THE EFFECT OF HARMONIC AND INHARMONIC FREQUENCY COMPONENTS ON THE PERCEPTION OF LOUDNESS AND ANNOYANCE IN COMPLEX SOUNDS

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ABSTRACT

Twenty-four students judged a series of complex sounds (half of which were harmonic and half of which were inharmonic in relationship) for loudness and for annoyance using a paired comparison method. One-half the stimuli had logarithmic tone centers (LTC) lower than that of the standard. All of the sounds were judged without white noise and half of them were judged with white noise at four intensity levels. In addition, for half of the sounds the subjects were asked to state the number of tones they heard in each complex. One form of the Polygon Preference Test was given to all Ss to measure preference for complexity or simplicity.

Inharmonic sounds without white noise were heard as louder and more annoying than harmonic sounds. A change in frequency between standard and comparison stimuli did not affect loudness judgments but low frequency comparison stimuli were perceived as less annoying than high frequency comparison stimuli. At -20 db. white noise reduced perceived loudness below that of the no white noise condition, but heightened the perception of annoyance. White noise, at -20 db. reduced the difference between harmonic and inharmonic complexes for both loudness and annoyance.

Subjects heard more tones in inharmonic complexes than harmonic complexes, with subjects with higher scores on preference for complexity perceiving a greater difference. Generally, there were no significant differences between groups but changes in LTC of comparison stimuli, relative to the standard, primarily affected the Low preference for complexity group.

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INTRODUCTION

This paper will discuss a series of experiments concerned with the perception of noise, both as to loudness and to the quality of annoyance, and the possible influence on that perception of the harmonic or inharmonic frequency relationships within a complex noise. All sounds are characterized by frequency. If two or more pure tones at different frequencies are sounded simultaneously the relationship between the tones will be either harmonic or inharmonic. The terms harmonic and inharmonic refer to the pattern of waveforms which are produced when a single tone of definite pitch is sounded. The components which go into making up the complex sound are called partials, the partial having the lowest frequency being the fundamental. Partials having higher frequencies than the fundamental are called overtones. If the frequencies of these overtones are exact multiples of that of the fundamental the relationship of the partials is considered to be harmonic. If the frequencies of the overtones are not exact multiples of the fundamental, the partials are referred to as inharmonic.

In dealing with noise as an experimental variable we are involved with a subjective definition which attempts to take into account both the physiological and psychological characteristics of the individual as well as the physical characteristics of the stimuli. A thorough discussion of the problems encountered in defining noise is contained in G.W. Kayes' (1932) monograph, <u>The Measurement of Noise</u>. Kayes points out that it is possible to produce a musical tone of such intensity and frequency, such as a shrill, loud oboe note, that any observer would experience it as a highly objectionable noise; whereas, some sounds which by physical definition are noise may be entirely pleasant in a given context, for instance, rain. A review of some definitions of noise reveals this problem clearly. On the one hand there are statements describing the physical events which produce noise and by this criterion noise is chiefly distinguished from tone by its lack of sustained frequency - that is, stimuli which cannot be separated into periodic vibrations (Bartlett, 1934, Geldard, 1959). On the other hand Bartlett (1934, p2), suggests that "noise is any sound which is treated as a nuisance," thus defining noise only in terms of the quality of annoyance. Osgood (1953, p. 85) defines noise as "a complex of frequencies assembled more or less at random and having no recognizable pitch." In this present experiment the noise stimuli conform to Osgood's definition and have no recognizable pitch or sustained frequency; however, the complex of frequencies was assembled to produce certain predetermined relationships. Implicit in the experimental situation was the assumption that this kind of noise in an ordinary situation would be, if not actually annoying, at least unwanted, which accords with the standard definition of noise given by the Acoustical Society of America. "Noise is. . .associated with any undesirable sound (Kunen, 1935, p.5)."

Concurrent with the increased industrialization of western society, the majority of the early psychologically oriented research that was concerned with noise involved the effect of noise on the listener. One early study was the effect of noise on the work output of weavers in a textile factory. The results showed a 12% increase in efficiency with a reduction of noise (Weston & Adams, 1932). The early laboratory studies include a study of the effects of noise on a simple learning task (Morgan, 1917), and on doing mental arithmetic (Harmon, 1933). These studies indicate a temporary effect associated with the onset of noise and the cessation of noise but no major overall interference with the efficiency of subjects with noisy conditions. During World War II a great deal of research was done concerning the interference of noise with communication by speech or other types of auditory signals. It was firmly established that the presence of noise was a major disruptive factor in verbal communication and could distract or mask other auditory signals (Kryter, 1950). A later series of experiments (Broadbent, 1958) seem to indicate that noise can have considerable effect on efficiency in performing some tasks, such as visual signal detection tasks.

There has also been a concern over the possibility of permanent impairment in the hearing of workers who are required to tolerate excessively noisy working conditions. In the course of investigations in this area it has become clear that some people are more noise susceptible than others and consequently in some industries efforts are made to screen applicants for noise susceptibility. The American Standards Committee instigated an investigation to ascertain permissible daily quotas of noise, without subsequent damage to hearing. The results of their investigation (Beranck, 1966) suggest that the maximum noise tolerance for most people, without damage to hearing, for an eight-hour worker's day, is 85 decibels (for each of the octave band frequencies above 700 c. p. s.).

Several factors have been established as contributing to the annoying quality of noise. If there is difficulty in locating the specific direction from which a noise is coming, the noise will be particularly distracting (Sabine & Wilson, 1943). Irregular mechanical noises are initially unpleasant (Pollock & Bartlett, 1932), and intermittent noises to which the listener has no opportunity to adapt are more disconcerting than a continuous noise (Cassell & Dallenbach, 1918). In experiments designed to investigate the relationship of annoyance to sound frequency, Ss typically were first asked to adjust two tones, or bands of noises, to equal loudness. Then the tones were judged for comparative annoyance. It was found that sounds involving high frequencies were considerably more annoying than sounds involving middle or lower frequencies even though they were of supposedly equal loudness (Laird & Coye, 1929; Reese and Kryter, 1944). That high frequencies have an effect far out of proportion to their relative intensity is a major consideration for acoustical engineers (Kunen, 1939).

Loudness itself is a variable in the judged annoyance of noise. With frequency held constant, the greater the perceived loudness the more annoying the noise will seem (Kryter, 1950). The perceived loudness of sounds is in turn affected by several variables, one of which is frequency. Before discussing the relationship between frequency and loudness, though, a clear distinction must be made between loudness and intensity. Loudness is a response variable involving a subjective judgment by the observer. Intensity is a function of the physical stimulus, measurable by audiometer, usually in decibels, or sound pressure levels. In the middle frequency range (approximately 300 to 3,000 c.p.s.) the relation between loudness and intensity is relatively independent of frequency. At frequencies above this range, given equal intensity, the loudness decreases slightly as the frequency increases. Conversely, at lower frequency range, loudness decreases as frequency decreases.

Another known variable affecting loudness is duration of stimulus. The thresholds at which both pure tones or bands of noise will be perceived are dependent on duration (Licklider, 1951). The perceived loudness of sounds well above threshold is also affected by duration. Most studies typically show that as the intensity of a tone is lowered perceived loudness will remain constant if the duration of the tone is extended. However, there are limits to the effect of duration. In a recent experiment loudness of a pure tone, measured by a scaling technique, was studied as a function of stimulus intensity. The results suggest that maximum level of loudness occurs at one second, after which sensory fatigue and adaptation effects may occur (Ekman _et al_., 1966).

In the published experiments with the loudness of complex sounds, summation in loudness seems to occur when one tone is sounded simultaneously with another (Baier, 1935). There is considerable evidence that the band width, i.e., the spacing between the top and bottom frequencies in a complex sound, has no effect on loudness until a critical band width is reached. However, after this critical band width is reached, perceived loudness increases as the frequency band width increases. The point at which the critical band width is reached varies in relation to the tone center of the frequencies in the complex. The lower the tone center of the frequencies in the complex, the more narrow the critical band width. Other variables apparently affecting critical band width are the spacing of the frequencies within the band and the sound pressure level of the complex sound (Scharf, 1961; Zwicker, _et al_., 1957).

