest another explanation, however, the unique results at 500 Hz leaves this possibility open at this frequency.

Loudness increases obtained for the 2000-Hz tone at different tone levels follow a pattern generally similar to that found for the 1000-Hz tone as is shown in Figure 13 and in the more detailed Figure 11 a, b, c, and d. Greater loudness increases usually occur at the medium tone levels, while smaller increases are found at the low and particularly at the high tone levels. The data, as shown in Figure 11, indicates that this basic relationship varies somewhat with noise type and noise level, since under the high-level, broad-band noise condition slightly smaller loudness increases were obtained at medium tone levels than were recorded at low tone levels. At 1000 Hz this occurred with the high-level, narrow-band noise only. Under the narrow-band, high-level noise condition the loudness increases observed at 2000 Hz were nearly as great at low tone levels as at medium tone levels. Thus, it is seen that the curve obtained for the 2000-Hz tone also shows the tendency noted earlier at 1000-Hz of producing equal or slightly greater loudness increase at tone levels somewhat below the noise spectrum level when the contralateral noise is intense.

Relationships Between Test Tone Frequency, Noise Bandwidth and Noise Level

A stated purpose of this study was to compare the loudness increases produced in test tones under broad- and narrow-band noise conditions. Another was to determine if differences in loudness change exist between tones that are below, at the center of, and above the bandwidth of the narrow-band noise. These noises were presented at levels both above and below those which should elicit the acoustic reflex.

Figure 14 shows the mean loudness increase obtained at the three test frequencies under broad- and narrow-band noise conditions at both high and low noise levels. Loudness increases shown under the narrow-band noise condition are, on the average about 0.7 dB greater

