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THE PLEASINGNESS OF SEQUENTIAL AND SIMULTANEOUS  
PAIRS OF TONES: EFFECTS OF WAVEFORM, DISSONANCE, AND DELAY

by

Robert W. Whissell  
H.B.A., Laurentian University, 1977

A Thesis

Submitted to the Faculty of Graduate Studies through the  
Department of Psychology in Partial Fulfillment  
of the Requirements for the Degree of Master of Arts  
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1982

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## ABSTRACT

Two experiments were conducted to examine the effects of dissonance, waveform, delay, musical interval, and musical experience on pleasingness ratings for simultaneous and consecutive tonal intervals. Dissonance estimates were obtained by a curve fitted model adapted from Plomp and Levelt's (1965) dissonance theory.

In the sequential tones experiment, 41 subjects assigned ratings of pleasingness of tone pairs and preference for the better sounding element of tone pairs. Two hundred and ten taped tone pairs from a frequency range of 300 to 2600 Hz were delivered in sine or square waveform, at two delay times (100 and 500 ms), at 70 db SPL, by headphones to the subjects. Subjects were randomly assigned to the waveform and delay combinations. Dissonance was a very weak positive factor for pleasingness ratings. An expectancy model for the pleasingness of sequential tones was proposed. Individual tone preferences were supported by other research findings for the inverted "U" shaped preference curve.

In the second experiment, 23 subjects rated the pleasingness of taped simultaneous wave tones for Pythagorean musical intervals in a frequency range from 50 to 800 Hz. Calculation of dissonance, via the curve fitted model, re-

ceived support by the replication of classical findings. Dissonance, here, was strongly and negatively related ( $r = -.82$ ) to Pleasingness ratings.

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## CHAPTER I

### INTRODUCTION

One of the major issues among philosophers and theoreticians since the time of Plato has been the resolution of the mind-body problem: a contemplation of the relation or dichotomy inherent between that which exists and that which is perceived as existing. Fechner, a German physicist and pioneer psychologist, in his work on psychophysics and aesthetics examined functional operations linking the psychic and the physical (Marx and Hillix, p. 37, 1973). Indeed, many phenomena such as perceptual illusions, taste preference, or acoustic preferences are really investigations into the mind-body problem. In the case of sound, many types of sonic stimuli are received from the environment which surrounds us; but is what we seem to "hear" in fact an accurate representation of the physical sensation that was received? Sound has long been a message carrier: sound has certain physical properties, frequency (vibrations per second), intensity (amplitude or displacement of the vibration), timbre (quality of simultaneously born frequencies), and pulse (timing between successive sound wave units). These dimensions have fallen under the examination of psychologists who have

noted how intimately man's behaviour has been modified by sound. The experiments in this study focus on frequency and interval preferences for pairs of tones.

In 1929, Laird and Coye looked at the relative "annoyingness" of one tone or another in a tone comparison task. They found frequencies in the range of 256 to 1024 Hz to be less annoying than 120 Hz and below or 2048 Hz and above. Their annoyingness curve seemed to be a simple inversion of the tonal preference curves discussed below.

De Souza et al. (1974) used the equal loudness curves as mapped by Fletcher and Munson (1933) to ensure that all tonal stimuli were delivered at equal subjective loudness levels. The equal loudness curves controlled for preferences which might have been a result of loudness rather than the experimental variable, frequency. The De Souza et al. data showed a peak in frequency preference at 400 Hz (and an inverted "U" shape for the preference curve).

In a study conducted for the National Bureau of Standards in Washington (D.C.), a re-determination of the equal loudness contours was carried out by Molino (1973). Molino established equivalence curves for the comparison of tone frequencies of 125, 1000, and 8,000 Hz at various decibel levels of intensity 0, 10, 40, and 70 db SPL. Molino found his data to be comparable to that of Kingsbury (1927) for sound pressure levels, (especially in the 150 to 4,000 Hz

range). In comparison with the data of Fletcher and Munson (1933), (the other early experiment using earphones), an upward shift of 10 db for the Molino and Kingsbury data made the curves more compatible with those of Fletcher and Munson. The data of Molino (1973), Kingsbury (1927), and International Organization for Standardization (1959) for the middle frequency ranges, 200 to 4,000 Hz, agree except for a minor discrepancy in shape around the 2,000 Hz mark.

The Robinson and Dadson (1956) data for free field equal loudness contours, fall under criticism from Molino who notes that in comparison with the earphone data studies even allowing for threshold adjustments, correspondence was not close (Molino, 1973). Because of the general flat contour of the 70 phon equal loudness curve, as shown in Molino's and others' data, it would seem that this intensity would be useful as an equal loudness control; such a control was used in the Berlyne et al. (1967) experiments.

Vitz (1972) studied both frequency and loudness preference. For three levels of loudness intensity, he found that frequency preference peaked in the range from 400 to 750 Hz, with slow declines on either side.

A brief comparison between the frequency preference curves of Vitz (1972) and De Souza et al. (1974) shows the value of the equal loudness curves in clarifying frequency preference. The equal loudness curves of De Souza et al. have a distinct peak at 400 Hz while those of Vitz, which do

not use such a control, display a more rounded preference function. Since both Vitz and De Souza et al. have only sampled a small number of frequencies, the continuity of data points for a preference curve is not complete.

Using foghorns Molino et al. (1974), established higher preferences for pure tones of 300, 500, and 835 Hz or a composite tone composed of these frequencies rather than any composite tones having a component of 120 Hz.

Patchett (1979) examined the most pleasant acoustic setting made by subjects who used frequency as a free response variable. He found judgements focusing in a narrow band centering on 399 Hz. The coincidence between the finding of Patchett (whose stimuli were administered at constant intensity) and the findings of De Souza's preference curve with its peak at 400 Hz using equal loudness suggest that an absolute preference point or band around 400 Hz might exist. The following series of articles explores the preference aspect in pairs of tones, often referred to as dyads or intervals. But first, a historical introduction is in order.

The perception of certain combinations of tones as being more pleasing or aesthetically stimulating may explain the type and arrangement of music that has entertained man throughout the ages. For Pythagoras, (as in Helmholtz, 1954, p. 1), the key factor for aesthetic enjoyment in music dealt with establishing ideal ratios of the frequencies of the particular notes involved. The rationale for this approach was

philosophical in nature and based upon assumptions of arithmetic purity and beliefs of number and harmony which were in vogue at the time and took the form of a kind of arithmetic mysticism as in Portnoy (1954). The followers of Pythagoras expanded on the belief and became more radical, espousing that numbers were the basis of nature, and that man as a part of nature should be expressed as some combination of numbers or other. Logically, then, man's endeavours in the arts ought to reflect his numerical basis in nature and since nature was benevolent, then, man's efforts in the arts should have some moral value. By this chain of reasoning, the Pythagoreans had concluded that music itself (as an art) had moral value, which no doubt they had chosen to protect with some arithmetic rule of precision. Aristotle, as quoted in Portnoy (1954), is reported to have said of the Pythagoreans: "they saw that modifications and the ratios of musical scales were expressible in numbers; since, then, all other things seemed in their whole nature to be modelled on numbers, and numbers seemed to be the first things in the whole of nature, they supposed the elements of numbers to be the elements of all things, and the whole heaven to be a musical scale and a number" (p. 6-7).

Later Pythagoreans actually contended that the speeding heavenly bodies did produce music which unfortunately man could not hear, because he was so accustomed to it. For this school of thought, the numbers from one to four assumed a

great importance. Legend has it that Pythagoras by means of experimentation with stringed instruments found the optimal ratios of parts of the string to the whole which produced more aesthetic sounds. These were 2:1, 3:2, 4:3, and various other ratios of integer numbers. Here were the octave, perfect fifth, and perfect fourth. The two musical instruments of the time were the lyre and the flute. The music of the era was melodically organized and not harmonized. Strings were plucked or notes were played serially. For the lyre establishing ratios that were acceptable, for strings in excess of three or four would be difficult, owing to the cultural inertia of the time. The route towards an acceptable musical scale would be many centuries in the making. Today, the tuning scales are the Pythagorean, Natural or (Just) Intonation, and the Equal Tempered which had their basis in many 3 and 4 tone subscales. Wood (1975) provides a brief review of these developments (as do many textbooks on musical history or philosophy, with greater enlargement). The Pythagorean scale has formulae for optimally pleasing combinations of tones, however it has the drawback of thereby creating many horribly dissonant (or unpleasant sounding) combinations for the cases where tonal intervals do not combine ideally, and during rendition these notes would be avoided. The current equal tempered approach has divided each octave (2:1) interval into twelve semitones of equal "size", where two semitones equal one whole tone. The concept of equality is somewhat of a



misnomer, since each successive tone is approximately 1.06 times the frequency of the note below. The structure of the equal tempered approach was primarily governed by the limited number of discrete notes that could be fitted onto certain keyed instruments and also by the ease of departure or transition of melody into different keys. Notably, some frequency differences between sharps and flats were ignored and presumed to be sounded as the same note, (for instance, C sharp = D flat, F sharp = G flat, etc). In the equal tempered scale, the Pythagorean consonancies because of the "equal" interval width are tuned sharper or flatter as the system dictates. The piano is the perfect example of an equal tempered instrument. Another scale, the Just Intonation scale, can be used by either violinists or singers to produce frequency intervals that are perceived to be better than what the Pythagorean system or Equal tempered scale has to offer, particularly for thirds and sixths. A Just Intonation singer modulates the frequency of the note sung to some ideal perception of what that note should be, given the context of the musical situation. Just Intonation means singing of close Pythagorean consonancies or the singing of slightly sharper or flatter notes than in the musical text.

The foregoing discussion suggests that a measurement of interval or sequence preferences is highly related to the structure of musical scales or compositions. Scale constructors attempted to build into their tuning scales desired

consonancies while trying to avoid dissonant intervals. But, such scales could also reflect social pressures, or natural preferences. The state of research on whole scales is very much at a beginning level, however, since such investigation is a new concept.

O'Keefe (1975) examined preferences for paired musical excerpts playing in either the Just Intonation or Equal Tempered scale for the classical pieces "Silent Night" and "America the Beautiful". The song "Silent Night" produced no significant differences in scale preferences. However, the renditions of "America the Beautiful" were significantly preferred in the Just Intonation scale. The author indicated the subject pool, composed of moderately trained and relatively untrained musicians, preferred Just Intonation. The observation tends to substantiate the view that scale systems could be chosen to complement the song context, thereby indirectly accounting for the stubbornness of some musicians to adopt the Equal Tempered scale. A view noted by Menuhin & Davis, (1979) was that modifications of the Equal Tempered Scale (flattening or sharpening of some notes) were not approved by musical purists. In addition, O'Keefe noted that his findings might be in conflict with those of Ward and Martin (1961) who found the reverse situation in scale preferences for sequences of individual tones, rather than musical excerpts. More research is needed to clarify the findings of these two experimental studies.

The preference for certain sounds or combinations of sounds in sequence is a form of harmonic logic and is related to the "tonality" of musical pieces. Paul Hindemith, (1961, p. 64) claimed that "Tonality doubtless is a very subtle form of gravitation". Music that has tonality is structured around a keynote or "Tonic" around which the other tones are organized. From Machlis (1961, p. 32) the following quotation about tonality describes its importance.

The sense of relatedness to a central tone is known as 'tonality'. It has been the fundamental relationship in our music. As Roger Sessions has written, 'Tonality' should be understood as the principal means which composers of the seventeenth, eighteenth, and nineteenth centuries evolved of organizing musical sounds and giving them coherent 'shape'.

A group of related tones with a common center or Tonic is known as a 'key'. The tones of the key serve as a basic material for a given composition. The key, that is, marks off an area in musical space within which musical growth and development take place.

Composers heightened their musical effect by moving or "modulating" from the home key to a new key, and returning. (Machlis, 1961). Twentieth century composers sometimes used bi- and polytonality, that is, multiple home keys.

Menuhin & Davis (1979), provide a summary of the atonal musical theory of Schoenberg which, like Bach's approach,

stresses the equality of all the keys. Menuhin & Davis noted that Schoenberg based his system on the 'tone row', the arrangement of the twelve semitones of the octave, in a given order. For Schoenberg, the composer could not repeat any tones until the entire sequence had been used. Both melodies and harmonies had to use the tone row. However, the authors noted that Schoenbergian music despite a demanding novelty became accepted in operas before the turn of the twentieth century. Myers (1968) observed the abandoning of tonality in favour of twelve-tone composition or in general, atonal music was the most clear trend in twentieth century music. However, he noted that several "masterpieces" of the twentieth century still used the principle of tonality. Also, a great amount of twentieth century music remains at least bitonal or polytonal rather than atonal. As a generality Myers offered that "Thus we see a gradual growing of tonal emancipation..." and provided several examples. The study of preferences of sequential tones represents a very basic investigation of tonality: the shifting of preference patterns from note to note.

The bulk of the research on tone preference seems to have been done with tone pairs or intervals, and is closely involved with the notion of consonance and dissonance. Most of the studies attempted to use ratings or rankings of tonal pairs according to different aesthetic criteria. Historically, the subjects have shown themselves to be at least divisi-

ble into two broad categories, musicians and non-musicians.

In 1918, Malmberg required a group of musicians and psychologists to rank two-tone combinations for "smoothness, purity, and blending". The orderings were highly correlated and yielded a consonancy-dissonancy series headed by octave, perfect fifth, and major sixth.

In 1928, Guernsey produced a similar ranking with respect to consonance using musicians. However, when judgements were required under the category of pleasantness, the order was different. The judgements were ordered sixths, thirds, perfect fourth, and minor seventh.

In 1914, Valentine developed a preference rating scale that was similar to that of Guernsey in 1928 who used a seven-point pleasing-displeasing continuum. The list was headed by minor third, octave, major sixth, and minor sixth.

From the above evidence, for the sample populations, (the musicians), the concepts of consonance and dissonance clearly differ from impressions of pleasingness or displeasingness.

Van de Geer, Levelt, and Plomp (1962) asked non-specialists in music to rate tone pairs on seven-point scales of consonant-dissonant, beautiful-ugly, and euphonius-noneuphonius. Under factor analysis, Van de Geer et al. found the scales to be representative of a common dimension for tone rating. Highest locations were awarded to sixths, thirds, and fourths.

To clarify the dichotomy between laymen and musicians, Frances (1958) found that laymen awarded the higher ratings to the octave and fifth as compared to the musicians. Frances also compared two series of five-tone chords, one markedly dissonant and the other consonant, he found the professional musicians rejected the consonant chords.

According to the literature, musicians and laymen have different preference criteria which they use to evaluate tonal dyads (intervals). Also, there are a number of scales of aesthetic preference associated with tone pair comparisons. Specifically, consonance and dissonance could mean different things to different groups, and consonance is not necessarily the sole criterion for pleasingness.

Many theories attempt to explain the factors underlying dissonance. Herman Helmholtz (from 1877 translated in 1954) defined consonance as an absence of beats between simultaneously sounded tones. A beat (or beats) is the regular interruption of a perceived musical note (or notes) by short pulse (or pulses) of higher intensity noise. The beat is the product of periodic wave summation and cancellation. When wave trains of component frequencies for a note are in phase at relative maximum amplitudes, a beat will occur. To continue, then, for Helmholtz, consonance for complex tones, that is, tones carrying upper overtones would mean that the overtones would tend to harmonize (with the fundamental) and be without beats. On the other hand, dissonant overtone combinations

would produce beats. (The beats may not be able to be heard, but add to the psychological roughness of the impression given by the notes being played).

For simultaneous sounding of pure tones, Helmholtz advocated that dissonance is due to beats between the tones depending on the interval (frequency difference) between the notes, (known as the beat frequency).

According to Berlyne (1971), Stumpf in 1893 countered Helmholtz's conception of dissonance by stating that dissonance could occur without beats. From his experimentation, Stumpf concluded that consonant tone pairs were harder to discriminate and he proposed the notion of "fusion". This was the tendency of component tones to be heard as a unit or whole under conditions of consonance. The idea was that in consonance, tones were fused into a kind of irreducible Gestaltist whole that was not analyzable into subparts. Hence, the ideal or consonant two-tone clang could not be perceived as two, but instead as one tone. However, a factor analytic study by Van de Geer, Levelt, and Plomp (1962) disclosed the fusion dimension (composed of the adjectives; simple-multiple, rough-smooth, and active-passive) was independent of the factor "consonant-dissonant": further, the investigators found the degree of fusion increased with frequency disparity between the tones. Also, according to Plomp and Levelt (1965), Stumpf subsequently found weakness in the theory.

Krueger's interference theory (1903-1904) bore some sim-

ilarity to that of Helmholtz. However, Krueger emphasized the importance of the beating of difference tones against each other: (A difference tone is similar to a beat frequency between members of a tone pair, but, it refers to the beats that are a result of disharmony between conflicting ratios of partials to themselves or to fundamentals). For Krueger consonance was achieved by duplication or similarity of the difference tones. More consonant intervals would have more successive difference tones oscillating at the same frequency. This would in turn give rise to the overall sensation of fewer components and hence, develop a simpler and more aesthetic impression.