The possibility of harmonic and inharmonic frequency relationships within complex sounds as another variable in perceived loudness was investigated in an experiment which required Ss to make absolute judgments for loudness of various sounds compared with a standard consisting of jet noise. Under these conditions no effect was observed which would suggest that inharmonic complex sounds are perceived as louder (Pearsons, 1968). In 1960 an unpublished experiment was done as part of an investigation of ventilator noise in staterooms on an ocean liner. There were complaints that certain staterooms were unacceptably noisy. However, when measured by audiometer these staterooms had no greater and sometimes lower intensity of noise than staterooms perceived as quiet. Tapes were made in each stateroom and the frequencies analyzed. The results indicated that frequency peaks in the "noisy" staterooms were inharmonic in relation to one another and those in quiet staterooms were harmonic in relationship (Fowler, 1967).

Fowler's conclusions were tested under laboratory conditions (Berenson, 1968) using a tape containing a series of inharmonic and harmonic complex frequencies. Subjects were asked to judge the loudness and the annoyance of each stimulus compared to a standard, which was harmonic. All the complex frequencies sets were of the same intensity. The hypothesis that a noise consisting of a complex of inharmonic frequencies would be judged louder and more annoying than a noise consisting of a complex of harmonic frequencies was supported by the results of the experiment. There was a significant positive relationship between loudness and inharmonic components ($t = 2.43$, $df = 9$, $p < .05$, $rm = >.6$). For annoyance, although judgments were in the same direction, the results were not significant.

The results did seem to warrant the planning of another experiment. No changes were made in the basic design and method of the original study, however, a further control was added to the stimulus sounds. In the pilot study the frequency range of the stimuli had been controlled so that all frequencies were in the middle range (300 to 3,000 c. p. s.). In the new experiment the stimuli were so constructed so that in addition the logarithmic tone center of each of them was the same. Also the possible masking effect of white noise on complex sounds was investigated, thus the inharmonic and harmonic stimuli were judged with and without white noise. The results of this experiment strongly suggest that inharmonic frequency components of complex sounds do influence the perception of loudness, so that these sounds appear significantly louder than sounds composed of harmonic frequencies (without white noise, *t* = 3.46, *df* = 17, *p* < .01, *rm* > .6 with white noise, t = 8.88, *df* = 17, *p* < .001, *rm* > .7. Furthermore, in this experiment there was a relationship between annoyance and inharmonic components in the same direction (with white noise, *t* = 8.08, *df* = 17, *p* < .001, *rm* > .7; without white noise, *t* = 13.92, *df* = 17, *p* < .001, *rm* > .7). Judgments of loudness for stimuli with white noise and stimuli without white noise were compared. Stimuli with white noise were judged to be significantly louder than stimuli without white noise (*t* = 2.93, *df* = 17, *p* < .01, *rm* > .55). Apparently, white noise at the level used (-10 db relative to the stimuli) summed, in intensity, with the stimuli to raise the perceived loudness. However, when the judgments were for annoyance the white noise apparently masked some of the noxiousness of the inharmonic components, and the significant difference between conditions was in the opposite direction from that of the loudness judgments (*t* = 2.96, *df* = 17, *p* < .01, *rm* > .55).

If harmonic and inharmonic relationships do affect both perception of loudness and of annoyance of sounds the theoretical explanation of the phenomena can be related to several areas. The first area is that of musical theory. The harmonic, inharmonic relationships are an integral part of the western musical system. Harmonic chords, or chords based on the harmonic ratio were the earliest utilized in musical composition and even today these chords are considered consonant and chords utilizing inharmonic intervals are defined as dissonant. Some musical theorists consider that our musical system developed from the perception of the overtones which occurred when a single note was played on an instrument, such as a pipe (McHose, 1947).

The theoretical explanation of the difference in quality between harmonic and inharmonic musical chords has been that of beats (Helmholtz, 1885). When two musical tones, which differ in frequency by a few cycles per second, are sounded together, another sound arises which is perceived by the ear as a single tone midway in frequency between the two original tones. If the two original tones are inharmonic in relationship, the beats will be more rapid and the result is a rough quality to the sound. This effect will occur whether the relationship is based on the absolute scale, which was used in this experiment or the well-tempered scale which is used in tuning western musical instruments (Taylor, 1965; Seashore, 1938). However, if the sound heard is produced by pure tones, in which there are no beats, and the same effect occurs, some other explanation must be advanced. There is evidence that pure tones will produce the same effect of roughness when they are in inharmonic combinations (Taylor, 1965). However, as Taylor points out, even when pure tone is produced, pure tones are not heard as such because of the non-linear properties of the ear. Other tones, called combination tones are heard as the difference in frequency of two (or more) tones is increased. The combination tones which appear have frequencies equal to the sum and to the difference of the frequencies of the two original tones and are referred to as sum and difference tones. The more complicated the interval ratio between frequencies the more sum and difference tones are introduced. At the octave, only two new tones appear; at the fifth and fourth, four new ones appear. At the other intervals there are considerably more (Taylor, 1965). The octave and the fifth occur first and second, respectively, in the harmonic interval series. In other words, there is considerable simplification at these intervals in the number of combination tones present. This being the case, subjects should hear more tones when presented with an inharmonic complex than when presented with a harmonic complex. It is possible that subjects hear complex inharmonic sounds as louder due to summation of the greater number of sum and difference tones present. It is also possible that the roughness, or annoying quality of inharmonic complexes may be related to the tolerance or preference of the observer for complexity. It is well established in the area of visual perception that there are definite individual preferences for simplicity or complexity of stimuli. This preference has been related to information processing (Munsinger, 1964). It would appear that individuals prefer amounts of complexity just slightly above their capacity to process the various pieces of information present in the stimuli. There is of course considerable individual variation along this dimension. It is possible that the number of tones (both original and sum and difference) perceived when inharmonic sounds are produced are considerably more than the average observer's capacity to process and consequently the sound is disliked or becomes annoying. If so, in order to test the hypothesis observers must be asked how many tones they hear when they are presented with a harmonic complex and with an inharmonic complex. Then if a difference in number of tones heard in the two complexes exists, it would be useful to compare individual data with scores for the same subjects on some well-established test - not necessarily auditory - for preference for complexity or simplicity.

Another experimental consideration concerns the use of white noise to mask the annoying quality of inharmonic complexes. If it can be experimentally established that inharmonic complexes are perceived as louder and more annoying, white noise added to the original stimuli may function as a masking agent to reduce the difference between the perception of inharmonic and harmonic complexes. There is evidence that white noise can be an effective masking agent (Tanner, 1958) and also that background noise can inhibit the summation of loudness that occurs for complex sounds after a critical band width point is reached (Scharf, 1961). As the level of background noise is raised, the increase in loudness that usually accompanies an increase in band width becomes smaller and smaller. It would seem reasonable to predict that the addition of white noise to inharmonic and harmonic stimuli could reduce the perceived difference in loudness and in annoying quality between the two types of stimuli. There was some evidence from the previous experiment utilizing white noise (Carroll, 1968) that white noise does reduce differences between harmonic and inharmonic complexes when the judgment is for annoyance. In the design of this experiment it was decided to vary white noise levels sounded with selected stimuli to determine, if possible, the optimum level of white noise for reduction of differences between stimulus types.

In the previous experiments (Berenson, 1967; Carroll, 1968) the frequency band width of each stimulus was different, possibly confounding the results. Consequently in the new experiment stimuli were constructed so that they had identical frequency band widths. If, given this control, the same effect was observed it would strongly suggest that inharmonic-harmonic relationships are a variable in perceived loudness and annoyance of noise. In order to keep frequency band width constant it was necessary to vary the logarithmic tone center (LTC) of the stimuli, one group of comparison stimuli having a LTC the same as the standard and one group of comparison stimuli having a LTC lower than that of the standard. The opportunity was thus available to investigate the effect of a change in LTC between standard and comparison sounds.

The present study is directed at answering the following questions: Are inharmonic stimuli perceived as louder and more annoying that harmonic stimuli; and, if this harmonic-inharmonic difference is found, does it occur independently of a change in the LTC of the stimuli, relative to the standard? As a possible explanation of this difference, do subjects hear more tones in an inharmonic complex than they do in a harmonic complex? Will the addition of white noise to the stimuli reduce the inharmonic-harmonic difference by masking; and, if so, what is the optimum intensity level of white noise, relative to the standard, which would reduce the inharmonic-harmonic difference with a minimal increase in perceived loudness and annoyance? Finally, is there a relationship between subject's preference for complexity or simplicity (based on scores on a visual test) and their perception of perceived loudness and annoyance of inharmonic or harmonic complexes?