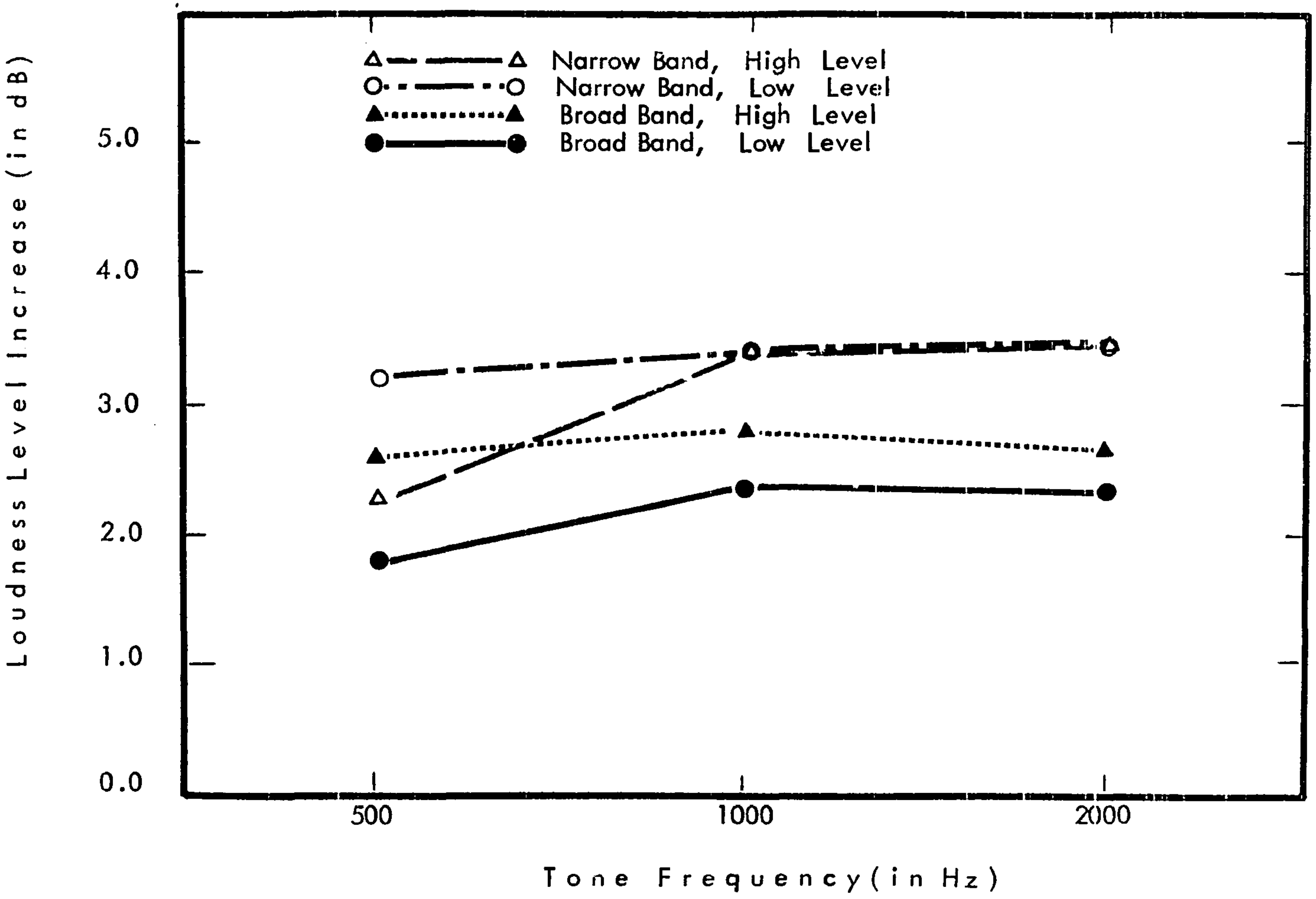

Figure 14 - Mean loudness increases produced by all subjects across all other conditions as a function of tone frequency with noise type and noise level as running parameters

for the 500-Hz tone and about 1.1 dB greater for the 2000-Hz tone than obtained under the broad-band noise condition. With the exception of one data point there is no interaction. The data point at 500 Hz with the high-level, narrow-band noise suggests that this is the only noise which produced a significant effect attributable to acoustic reflex activity, under all other circumstances frequency of the test tone has little effect on the loudness increase produced with narrow- or broad-band noise.

The level of the thermal noise in the region of 500 or 2000 Hz was reduced by about 29 dB by the filter. Therefore, the equal loudness increases experienced for the 2000-Hz tone and the 500-Hz tone on one condition under the narrow-band noise condition may be due to a kind of frequency spread of summating effects. The downward spread of loudness summation was also observed in Vigran's (35) study where the 1/3-octave band of contralateral noise centered at 2500 Hz was always higher in frequency than the test tones. The results of this study indicate very little frequency effect, at least when the tones are within one octave of the center of the noise band.

The Magnitude of Loudness Changes Compared With Those Obtained in Other Studies

It has been observed that the mean loudness changes given above for the present study are considerably smaller than those observed by any of the other investigators cited who demonstrated loudness increases regardless of the method by which they were obtained. For example, the maximum mean loudness level increase of from 3.0 to 4.5 dB shown for Study II is not as great as the 12- to 13-dB increases observed by Rowley (27), and 6- or 7-dB increases reported by Egan (7), or the 7.5-dB increases reported by Vigran (35). (Shapley (20) reported mean loudness decreases of 15.1 dB while Loeb and Riopelle's (17) subjects produced loudness decreases of from 7 to 8 dB. The mean loudness changes produced by Prather's (24) subjects ranged from loudness decreases of 4.0 dB to increases of about 8.0 dB, (depending upon the listening conditions and the type of judgment required of the listener.)

The loudness level change of from 2.0 to 4.5 dB obtained in this study represents loudness ratios of about 1.2 to 1.4 to 1 which are somewhat smaller than the binaural-monaural loudness ratios for pure tones of 1.4 to 2.3 to 1 observed by Reynolds and Stevens (26) or the 1.5 to 2.6 to 1 ratio of loudness increase in the presence of contralateral noise observed by Rowley (27). There appears to be no immediate explanation for the smaller loudness level increases obtained in this study. However, the fact that all of the other studies which produced greater loudness changes contained a silent period in the timing sequence of tone and/or noise presentation while this one did not should receive further study as well as the relationship of this variable to the subjects response criterion as discussed earlier.

CHAPTER V

SUMMARY AND CONCLUSION

Introduction

The effects of contralateral noise on the perceived loudness of monaurally-balanced pure tones have been investigated rather extensively, but many of these previous studies (4, 7, 24, 29) have produced conflicting results. Some (4, 14, 29) have shown decreases in the loudness of pure tones when they were paired with noise in the opposite ear. This effect has generally been attributed to the action of the acoustic reflex, since it is known that the reflex is activated bilaterally by high-level noises and that it attenuates the transmission of sound to the inner ear (14, 17, 19, 25, 29). Loudness decreases have also been attributed to transcranial masking when high-level noises and low-level tones have been involved (27).