The interference models of Helmholtz and Krueger have found some recent support. In experiments of dichotic tonal presentation (two tones, one to each ear by earphones), as in Sandig (1939), intervals of dissonant frequency difference such as the major second and the major seventh were found to be more consonant in the dichotic task. To simplify, if tones are simultaneously sent to the same ear, interference may result at the point of reception, giving rise to the perception of dissonance. If the tones are separated, (one per ear), then each ear could process the signal carried by that tone without interference and therefore with perception of consonance. The studies importantly suggest the locus of the psychological impression of consonance or dissonance as originating somewhere at the receptor site, rather than at higher



and more integrative cognitive levels.

Lipps in 1885, postulated that acoustic vibrations were unconsciously counted and that in the case of consonancy many acoustic vibrations coincide, leading again to a parsimonious structure for aesthetic consonance. Lipps must contend with the objection that the relations of consonancy are not eliminated when notes are slightly mistuned (e.g., 201:300 instead of the fifth 200:300, see Peterson and Smith, (1930)). The major flaw in the theory is the assumption that the ear is able to unconsciously resolve or count all component frequencies for complex intervals.

Others have proposed cultural theories for consonance and dissonance. The formulation by Lundin (1947, 1968) of a theory for cultural explanation of consonance and dissonance was greatly influenced by another pioneer in the field of musical measurement, C. E. Seashore. After showing the dichotomy between frequency and pitch, that is, that pitch is the psychological correlate of frequency and is subjective in nature, Lundin quotes Seashore (p. 25):

Pitch discrimination is not a matter of logical thought. It is rather an immediate impression, far more primitive than reflective thought, and dependent upon the presence or absence in various degrees of the sensitive mechanism of the inner ear.

(Later in 1938)...Training, like maturation results in conscious recognition of the nature of pitch, its mean-

ing, and the development of habits of use in musical operations. Training probably does not modify the capacity of the sense organ any more than the playing of the good violin may improve the quality of its tone.

For Lundin, "the consonance or dissonance of a musical interval is merely an individual judgement that is culturally determined rather than caused by some absolute property of the stimuli" (p. 98). He supported his arguments by proofs from other researchers. Lundin noted, firstly, that the criteria used by individuals for their judgements is a function of cultural influence. According to Bugg (1933), untrained persons tend to be more influenced by affective factors in their judgement. Consonance and dissonance is more a product of like or dislike of a musical interval. Valentine (1914) found children's preferences to vary across school groups, and that as a child grows older there was a development of certain kinds of consonance preference. Collman (1972) found a significant relationship between the ability to distinguish pitch and the capacity to discern consonance (as adults defined it to be) for elementary school children. As well, he noted that aesthetic judgement was more highly related to mental age than is visual discriminative judgement. Collman proposed that early instruction in music would facilitate the development of pitch discrimination and consonance preference.

Lundin also suggested that judgement of consonance could

be modified by repetition (of dissonant intervals), as in Moore (1914). Meyer (1903) found subjects with an initial dislike for quarter-tone Asiatic music developed greater preference for it with repetition. Finally, Lundin postulated that judgements of consonancy are contextually bound, and comparative in value; the musical setting determines the consonancy for individual tone intervals. To finish with a final appraisal from Lundin (p. 100), "The judgement which we will make will be a function of many conditions. Some of these we have mentioned: the particular criterion which one selects as a standard for his judgement, previous experience with the interval, the context in which the interval appears, and general and specific cultural background so far as music is concerned, and more particularly so far as consonance and dissonance are concerned." Perhaps, concerning the Pythagoreans, and in favour of his cultural views, Lundin (1967, p. 69) noted that the Greeks might have preferred a scale smaller than our octave and that many different scales have appeared in a variety of cultures.

Plomp and Levelt (1965) took a physiological stand on consonance and dissonance and found some support for Helmholtz's interference theory from an approach dependent on beats via a critical bandwidth. The assumption of the critical bandwidth is that the frequency separation of tones in a tone interval could affect the consonancy or dissonancy of that tonal pair. As shown pictorially by Plomp and Levelt,

in 1965, for a tone pair with a mean frequency of 500 Hz, the critical bandwidth was roughly in the range of 10 to 75 Hz. Their analysis also continued to show that the critical bandwidth is greater for tone pairs with higher mean frequencies, and lesser for lower. Maximal dissonance as Helmholtz (1877 translated 1954) had thought of it was around 33 cycles per second difference between the tones, but, Plomp and Levelt had shown it to be roughly 25% of a critical bandwidth which increased in size with the mean frequency. The idea of dissonance as being maintained by roughness beats was upheld. Plomp and Levelt performed some statistical applications of the critical bandwidth to Bach's Trio Sonata for Organ No. 3 in C minor and Dvorak's String Quartet Op. 51 in E flat major. They noted that difference tones fell quite often within the critical bandwidth but almost always tended to exceed the very dissonant 25% mark of the critical bandwidth. It is important to note that not all beating is necessarily unpleasant in nature.

The mechanics of the critical band width effect come from interference patterns in the inner ear. The cochlea of the ear, which receives its acoustic input from a collection of small bones that beat on a skin membrane, is optimally sensitive to successively lower pitches along its length (as distance from the stapes increases as in Kling and Riggs, 1972). To be heard as a certain pitch, a frequency of vibration must stimulate a given area along the basilar membrane

of the cochlea. On the basilar membrane, the proximity of two stimulation areas, (one for each of two tones) determines the extent of mutual or harmonic benefit. Dissonance then, is equated with partial and destructive overlap of stimulation areas, that is, being inside a critical bandwidth. Consonance is related to complete overlap of stimulation area (unison), or complete separation of stimulation areas. A quote from Galileo Galilei in 1638, as in Crew and Salvio (1963) gives an early view of dissonance.

Agreeable consonances are pairs of tones which strike the ear with a certain regularity; this regularity consists in the fact that the pulses delivered by the two tones, in the same interval of time, shall be commensurable in number, so as not to keep the eardrum in perpetual torment, bending in two different directions in order to yield to the ever-discordant impulses (p. 100).

The notion of the eardrum as experiencing dissonance as a painful vibration pattern represented an earlier view of the mechanics of dissonance. It remained largely to Von Bekesy, centuries later, who won the Nobel Prize for his research in audition, to assist in the discovery of the locus of dissonance perception. Von Bekesy showed that neither harmonics nor difference tones were the result of eardrum vibration pattern, nor were harmonics the result of middle ear distortion. Von Bekesy indicated that difference tones might be

able to be generated in the middle ear (Kling and Riggs, (1972). More recently, the theory of the origin of harmonics has been speculated to be in fluid eddies of the inner ear or as being in the proximity of neural auditory fibers under the basilar membrane (Kling & Riggs, 1972).

Oddly, without such interference mechanisms, patterns of consonance and dissonance would probably not exist for the human listener, since otherwise tolerance for many pairs of sounds might be equal, and without the interference patterns for consonance and dissonance; the calibration of musical scales into discrete steps (for harmony) would not have any meaning.

To summarize, the degree of frequency separation for the components of a two-tone interval is the crucial variable in determining the relative consonancy of the perceived note or notes. If the degree of separation is within a certain span (which might be a mechanically critical distance on the basilar membrane) then the perception might be one of dissonance.

An article by Soderquist (1970) concerned itself with "frequency analysis and the critical band"; it investigated subject's ability to discriminate (as a forced choice task) alternative frequencies that were or were not components of the complex tone. The subjects indicated which of the two comparison tones coincided with some frequency component of the complex stimulus tone, (a tone constructed of many enhar-

monic overtones, to avoid harmonic cues). The experiment found that musicians out-performed naive subjects in the ability to discern greater numbers of the enharmonious tone components.

As a final conclusion to his article, Soderquist hypothesized that musicians were able to separate out more components because they had a narrower and more rectangular critical band. Therefore, musicians had more discrimination power and greater accuracy than "naive" individuals.

Terhardt (1973) countered the adequacy of the most widely accepted view on consonance-dissonance (that of the critical band, Plomp and Levelt, 1965) by stating that firstly, roughness (dissonance) can be perceived by subjects for notes separated by an interval that is wider than critical and secondly, that dichotic or successive tonal stimuli produce no roughness, (this is contrary to Maher, 1975), and thirdly, that complex tones as elements of music are never dissonant. Terhardt seems to indicate that complex tones are not dissonant in themselves, but rather that musical context brings about the perception of dissonance for the complex tone.

The model which Terhardt develops for musical perception is based on pitch associations that are adapted from experience with frequency associations in speech formants. He proposed two types of tonal evaluation. These are: the catabolic, or analytic mode, which permits the listener to break a complex tone into its spectral (pure tone) components.

Terhardt's second type is anabolic, a synthetic mode, which results in a Gestaltist perception, which enables the subject to develop a harmonic unity or "Virtual Pitch" from the tonal components. The model itself suggests that cognitive analysis will extract the spectral cues and compare the lowest received frequency against a learned value in a large matrix of such associations that might correspond to a template for goodness of impression. The relative harmony of the individual frequencies taken in this way is evaluated as a resistance factor. If a set of such resistance values is small enough, a particular "synthetic frequency" might be heard as a virtual pitch.

Terhardt asserts the model accounts for harmonic ratios, missing fundamental frequency data (how two complex tones, one of which lacks the fundamental could be perceived as similar), and problems associated with enharmonic pitch residues (shifting of all component frequencies by some amount of frequency constant which lowers harmonicity). The adequacy of the model to explain other phenomena is a topic for further research. The model differs from the critical band explanation in that interval preference is explained by associations at a higher neural level, rather than by interference pattern in the receptor (inner ear).

Irvine (1945) proposed a wave pattern explanation for the aural determination of consonance and dissonance. By developing sine wave curves for pure tones and producing graph-



ic sound wave interference patterns for various intervals, Irvine was able to analyze the patterns for consistencies that might allow the separation of consonance from dissonance via wave form. He showed that dissonant wave patterns were longer and slower in cycles per second. Consonant complex wave patterns were shorter and faster by comparison. He was able to rank the interval patterns according to length groupings (starting with the shortest) and he obtained: group 1, octave 2:1, group 2, fifth 3:2, and group 3, fourth 4:3, and major sixth 5:3, etc. The interference pattern analysis produced the same first few consonancies as were noted by Pythagoras.

Irvine was uncertain, however, if intervals having the same length of complex wave train pattern could have roughly equal consonancy, for instance, the major third (subjectively quite consonant) was grouped with the major ninth (considerably less consonant). Irvine also suggested that the ear is capable of frequency separation by analysis of phase and amplitude changes in the waves (what he referred to as hearing out "bumps" per second and noting their relative size).

Maher (1976) dealt with the "Need for Resolution" of harmonic intervals. Maher objected to Lundin's (1973) cultural determination of consonancy, since the direction that empirical researchers had taken was not toward a cultural hypothesis. Maher indicated that there may indeed be some pan-cultural basis for perception of musical intervals, and

felt the critical band data could not be ignored. Yet, because he was able (Maher, 1975) to find dissonance that persevered in sequentially sounded interval component tones, he attempted to reject the critical band as a complete explanation, because it would require physical interactions on the basilar membrane, which presumably would not be present in a sequential presentation of tone stimuli.

Maher contended that the literature suggested somehow "a need for resolution" based on Cazden's (1945) observation that "A dissonant interval causes a restless expectation of resolution," (hence a need to move towards a more consonant interval afterwards)..." A consonant interval or chord seems restful compared to a dissonant interval or chord, which appears to call for a resolution into a following consonant interval or chord" (Maher, 1976, p. 262-263).

Maher chose to have different cultural groups rate tonal stimuli under the construct of restful-restless. He found that Indians (East) and Canadians rated the interval stimuli similarly, with some minor exceptions. The minor second which Canadians rated as unrestful (dissonant), the Indians found to be neutral. This he observed might call critical band theory, (as an absolutist approach), into question. Maher theorized that such formulations as the critical band and culture mediated hypotheses ought to be considered as "limiting factors" and not "determining" ones for the perception of consonance.

Guilford (1953) did a re-analysis of data from an earlier experiment by Singer and Young (1941) who ran a poorly controlled pleasantness-unpleasantness preference experiment. Guilford showed the decline in affective value for all frequencies of sound, given intensity increase, however, this finding is much clearer in Vitz (1972).

Berlyne et al. (1967) found lower EEG desynchronization (time taken to restore alpha, a resting brain wave electrical level, as a measure of the disruptive capacity of the tone), in response to pure tone frequencies approximately located in the 500 to 800 Hz range, (corresponding to the "pleasantness range" in other studies). Berlyne et al. suggested several hypotheses to account for the less enduring arousal response for stimuli of frequency similar to speech (the 500 to 800 Hz range). The number of stimulus frequencies and the range selected by Berlyne et al. were not sufficiently large to warrant the assumption of a sensitive range on the basis of their data alone, except as an extrapolation. Their frequencies were a limited sample of stimuli, usually four pure tones for each of the reported experiments.

In one experiment, Berlyne et al. (1967) used seven-point semantic differential ratings for complex-simple, pleasing-displeasing, and interesting-disinteresting. All stimuli were adjusted for equal loudness criteria. Interval pairs were more complex and interesting than single tones.

The quadruple tone was more interesting and complex than the singles or the interval pairs. Also, Berlyne et al. found the square wave tones showed significant rating differences under complexity and interestingness, but found no such effect for the sine wave data. They attributed the reduced complexity and interestingness under sine wave conditions to be an outcome of musical experience.

Curiously, the study found no significant differences in pleasingness for concords over discords, although the difference was in the expected direction. The lack of a significant finding for the consonancy stimuli may reflect the shortage of stimuli.

Concerning the relationships between pleasantness, complexity and interestingness, only the interestingness and complexity constructs were found to be significantly correlated at  $r = + .58$ , i.e., medium strength. For Berlyne et al., their "pleasantness" findings for pure tones concur with the familiar data on that dimension, higher preferences being associated with frequencies around 500 Hz (regardless of wave type). For loudness controls, the investigation entailed an increase of 10 db (a doubling of perceived loudness), from 80 to 90 db SPL; the increase tended to have a disruptive effect on many preference patterns.

Whissell and Whissell (1979) found pleasantness ratings to interact with intensity level and eye colour. Under increases in loudness of stimulus frequencies, the preference

pattern of brown-eyed subjects remained stable, but lowered, whereas the response priorities in preference for blue-eyed subjects underwent inversion in the normal "pleasantness range" for the higher of the two intensity conditions (85 db SPL). They suggested a learning-genetic model that accounted for eye colour differences by melanin concentrations, and for sex differences by social reinforcement patterns that might explain the data.

Parham (1968) had subjects rate the complexity, interestingness, and pleasingness of a variety of acoustic stimuli. He found increases in complexity and interestingness to be associated with larger numbers of component frequencies in the presented tones. Also, he noted that square wave sounds were rated as more complex and interesting, but less pleasing than equivalent sine wave stimuli. For a frequency band from 256 to 1024 Hz, Parham found complexity ratings to rise and then fall, while pleasingness ratings tended toward decline.

For tones that have harmonics, Doehring (1968) found that successive presentation lead to better discrimination of the tonal components than did simultaneous presentation. For pure tones, simultaneous or successive presentation made little difference in discriminability. Doehring speculated that the complex piano notes (having harmonics) made two-tone discriminability more difficult than did pure tone components for musical intervals, (Doehring, 1971).

### Purpose of the Study

The foregoing literature review has considered the historical and experimental notion of dissonance and consonance. Music theorists attempted to move towards consonant tone combinations and away from dissonant ones. The explanation of dissonance has been attempted by a wide variety of theories. The critical band theory of Plomp and Levelt (1965), (developed from the Helmholtzian concept of beats and "psychological roughness"), is a theory that is empirically testable. Since dissonance is not a commonly understood term, the current study attempts to relate dissonance to psychological pleasingness. The study makes a notable departure from the literature in presenting tone pairs both successively and simultaneously. (Most of the literature involves studies of simultaneous tonal intervals). Similar pleasingness patterns despite delay between tones might imply a cultural basis for preference of sound pairs (Maher, 1976). However, if pleasingness patterns in consecutive and simultaneous tones are found different, interference theories (proposing dissonance as a product of the "beats" of simultaneous waves) receive support instead.

Another question appears to arise in the literature. "What sound frequencies do we prefer?" Some sonic frequencies are more preferred than others, (Vitz, 1972; Whissell & Whissell, 1979, De Souza et al., 1974; Laird & Coye, 1929;

Berlyne, 1967; Parham, 1968; etc.). These studies differed widely in their experimental approach, and in all cases except that of Patchett, sampled the tone continuum more discretely than continuously. The study undertaken develops a pleasingness mapping for many frequencies in the range from 300 to 2600 Hz.

### Statement of the Problem

The investigation was divided into two halves, one handling sequential tone pairs and the other examining simultaneous tone pairs.