METHOD

Subjects

Twenty-four undergraduate students at the College of William and Mary served as subjects. These students were all enrolled in an introductory psychology course, and received credit toward a course requirement. None of the subjects had any known hearing difficulties.

Apparatus

A monaural tape was made on which all sounds were of equal intensity - 45 db. The tape was arranged in three sections. In sections one and two a standard sound occurred throughout, which was always the same. In the first section eight comparson sounds were used, four inharmonic and four harmonic. All sounds consisted of four frequencies sounding simultaneously. The frequencies for each stimulus are listed in Appendix I. The high and low frequencies of the standard and two of the harmonic comparisons were identical, being 350 and 1,750 c. p. s., respectively. Two of the inharmonic comparisons were centered in the same frequency range. The remaining four comparisons, two harmonic and two inharmonic, were of a lower frequency, the low and high frequencies of each set being within 5 c. p. s. of 280 and 1,680 c. p. s. The frequency band width for all sounds was identical, being 1,400 c. p. s.

In section one 16 standards and 16 comparisons occurred, each stimulus being heard twice in an ABBA pattern: A = harmonic, B = inharmonic. Consequently, 32 comparison judgments were obtained. In section two only two inharmonic and two harmonic comparisons were taped, one each of each frequency level, those being A_1, A_3 and B_1, B_3. These comparisons were sounded with white noise at four levels of intensity, -5, -10, -15, and -20, relative to stimulus intensity. Each comparison was heard twice with each intensity level, making 64 comparisons. There was no white noise with the standard, and the comparisons were presented in a random order.

Section three differed from the previous sections in that no standard was used. Four comparison sounds were taped, identical to those used in section two, however without white noise. Each comparison was presented twice, in a random order. Throughout the tape each stimulus sounded two seconds. In sections one and two there was a three-second interval between the standard and each comparison and a five-second interval between pairs. In section three there was a ten-second interval between stimuli.

The tape was made using four General Radio, Model 1210-C frequency oscillators, a Hewlett Packard, Model 52-45L Frequency Counter, an Ampex, Model #860 tape recorder, and one Grason-Stadler random white noise generator, full frequency range, Model #455-B. The tape was single channel. The tape was presented to the subjects in a large audio-visual laboratory. Each subject listened through individual earphones. The tape machine was a Viking, Model #87 Frequency response, 40 - 18,000 c. p. s. and amplified by a Bogen TA 100 amplifier, with a frequency response of 30 - 25,000 c. p. s.

A set of slides from Munsinger's (1964) Polygon Preference Test were used for the visual stimuli. These consisted of eight slides, black on white, of asymmetrical, geometrical figures. The slides varied in complexity depending on the number of turns (or points) each figure contained: 5, 6, 8, 10, 13, 20, 31, or 40. These slides were projected on the white wall of the audio-visual laboratory. Two slide projectors were used so that the slides were shown in pairs, in every possible combination, 28 presentations in all.

Data sheets, appropriate for each section, were provided for the subjects' reports.

Procedure

A copy of the instructions read to subjects for all sections is included in Appendix II. The subjects were run in two groups, on two week nights, 10 and 14 subjects per group. In the first session subjects were asked to judge loudness for sections one and two, and then annoyance for the same sections. In the second session subjects judged annoyance first. For section three the subjects were required to state how many tones they heard in each complex sound. At the conclusion of the tape the Polygon Preference Test was administered. Subjects were asked to indicate on their answer sheets which figure, in each pair, they preferred.

RESULTS

The means of all judgments for each subject, under all experimental conditions submitted to statistical analysis, and each subject's score on the Polygon Preference Test (PPT) are presented in Tables 1 and 2. Subjects were divided into two groups of 12 each, by a median split of the complexity-simplicity (PPT) scores. The high PPT group had a greater preference for complex figures.

The judgments for loudness without white noise for each group of subjects were compared in a three-way analysis of variance, with repeated measures, under four conditions: high LTC stimuli, harmonic and inharmonic, and low LTC stimuli, harmonic and inharmonic. The means for each group in all conditions are presented in Table 3, and the analysis of variance is presented in Table 4. One significant result was found. All subjects in all conditions heard inharmonic complexes as significantly louder than harmonic complexes ($\underline{F}$ = 20.138, $\underline{df}$ = 1/22, $\underline{p}$ < .01, $\underline{rm}$ > .65).

Judgments for annoyance without white noise were treated in a three-way analysis of variance identical to the analysis for judgments of loudness. The means for each group, in all conditions, are presented in Table 5 and the analysis of variance is presented in Table 6. Inharmonic sounds were judged significantly more annoying than harmonic sounds in three conditions ($\underline{F}$ = 5.893, $\underline{df}$ = 1/22, $\underline{p}$ < .05, $\underline{rm}$ > .45). Although no significant difference between groups of subjects was revealed in this analysis, subjects in the low PPT group, in the low LTC condition judged harmonic

TABLE I

POLYGON PREFERENCE TEST SCORES, MEANS FOR LOUDNESS AND
ANNOYANCE JUDGMENTS, WITHOUT WHITE NOISE, UNDER ALL CONDITIONS,
AND MEANS FOR NUMBER OF TONES HEARD FOR HARMONIC AND
INHARMONIC COMPLEXES, FOR ALL SUBJECTS

		LOUDNESS High-LTC-Low				ANNOYANCE High-LTC-Low				H TONES Mean	
Subject #	PPT	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.
22	26	52.75	60	45.5	61	51.75	62.25	46.5	44.25	2.25	3.25
17	25	45	60	52.5	72.5	52.5	67.5	47.5	27.5	2.5	2.5
20	23	50	52.75	50.25	52.25	52.5	57.5	53.5	49	1.25	2
3	23	49.25	50.5	9.75	8.75	50	36.25	57.5	70	1	2.5
2	20	55.75	55.75	47.75	34.25	52.5	52.25	60.75	46	1.25	2.5
8	20	50	67.5	52.25	56.25	47.5	71.25	46.25	63.75	2	2.875
5	19	48.75	56.25	33.50	52.50	55	58.75	40.5	56.75	2.5	3.75
16	18	61.25	57.5	63.75	57.5	62.50	66.25	60	57.50	1.5	2.25
14	18	48.75	53	43	48.5	46.25	55.75	66.25	68.75	2.25	3.5
15	17	48.75	51.25	45	50	48.25	60	45	57.5	2	2
24	17	53.25	53	51.25	68.25	58.75	61.25	52.5	57.5	1.25	3.5
23	17	42.5	55	63.75	70	48.75	67.5	41.25	58.75	2.5	3.75
1	16	49.5	52.5	63.75	73	55	63.75	55	57.5	1.25	1.5
7	15	60	67.5	73.75	76.25	55	67.5	50	32.5	1.5	2.75
26	14	55	58.75	45	53.75	52.75	58.75	62.5	47.25	2	2
18	14	48.75	57.5	52.5	43.75	50	63.75	61.25	43.75	1	2.25
13	14	45.75	51.5	50.25	55.5	60	62.5	41.25	42.5	3.75	2.5
4	14	50	60	53.75	55	51.25	57.5	56.25	50	2.75	2.5
11	12	52	56.5	37.5	39.25	45.75	56	58	44.75	2	3.25
6	11	41.25	45	36.25	56.25	53.75	81.25	42.5	72.5	2	3.25
25	11	51.25	53.5	48.75	53.25	51.25	53.75	57	45	1	1.25
10	10	45	51	43.25	37	52.5	71.25	38.75	33.5	2	3.75
19	7	50.5	54.25	43.5	46.5	57.5	67.5	52.5	37.5	1.5	3.75
21	7	51.25	53.75	52.5	58.75	54.75	65	49	45	2.25	2.75