Other studies in which monaural loudness balances were performed using pure tones (24, 27, 35) and speech (7) have found loudness increases in the presence of contralateral noise, even though the psychophysical techniques or physical parameters, or both varied from study to study. This increase has been attributed to the principle of binaural summation of loudness by the authors of all these studies. However, some authors (24, 29) acknowledge the possibility of a loudness increase due to the facilitory action of the middle ear muscles at frequencies above 1000 Hz.

One study (24) found differing results across similar stimulus conditions, depending upon the subject's listening task. Loudness *decreases* were generally experienced when the subjects balanced only the relative loudness of tones in quiet against the loudness of the same frequency tone sounded in the presence of a contralateral noise. However, when adjustments were made to equate also the apparent pitch of the two successive tones then loudness *increases* were obtained.

The results of the literature reviewed supported the following generalizations. First, greater loudness decreases were obtained at frequencies below 1000 Hz (14, 29) and second, loudness decreases were obtained for the intensity combinations of low tone and high contralateral noise levels or high tone and high noise levels (24, 27, 35). Third, loudness increases were obtained in the presence of contralateral noise at frequencies of 1000 Hz and higher (24, 27, 35), at low tone and moderate noise levels (24, 27), or at moderate tone and high noise levels (24, 27, 35), at least under conditions where tones being compared were within the frequency band of the contralateral noise (24, 27, 29) or below the noise band in frequency (35).

Experimental Design and Procedure

Two studies are reported which are identical in most respects but which differ with respect to the criteria the subjects were instructed to use in evaluating the relative loudness of a series of monaurally-presented pure tones of the same frequency, every other one of which was accompanied by a contralateral noise burst. The main purpose of both studies was to investigate the effects on the loudness of a pure tone resulting from being paired with a contralateral noise when noise type, noise level, tone frequency, and tone level were systematically varied. Specifically, a broad and an octave-bandwidth noise were each presented to the left ears of four subjects at a high level which should elicit the acoustic reflex and also at a low level which should not. The test stimuli were presented to the right ear and included a 1000-Hz tone which was at the center of the one-octave band of noise, a 500-Hz tone which should have been affected by the acoustic reflex, and a 2000-Hz tone which was higher in frequency than the noise band and which should not have been influenced by the reflex.

Each tone was presented at three levels that varied with each noise type and noise level. The medium tone level always approximated the spectrum level of the noise, irrespective of noise type or noise level. The purpose of this arrangement was to further investigate Rowley's observation that maximum summation (or loudness increase) usually occurs at tone levels which approximate the spectrum level of the noise.

Two procedural effects were investigated also. It was observed in some studies that the tone presented with the noise (TWN) had been varied by the subject (24, 29) while in others the tone appearing alone (TA) had been the variable (comparison) tone (35). The TWN-TA variable was tested by having subjects vary both the tone-with-noise and the tone alone under all of the stimulus conditions. Although other investigators reported having their subjects approach the balanced condition from both directions there was no evidence of any systematic study being made of this variable. Neither was there any discussion as to how the apparent loudness change differs, depending on the direction of approach. Based on the differences shown during a pilot study it was decided that in the present study separate measures would be obtained according to whether the balanced condition was initially approached from an intensity below or from above the intensity of the standard tone.

In the first study four trained, normal-hearing adults--sophisticated in psychophysical procedures--used the method of adjustment to obtain monaural loudness balances under the conditions described above. Prior to the gathering of the data each subject was given several training sessions during which he practiced the experimental task until consistent measures were obtained. It was implied in the instructions given to these subjects during the training sessions (see page 47) that they would learn to disregard the contralateral noise and to concentrate on matching only the loudness of the two test tones appearing alternately in the test ear.

The data were collected in two listening sessions of approximately one and one-half hours each. Conditions were the same in each session except that narrow-band noise was presented during one session and broad-band noise during the other, the order varying with the subject. Under each noise type the 36 combinations of the four stimulus parameters plus the two procedural effects investigated were presented in as nearly a balanced order and balanced coincidence as possible.