The primary concern of the first experiment was to measure the relative pleasingness for sine or square wave sounds, and to examine the relative preference for one tone of the pair or the other. For pleasingness ratings, the relevant hypotheses are that intervals, musical experience, tonal delay, waveform, and dissonance, or their interaction affect tone pleasingness ratings. For tone pair member preferences, the specific hypothesis is that peak pleasingness ratings are expected for tones in the 400 to 800 Hz range. The study compares data findings for musical intervals with classical observations of consonance and dissonance. As well, the implications of dissonance findings are compared with dissonance theories.

For the second experiment, the attempt was made to replicate classical dissonance findings, and provide empirical support for the dissonance model (Appendix B) as used in both experiments. In addition, how pleasingness ratings change with musical intervals was examined. And finally, how dissonance is related to psychological pleasingness was explored.

The two experiments were compared for differences in pleasingness ratings for those intervals they have in common, to obtain information about how pleasingness differs between sequential and simultaneous soundings of tone pairs.



## CHAPTER II

Two experiments were conducted at Laurentian University. These studies are reported separately, under the headings of Experiments One and Two.

### EXPERIMENT ONE

The first experiment tested differences in pleasingness and tone preference ratings of tonal interval stimuli that were separated by two types of delay, presented under two types of waveform (sine and square), and which had various dissonance values.

While sine waves are the most common in natural occurrence, square waves were also used to provide a range of dissonance values, (see Appendix B). Delay interval of the tones was examined for the change in pleasingness with respect to time between tones.

### METHOD

#### Subjects

The subjects were 41 female student volunteers from introductory and extension courses in psychology. Most sub-

jects were paid for participation by an in-course credit of 2%. Volunteers who were not eligible for the credit received three dollars for participating. Most of the subjects were in an age range from 19 to 28. In addition, the musical experience of subjects was recorded, as defined by years of 'formal musical instruction', regardless of the instructed instrument. Experience was classified: (zero as naive, one to two years as medium, and more than three years as expert). Subjects were randomly assigned to treatment conditions.

#### Apparatus and Procedure

The testing location was below ground level in an acoustic chamber (Industrial Acoustics: model 1203A, capable of attenuating about 70 db of ambient environmental noise). In the acoustic chamber, subjects were comfortably seated at a desk under indirectly lighted conditions. The taped stimuli were delivered binaurally by headphones (capable of reducing the external noise factor a further 15 to 20 db). The headphones, type ME 70, by Madson Electronics of Canada were connected to a stereo cassette player of metal compatible type model KD-A22 made by the Victor Company of Japan (JVC), situated inside the chamber with power supplied by Jones plugs in the chamber walls.

The tape cassettes were chromium dioxide FX-II, made by the Fuji Photo Film Company of Tokyo, Japan.

Tape Construction. The frequency range of the stimuli varied from 300 to 2600 Hz. Tones below 300 Hz, were precluded from study because of acoustic anomalies associated with the control for equal loudness of low frequencies. The stimuli were 300, 400, 500, 600, 700, 800, 900, 950, 975, 1000, 1025, 1050, 1100, 1200, 1400, 1600, 1800, 2000, 2200, 2400, and 2600 Hz, administered at 70 db SPL.

The stimuli were paired in a A-B, C-A order such that a tone appeared as first or second member in a pair an approximately equal member of times. Order permutations were not allowed. Accordingly, the generated pairs list was of size  $N(N-1)/2$  or 210 pairs. Waveform of the stimuli was either sine or square.

Given the two waveform types and the two delay conditions, 4 random stimulus versions were created. Those were: sine at 100 ms delay, sine at 500 ms delay, square at 100 ms delay, square at 500 ms delay. Each version was segmented into 4 cassettes of approximately 52 tone pairs each. When assigned a waveform and delay condition, a subject received a random administration of the cassettes (one through four), to avoid serial position effects.

Apparatus and Procedure for Tape Construction. The design schemata for the taping circuits is given in Appendix A. Two Heathkit sine-square wave generators, model 1G-82 (vacuum tube) capable of delivering the required frequencies in

either waveform were used. A Heathkit frequency counter, model 1B-101 was used to set tonal stimuli within an error tolerance of plus or minus 1 Hz.

The electrical signals from the generators were fed by coaxial cable into a switching mechanism which allowed first one tone, then the other to be checked for frequency accuracy by the frequency counter. As well, from the tone generators, the signals were fed through two relay mechanisms (one make-shift, the other a Drive Control Console, Gerbrands model G1171), to a 4-channel Digital millisecond timer, Gerbrands model 300-4L, and into the tape recorder. A Bruel and Kjaer, type 2203 sound level meter which received mechanical signals from an acoustically coupled artificial ear (Bruel and Kjaer, type 4152) was peripherally connected to the circuit to adjust tones for equal loudness.

The tones were adjusted singly for equal loudness at 70 dB SPL using the C scale on the sound level meter (which is the scale relevant to the human equal loudness contour for this intensity).

Once the stimuli were set in terms of frequency components and calibrated to 70 dB SPL of loudness, the millisecond timer sequenced the taping of the stimuli. The duration of the first tone was 1000 ms, followed by a delay of 100 ms or 500 ms (depending on the delay version being recorded), then the second tone was on for 1000 ms, and finally there followed a 7-second inter-pair interval time period. (This was

the time period during which subjects recorded their judgments). At the conclusion of the inter-pair interval, the operator placed the tape recorder on pause and prepared the next pair of tones for recording.

Four random sequences of the two hundred and ten tone pairs had been created. One different sequence was used for each of the four possible waveform and delay combinations. Each random sequence was taped into 4 cassettes of approximately 50 tones each to allow randomization of presentation order to control for serial position effects.

Testing Procedure. The subjects attended two one-half hour sessions during which they received one of four different waveform by delay stimulus versions, administered in randomized cassette orders. The sittings were on separate days to control fatigue. There were approximately 10 subjects for each of the four waveform and delay possibilities. The experimenter, after an introduction to the subject, obtained the name, and the musical experience. The experimenter selected at random a waveform and delay condition to be given to the subject. In addition, the 4 cassettes (for the 210 tone pairs), of that wave delay condition were assigned a random presentation order. Two cassettes were administered per session. The subject was then seated in the acoustic chamber, and given a short taped set of standard instructions. (See Appendix C).

In addition, the subject was given a sample coding form and pencil to record practice judgements. See Appendix D for an example of the coding form. Following the instructions, the tape was started, and the experimenter left the acoustic chamber. At the conclusion of the instructions tape, the experimenter re-entered the chamber and enquired if there were any questions. If there were none, and the subject was satisfied that she knew what was expected of her, then the experimenter presented the first cassette of the assigned version of waveform and delay. The time interval between the presentations of the first and second cassettes was approximately 2 minutes. After the first session, a time (not on the same day), was confirmed as the date for the second testing session. When a subject not be obtainable for a second testing or be unable for some reason to complete the first or second testing, she was deleted from consideration and a replacement subject called in. On the second testing day, taped instructions were not given, except, a question to confirm that the subject understood that the procedure was the same as before. Following the completion of the second session, subjects were debriefed.

### Design

The design of the experiment was a  $2 \times 2 \times 3 \times 210$ , "partially" repeated measures having 2 levels of delay between tones, 2 types of waveform (sine or square), 3 levels

of musical experience, and 210 pairs of stimulus tones. The dependent measures, repeatedly evaluated within subjects for each of the 210 pairs, were frequency preference, (preference for one of the two tones presented), and pair rating, (how pleasing a particular pair was deemed to sound together).

## CHAPTER III

## RESULTS

The stimulus array for the first experiment consisted of sequential paired tones separated by a variable time delay. Responses were obtained for the subject's rating of the pleasingness of a tone pair (from 1, very displeasing to 7, very pleasing), and the choice of the preferred tone in a tone pair.

Pleasingness

Each subject rated 210 tone pairs, but 3 pairs were withdrawn later because of incorrectly recorded frequencies. There remained 207 tone pairs for analysis. Four groups of subjects were randomly assigned to the four combinations of waveform (sine or square) and delay (100 or 500 msec). The treatment groups had unequal N's of 11, 11, 10, and 9 for a total of 41 subjects. This gave a grand total of 8,487 tone pair ratings. This number also applied to the number of preference ratings recorded below, since both judgements occurred after a tone pair was presented.

To plot a continuity of intervals across a range from 1:1 to 3:1, a variable, tone ratio was created. Tone ratio was the higher frequency of a tone pair divided by the lower frequency. Tone ratios were established as decimals in in-



crements of .05, and plotted as midpoints. The mean pleasingness values as a function of tone ratio by waveform and delay are shown in Figures 1 and 2. Note that the tone ratios do not exceed 3.0 (three times the fundamental or 3:1), since there were fewer data points beyond this ratio, and continuity would not be as complete. Pleasingness ratings were observed to decline with larger tone ratios, however, some exceptions to this trend appeared.

To compress and clarify the major analysis, the 207 effective tone pairs were reclassified into eight "intervals" in terms of tone fractions reduced to their simplest terms. Six of these, (CD, 9:8; CE, 5:4; CF, 4:3; CG, 3:2; CA, 5:3; CC, 2:1), were Pythagorean musical intervals within an octave bandwidth; the other two were wider ranges pooling (a) all other intervals less than octave and (b) all ratios of greater than octave separation (2:1). Figure 3 shows the mean pleasingness scores for these intervals, pooled for all four combinations of waveform and delay. The interactive effect of wave, delay, and intervals (expressed in decimal) on mean Pleasingness ratings is shown in Figure 4.

To determine the significance of the above results, a 2 x 2 x 3 x 8 non-repeated analysis of covariance was undertaken. (See Table 1). The dependent variable was rated pleasingness of tone pairs. The analysis contained 2 levels of delay, 2 levels of waveform, 3 levels of musical experience, and 8 levels of musical "intervals" to compress the 207

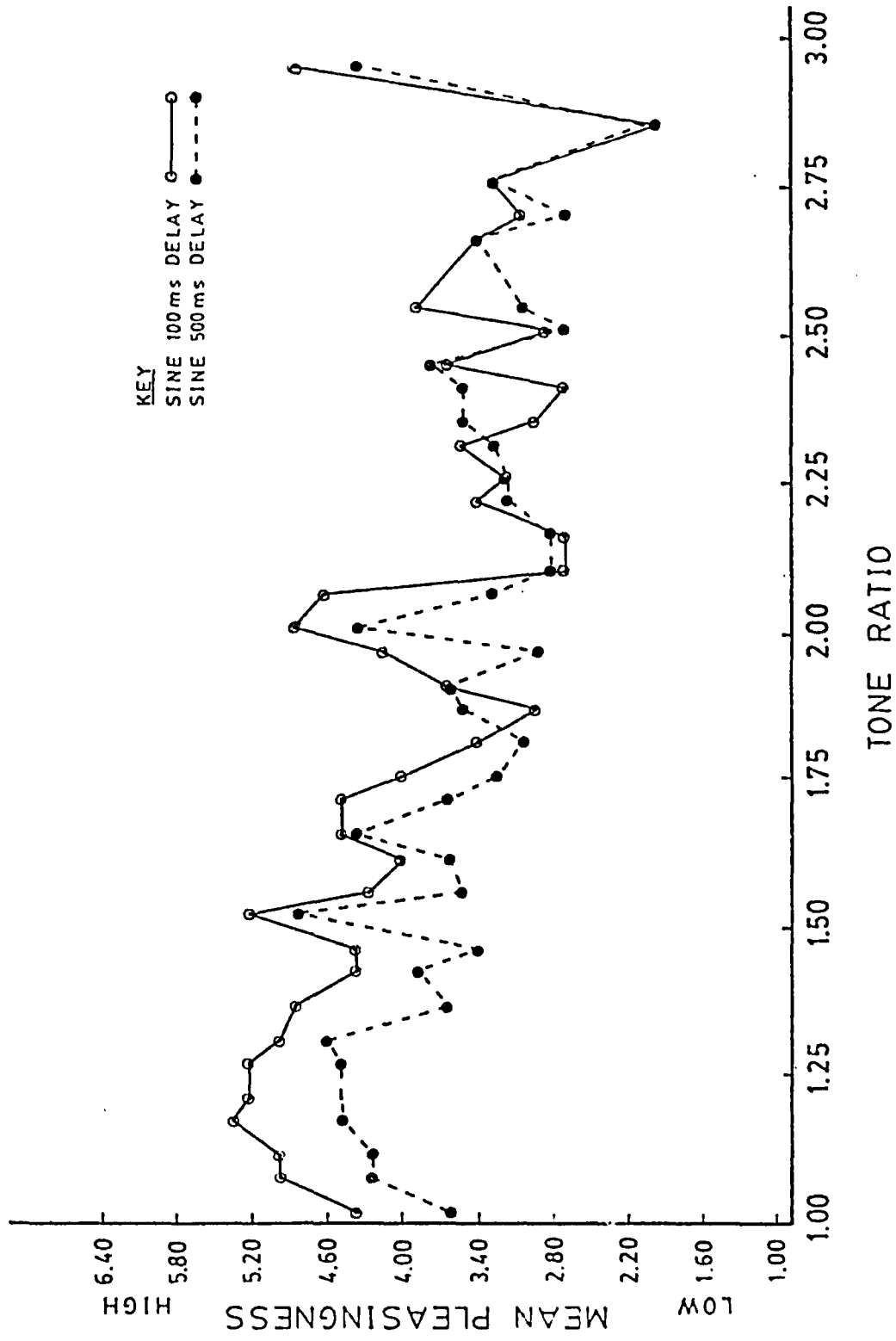


Figure 1. Mean pleasingness by tone ratio for sine waves.

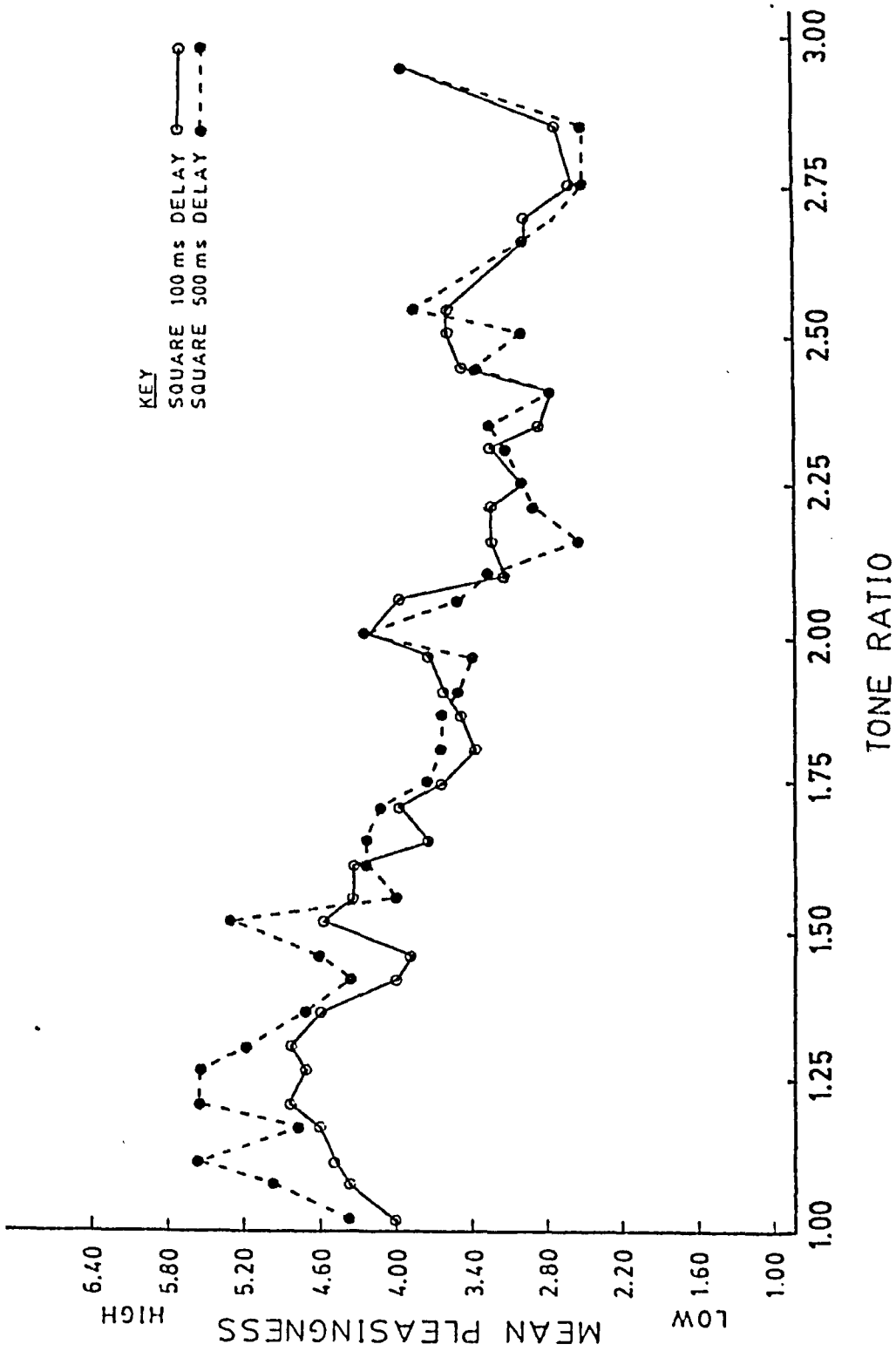


Figure 2. Mean pleasiness by tone ratio for square waves.