TABLE 2

MEANS FOR ALL SUBJECTS IN ALL CONDITIONS FOR TWO LEVELS OF WHITE NOISE

	LOUDNESS White Noise Level								ANNOYANCE White Noise Level							
	(0) High-LTC-Low				(-20)High-LTC-Low				(0) High-LTC-Low				(-20)High-LTC-Low			
Subject #	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.
22	53	67.5	58.5	62.5	50	58.5	53	52.5	52.5	40	60	50	68.5	53.5	64	58
17	40	65	80	75	52.5	50	50	50	40	35	70	30	70	30	50	35
20	50	53	50	51	50.5	51.5	50	51	55	47	56	48	62.5	55	62.5	57.5
3	51	48.5	12	9.5	47.5	50	37.5	32.5	50	57.5	55	67.5	52.5	37.5	55	42.5
2	59	53	35.5	36	53.5	45	53.5	60	47.5	52.5	42.5	47.5	55	46	57	47.5
8	52.5	67.5	55	50	47.5	40	40	40	52.5	50	72.5	67.5	60	55	67.5	57.5
5	50	55	43.5	55	40	38.5	37.5	43.5	55	47	55.5	61.5	60	52.5	56	59.5
16	62.5	62.5	65	65	50	45	60	47.5	52.5	40	72.5	65	90	82.5	82.5	80
14	50	54	45	46	42.5	40	42.5	42.5	47.5	50	57.5	62.5	75	86	88	91.5
15	50	50	50	50	49	55	50	55	50	45	62.5	57.5	67.5	67.5	77.5	72.5
24	49	51	65	69	50	45	43.5	40	60	42.5	62.5	67.5	62.5	37.5	50	40
23	40	50	75	70	42.5	42.5	50	47.5	52.5	47.5	67.5	57.5	67.5	35	50	62.5
1	58	53.5	77.5	73	47.5	35	60	65	50	60	57.5	60	60	75	67.5	65
7	55	67.5	77.5	77.5	55	60	55	65	60	67.5	30	32.5	72.5	47.5	65	42.5
26	55	57.5	55	57.5	60	67.5	67.5	67.5	52.5	52.5	61.5	55	72.5	67.5	82.5	65
18	50	57.5	42.5	45	55	50	45	45	50	62.5	45	45	72.5	42.5	70	42.5
13	48.5	55.5	59	53.5	54	46.5	37.5	42.5	60	32.5	65	39	70	43.5	56.5	47.5
4	47.5	62.5	55	55	50	40	42.5	40	52.5	45	60	50	45	45	50	30
11	52.5	56.5	37.5	37	42.5	42	44	42	42.5	48.5	51.5	43	49.5	45.5	39	50
6	45	40	57.5	50	47.5	37.5	47.5	42.5	55	37.5	82.5	75	57.5	40	35	45
25	49.5	53.5	54	54	48	45	45.5	45.5	50	44	55	45	57.5	44	42.5	42.5
10	52.5	51.5	40	35	48	49.5	32.5	31	55	25	70	34	42.5	36.5	55	32.5
19	52.5	55.5	49.5	46	53	54.5	43	42.5	52.5	35	70	37.5	65	40	70	42.5
21	47.5	55	65	55	45	32.5	40	35	64.5	40	67.5	40	57.5	40	47.5	47.5

TABLE 3

MEAN LOUDNESS JUDGMENTS OF ALL SUBJECTS IN ALL CONDITIONS, WITHOUT WHITE NOISE

	LTC			
	High		Low	
	Harmonic	Inharmonic	Harmonic	Inharmonic
High	50.500	56.041	46.854	52.646
Low	50.020	55.145	50.062	54.020

TABLE 4

ANALYSIS OF VARIANCE FOR LOUDNESS JUDGMENTS WITHOUT WHITE NOISE

Source	df	MS	F
A (PPT)	1	15.442	.0664
Subjects w/groups	22	232.398	
B (High-Low LTC)	1	99.026	.6718
AB	1	53.250	.3612
B x Subjects w/groups	22	147.398	
C (Har.-Inhar.)	1	625.358	20.138 †
AC	1	7.501	.2415
C x Subjects w/groups	22	31.053	
BC	1	1.167	.0023
ABC	1	3.104	.0662
BC x Subjects w/groups	22	495.325	

† = .01 level

TABLE 5

MEAN ANNOYANCE JUDGMENTS OF ALL SUBJECTS IN ALL CONDITIONS, WITHOUT WHITE NOISE

		LTC			
		High		Low	
		Harmonic	Inharmonic	Harmonic	Inharmonic
PPT	High	52.187	61.375	51.458	54.770
	Low	53.291	64.041	52.000	45.979

TABLE 6

ANALYSIS OF VARIANCE FOR ANNOYANCE JUDGMENTS WITHOUT WHITE NOISE

Source	df	MS	F
A (PPT)	1	30.095	.5558
Subjects w/groups	22	54.139	
B (High-Low LTC)	1	1068.334	11.751†
AB	1	216.748	2.362
B x Subjects w/groups	22	91.765	
C (Har.-Inhar.)	1	445.267	5.893*
AC	1	90.578	1.199
C x Subjects w/groups	22	75.554	
BC	1	770.250	2.410
ABC	1	178.08	.5570
BC x Subjects w/groups	22	319.671	

† = .01 level
* = .05 level

stimuli as more annoying than inharmonic stimuli. The LTC of the comparison stimuli, relative to the standard, had a significant effect on annoyance ratings for all subjects. Those stimuli with low LTC were judged significantly less annoying than those stimuli having a high LTC ($F = 11.751$, $df = 1/22$, $p < .01$, $rm > .55$). The decrease in ratings between high and low LTC stimuli occured primarily for inharmonic stimuli.

The number of tones heard in harmonic complexes and in inharmonic complexes were compared in a two-way analysis of variance, for high and low PPT groups. The mean number of tones heard by each group in each condition and the analysis of variance are given in Tables 7 and 8. Significantly more tones were heard in inharmonic complexes than in harmonic complexes ($F = 19.565$, $df = 1/44$, $p < .01$, $rm > .55$). A significant interaction occurred ($F = 5.371$, $df = 1/44$, $p < .05$, $rm > .3$) between PPT groups and number of tones heard in harmonic and inharmonic complexes. The Newman-Keuls method (Winer, 1962) was used to make multiple comparisons between means. This procedure utilizes a truncated studentized range statistic which is adjusted to avoid inflating the probability level through multiple comparison. The results of the Newman-Keuls test are presented in Table 9.

The largest differences between means (1.011, .948, $p < .01$) are between the High PPT group's judgments of number of tones in inharmonic complexes and both High and Low PPT group's judgments for number of tones in harmonic complexes. There is also a significant but smaller, difference between means for the low PPT group judgments of number of tones in harmonic complexes. The most number of tones for inharmonic complexes and the least number of tones for harmonic complexes is reported by the High PPT group.

TABLE 7

MEAN NUMBER OF TONES HEARD BY ALL SUBJECTS IN EACH CONDITION

		Harmonic	Inharmonic
PPT	High	1.854	2.865
	Low	1.917	2.625

TABLE 8

ANALYSIS OF VARIANCE FOR NUMBER OF TONES

Source	df	MS	F
A (PPT)	1	.095	.2097
B (Har.-Inhar.)	1	8.863	19.565 †
AB	1	2.433	5.371 *
AB x Subjects w/groups	44	.453	

† = .01 level

* = .05 level

TABLE 9

NEWMAN-KEULS TEST FOR NUMBER OF TONES

	Condition	Hi PPT Har.	Lo PPT Har.	Lo PPT Inhar.	Hi PPT Inhar.
Ordered Means		1.854	1.917	2.625	2.865
Difference between means	Hi PPT Har.		.063	.771*	1.011†
	Lo PPT Har.			.708*	.948†
	Lo PPT Inhar.				.240
	Hi PPT Inhar.				

df = 44
n = 12

† = .01 level
* = .05 level

The mean scores over all subjects for all stimuli heard in the section with white noise, at each white noise level, was plotted with the mean scores over all subjects for the identical stimuli (A_1, A_3, B_1, B_3) with no white noise. The graphs for loudness judgments, and for annoyance judgments, are presented in Figures 1 and 2. It can be seen that at the highest level of white noise (-5 db, relative to the standard), the stimuli are judged to be the loudest, and also the most annoying. As the white noise level is reduced, reductions in the judgments occur in a consistent manner, until the lowest level of white noise (-20 db.) is reached. At -20 db. white noise level the mean loudness judgments are below the mean loudness judgments for 0 white noise level. Mean judgments for annoyance, for inharmonic stimuli, are the same at -20 db. white noise level and 0 white noise level. However, mean judgments of harmonic stimuli continue to drop, being less at the 0 white noise level than at the -20 white noise level.