The alternating standard and comparison tones both had the same on-times of 400 msecs, separated symmetrically by off-times of 600 msecs during a given two-second period. The contralateral noise was on for 400 msecs and then off for 1600 msecs before being paired with the next standard or comparison tone.

In the second study four normal-hearing, previously inexperienced subjects were used. The procedures were essentially the same as in Study I except that each subject was asked to follow a specific listening criterion; namely, to consider the tone heard with the contralateral noise together with the tone's associated noisiness as a single complex signal against which he should compare the loudness of the tone heard without the noise.

The data from both studies were evaluated using an analysis of variance designed for multi-factor experiments having repeated measures (40).

Results

Study I

The data from Study I showed that Subjects #1 and #3 obtained mean loudness changes across conditions which were almost equal and opposite to those shown by Subjects #2 and #4. The mean loudness increase averaged across all subjects was less than 0.3 dB. Because of the divergence of the two pairs of subjects it was decided at this point to carry out the second study. However, it seemed worthwhile to evaluate the results of Study I by treating Subjects #1 and #3 and Subjects #2 and #4 as two separate groups in order to obtain an impression of the magnitude of the differences, whatever their cause, and also to obtain some evaluation of the influence of the other main effects.

This analysis showed significant differences between the two groups. Group #1 (Subjects #1 and #3) produced an overall mean loudness increase of 2.4 dB. Group #2 (Subjects #2 and #4) produced an overall mean loudness decrease of 1.8 dB. The difference between these two groups is significant at the .05 level.

When the four subjects were questioned as to possible reasons for the large discrepancies in results it was determined that there were differences in the applied listening criteria. Subjects #2 and #4 (those that produced loudness decreases) reported that they had mentally tried to suppress or block out both the contralateral noise and the added noisiness around the tone which was presented with the noise, during the balancing task. They had tried to concentrate on only the tone itself which seemed to appear in the midst of the noise. The other two subjects (#1 and #3) reported that they had considered the tone and its associated noisiness as a sort of combined complex tonal-like signal to which it was easier for them to match the tone occurring alone. The use of this criterion apparently resulted in the loudness increases. It was apparent from these comments that either loudness decreases or increases could be obtained depending upon whether a subject attended to only the pure tone element of the complex or whether he included in his judgments the fringe area noisiness which accompanied the tone appearing with the contralateral noise.

A number of studies (22, 24, 29, 30, 34) were reviewed in which the authors discussed the differences in results which appeared to be connected with either differences in the perceived character of the signal or with variations in interpretations of instructions to do an assigned psychophysical task. It is suggested that some of the divergent results obtained in some of the loudness balance studies reviewed in Chapter II (24, 29) were produced in part by differences in the criteria used by the subjects in performing the assigned task.

Also significant at the .05 level of confidence was noise type which showed an overall loudness increase that was 1.1 dB larger under the narrow-band noise condition. None of the interactions between noise type and the other conditions was significant.

A small but significant (.05) interaction was shown between the procedural variable of TWN-TA and tone level. When the tone alone (TA) was varied by the subject smaller loudness increases were experienced at low and high tone levels while larger increases were found at medium tone levels. When the tone-with-noise (TWN) was varied the reverse order was true, except that the greatest loudness increase also occurred at the low tone level.

No other main effects or interactions were significant.

Study II

In this study all subjects were requested to maintain the same listening criterion as that described for Group #1 (Subjects #1 and #3) in the first study (see page 53). Their ability to maintain this criterion is indicated by the overall mean loudness increase of 2.8 dB, obtained for all subjects across conditions. This value compares favorably with the mean of 2.4 dB obtained by Group #1 of Study I across the same conditions. It was also noted that the overall mean loudness increase for each subject in Study II ranged from 2.0 dB for Subject #4 to 3.8 dB for Subject #1. This range of only 1.8 dB could be cited in evidence that these previously inexperienced subjects were using essentially the same listening criterion. There were no mean loudness decreases obtained in Study II under any condition.

In comparing the results of Studies I and II it was apparent that the instructions given the subjects were of paramount importance. On the other hand it was found that previous training of subjects for the loudness-balance task was relatively unimportant in obtaining reliable results. In fact, unless instructions are very specific a subject can be trained to follow a criterion different from that intended by the investigator.