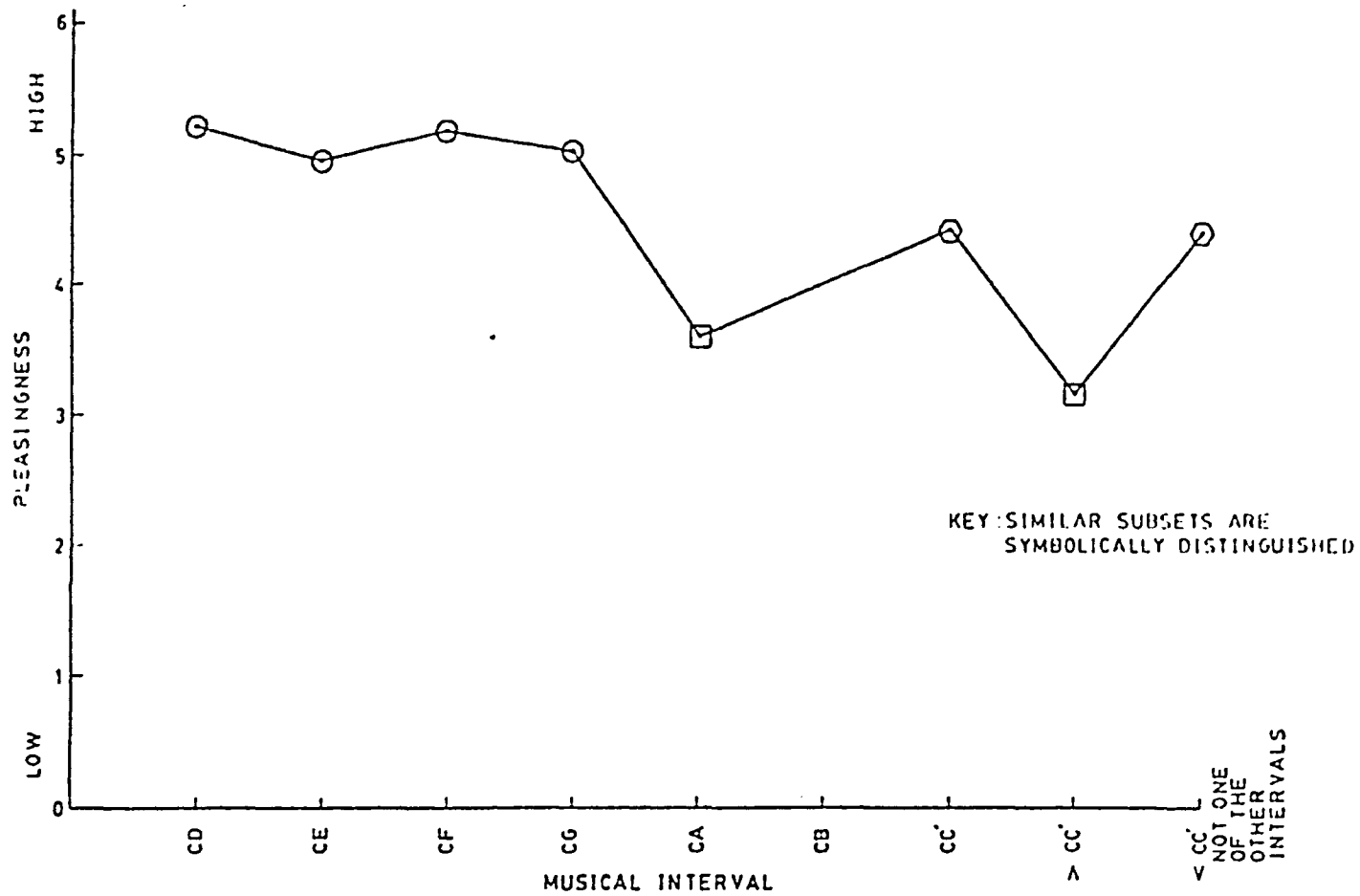


Figure 3. Mean pleasingness by musical interval for all waveforms and delay conditions.

TABLE 1  
 Analysis of Covariance for Pleasingness Ratings by Frequency  
 Separation (Covariate) by Wave by Delay by Interval by Musical Experience

Source	SS	df	MS	F
<b>Covariate</b>				
Frequency Separation	3958.61	1	3958.61	1728.64*
<b>Main Effects</b>				
Intervals (Int)	670.07	7	95.72	41.80*
Waveform (Wave)	0.04	1	0.04	0.02
Delay	36.20	1	36.20	15.81*
Musical Experience	22.56	2	11.28	4.93*
<b>2-Way Interactions</b>				
Interval/Waveform	69.51	7	9.93	4.34*
Interval/Delay	27.39	7	3.91	1.71
Interval/Musical Exp.	256.12	14	18.29	7.99*
Wave/Delay	116.54	1	116.54	50.89*
Wave/Musical Exp.	261.70	2	130.85	57.14*
Delay/Musical Exp.	129.94	2	64.97	28.37*
<b>3-Way Interactions</b>				
Int/Wave/Delay	154.49	7	22.07	9.64*
Int/Wave/Musical Exp.	125.83	14	8.99	3.93*
Int/Delay/Musical Exp.	133.99	14	9.57	4.18*
Wave/Delay/Musical Exp.	173.10	2	86.55	37.79*
<b>4-Way Interaction</b>				
Int/Wave/Delay/Musical Exp.	133.60	14	9.54	4.17*
Explained	6334.77	96	65.88	28.77*
Residual	19213.17	8390	2.29	
Total	25537.94	8486	3.01	

\* $p < .001$

tone pairs, (since many intervals were similar, e.g., 300:100, 600:200, 900:300, 1200:400, 1800:600, and 2400:800 despite changes in the magnitude of the tones involved). A covariate, the frequency separation (difference) of the tones involved, was used in the analysis, to ascertain whether or not the frequency distance between the tones, had an effect on the pleasingness ratings. The use of a covariate having relationship to predictor variables is, according to Harris (1975, p. 21) a legitimate use, and from Nie et al. (1975, p. 409) a less common technique when "covariate and factor effects may be of equal interest, and there may be not causal priority between them."

The use of a non-repeated analysis rather than a repeated one was a statistically conservative choice, since although the df in the independent design are larger, the pooled error term is also larger than would be obtained from a repeated measures approach. Repeated measures analysis requires more computer core space, because of the number of cells implied in the design, and is computationally more expensive.

The rationale for the usage of frequency separation as a covariate was to separate and accentuate differences attributable to itself and the independent variable interval. The larger the tone interval, the greater the implied frequency separation. With the magnitude of frequency separation controlled, a purer measure of the interval effect could be ob-

tained.

The frequency separation covariate was shown to be significant at  $p < .001$ . A subsequent partial correlation of frequency separation with the pleasingness ratings was  $-.398$ . (Intervals, waveform, and delay factors were partialled out). In general, the larger the frequency separation of the component tones in a pair, the lower the rated pleasingness.

The main effect of interval (where the 8 levels were selected tone ratios: 9:8, 5:4, 4:3, 3:2, 5:3, 2:1, less than octaves but not a selected ratio, and greater than octave), was significant at  $p < .001$ . The breakdown of the non-covariied form of these data is shown in Figure 3. Means in all figures were calculated without involving the covariate.

The main effect for delay is shown more clearly as an interaction between waveform and delay as in Figure 4. The main effect of musical experience was significant, but its F-ratio was marginal. The two-way interaction of interval by waveform was significant but a had small F-ratio of 4.34. The interaction of interval by musical experience was significant at  $p < .001$  and is shown in Figure 5. In Figure 5, the intervals have been converted to decimals, and additional points for values between the intervals have been added for descriptive purposes. All the other two-way interactions, wave by delay, wave by musical experience, and delay by musical experience were subsumed in the three-way interaction of wave by delay by musical experience described below.

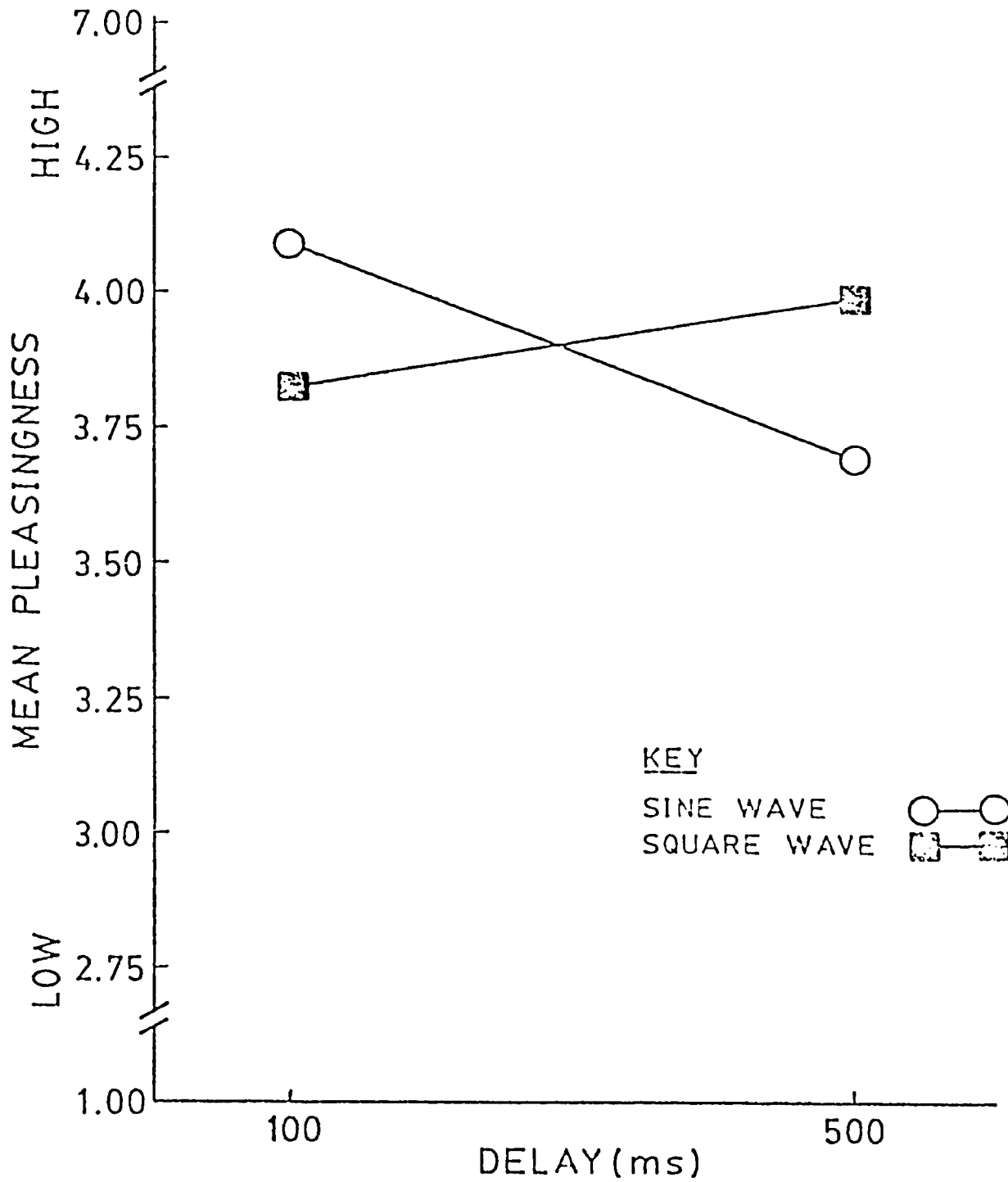


Figure 4. Mean pleasingness by waveform by delay



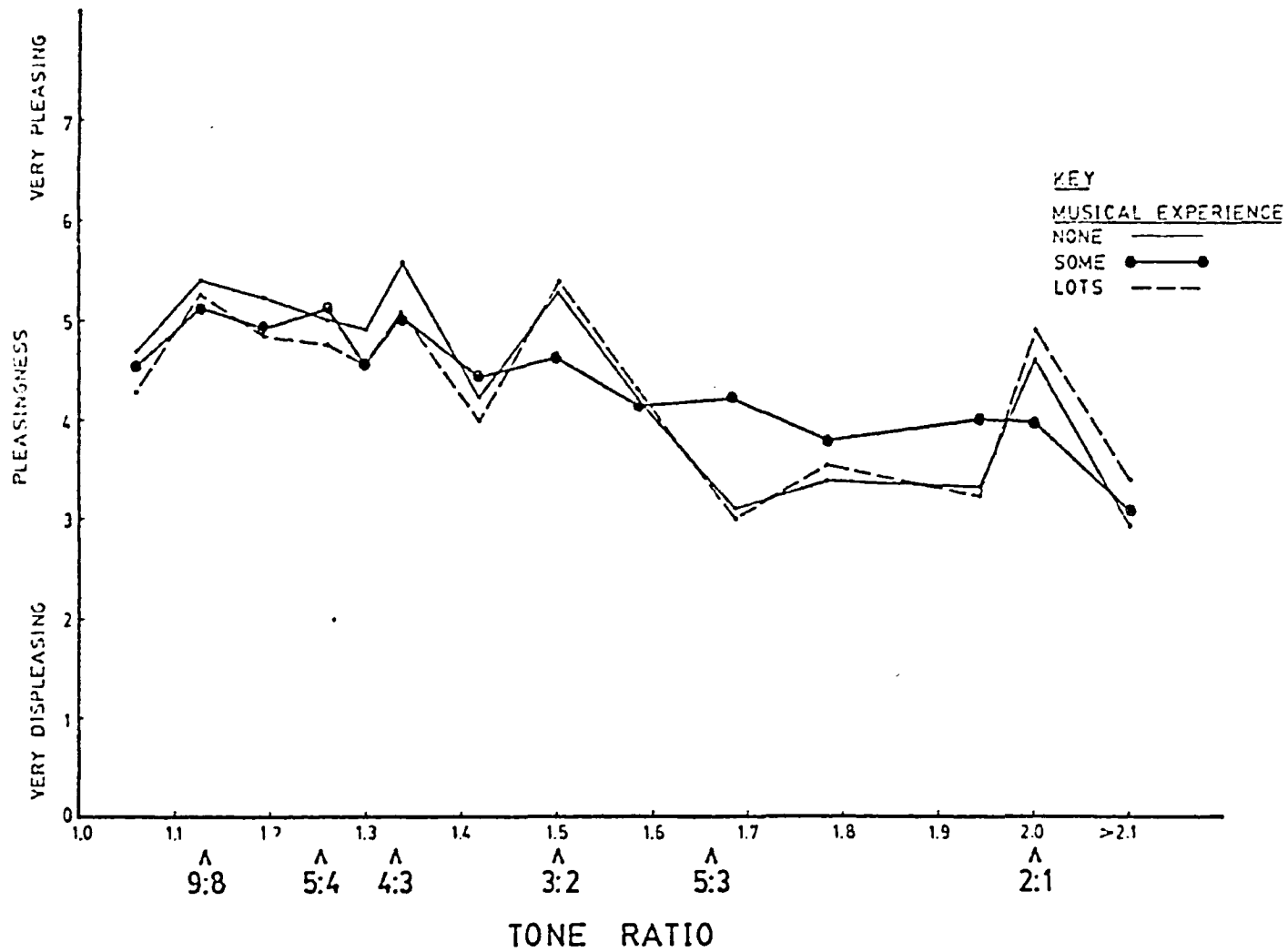


Figure 5. Effect of musical experience and tone ratio on pleasingness

The significant three-way interaction of interval by wave by delay, at  $p < .001$ , is shown in Figure 6. Figure 6 shows the pleasingness of the waveform and delay combinations for the set of interval stimuli (9:8, 5:4, 4:3, 3:2, 5:3, 2:1, greater than 2:1, and values between these intervals) converted to decimals.

The three-way interactions of interval by wave by musical experience,  $F = 3.93$ , and of interval by delay by musical experience,  $F = 4.18$ , although significant at  $p < .001$  were treated as being marginal in importance because of small F-ratios.

The three-way interaction of wave by delay by musical experience was significant  $p < .001$ , with F-ratio = 37.79 and is shown in Figure 7. It shows that the musically "expert" rated both square wave stimulus sets as more pleasing. The musically "naive" rated the 100 ms sine and 500 ms square waves as being more pleasing. Those with "medium" musical experience rated as highest in pleasingness the sine 100ms condition.