Since the primary concern of this experiment was the level of white noise which would mask, or reduce, the perceived differences between harmonic and inharmonic stimuli without concommitantly raising the overall level of perceived loudness and annoyance, only the -20 db. white noise level and the 0 white noise level were analyzed statistically. The mean judgments for loudness and for annoyance were analyzed (separately) in four-way analyses of variance, for repeated measures, the factors being: High-Low PPT groups, -20 db. and 0 white noise levels, High-Low LTC, and harmonic-inharmonic stimuli.

The mean loudness judgments for each group in every condition are given in Table 10 and the analysis of variance for loudness is given in Table 11. For loudness judgments white noise level is an important

FIGURE I

MEAN LOUDNESS JUDGMENTS FOR FIVE
LEVELS OF WHITE NOISE

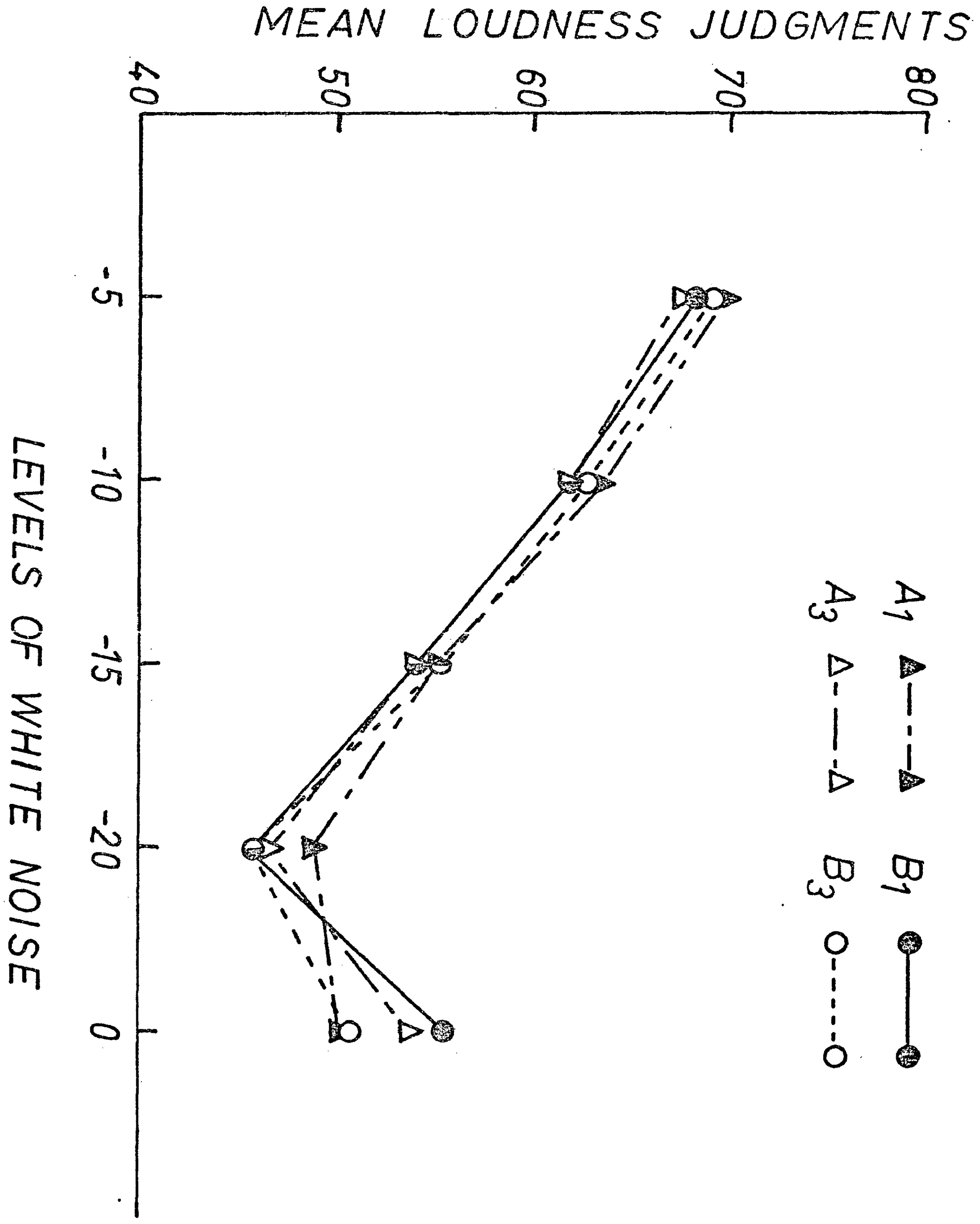

FIGURE II

MEAN ANNOYANCE JUDGMENTS FOR FIVE
LEVELS OF WHITE NOISE

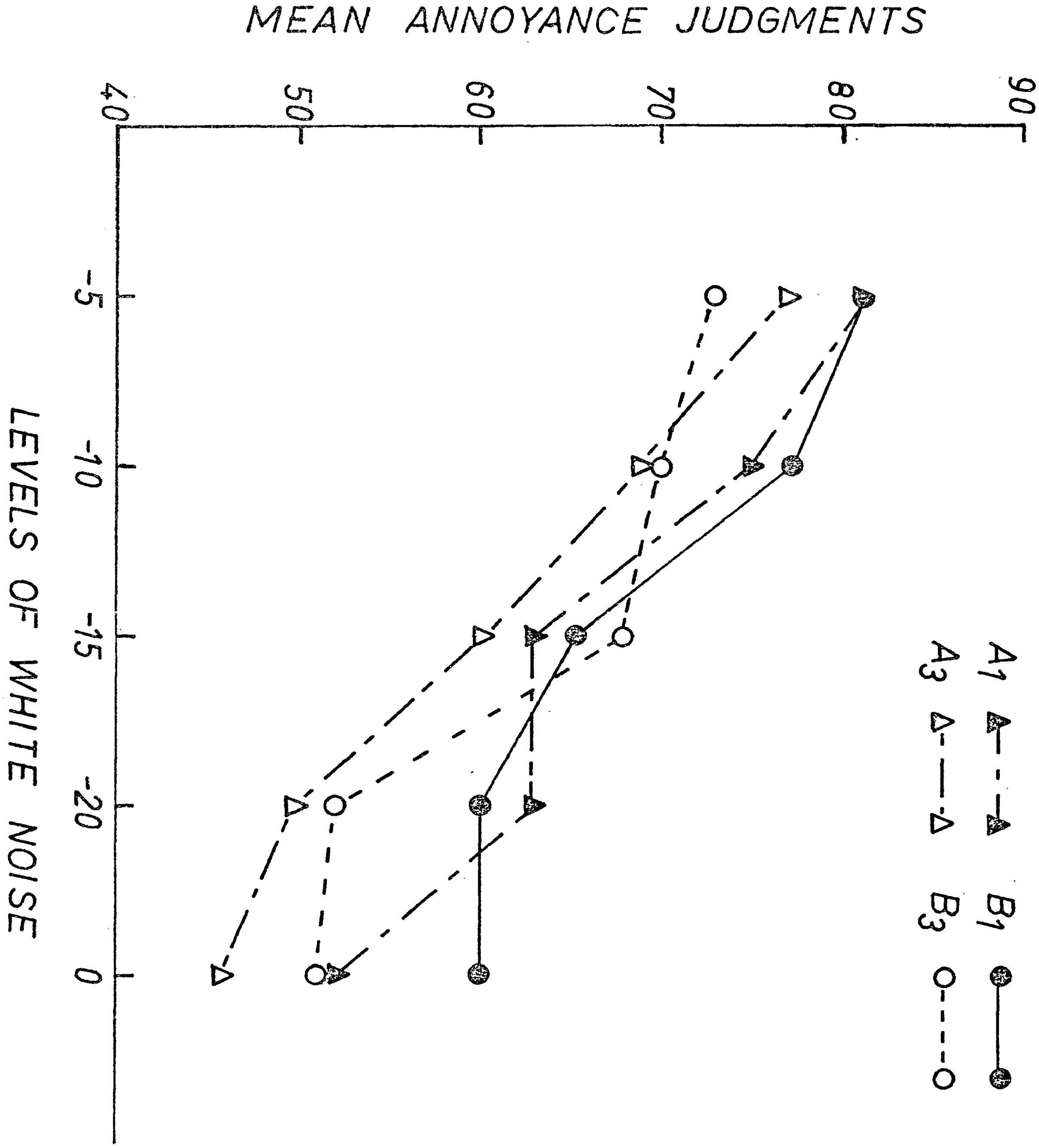

TABLE 10

MEAN JUDGMENTS FOR LOUDNESS FOR ALL SUBJECTS IN ALL CONDITIONS FOR TWO LEVELS OF WHITE NOISE

White Noise Level		-20				0			
		LTC							
		Low		High		Low		High	
		Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.
PPT	High	47.29	46.83	47.96	46.75	52.88	53.25	50.58	56.42
	Low	46.67	46.96	50.46	46.67	55.83	53.21	51.13	55.5