It was observed that the mean loudness level changes obtained in this study were considerably smaller than those observed by all other investigators (7, 17, 24, 27, 29, 35) reporting similar studies regardless of the methods used. There seems to be no immediate explanation for this. However, it was noted that all of the other investigators inserted a silent interval in the timing sequence governing the presentation of the standard and comparison tones while this study did not.

The analysis of variance showed that tone frequency, tone level and the procedural variable of down-up (i. e. direction of initial approach to the balanced condition) were the significant variables in determining the loudness level increases obtained for pure tones heard in the presence of contralateral noise.

No other main effects or interactions were significant.

The greatest mean loudness increase obtained across all conditions as a function of tone frequency was obtained with a 1000-Hz tone while the smallest increase was found for the 500-Hz tone. These results were expected since the 1000-Hz tone equalled the center frequency of the contralateral noise in the case of the narrow-band noise and the 500-Hz tone should have been most affected by the acoustic reflex. However, the difference between the mean loudness increases obtained for these two tones was surprisingly small (0.5 dB). Still, a very small intersubject variability factor caused the tone frequency main effect to be significant at the .01 level of confidence. The significant tone frequency effect was also found in other studies (17, 24, 29, 35). A breakdown of these data by noise level and noise type (Figure 14) revealed that this significant result occurred largely on the basis of the outcome at 500 Hz with the high-level, narrow-band noise. It was thought that this noise was the only one which elicited an effective acoustic reflex.

The significant tone level main effect found in this study agrees with the results obtained by Loeb and Riopelle (17), Prather (24) and Vigran (35) but differs from the non-significant result found by Shapley (29). The greatest loudness increases were generally obtained at the medium tone levels. Since these levels were selected to approximate the spectrum level of the noise, regardless of noise type and noise level this outcome supports Rowley's (27) observation that the greatest loudness increase can be expected at tone levels which approximate the noise spectrum level. The smallest loudness increases were found at tone levels which were above the spectrum level of the noise. This was also noted by Rowley and can be seen in the results of other investigators (7, 24, 35) as well.

Although there were no significant interactions among stimulus parameters, a number of interesting relationships between tone level and/or tone frequency and the contralateral noise conditions were observed. For example, it was noted that at high noise levels the tone levels that are somewhat below the noise spectrum level may produce equal or slightly greater loudness summation effects. Rowley also has noted similar exceptions to his observed tone-level, noise-spectrum-level relationship. It was seen also in Vigran's (35) study that the greatest loudness increases were obtained at tone levels that were up to 10 dB below the noise spectrum level.

There was very little interaction noted between the 500-Hz tone and tone level under any of the contralateral noise conditions. Notably absent was the greater loudness increase shown at medium tone levels for the 1000- and 2000-Hz tones. This may suggest an energy-limiting effect of the acoustic reflex as suggested by Loeb and Riopelle (17). While the acoustic reflex may be responsible for this effect in the present study, the data do not clearly suggest this or any other factor as an explanation since the results are similar under all contralateral noise conditions. The greater loudness increase at medium tone levels may occur only when the test tone is within or above the noise band or it may simply be absent at 500-Hz.

Under the high-level, narrow-band noise condition the curve for the 500-Hz tone dropped sharply at the high tone levels, showing about 1.5 dB smaller loudness increases than were shown for either the 1000- or 2000-Hz tones. This indicates that under this condition there was either less loudness summation present, a greater counteracting force (which could be attributed, at least in part, to the acoustic reflex), or a combination of these factors.

Loudness increases obtained for the 2000-Hz tone at different tone levels follow a pattern similar to that obtained for the 1000-Hz tone with greater loudness increases shown at medium tone levels and smaller increases shown at low and particularly at high tone levels. The greatest increases are shown under the low-level, narrow-band noise condition, although increases as great were obtained under the high-level, narrow-band noise condition at 1000 and 2000 Hz tone frequencies. Greater loudness increases were obtained at practically all tone levels and for all frequencies under the narrow-band noise conditions. However, the noise type main effect did not reach statistical significance. It was shown also that the loudness increases produced in the 500-Hz and 2000-Hz tones under the narrow-band noise condition are greater than under the broad band condition even though the tones are not overlapped by the bandwidth of the narrow-band noise.