The four-way interaction of interval by wave by delay by musical experience was significant at  $p < .001$  but marginal in terms of the magnitude of its F-ratio.

#### Subsidiary Analysis for Table 1

Several one-way analyses of variance were conducted, without benefit of a covariate. Significant results were

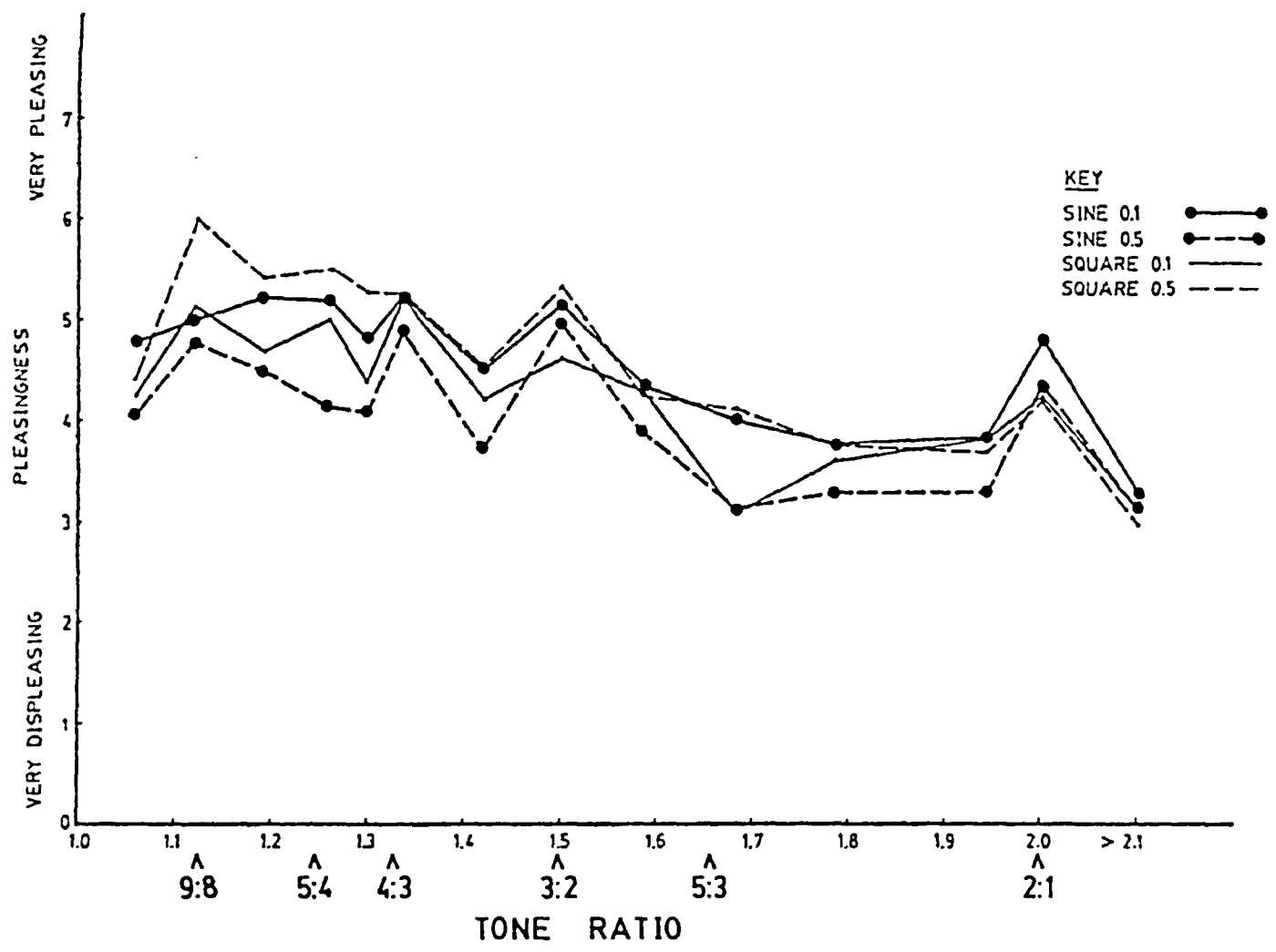


Figure 6. Mean pleasingness by tone ratio for sine and square wave sequential tones under 100 or 500 ms delay.

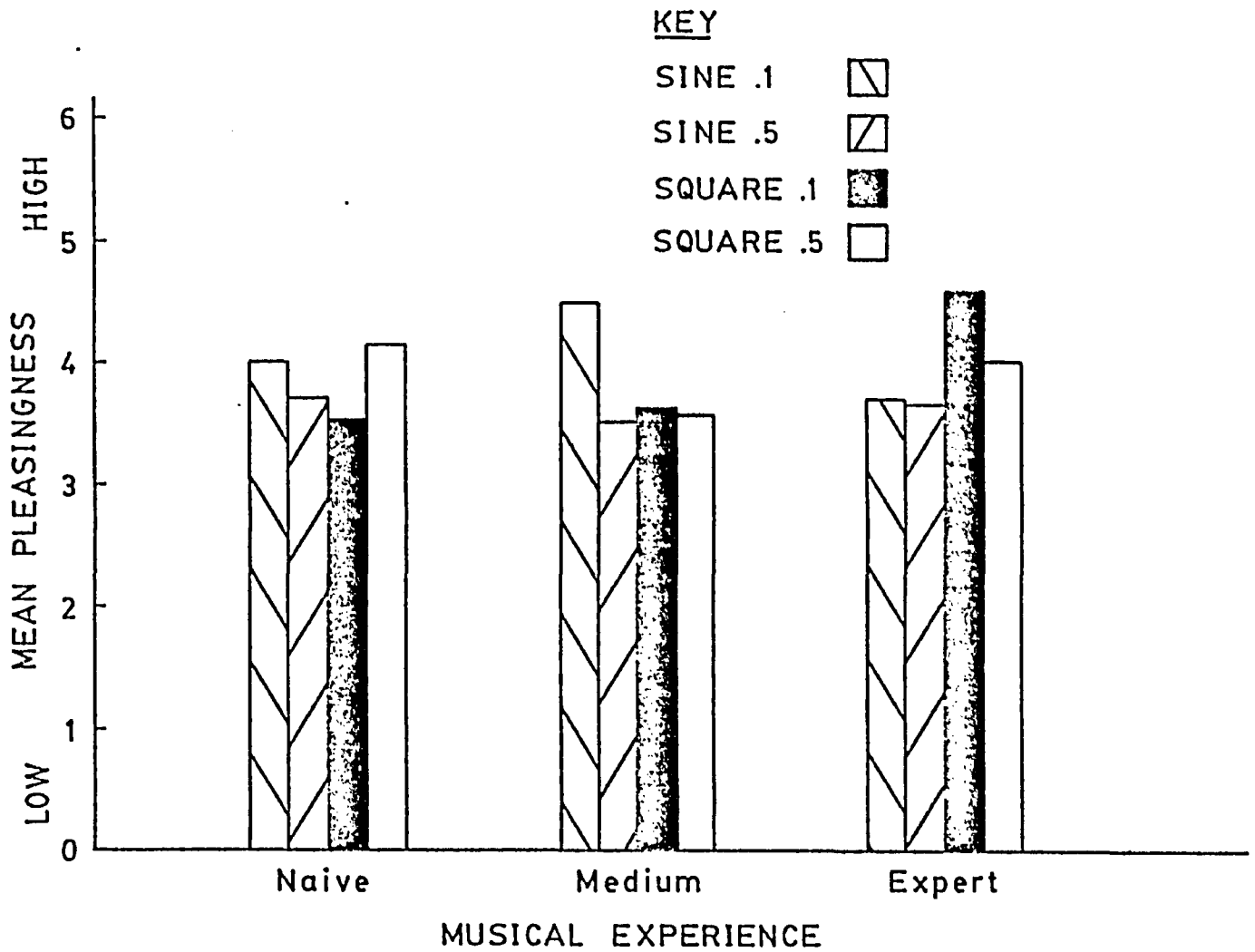


Figure 7. Mean pleasingness by musical experience by waveform by delay (100 or 500 ms) in sequential tones.

subjected to post-tests which are reported below.

Duncan post-tests, (Nie et al., 1975), at alpha = 0.05, for homogeneous subsets, for the significant differences associated with interval produced the following. Firstly, the most pleasing intervals were CD, CF, CG, and CE, with means of 5.23, 5.19, 5.01, and 4.98 respectively. Secondly, intervals of octaves or non-standard musical intervals less than octave received intermediate pleasingness ratings. Their means were 4.40 and 4.34 respectively. Thirdly, intervals of CA or intervals greater than octave ratio received the lowest pleasingness ratings. These means were 3.59 and 3.13 respectively. Figure 3 shows the mean pleasingness by musical interval relationship, for all wave forms and delays collectively.

Duncan post-tests, (Nie et al., 1975), at alpha = 0.05, for homogeneous subsets, were conducted for the significant one-way analysis of variance for all wave-delay groupings. The findings were as follows. Firstly, highest pleasingness ratings were assigned to sine waves at 100 ms delay, and square wave tones at 500 ms delay. These means were 4.10 and 4.00 respectively. Secondly, middle pleasingness ratings were given to square wave tones at 100 ms delay, with a mean pleasingness of 3.83. Thirdly, lowest pleasingness ratings were given to sine wave tones at 500 ms delay, with a mean of 3.69. See Figure 4 for the interaction of waveform and delay on pleasingness ratings.

A one-way analysis of variance conducted for the significant main effect of musical experience was only suggestive in strength, when done in the non-covariates analysis. The F-ratio was 2.38 with  $p < .1$  and was not significant. However, in a factorial breakdown of wave by musical experience, certain significant variations were found. Figure 7 describes these interactive relationships.

### Dissonance

Table 2 shows an 8 x 2 analysis of variance for square wave tone pairs with dissonance category and delay (100 ms or 500 ms) as independent variables; the dependent measure was pleasingness ratings for the tone pairs. Dissonance estimates for tone pairs were obtained by applying a mathematical model explained in Appendix B. The estimates were categorized into 9 increments of .25 from 0.0 to 2.25. For the purpose of analysis, dissonance df were reduced by one for each category that had no cases in it.

The major finding of the analysis was that dissonance categories were significantly different at  $p < .001$ , as a main effect, with a large F-ratio of 71.74. However, when a follow-up analysis of covariance was conducted, with frequency separation as covariate, there was a huge significant effect for the covariate with  $F = 897.90$ ,  $p < .001$ ; and a marginally significant main effect for dissonance category,  $F = 7.73$ ,  $p < .001$ . Therefore, there appeared to be a lot of common var-

TABLE 2  
 Analysis of Variance of Pleasingness Ratings  
 by Dissonance Category and Delay

Source	SS	df	MS	F
Main Effects	1396.29	8	174.54	64.06*
Dissonance Categories	1368.33	7	195.48	71.74*
Delay	27.95	1	27.95	10.26*
Two-Way Interaction	84.28	7	12.04	4.42*
Dissonance Category/Delay	84.28	7	12.04	4.42*
Explained	1480.57	15	98.71	36.23*
Residual	11800.54	4331	2.73	
Total	13281.11	4366	3.06	

p <.001\*

iance between dissonance category and frequency separation. The mean Pleasingness ratings for the various dissonance groupings by the 500 and 100 ms delay conditions for the square wave tones are shown in Figure 8. The significant effect  $p < .001$  for delay was higher pleasingness assigned to the longer of two delays. The interaction of delay and dissonance grouping was marginal in F-ratio magnitude. Dissonance category 5 had no cases in it, therefore df in the analysis of variance were 7, and not 8. Highest pleasingness was noted for middle dissonance categories, while the general trend in the curves was higher pleasingness for tone pairs having higher dissonancy. The means for the interaction of dissonance categories by square wave delay types are found in Appendix E. Correspondingly, Table 3 reports t-tests using sine wave intervals with less than octave separation of tones for both delay conditions. The t-test analyses (see Table 3) indicated a higher preference for dissonant sine wave tones regardless of time delay between the tones. These results were similar to those for the square waves. The histograms for the sine wave stimuli are shown in Figure 9.

### Tone Preferences

A mapping of the proportion of times a tone was selected as being the more preferred tone in a pair combination is shown in Figure 10. The curves indicate a higher preference for the lower frequencies and a declining preference as the



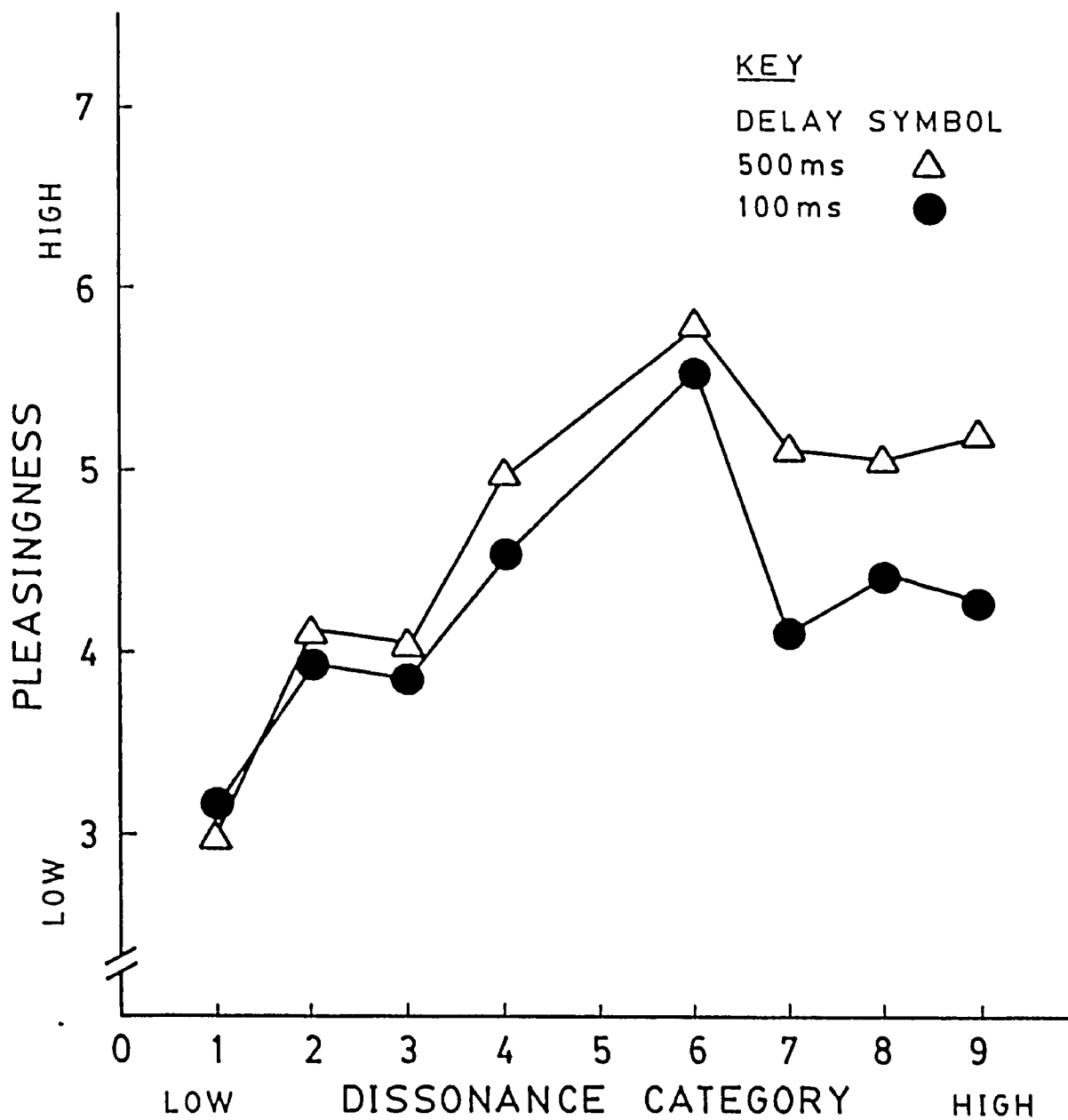


Figure 8. Pleasingness by dissonance category by delay for square wave intervals.