TABLE II

ANALYSIS OF VARIANCE FOR LOUDNESS JUDGMENTS AT TWO WHITE NOISE LEVELS

Source	df	MS	F
A (PPT)	1	14.908	.0449
Subjects w/groups	22	331.657	
B (White noise level)	1	1816.095	13.631 †
AB	1	.293	.0021
B X subjects w/groups	22	133.228	
C (Hi-Lo LTC)	1	4.845	.0231
AC	1	.105	.0005
C X subjects w/groups	22	208.995	
D (Har.-Inhar.)	1	5.845	.2462
AD	1	29.688	1.25
D X subjects w/groups	22	23.735	
BC	1	23.731	.2576
ABC	1	28.907	.3138
BC X subjects w/groups	22	92.091	
BD	1	129.199	10.649 †
ABD	1	5.169	.426
BD X subjects w/groups	22	12.132	
CD	1	43.606	2.782
ACD	1	2.408	.1536
CD X subjects w/groups	22	15.674	
BCD	1	224.251	13.555 †
ABCD	1	17.824	1.077
BCD X subjects w/groups	22	16.543	

† = .01 level

factor. Stimuli heard with 0 level white noise were judged to be significantly louder than stimuli heard with - 20 db. white noise level ($\underline{F}$ = 13.631, $\underline{df}$ = 1,22, $\underline{p}$ < .01, $\underline{rm}$ > .6). White noise level interacts with harmonic-inharmonic stimuli ($\underline{F}$ = 10.649, $\underline{df}$ = 1,22, $\underline{p}$ < .01, $\underline{rm}$ > .55) and both these factors interact significantly with the LTC of the stimuli ($\underline{F}$ = 13.555, $\underline{df}$ = 1,22, $\underline{p}$ < .01, $\underline{rm}$ > .6). These two interactions were analyzed using the Newman-Keuls test and the results are presented in Tables 12 and 13. The Newman-Keuls test reveals that both harmonic and inharmonic stimuli at 0 white noise level are judged as significantly louder than either harmonic or inharmonic stimuli at -20 db. white noise level. However, when High or Low LTC is included, the relationship between judgments of harmonic and inharmonic stimuli atthe 0 white noise level changes. High LTC inharmonic stimuli are judged significantly louder than High LTC harmonic stimuli, but they are also judged as significantly louder than Low LTC inharmonic stimuli. Furthermore, Low LTC harmonic stimuli are judged significantly louder than Low LTC inharmonic stimuli, at the 0 white noise level.

The analysis of Annoyance judgments at two levels of white noise produced two main effects. The means for all groups in each condition and the analysis of variance are presented in Tables 14 and 15. Inharmonic stimuli were perceived as more annoying than harmonic stimuli ($\underline{F}$ = 4.639, $\underline{df}$ = 1,22, $\underline{p}$ < .05, $\underline{rm}$ > .4) and High LTC stimuli were perceived as more annoying than Low LTC stimuli ($\underline{F}$ = 25.784, $\underline{df}$ = 1,22, $\underline{p}$ < .01, $\underline{rm}$ > .7). Although there was no main effect for white noise level, white noise level interacted with the harmonic-inharmonic character of the stimuli ($\underline{F}$ = 10.719, $\underline{df}$ = 1,22, $\underline{p}$ < .01, $\underline{rm}$ > .55). The means for this interaction were compared using the Newman-Keuls test and the results are presented in Table 16. It can be seen that harmonic and inharmonic stimuli at -20 db.

TABLE 12

NEWMAN-KEULS TEST FOR LOUDNESS JUDGMENTS, AT TWO WHITE NOISE LEVELS, HARMONIC AND INHARMONIC STIMULI

Condition:	-20, Inhar.	-20, Har.	0, Har.	0, Inhar.
Ordered Means	46.80	48.09	52.60	54.59
-20 Inhar.		1.29	5.80†	7.79†
-20 Har.			4.51†	6.50†
0 Har.				1.99*
0 Inhar.				

TABLE 13

NEWMAN-KEULS TEST FOR LOUDNESS JUDGMENTS AT TWO WHITE NOISE LEVELS, HIGH-LOW LTC, HARMONIC AND INHARMONIC STIMULI

Condition	-20 Hi-I	-20 Lo-I	-20 Lo-H	-20 Hi-H	0 Hi-H	0 Lo-I	0 Lo-H	0 Hi-I
Ordered Means	46.70	46.90	46.98	49.21	50.85	51.15	54.35	55.96
-20 Hi, I		.19	.27	2.5	4.14*	4.44†	7.65†	9.25†
-20 Lo, I			.08	2.31	3.96*	4.25†	7.46†	9.06†
-20 Lo, H				2.23	3.88*	4.17†	7.38†	8.98†
-20 Lo, I					1.65	1.94	5.15†	6.75†
0 Hi, H						.291	3.50*	5.10†
0 Lo, I							3.21*	4.81†
0 Lo, H								1.6
0 Hi, I								

† = .01 level
* = .05 level

TABLE 14

MEAN JUDGMENTS FOR ANNOYANCE FOR ALL SUBJECTS FOR TWO LEVELS OF WHITE NOISE

		-20				0			
		Low		High		Low		High	
		Har.	Inhar.	Har.	Inhar.	Har.	Inhar.	Har.	Inhar.
PPT	High	53.17	58.67	65.92	63.33	46.16	56.83	51.25	61.67
	Low	47.25	46.04	60.17	56.71	45.83	46.33	53.71	59.63

TABLE 15

ANALYSIS OF VARIANCE FOR ANNOYANCE JUDGMENTS FOR TWO WHITE NOISE LEVELS

Source	df	MS	F
A (PPT)	1	1250.48	3.357
Subjects w/groups	22	372.428	
B (White noise level)	1	690.084	2.635
AB	1	330.791	1.263
B X subjects w/groups	22	261.838	
C (Hi-Lo LTC)	1	3843.131	25.784 †
AC	1	240.796	1.615
C X subjects w/groups	22	149.046	
D (Har-Inhar.)	1	478.172	4.639*
AD	1	354.838	3.442
D X subjects w/groups	22	103.075	
BC	1	81.379	.9607
ABC	1	23.339	.2755
BC X subjects w/groups	22	84.708	
BD	1	619.921	10.719 †
ABD	1	32.464	.5613
BD X subjects w/groups	22	57.831	
CD	1	24.083	1.192
ACD	1	107.959	5.344*
CD X subjects w/groups	22	20.199	
BCD	1	168.751	2.353
ABCD	1	.125	.0017
BCD X subjects w/groups	22	71.696	

† = .05 level
* = .01 level

TABLE 16

NEWMAN-KEULS TEST FOR ANNOYANCE JUDGMENTS AT TWO WHITE NOISE LEVELS, HARMONIC AND INHARMONIC STIMULI

	Condition	0, Har.	0, Inhar.	-20, Inhar.	-20, Har.
Ordered Means		49.24	55.99	56.19	56.63
	0 Har.		6.75†	6.95†	7.39†
	0 Inhar.			.20	.64
	-20 Inhar.				.44
	-20 Har.				

†=.01 level

white noise level, and inharmonic stimuli at 0 white noise level, are all judged significantly ($p < .01$ more annoying than harmonic stimuli at 0 white noise level.)

Another significant interaction occurred between harmonic-inharmonic character of the stimuli, LTC of the stimuli and PPT groups, ($F = 5.344$, $df = 1,22$, $p < .05$, $rm > .4$). The results of a Newman-Keuls test of means involved in this interaction are given in Table 17. The High PPT group judged High LTC inharmonic stimuli as significantly more annoying than any group in any other condition. Conversely, the Low PPT group with Low LTC stimuli, judged both harmonic and inharmonic stimuli as significantly less annoying than any group under any other condition. The inharmonic stimuli are judged more annoying than the harmonic stimuli within each condition with the exception of the Low PPT, Low LTC condition and that difference was not significant. There is a clear difference between groups and between High and Low LTC stimuli.