The noise level main effect was not significant and there was essentially no numerical difference between the mean loudness increases obtained at low noise levels and those obtained at high noise levels. Of course, the noise-level, tone-level interaction would not be expected to be significant since the medium tone levels were selected to approximate the noise spectrum level regardless of noise type or noise level. The non-significance of this interaction adds further support to the generalization concerning the tone-level, noise-spectrum-level relationship.

The procedural variable of TWN-TA was not significant in this study nor was there a significant interaction between this variable and tone level as was found in Study I. However, there was a significant difference according to whether the loudness balance was initially approached from a level above or from a level below the level of the standard tone. Consistently greater loudness increases were obtained when the loudness balance was initially approached from a level below the standard tone level.

In conclusion, the two studies summarized in the foregoing discussion have supported results of certain previous studies in demonstrating that a noise presented to one ear increases, under certain conditions, the loudness of a pure tone presented simultaneously to the other ear. The magnitude of the loudness increase has been shown to be related to (1) the instructions given to the subject and his consequent criterion for making loudness balance judgments (2) the intensity level and frequency characteristics of the stimulus parameters, and (3) a variable in the subjects' response procedure.

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APPENDIX

TABLE 2

SUMMARY OF THE ANALYSIS OF VARIANCE FOR STUDY II INTERACTIONS BETWEEN MAIN EFFECTS ONLY

Source	Degrees of Freedom	Mean Square	F
Noise Type X Noise Level	1	0.17	0.01
Subject X Noise Type X Noise Level (Error 3)	3	12.86	3.96[b]
Noise Type X Tone Frequency	2	2.59	1.62
Subjects X Noise Type X Tone Frequency (Error 5)	6	1.60	0.49
Noise Level X Tone Frequency	2	6.51	0.31
Subject X Noise Level X Tone Frequency (Error 6)	6	20.95	6.40[b]
Noise Type X Tone Level	2	8.56	1.24
Subjects X Noise Type X Tone Level (Error 8)	6	6.89	2.12[a]
Noise Level X Tone Level	2	2.59	0.31
Subjects X Noise Level X Tone Level (Error 9)	6	8.43	2.60[a]
Tone Frequency X Tone Level	4	6.85	0.99
Subjects X Tone Frequency X Tone Level (Error 10)	12	6.94	2.14[a]
Noise Type X TWN-TA	1	0.00	0.01

(Continued on next page)

[a] Significant at the .05 level of confidence.

[b] Significant at the .01 level of confidence.

TABLE 2 (continued)

SUMMARY OF THE ANALYSIS OF VARIANCE FOR STUDY II INTERACTIONS BETWEEN MAIN EFFECTS ONLY

Source	Degrees of Freedom	Mean Square	F
Subjects X Noise Type X TWN-TA (Error 12)	3	0.86	0.27
Noise Level X TWN-TA	1	0.01	0.13
Subjects X Noise Level X TWN-TA (Error 13)	3	0.11	0.04
Tone Frequency X TWN-TA	2	1.54	1.43
Subjects X Tone Frequency X TWN-TA (Error 14)	6	1.07	0.33
Tone Level X TWN-TA	2	1.22	3.35
Subjects X Tone Level X TWN-TA (Error 15)	6	0.36	0.11
Noise Type X DOWN-UP	1	50.76	3.42
Subjects X Noise Type X DOWN-UP (Error 17)	3	14.85	4.58[a]
Noise Level X DOWN-UP	1	22.56	3.61
Subjects X Noise Level X DOWN-UP (Error 18)	3	6.24	1.93
Tone Frequency X DOWN-UP	2	1.34	0.70
Subjects X Tone Frequency X DOWN-UP (Error 19)	6	1.92	0.59
Tone Level X DOWN-UP	2	11.87	2.17

(Continued on next page)

[a] Significant at the .05 level of confidence.

[b] Significant at the .01 level of confidence.

TABLE 2 (continued)

SUMMARY OF THE ANALYSIS OF VARIANCE FOR STUDY II INTERACTIONS BETWEEN MAIN EFFECTS ONLY

Source	Degrees of Freedom	Mean Square	F
Subjects X Tone Level X DOWN-UP (Error 20)	6	5.48	1.69
TWN-TA X DOWN-UP	1	4.69	8.84
Subjects X TWN-TA X DOWN-UP (Error 21)	3	0.53	0.16
Within Cell	436	3.24	