TABLE 3

T-Tests for Pleasingness Under Dissonance or No Dissonance  
Rating for Sine Wave Intervals Under Two Delays

Sine	N	$\bar{X}$	S.D.	$S_{\bar{X}}$	T	df
<u>500ms Delay</u>						
Non Dissonant	828	3.98	1.59	0.055	-2.47+	1114
Dissonant	288	4.25	1.70	0.100		
<u>100ms Delay</u>						
Non Dissonant	1012	4.54	1.53	0.05	-4.53*	1362
Dissonant	352	4.99	1.80	0.10		

\*  $p < .001$

+  $p < .05$

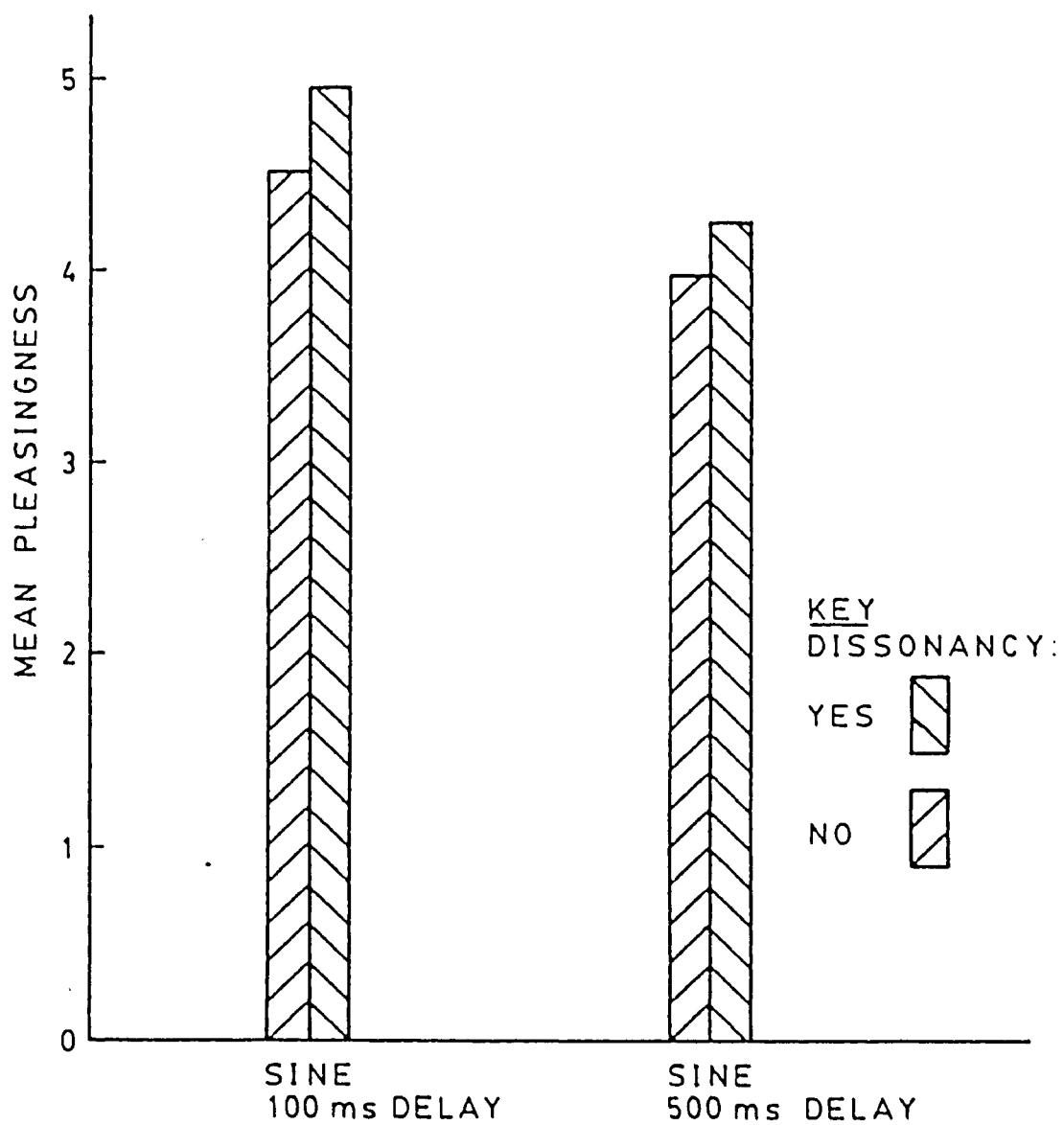


Figure 9. Pleasiness histograms for dissonant or non-dissonant sine wave tones under delay.

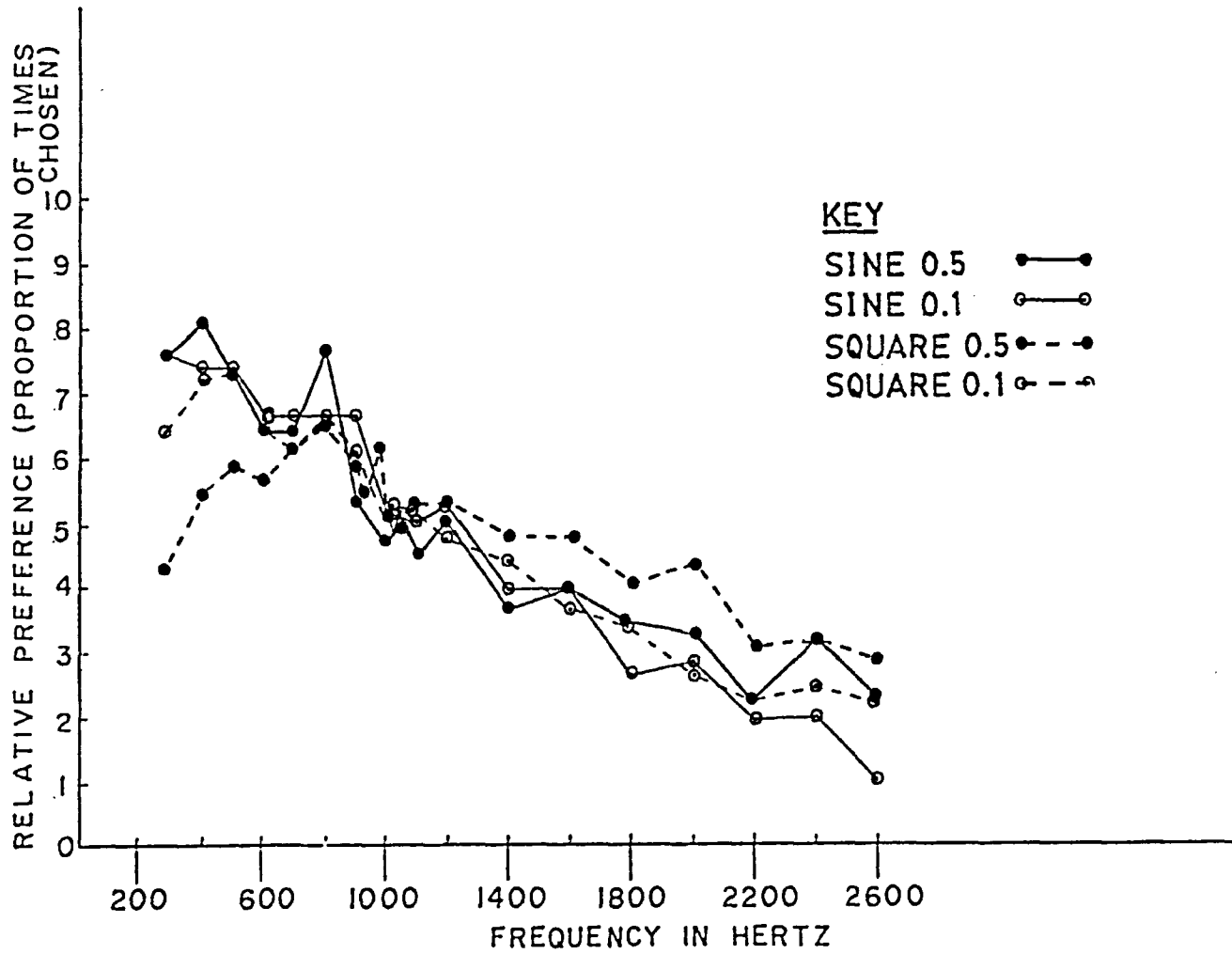


Figure 10. Standardized preference proportion (relative to other frequencies) vs. frequency in hertz.

stimuli move away from 400 Hz. Spikes occurred in the preference curve at integral multiples of 400 Hz.

A z-test analysis, Runyon and Haber (1980, p. 110-111), shown in Table 4 indicates that preferred element of a tone pair may vary with wave and delay conditions.

TABLE 4

Results for Preference of  
First or Second Tone  
by Waveform and Delay (z-tests)

	DELAY	
	100ms	500ms
Sine	+3.03*	+1.49
Square	-.95	-2.83*

\*  $p < .01$

+ z score means preference for  
the first presented tone of  
an interval.

- z scores means preference for  
the second presented tone of  
an interval.

## CHAPTER IV

## DISCUSSION

When pleasingness of sequential tones in pairs was plotted against approximate tone ratio, as in Figures 1 and 2, two events were observed to happen. Higher ratings of pleasingness were assigned for tone ratios closer to unity, and large spikes in the pleasingness curve for particular tone ratios were noted.

Expectancy in Consecutive Tones

Figures 1 and 2, showed tone ratios beyond 1.67, (the C to A interval of 5:3), received lower pleasingness ratings than those below 1.67. From Figure 3, the Duncan post-test means for significance between the interval categories shows the intervals 9:8, 5:4, 4:3, and 3:2, significantly higher in pleasingness than 2:1 or other intervals (clustered) less than octave. The 5:3 or intervals (clustered) greater than the octave were significantly lowest in pleasingness.

The significant, ( $p < .001$ ), correlation between pleasingness and frequency separation of the tone pairs was  $-.40$ . Higher pleasingness was associated with frequency closeness of the stimuli, (controlling for interval, waveform, and delay factors). These findings support an expectancy hypothesis that higher aesthetic pleasingness is given to sequen-

tial tones separated by narrow frequency differences. The listener might be prepared to hear a sequential note having a frequency that differs slightly from the frequency of the first note presented: a note that was less than the CA, (5:3), interval for the lower tone of the pair. This appears to be a form of musical melodic expectancy. Garner (1970), showed a high correlation between ratings of belongingness and "goodness" in terms of aesthetic preference (for shapes). Munsinger and Kessen (1966) showed there was a relationship between simplicity of form and "goodness". From these experiments and others, Posner concluded that there was general support for Garner's observation that "our judgement of pattern depends heavily upon the set of related patterns which are stored in memory" (Posner, 1973, p. 60). By way of analogy, such findings and postulations may be important for the perception of a sequential series (albeit only dyadic) of tones. Tones within a given frequency separation from a particular or key tone may be deemed (at some cognitive level) as belonging together and such groupings might have higher aesthetic value assigned to them if a related member were sounded.

This assumption of an expectancy factor in Pleasingness ratings of consecutive tone pairs draws support from the theory of "propinquity" in melody (as in Chandler, 1934). The idea is tonal progression from one note to the next is given greater cohesion and unity if the interval steps are



small. Exposure to music, (always serialized melodically), may acquaint the listener with what comes next in a music series or what he could expect to follow any given tone. For a discussion of associations in serial learning, see Mednick, 1964, p. 62-63.

Ortmann (1937) sampled interval changes from many classical compositions and found intervals of unison or seconds, followed by thirds and fourths in highest frequency of occurrence. The trend was for smaller intervals to have larger frequencies of occurrence with the exception of octaves, fifths, and fourths which were assigned relatively higher frequencies as well. The data presented in Figures 1 and 2 show the higher pleasingness of smaller intervals as well as the octave and fifth.

Equating the higher occurrence of the small intervals with the attempt of the composers to provide greater aesthetic pleasure for their audiences, and allowing that the current study shows higher pleasingness of smaller intervals or tones separated by smaller frequency differences a principle is stated: Pleasingness of successive tones (simple melody) can be given by small interval movement (narrow frequency differences) in the tones.

More generally, pleasingness preference for certain expected pairs of sounds as opposed to others appears to argue against the acceptability of writing musical scores in a Schonbergian (as in Menuhin & Davis, 1979) twelve-tone sys-

tem, (where each tone is assigned an equal appearance); it provides some endorsement of the importance of the "tonic" or home key in a musical piece from which notes depart (to create tension) and return (to resolve tension), as in Machlis (1961).

### Patterns in Pleasingness Ratings

In both Figures 1 and 2 (sine and square stimulus pairs respectively), there appeared to be a consistent pattern for certain ratios to be favoured as either peaks or troughs in the pleasingness curves, regardless of delay factors. Pairs having one tone frequency that was an integer multiple of the other frequency ( $N:1$ , where  $N$  is an integer) had higher pleasingness ratings. (Perhaps there are others). These observations are supported in part by the one-way analysis of variance for Interval coded in Figure 3. A possibility for further investigation is the use of time series analysis to test the regularity of these "octaval" intervals.

### Dissonance

Dissonance, for sequential tones was a weak factor in the determination of pleasingness ratings. There was no evidence to support the notion that the normally dissonant musical second, (CD with interval of  $9:8$ ), for simultaneous intervals retained such dissonance properties in a sequential sounding situation, see Figure 3. The  $9:8$  interval was clus-

tered among the most pleasing of the Interval groupings. For studies illustrating the classical dissonance effects of simultaneously sounded tones see Malmberg, 1918; Guernsey, 1928; Van de Geer et al., 1962. Point biserial correlations (Bruning & Kintz, 1977) between the binary variable of sine wave dissonance and pleasingness ratings were: .14, with  $p < .001$  for 500 ms delay, and .22 with  $p < .001$ , at 100 ms delay. Dissonant tone pairs, regardless of delay were rated as more pleasing, see Figure 9. For square wave tones, see Figure 8. The relationship between dissonance and pleasingness was an inverted 'U' shape, having higher pleasingness for middle dissonance categories. However, the general trend was for higher pleasingness to accompany higher dissonance groupings. Pearson coefficients, for square waves, not the exact measure for a non-linear relationship, were lower than the ones for sine waves, but still significant at  $p < .001$ . Therefore, dissonance, as evidenced by severely attenuated correlation coefficients with pleasingness was a weak positive contributor to the pleasingness ratings of sequential sounded tones.

The weakness of the dissonance factor in sequential tones tends to support the interference theories of dissonance, (Plomp & Levelt, 1965; Helmholtz, 1954). Since, the effect of dissonance has a strong negative effect in simultaneous tones, and a near zero, positive effect in a consecutive situation, the data presented are also supported by di-

chotic studies in tonal preferences, (Sandig, 1939).

### Musical Experience, Delay, Waveform, and Pleasingness

The interaction of waveform by musical experience is shown in Figure 7. The musical "experts" significantly preferred the more complex stimulus patterns, (square wave tones under 100 ms delay), followed by square wave tones under 500 ms delay. Those with "medium" musical experience found the sine wave at 100 ms delay the most pleasing. The musically "naive" rated both the square 500 ms delay and the sine 100 ms delay as highly pleasing. If pleasingness ratings for the 100 ms sine conditions were related to lack of an ear for complexity, and choice of higher pleasingness ratings for 500 ms square, a choice for complexity, it might affirm the inclusion of potential musical "experts" in the "naive" group having no musical training. The category of "medium musical experience" (one to two years of piano) may have selected out those with a lower aptitude for musical attainment. In other words, they might have gone on to higher levels of musical expertise but might not have had the "ear" or the ability. These observations are supported by studies involving the effect of musical experience on tonal discrimination, (Soderquist, 1970; Collman, 1973; Doehring, 1971). Typically, the more musically experienced show stronger discrimination patterns in tone evaluation.

The above discussion suggests that greater musical ex-

perience of the listener could imply greater preference for more complex stimuli, if the rated dimension were pleasingness; moreover, it suggests that the interaction between temporal delay and complexity of stimulus (via waveform) be investigated further.

### Tone Preferences

In Figure 10, a mapping of the relative proportion of times (standardized out of unity), that a tone was selected as better element of a tone pair, against its own frequency was plotted. The general contour for sine waves was decreasing, while for the square wave curves, there was an initial rise followed by a slow decline. The decreasing trend from a peak at 400 Hz in all curves was in agreement with many tonal preference studies (Laird & Coye, 1929; Vitz, 1972; De Souza et al., 1974; Parham, 1968; Patchett, 1979). The lower and slower initial rise of the square wave tones for tone fundamentals for 300 and 400 Hz could be connected with difficulties of the sound level meter to adequately adjust loudness contours for complex square wave tones having lower frequencies. Taking all curves into account, there appeared to be maxima associated with the 400 and 800 Hz tones. Local maxima were located at integer multiples of 400 Hz. It appears that preference continuum, from 300 to 2600, is responsive to the 400 Hz tone and its integer multiples. Even the absolute preference mapping continuum of Patchett (1979) displays

small relative maxima at similar points. The finding bears careful replication.

## CHAPTER V

## METHOD

The first experiment shows that, for sequentially presented pairs of tones, the more dissonant pairs (as theoretically calculated) were rated as more pleasing. The classical literature on dissonance for simultaneous tones indicates that dissonance is a strong negative factor for aesthetic ratings. It was essential to repeat the experiment, in part, using simultaneously presented pairs, to confirm that dissonance and pleasingness are strongly and negatively related for simultaneous tone pairs. In addition, stimuli were selected to provide a range of theoretically dissonant combinations of tones, to test the adequacy of the Plomp & Levelt (1965) critical band theory and the model used to apply it to the data.

Since sine wave stimuli are pure tones, any pair of sine waves is either dissonant or not, and only two dissonance values can be investigated using them. Square wave tones which have regular known overtones, were used since the degree of dissonance, and its relative strength could be estimated (as in Appendix B).