The overall results of all statistical analyses indicate that inharmonic stimuli are heard as significantly louder and more annoying than harmonic stimuli, without white noise. The effect of a change in LTC between standard and comparison stimuli is generally not significant for loudness judgments. However, when the judgments of one-half the comparison stimuli from the loudness, without white noise, section were analyzed in relation to the same stimuli heard with -20 db. white noise, the change in LTC resulted in a reversal of the harmonic-inharmonic judgments so that Low LTC harmonic stimuli are judged significantly louder than Low LTC inharmonic stimuli. A change in LTC of comparison stimuli relative to standard stimulus has a larger effect on annoyance judgments than loudness judgments. With and without white noise Low LTC stimuli are judged significantly less annoying than High LTC stimuli.

TABLE 17

NEWMAN-KEULS TEST FOR ANNOYANCE JUDGMENTS (WHITE NOISE) HI-LO PPT GROUPS, HI-LO LTC, HARMONIC AND INHARMONIC STIMULI

Cond.	Lo PPT LoLTC-Inh.	Lo PPT LoLTC-H.	Hi PPT LoLTC-H.	Lo PPT HiLTC-H.	Hi PPT LoLTC-Inh.	Lo PPT Hi-I.	Hi PPT Hi-Har.	Hi PPT Hi-I.
Ordered Means	46.19	45.54	49.67	56.94	57.75	58.17	58.58	62.25
Lo Lo-I		.35	3.48*	10.75†	11.56†	11.98†	12.39†	16.06†
Lo Lo-H			3.13	10.40†	11.21†	11.63†	11.94†	15.71†
Hi Lo-H				7.27†	8.08†	8.50†	8.91†	12.58†
Lo Hi-H					.81	1.23	1.64	5.31†
Hi Lo-I						.42	.83	4.50*
Lo Hi-I							.41	4.08*
Hi Hi-H								3.67*
Hi Hi-I								

† = .01 level
* = .05 level

The data for the number of tones heard in harmonic and inharmonic complexes reveals that subjects hear a significantly greater number of tones in inharmonic stimuli than in harmonic stimuli.

The addition of white noise to the stimuli results in higher loudness and annoyance judgments at three of the white noise levels used (-5 db., -10 db., -15 db., relative to the standard). However, at -20 db. white noise level, for loudness judgments, white noise significantly reduced the perception of loudness for both inharmonic and harmonic stimuli, in all conditions, in comparison to the 0 white noise level. White noise at this level (-20 db.) is not so effective in masking perceived annoyance of stimuli. It does, however, reduce the difference between perception of annoyance of harmonic and of inharmonic stimuli so that there is no significant differences between the two conditions.

No difference between PPT groups is found for loudness judgments, with or without white noise. When number of tones is judged there is no significant difference between groups but the High PPT group perceived the most number of tones in inharmonic stimuli and the least number of tones in harmonic stimuli, with the means for the Low PPT group falling between.

Difference between groups was found for annoyance ratings, with white noise, related to LTC of stimuli. The Low PPT group judged Low LTC stimuli, harmonic and inharmonic as significantly less annoying than any group in any other condition. Furthermore, this group heard Low LTC harmonic stimuli as slightly (although not significantly) more annoying than Low LTC inharmonic stimuli both with and without white noise.

DISCUSSION

The results of this experiment are consistent with the results of previous experiments (Berenson, 1967; Carroll, 1968), indicating that sounds with inharmonic frequency components are perceived as louder and more annoying than sounds with harmonic frequency components. Furthermore, it seems clear the effect in previous experiments was not produced by frequency band width differences. Therefore, inharmonic-harmonic relationships are important in the perception of loudness and annoyance of sounds.

A change in logarithmic tone center (LTC) between standard and comparison stimuli had little effect on loudness judgments of all stimuli without white noise. In the analysis of white noise data four comparison stimuli (A_1, A_3, B_1, B_3) without white noise were included. The results indicate that Low LTC harmonic comparison stimulus A_3 is perceived as significantly louder than Low LTC inharmonic comparison stimulus B_3. It should be noted that although there was no significant difference between groups in this analysis, only subjects in the Low PPT group (see Table 10) heard harmonic stimuli as louder than the inharmonic instimuli, and this result is consistent with Low PPT group judgments for annoyance with Low LTC stimuli, both with and without white noise. A possible explanation for this reversal of loudness judgments for A_3 and B_3 is that these two comparison stimuli were the first two Low LTC comparison stimuli the subjects heard and that the change in frequency was temporarily distracting.

There is also the possibility that there are differences within harmonic complexes and within inharmonic complexes which further influence the perception of loudness. In musical theory, particularly for the inharmonic (dissonant) intervals, a distinction was traditionally observed that some dissonant intervals were "worse," or in eighteenth century terms, more forbidden, than others (McHose, 1947). Harmonic (consonant) chords were also distinguished as being weak or strong. Taylor (1965) has demonstrated that inharmonic pure tones produce the same quality of roughness as inharmonic musical tones. One could speculate that some inharmonic pure tone combinations were worse (more offensive) than other inharmonic pure tone combinations and that some harmonic pure tone combinations are more pleasant that others. Further investigation of the effect of frequency changes between standard and comparison sounds seems warranted. An experiment designed to examine differences between harmonic and between inharmonic sounds as to loudness and annoyance would also be interesting.

Annoyance judgments for stimuli without white noise were more variable than loudness judgments. The frequency of the LTC of comparison stimuli, in relation to the standard, was a large factor affecting annoyance judgments. As a result all Low LTC stimuli were judged as significantly less annoying than all High LTC stimuli. Harmonic stimuli were perceived as significantly less annoying than inharmonic stimuli but the effect was not so large as that for loudness judgments, nor was it as consistent. The Low PPT group perceived Low LTC harmonic stimuli as more annoying than Low LTC inharmonic stimuli. It will be recalled that this reversal by the Low PPT group of perception of harmonic and inharmonic stimuli occurred when half of the loudness judgments for stimuli without white noise were analyzed, although it did not occur for loudness judgments when all of the stimuli without white noise were included in one analysis. Another consideration in relation to this result is the known influence of high or low frequency on annoyance curves. Previous research relating annoyance to frequency (Laird & Coye, 1929; Reese & Kryter, 1944) indicates that sounds involving high frequencies are considerably more annoying than sounds involving middle or lower frequencies. Since no frequency above 1750 c. p. s. was included in this experiment, high frequency effects should not be the factor causing the observed result. These results suggest that the effect of high frequency is relative, that is, any change involving a lowering of frequency will tend to reduce annoyance. An examination of mean scores shows that in this experiment the reduction due to frequency change primarily affected inharmonic stimuli. It is possible that the change in LTC, relative to the standard, somehow counterbalanced the effect of the inharmonic variable.

When the number of tones heard in each complex was the criteria, there was strong evidence that inharmonic complexes are heard as containing more tones than harmonic complexes. This result was predictable from Taylor's (1965) observations concerning the added number of combination tones which are produced when inharmonic complexes are sounded. Although both high and low preference for complexity subjects heard more tones in inharmonic complexes, there is a difference between the groups. The Low PPT group heard less difference in the number of tones between harmonic and inharmonic sounds than did the High PPT group. At the end of the experiment, several subjects complained of the difficulty of making this judgment. Four tones were present in each stimulus, but the largest mean number of tones heard for inharmonic complexes was only 2.9 and for harmonic complexes 1.9, which is evidence of the difficulty of accurate discriminations in this task. Untrained observers were purposefully used for this experiment. It seems likely that with training subjects would make more accurate discriminations, that is, they would hear more tones. However, even though the subjects, in this experiment, heard fewer tones than were present in each complex, they did consistently hear more tones in inharmonic complexes and it is predicted that trained observers would produce the same result.

White noise, at the lowest level (-20 db.) reduced the perception of loudness, for all stimuli, harmonic and inharmonic. This is particularly interesting when one considers that the addition of any white noise at all actually raised the measurable intensity of the stimuli heard. The basic four tone stimuli were always of the exact same intensity, but any white noise sounded with the stimuli was additional (in intensity). This was clearly perceived by the subjects at higher white noise levels; however, stimuli combined with -20 db. white noise were heard as less loud than the same stimuli with no white noise at all, regardless of an interaction that occurred between High and Low LTC and the harmonic-inharmonic variable. The significant difference in perception of loudness between harmonic and inharmonic stimuli (without white noise) did not occur when -20 db. white noise was added. White noise was apparently effective in masking differences in perception of loudness between harmonic and inharmonic stimuli.