## Subjects

There were 23 female subjects who volunteered and received a 2% grade credit for participation in the experiment. Their age range was from 19 to 28.

## Apparatus and Procedure

Each subject was booked into one brief sitting during which she listened to and rated the stimuli on the tapes. The presentation of tapes was counterbalanced. The experimenter recorded the subject's musical experience (naive, medium, or expert) as in Experiment One, and the random tape order taken by the subject. Once the subject was seated in the acoustic chamber, the experimenter verbally explained that the object of the testing was to rate single sounds from "1 very displeasing to very pleasing." The subjects entered their ratings on a sheet of paper. Subjects were debriefed after all data were collected. The testing location and apparatus were the same as those described in Experiment One.

Tape Construction. The Experimenter developed a set of the stimuli to be tested; these were square wave tone pairs. Each pair consisted of a lower square wave tone, termed the "fundamental", and a higher square wave tone called the "higher tone". This distinction is made since all square waves have overtones, and the lower of the two square wave



tones is a true fundamental for all the overtones. For the lower tones, the fundamentals were 50, 100, 200, and 400 Hz. The "higher tones" were determined by multiplying a Pythagorean musical interval times the fundamental. These intervals were 9:8, 5:4, 4:3, 3:2, 5:3, and 2:1. These were musically a second, third, fourth, fifth, major sixth, and an octaval interval. Accordingly, there were 6 interval types by 4 fundamentals or 24 tonal combinations. See Table 5. Note that the product of the interval times the fundamental was rounded to the nearest whole number.

The pairs of square wave tones were presented simultaneously for one second. There followed a delay interval of six seconds during which time the subject recorded the pleasingness of the sounded interval. The tones were calibrated for frequency by the Heathkit frequency counter. The sonic intensity for each tone in the pair was set at 70 db SPL as measured by the sound level meter and then, the combined tones were recorded on tape. Two randomly sequenced tapes of the twenty-four stimulus pairs were created, to control for sequencing bias. Each tape was about five minutes in duration.

### Design

The design for the second experiment was a "partially" repeated measures design. It had two tape randomizations of tones repeated within subjects. The tapes were counter-

TABLE 5

Fundamental and Higher Tone Combinations: (Cell Entries are the Higher Square Wave Tones formed from the Product of Fundamental and Pythagorean Intervals in Hz)

Fundamentals(Hz)	Pythagorean Intervals					
	9:8	5:4	4:3	3:2	5:3	2:1
	Higher Square Wave Tones					
50	56	63	67	75	83	100
100	113	125	133	150	167	200
200	225	250	267	300	333	400
400	450	500	533	600	667	800

balanced in administration. Accordingly, the basic design was 2 x 2 x 24 partially repeated measures, with 2 orders of tape randomization, 2 reception sequences, and the twenty-four tones repeated within subjects. For simplicity in the presentation of analysis, data for each subject were averaged for each repeated tone pair. Also, subjects were classified into 3 levels of musical experience on the basis of their reported musical training.

## CHAPTER VI

## RESULTS

Tone Pairs

A preliminary 2 x 2 x 24 partially repeated analysis of variance for order, reception sequence, and tone pairs showed order and reception sequence were not biasing factors for the data.

A repeated measures analysis of variance was conducted for the 24 (averaged) tone pairs rated by the 23 subjects. The effect for tone pairs was significant at  $p < .001$ ,  $F = 40.68$ , see Table 6. However, tones pairs were subdivided into categories of six levels of Intervals and four levels of fundamental. Figure 11 plots the mean pleasingness of each tone pair with respect to its fundamental and (Pythagorean) interval. An honestly significant difference (HSD), from Runyon & Haber (1980, p. 276), of 1.08 showed the following differences between tones. In general, 50 Hz fundamental tones, or the 9:8 and the 5:4 intervals at a 100 Hz fundamental had the lowest pleasingness ratings. Other 100 Hz fundamental tones or higher fundamentals of the 9:8 interval were assigned medium pleasingness ratings. 200 and 400 Hz fundamental tones (not including the 9:8 interval) were assigned the highest pleasingness ratings. Means for all tones by interval and fundamental are shown in Appendix F.

TABLE 6

## Repeat Measures Analysis of Variance for Tones

Source of Variation	SS	df	Mean Square	F
Between Subjects	99.33	22	4.52	
Within Subjects	1602.97	529	3.03	
Between Tone Pairs	1040.34	23	45.23	
Residual	562.63	506	1.11	40.68*
Total	1702.30	551	3.09	
Grand Mean = 3.77				

\* $p < .001$

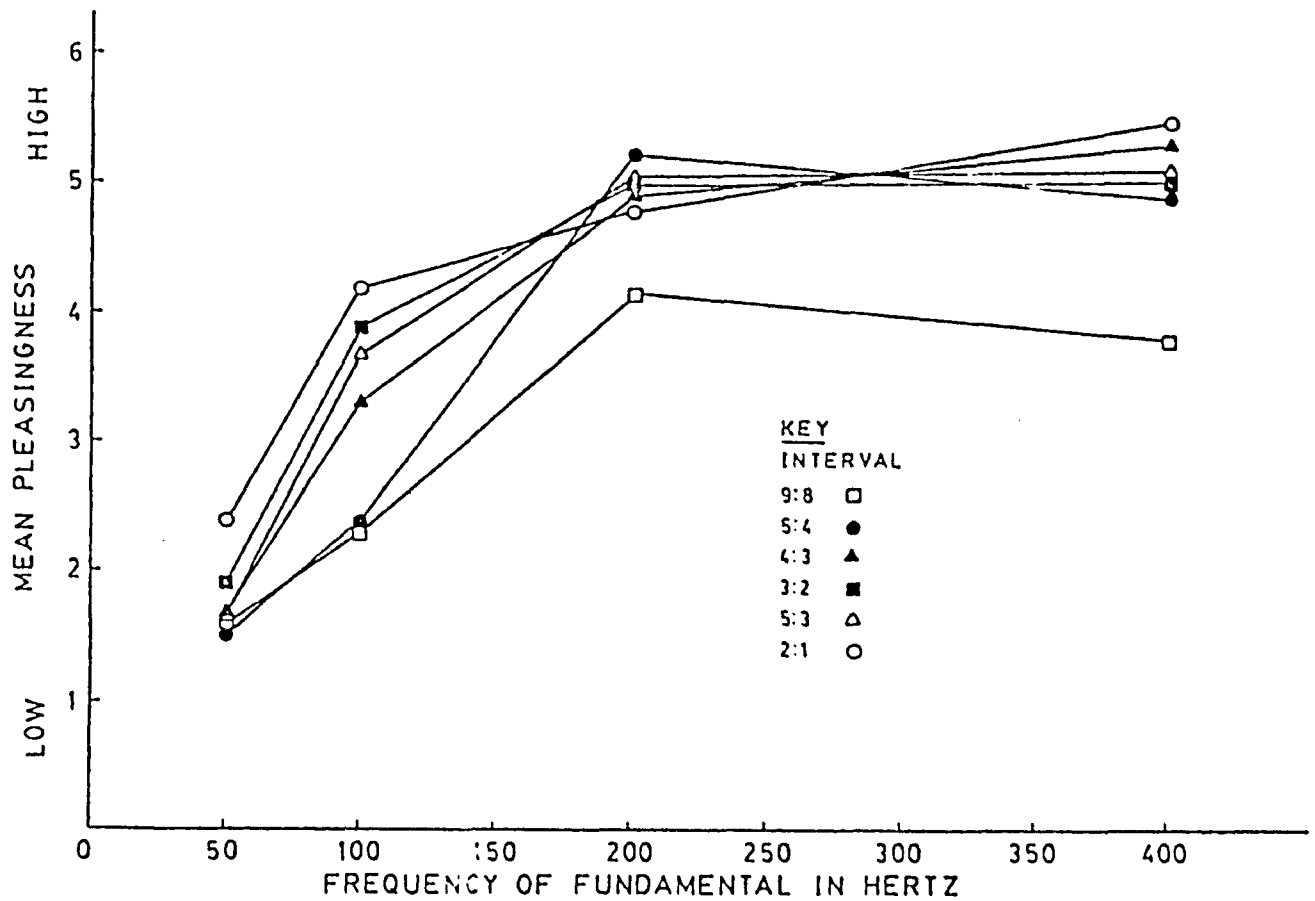


Figure 11. Mean pleasingness of square wave tone pairs as a function of fundamental and musical interval

### Dissonance and Musical Experience

A statistically conservative, 3 x 4 factorial analysis of variance for musical experience grouping ("naive", "medium", or "expert") by tone dissonance grouping (which separated dissonance, as calculated in Appendix B, into five categories ranged in increments of .5, from 0.0 to 2.5) and with rated pleasingness as dependent variable was conducted, (see Table 7). The dissonance category of 2, .5 to 1.0, which had no observations, was excluded from analysis and hence df for the analysis were 3. There was a significant main effect for musical experience of ( $p < .01$ ) and a significant main effect for dissonance groupings of ( $p < .001$ ). The interaction of the two variables was significant at  $p < .001$ . Figure 12 records the interaction of musical experience and dissonance grouping with mean pleasingness ratings as dependent measure. In Figure 12, it can be seen that the main effect for musical experience was the relatively higher ratings assigned by the most musically naive; the lowest ratings of pleasingness were given by the most musically experienced. The interaction of dissonance and musical experience showed that those with 'medium' musical experience were more conservative in pleasingness ratings of both high and low dissonance stimuli. The strong main effect ( $F = 292.78$ ) for dissonance grouping was that higher dissonance was associated with lower pleasingness scores.

Finally, the correlation between dissonancy scores and

TABLE 7  
 Analysis of Variance for Pleasingness  
 as a function of Dissonance Grouping  
 and Musical Experience

Source	SS	df	MS	F
Main Effects	1727.18	5	345.44	177.42*
Musical Experience	17.10	2	8.55	4.39†
Dissonance Grouping	1710.08	3	570.03	292.79*
Interaction Musical Experience/ Dissonance	64.84	6	10.81	5.55*
Explained	1792.02	11	162.91	83.68*
Residual	2126.08	1092	1.95	
Total	3918.10	1103	3.55	

\*  $\underline{p} < .001$

†  $\underline{p} < .01$



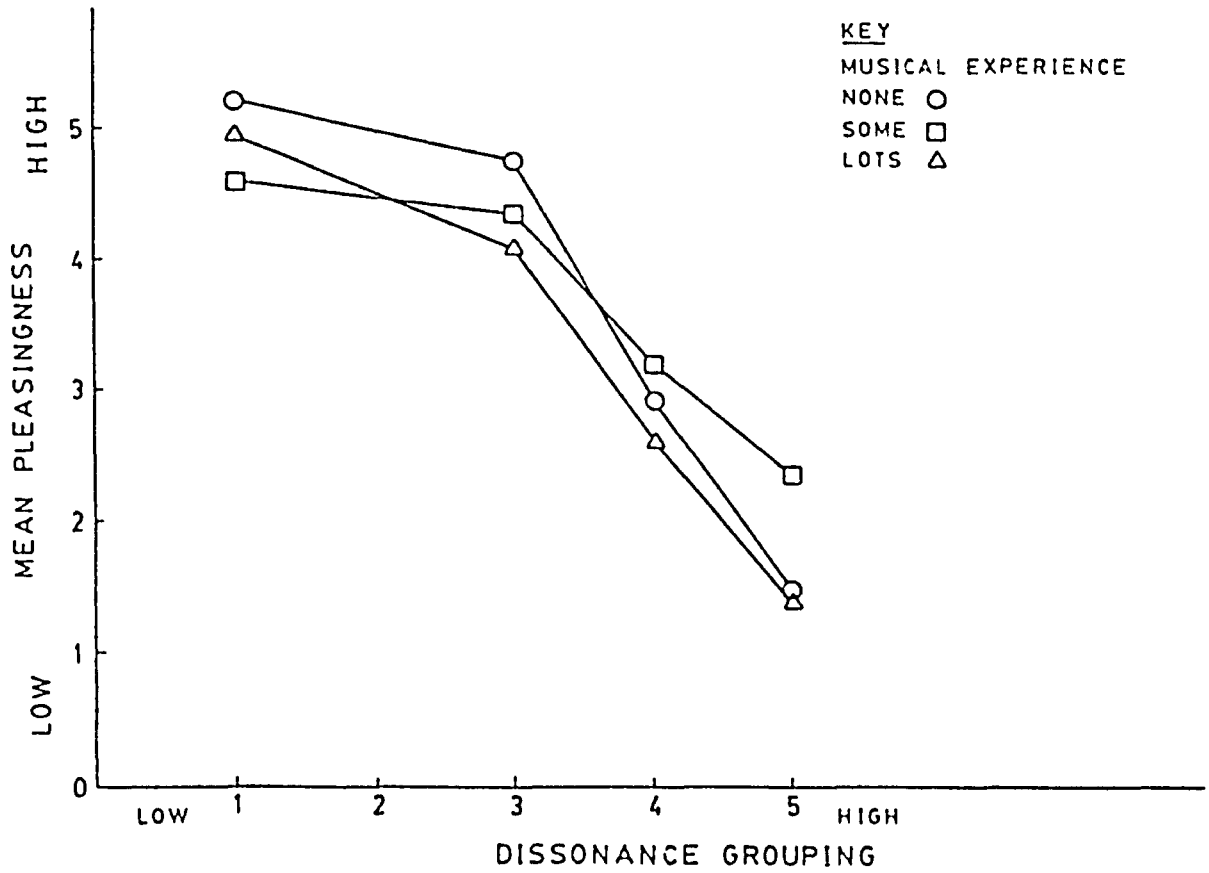


Figure 12. Effect of dissonance and musical experience on pleasingness of tone pairs.

Pleasingness ratings was  $-.82$ . High pleasingness scores were related to low dissonance estimates and vice-versa. Figure 12 indicates the relationship between dissonancy and pleasingness is strongly negative, but not strictly linear.

## CHAPTER VII

## DISCUSSION

Dissonance calculations using the critical band model, (Plomp & Levelt, 1965), figured on an a priori basis to correlate more strongly with the simultaneous tone pleasingness ratings, rather than the consecutive tones above. The reason is the critical band model was developed on simultaneous tonal intervals and several theorists have proposed interference models for dissonance, (Irvine, 1945; Helmholtz, 1954; Kruger, 1903; Plomp & Levelt, 1965). Also, dichotic listening studies have indicated the higher dissonance of simultaneous intervals, (as in Sandig, 1939).

The graded increments of fundamental tone for the intervals provided a range of theoretical dissonance estimates, using the model in Appendix B applying the critical band theory. Simultaneous sounding of lower frequency intervals was theoretically known to have higher dissonance effects, since the overtones involved would have more clashes within the critical band.

From Figure 11, it was shown that lower fundamental (frequency) tones having higher theoretical dissonance value received low pleasingness ratings. Post-hoc HSD tests for the tone pairs effect in Table 6 confirmed these findings. These findings follow the critical band theory (Plomp &

Levelt, 1965), which would have predicted higher dissonance ratings from more theoretically dissonant combinations. The finding of a clearly displeasing 9:8, (second), musical interval was consistent with research on preference patterns for simultaneous tones. (Malmberg, 1918; Guernsey, 1928; Valentine, 1914; Van de Geer et al., 1962; etc.). The dissonance data compares favourably with the classical literature on dissonance. The dissonance estimating model, which considers both clashes of fundamentals and overtones is therefore supported. Plomp & Levelt, (1965), do not consider overtone structures, but their model for sine wave pair dissonances was extended to account for complex wave dissonance by considering all "strong" pair wise clashes. (See Appendix B).

In addition, dissonance was strongly and negatively correlated  $-.82$  with pleasingness ratings. The correlation suggests that theoretical dissonance is measurable by psychological pleasingness. For the sample of university women having three classifications of musical experience, the relationship of dissonance to pleasingness is consistently strong and negative for simultaneous tonal intervals. The finding is supported by the literature. Bugg (1933) observed that untrained persons are influenced by aesthetic evidence factors in tonal rating; also, Guthrie and Morrill (1928) showed that ratings of consonance and pleasantness were similar for naive subjects. The musical "expert" in this research, with three

or more years of musical instruction is probably not an equal of the professional. However, whether or not professional musicians, statistically very small in numbers, consider pleasingness ratings as a measure of dissonance of tonal intervals is a matter for further research.

## CHAPTER VIII

## SUMMARY AND CONCLUSIONS

Figure 13 compares data from Experiments One and Two. The square wave pleasingness data for the 100 and 500 ms delay intervals were averaged to give a net delay effect for the first experiment. Specific tone intervals were taken from the more continuous data set in Experiment One to be compared with those from Experiment Two. Simultaneous intervals received lower ratings than the consecutive intervals. The result was probably the outcome of the strong dissonance effect associated with simultaneous intervals, and the selection of lower frequency tones in the second experiment which as a group had much higher theoretical dissonance (and hence lower pleasingness).

A major finding was the pleasingness of the intervals themselves. The 9:8 interval was rated as very displeasing for simultaneous tonal intervals, while being highly rated for consecutive intervals. Octaves for simultaneous intervals were favoured significantly over most intervals. But, in the sequential case intervals less than octave received higher ratings of pleasingness. The pleasingness quality of an interval appears to depend on an all or none delay interval between tones, (since rating patterns for 100 and 500 millisecond delayed tones were similar). The dissonance

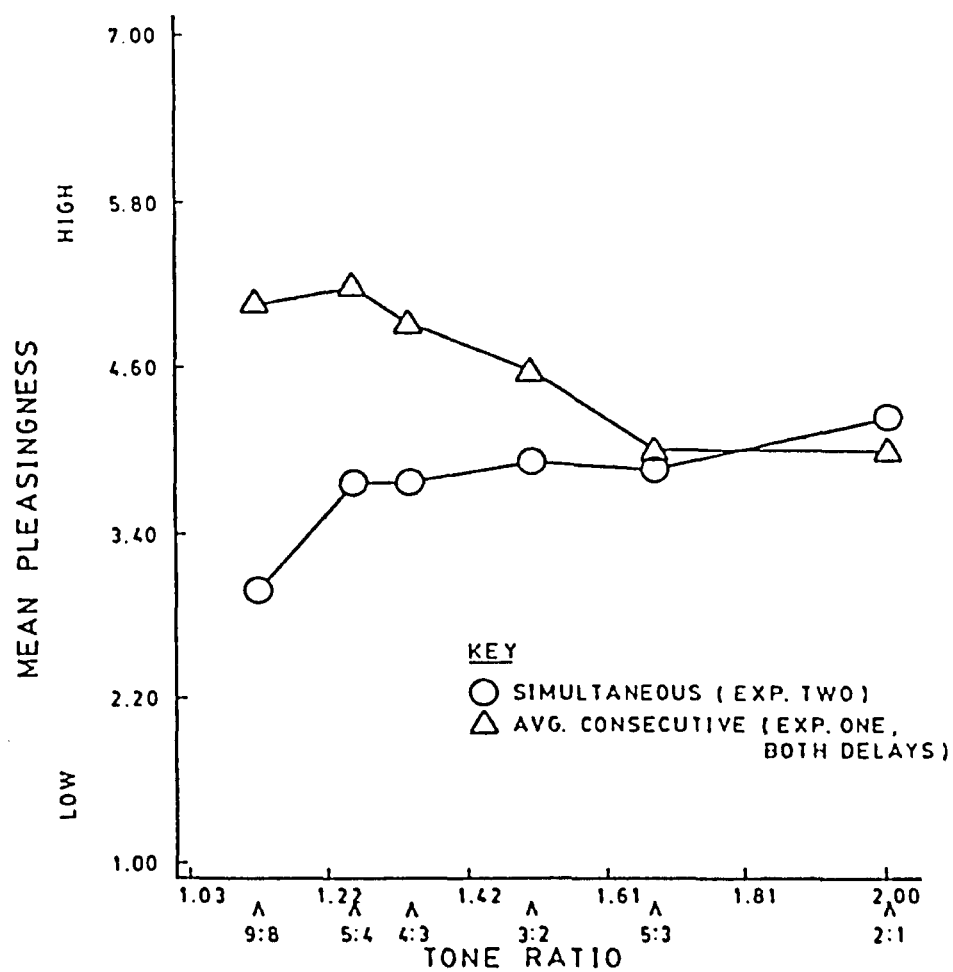


Figure 13. Comparison of mean pleasingness data for square wave intervals under simultaneous (experiment two) and consecutive (experiment one) presentation.

quality of the interval changes with all or none time delay between tones.

### Dissonance and Pleasingness

Dissonance appears to have a strong negative effect on pleasingness ratings for simultaneous tones, and a very weak (near zero) positive effect on sequential tones. Dissonance, by inference, appears to require the interference patterns present in simultaneous sounding of intervals. The correlational finding is supported by literature which observe that dissonance is reduced in sequential or dichotic, (Sandig, 1939), sounding of tones. The finding argues against Maher's (1976) assertion that some dissonance perseveres in sequential soundings, and is in favour of interference theories.

From the magnitude of correlation coefficient,  $-.82$ , of dissonance with pleasingness ratings, theoretical dissonance (as estimated by critical band overlaps) using the model of Plomp and Levelt (1965) is strongly and negatively related to psychological pleasingness for simultaneous tone intervals.

### Simplicity-Complexity

The division of subjects into groups of different musical experience did not produce findings of great strength. However, from several different analysis, the possibility of an underlying simplicity-complexity dimension was suggested. An interaction possibility may be that the more musically ex-



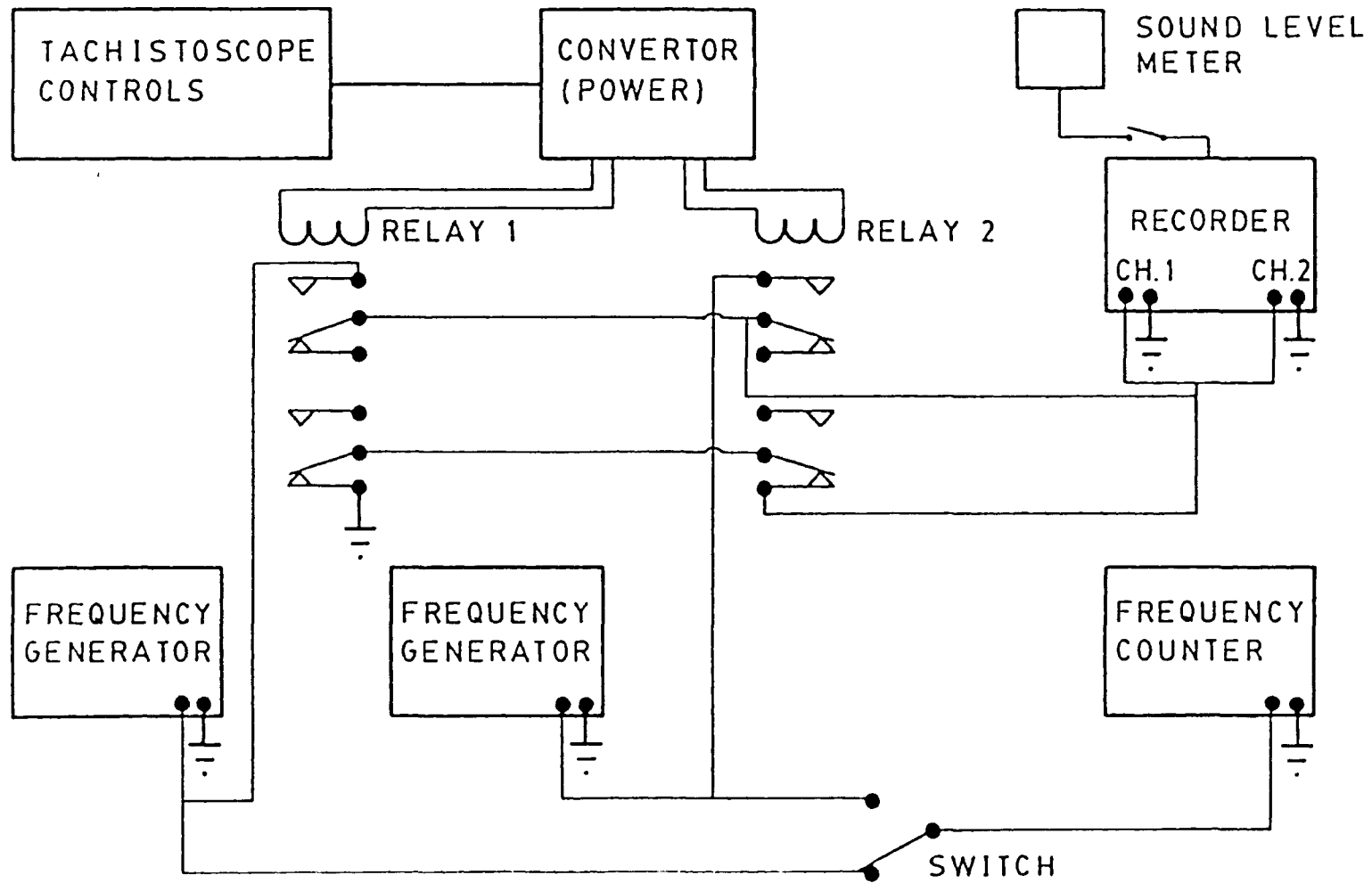
perienced prefer more complex stimuli, while the naive prefer simple stimuli, (where complexity is considered in terms of waveform and delay patterns). The complexity/experience interaction observed in the present experiment is consistent with results obtained by Berlyne et al. (1967).

#### Consecutive Tones - An Expectancy Model

For consecutive tone intervals, an expectancy model might explain the perception of pleasingness. Higher pleasingness ratings are assigned if the stimuli are either separated by an expected frequency difference of less than the C to A musical interval (or if the frequencies are an integer multiple apart). Implications for the expectancy approach were considered for propinquity in melody (Chandler, 1934) and the theory of tonality in music.

# TWO TONE CIRCUIT

NOTE: ALL CABLES ARE COAXIAL



Two Tone Circuit

## APPENDIX B

## Calculation of Dissonance

The theoretical determination of dissonance as a stimulus variable (to be related to judgements of Pleasingness) was a major concern in both experiments. The critical band theory of Plomp and Levelt, (1965), allowed the quantification of theoretical dissonance and was a testable proposition for the determination of pleasingness. Plomp and Levelt had proposed that the dissonance for pairs of simultaneous sound waves (sine or square) varied with the frequency difference between the waves. If the frequency difference was less than an amount deemed critical by the raters in their study (Plomp & Levelt, 1965), the pair of waves was rated as dissonant or not consonant. Several authors, also, (e.g. White & White, 1980) have published figures showing the change in critical band width as a function of the mean frequency of the tones given. These were to develop an estimate for the dissonance of pairs of tones.

Dissonance Structure of Sine and Square Wave Stimuli

A sine wave is a pure frequency, a single wave, assuming fidelity in the sound generator producing it. For a pair of sine waves, in terms of critical band theory, the frequencies involved are either within the critical band or not, that is,

dissonant or not.

A square wave is a set of pure tones, harmonic frequencies arranged in diminishing strength. There is a fundamental,  $f$ , and overtones at odd integer multiples of the fundamental. The series is  $f, 3f, 5f, 7f, \dots, (2N-1) \times f$ . However, the energy strength of the series is respectively:  $1, 1/3, 1/5, 1/7, \dots, 1/(2N-1)$  times the energy of the fundamental,  $f$ . The energy for each overtone, then, is the reciprocal of its position. For a pair of square waves, dissonance should represent the net effect of all dissonant clashes. If the fundamental of one wave was  $f$ , and the fundamental of second wave was  $y$ , then the net dissonant effect would be the sum of all possible dissonant combinations of  $f$  and  $y$ , weighted according to the energy strengths of the tones involved. However, the summation of an infinite series is not practical. Also, energy strengths decline appreciably after  $1/9f$ , and could be taken as too weak to affect the measure of dissonance. Moreover, since the human limit of hearing is near 20,000 Hz, overtones of greater frequency are not be heard.

Accordingly, the dissonance estimate for a pair of square waves was taken as the sum of the dissonant clashes with respect to their energies, from their fundamentals,  $f$  and  $y$ , to nine times their fundamentals,  $9f$  and  $9y$ . The amount of dissonance of the clash was estimated by the strength of the tones involved. On the basis of spread in scattergram

plots, for dissonant clashes, the lower of the two energy coefficients involved was the dissonance estimate for that combination. Total dissonance was the sum of the estimates for dissonant combinations.

#### Mathematical Formula for Dissonance

A Gaussian Elimination program, using data points from a critical band curve in White and White (1980), was used to develop a cubic polynomial to estimate dissonance for the stimuli in the experiments. (This provided critical band values for any pair of tones). Then, if the frequency difference of the tones was less than the critical band value a dissonance estimate was made, and added to the total dissonance; if not, the next pair of tones was examined, until all possible combinations for a particular set of square wave tones,  $f$  and  $y$ , was examined. Then, a new pair was taken.

The Fortran program, below, shows the calculation and summation of dissonance for square waves in Experiment Two. Please note that: IPOS is a position number (not used here); IP is the pleasingness rating; T1 and T2 are the fundamental tones,  $f$  and  $y$ , of the interval.

## FORTRAN PROGRAM

```

DO 1 N=1,48
      READ(21,50) IPOS,IP,T1,T2
50  FORMAT(I2,1X,I1,1X,F5.1,1X,F5.1)
      J=5
      DO 10 I=1,J
            P=(I*2)-1
            A(I)=T1*P
            B(I)=T2*P
            DISS=0.0
10  CONTINUE
      DO 20 I=1,J
            DO 30 II=1,J
                  XSUBT=A(I)-B(II)
                  XSUBT=ABS(XSUBT)
                  XRATIO=B(II)/A(I)
                  IF(A(I).GE.B(II))XRATIO=A(I)/B(II)
                  SUM=A(I)+B(II)
                  AVG=SUM/2.
                  DIFF=XSUBT
            X3=0.000000003*AVG**3.
            X2=0.00004*AVG**2.
            X1=0.043333335*AVG
            X0=80.
            ESTCB=X3+X2+X1+X0
            IF(DIFF.LE.ESTCB)GOTO 41
GOTO 30
            MII=(II*2)-1
            MI=(I*2)-1
            FRAC=1./MI
            XFRA=1./MII
            ESTF=FRAC
            IF(XFRA.LE.FRAC)ESTF=XFRA
            DISS=ESTF+DISS
30  CONTINUE
20  CONTINUE
      X=T1
      Y=T2
      XRATIO=Y/X
      IF(X.GE.Y)XRATIO=X/Y
      .
      .
      .
      etc.....

```

## APPENDIX C

## Standard Instructions to Subjects in Experiment One

"You are about to listen to pairs of tones presented in a sequence. Each pair will be followed by about seven seconds of silence, during which time you will indicate firstly, which of the two tones you prefer by circling a 1 or a 2, and secondly, how well you think the pair sounds together on a scale from 1 to 7: 1 being very displeasing and 7 being very pleasing. Again, you will circle your preference. Please do not miss any pairs, if you do so, please go to the next line for the next pair on your answer sheet. Here is a two pair example of tones. Please indicate your judgements accordingly. (Structure), 'beep' delay 'bop' lag 'beep' delay 'bop' lag. Did you indicate your judgements here? Please note that there may be a very faint after image here (circuitry resonance). Do not let this bother you and it does not count as a pair. If you have any questions please ask the experimenter to clarify things for you. You are now ready for the main tape series."

APPENDIX D  
Sample Coding Form

WF .5) Subset: 4123

Name: N.M.

Musical Preference Study

Pair Number	Better of Two		How Pleasing Together						
			1	to				7	
			Very Displeasing			Very Pleasing			
1	1	2	1	2	3	4	5	6	7
2	1	2	1	2	3	4	5	6	7
3	1	2	1	2	3	4	5	6	7
4	1	2	1	2	3	4	5	6	7
5	1	2	1	2	3	4	5	6	7
6	1	2	1	2	3	4	5	6	7
7	1	2	1	2	3	4	5	6	7
8	1	2	1	2	3	4	5	6	7
9	1	2	1	2	3	4	5	6	7
10	1	2	1	2	3	4	5	6	7
11	1	2	1	2	3	4	5	6	7
12	1	2	1	2	3	4	5	6	7
13	1	2	1	2	3	4	5	6	7
14	1	2	1	2	3	4	5	6	7
15	1	2	1	2	3	4	5	6	7
.	1	2	1	2	3	4	5	6	7
Etc. up to 210	1	2	1	2	3	4	5	6	7



## APPENDIX E

Means for Dissonance Group by Delay  
for Square Wave Tones

Dissonance Category	Square Wave Delay	
	100 msec	500 msec
1	3.17	3.03
2	3.98	4.12
3	3.86	4.07
4	4.55	5.00
5	No Cases	No Cases
6	5.55	5.80
7	4.14	5.17
8	4.44	5.08
9	4.27	5.20

## APPENDIX F

## Ranked Mean Pleasingness by Tonal Intervals and Fundamentals

Mean Pleasingness	Pythagorean Interval	Fundamental
1.56	5:4	50
1.61	5:3	50
1.63	9:8	50
1.63	4:3	50
1.94	3:2	50
2.33	9:8	100
2.39	2:1	50
3.11	4:3	100
3.37	5:8	100
3.70	5:3	100
3.85	9:8	400
3.89	3:2	100
4.18	9:8	200
4.22	2:1	100
4.83	2:1	200
4.94	5:4	400
5.00	4:3	200
5.02	3:2	200
5.02	3:2	400
5.11	5:3	200
5.23	5:3	400
5.28	5:4	200
5.30	4:3	400
5.50	2:1	400

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