Annoyance judgments with white noise are consistent with annoyance judgments without white noise. As has been observed, annoyance judgments, in general, are more variable and more affected by changes in LTC of stimuli than are loudness judgments. All High LTC comparison stimuli are judged significantly more annoying than all Low LTC comparison stimuli.. White noise at -20 db. is not effective in reducing perceived annoyance (relative to annoyance judgments without white noise). Both harmonic and inharmonic stimuli with white noise are perceived as significantly more annoying than harmonic stimuli without white noise. However, they are not significantly more annoying than inharmonic stimuli without white noise, nor is there a significant difference between inharmonic and harmonic stimuli with -20 db. white noise. So there is evidence that white noise does reduce perceived harmonic-inharmonic difference, for annoyance judgments; however, -20 db. is not the optimum level of white noise to reduce overall perception of annoyance. A further study could investigate white noise at lower levels, relative to the stimuli, than the ones used in this study. The inclusion of different comparison LTCs may have confounded the results for annoyance judgments, certainly it was a powerful variable in annoyance judgments. However, throughout the series of experiments concerned with the effect of harmonic-inharmonic relationships on perceived annoyance and loudness, the annoyance results have been more variable, within subjects, and less consistent between subjects, than loudness judgments. It seems apparent, and perhaps predictable, that annoyance judgments are more vulnerable to individual interpretation than loudness judgments. Instructions to subjects were carefully worded to avoid individual definition of the term annoyance. However, there is the possibility that a noise that would be distracting, if sounded for any length of time, could be interesting or intriguing when sounded for only two seconds.

One result of the annoyance judgments with white noise is very consistent with other results in this experiment. Again, the Low PPT group judge Low LTC stimuli as least annoying and there is a large significant difference between the judgments of this group, in this condition, and all other conditions, independent of PPT group. Furthermore, although the difference is small (and not significant) again the Low PPT group perceive harmonic stimuli (with Low LTC) as more annoying than inharmonic stimuli (with Low LTC).

There is no evidence from this study that there is any significant difference between subjects who prefer complexity and those who prefer simplicity when judgments of loudness are made. However, throughout the experiment there is evidence that Low PPT subjects are more affected by a change in frequency of comparison sounds, relative to the standard. This effect occurred in one instance for loudness judgments and consistently for annoyance judgments. There was also a difference between groups when number of tones in harmonic and inharmonic complexes were judged. The High PPT group heard more tones in inharmonic complexes, than the Low PPT group, but also heard fewer tones in the harmonic complexes, than the Low PPT group. This suggests that subjects who have high preference for complexity make finer distinctions as observers in an experiment such as this. It is possible that persons with high preference for complexity may be receiving more information, as well as prefering more information. Munsinger (1964) hypothesizes that people prefer stimuli which contain slightly more information than they can readily process. An intriguing possibility is that aesthetic judgments are related to the observer's ability to process information.

Any evidence of differences between High and Low PPT groups is, of course, inconclusive insofar as this study is concerned. The lack of clear-cut differences between groups could be due to a variety of factors. The Polygon Preference Test (PPT) may not be an appropriate instrument to use in a noise experiment. The PPT measures preference for visual complexity, while the main experimental stimuli are auditory. There is also the possibility that preference for complexity-simplicity is not related to the perception of differences between harmonic and inharmonic stimuli, although it is apparently related to changes in perception prompted by differences in frequency. The third, and to this writer, most likely possibility for the lack of clear-cut differences between groups is that the limited number of subjects necessitated a median split of the PPT scores. The range of scores was wide but showed a relatively normal distribution, with a cluster of scores in the middle range. To examine differences between groups more effectively it would have been necessary to first administer the PPT to a large group fo subjects, and then select very low and very high scorers to participate in the noise experiment. This type of pre-selection of subjects was not desirable for this experiment, since the primary variable under investigation was perception of harmonic-inharmonic complexes and a prior PPT test may affect the Ss' loudness and annoyance judgments. The evidence of possible differences between groups from this study suggests a study in which preference for complexity-simplicity is the main variable, and preselected subjects are used.

This experiment has added evidence to that already accumulated concerning the importance of harmonic-inharmonic relationships in the perception of loudness and annoyance. Changes in LTC between standard and comparison stimuli are not an important variable for loudness judgments, but do affect annoyance judgments so that high LTC stimuli are perceived as more annoying than Low LTC stimuli.

More tones were heard in inharmonic complexes, than harmonic complexes, by these subjects.

The addition of white noise (at -20 db.) to the stimuli reduced the perception of loudness and differences between harmonic and inharmonic complexes. For annoyance, white noise (at -20 db.) heightened the overall perception of annoyance but minimized the difference between harmonic and inharmonic complexes.

Evidence of differences between groups on preference for complexity or simplicity was not conclusive. There is evidence that the effect of change of LTC was a variable primarily affecting the Low PPT group, and there is some evidence that the High PPT group made finer discriminations than the Low PPT group.

APPENDIX I

FREQUENCY COMPONENTS OF STIMULI

COMPARISONS

	Harmonic		Inharmonic
A^1	350 c. p. s.	B^1	345 c. p. s.
	700		705
	1400		1390
	1750		1745
A^2	350	B^2	355
	1050		1060
	1400		1380
	1750		1755
A^3	280	B^3	285
	840		850
	1400		1390
	1680		1685
A^4	280	B^4	275
	840		837
	1120		1130
	1680		1675

Standard

350 c. p. s.
700
1050
1750

APPENDIX II

INSTRUCTIONS TO SUBJECTS

In this experiment you will hear a series of complex sounds which I would like you to judge for loudness. The sounds occur in pairs; the first sound in every pair is always the same throughout the entire experiment and has been arbitrarily assigned the number 50 on a loudness scale running from I to 100. The second sound in every pair is the sound I would like you to judge. Listen as carefully as you can and assign the second sound the number between I and 100 which you believe most accurately represents its loudness in relation to the standard sound (or first sound in every pair). For example, if the second sound in the pair appears to be louder than the first sound you would assign it a rating higher than 50; conversely if the second sound appears to be softer than the first sound you would pick a number lower than 50. This study is an investigation of the relative loudness of certain types of sounds and is in no way a measure of intelligence, or personality, factors. It is important in this type of study that the observer be conscientious and as accurate as possible in making his judgments, so it will be necessary for you to concentrate on each comparison sound as well as you can.

Now you will hear another series of sounds to be judged. The procedure is essentially the same as that of the first part of the experiment; however this time I would like you to judge for annoyance or distractibility instead of loudness. Try to use as a criteria what you imagine your tolerance for each sound would be if you had to hear it for any length of time, or if you were trying to study while the sound is on. Notice we are not concerned with loudness directly, but rather how distracting or annoying the sound seems to the observer. Again there are 16 judgments to be made, the first sound in each pair is assigned the number 50, and the other sound may be assigned any rating between 1 and 100. One is the lowest annoyance rating and 100 the highest.

Instructions for White Noise Section

In the next section you will follow the same procedure as before. First you will hear a standard, then a comparison, which you are to judge. As you see on your data sheet there are 32 comparisons to be judged. This time I would like you to judge them for loudness.

Another group, judge for annoyance.

Last Section

In this last brief section the procedure is different. There is no standard. Every sound you hear is to be judged. You will hear 8 sounds, spaced 10 seconds apart. As you listen to each sound, try to distinguish how many separate tones each sound has. In other words, each one of these sounds is complex, made up of two or more pure tones. I would like you to indicate on your data sheet, after each sound is heard, how many tones you hear.

SLIDES

You will be shown a series of slides of geometrical figures, two at a time. I want you to look at each pair and indicate on your answer sheet which figure you prefer. As you see on the answer sheet opposite each number is the letter L and the letter R. Indicate your preference by circling the appropriate letter, L for the left slide as you face the screen, or R for the slide on your right side as you face the screen. There will be 28 presentations. This test is concerned with aesthetic preference and is not correlated with intelligence, sex differences, or personality differences. These figures are not inkblots, or involved with any other projective technique.

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