JUDGMENT OF INTONATION IN THE CONTEXT OF THREE-PART WOODWIND ENSEMBLE PERFORMANCES

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The purpose of the study was to determine judgments of trained musicians regarding the intonation of complex tones in the context of synthesized woodwind ensemble performances. Problems included in the study were (1) estimation of the point in pitch deviation which would result in out-of-tune judgments, (2) investigation of timbral effects on judged intonation, and (3) investigation of effects of mistuning within differential voices.

Two hundred undergraduate and graduate music majors from two universities participated. Subjects were presented with one of two recorded sets of synthesized three-part woodwind ensemble performances and were asked to judge each example as in-tune or out-of-tune. Analyses of data using Chi-square ($\underline{p}<.01$) were undertaken to determine if differences in judgments of intonation existed relative to each of the research problems.

Results indicated that deviations had to reach ±18 cents before a majority of subjects made out-of-tune judgments. Examples which were in-tune according to equal temperament were judged as out-of-tune in 20 percent of the cases. Significantly more out-of-tune judgments were made for every additional ±6 cents deviation along a continuum from a standard of in-tune. Significantly more judgments of unacceptable intonation were made for examples containing sharp deviations than for examples containing flat deviations. Different timbres and/or timbral combinations had an

effect on judged intonation. Mistunings within differential voices sometimes effected significantly different judgments of intonation relative to the amount of pitch deviation and/or timbre, but not consistently.

Additional analyses were conducted to determine if differences in intonational judgments existed among subjects according to (a) area of performance concentration, (b) academic classification, (c) gender, and (d) institution attended. Differences existed relative to the area of performance concentration and academic classification of subjects. No differences existed according to gender or school of enrollment of subjects.

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CHAPTER I

INTRODUCTION

Background and Rationale for the Study

One of the most important goals for any musician or musical organization is that a performance be "musical." One dimension of the term "musical" is playing or singing with a degree of acceptable intonation. A satisfactory degree can be considered to be the amount of variance of pitch from a standard which can be tolerated by the listener. The impetus for this study was an interest in determining what prospective music educators consider to be good or bad intonation within the context of common practice musical settings.

The topic of intonation can be said to be subsumed under the larger heading of psychoacoustics, a branch of psychophysics. Studies in psychoacoustics primarily are interested in human responses to sound stimuli. In general, psychophysical research can be divided into two major categories: First, scientific investigation of the perceptual capabilities of an organism responding to sensory stimuli; and second, investigation of how an organism characteristically responds to sensory stimuli.

Music exists as it is heard by the perceiver and must be studied with considerations of that factor. Thus, researchers must combine the objectivity of the science of physics with the subjectivity of human psychology. To observe and measure perception, an awareness of its contextual nature is necessary. Investigations of perception in music are limited, however, by the absence of absolutes and, to some extent, by the degree to which the complex phenomena of music can be subjected to purely objective scientific analysis. Psychoacoustics appears to be at the center of most research in musical perception because it is based in musical behavior and more easily lends itself to narrow interpretation of objective results. For these reasons, the study of auditory phenomena constitutes a major area of the investigation of relevant variables in musical performance. One such variable in musical performance is pitch. Pitch perception has received much attention from acousticians and sensory psychologists, whose studies can be classed, for the most part, in the first category of psychophysical research, that of investigating the perceptual capabilities of individuals.

Pitch, the subjective attribute of frequency, pervades most music and is generally defined as the sensation resulting from the relative placement of a sound on a high-low continuum (11). According to Rasch and Plomp (11, p. 6), it is possible that the sensation of pitch varies as a result of noise components (inharmonic partials), or that the subjective character of a pitch differs when one compares the pitch of simple and complex tones. Among other factors affecting pitch perception are duration and intensity (1, p. 128). In psychoacoustical literature, the pitch of a simple tone is often indicated by its physical frequency expressed in Hertz (for a complex tone, by its fundamental frequency). Because a specific frequency is assigned to one tone only, it can be said that frequency is an approximate indicator of pitch sensation (11, p. 7). For musical studies, such as this, Rasch and Plomp as well as Backus maintain that it is reasonable to disregard the effects of duration and intensity on pitch perception and to use the terms "frequency" and "pitch" as essentially synonymous.

The scale on which various degrees of perceptible pitch are arranged has upper and lower limits which are biologically set by the response mechanism of the ear. For most humans with normal hearing, the average audible range of frequencies is from 15 to 15,000 Hertz (Hz); however, this varies from person to person (1, pp. 126-127). Early researchers identified the ability to distinguish differences in frequencies as pitch discrimination. Research has shown the individuals exhibit substantial differences in their ability to discriminate variations in pitch. To establish how acute an individual's pitch discrimination is, that person's ability to detect very small changes in frequency, or difference limen (DL), must be determined for various pitches. When the difference in frequency between two tones presented one after the other is too small, the associated sensation is judged as remaining the same (1, p. 127). As soon as the variation exceeds a "just noticeable difference" (jnd), or difference limen, a change in sensation is detected. Since the just noticeable difference is related to a physical magnitude (the stimulus), it is measurable and can be expressed by a number.

The difference limen varies for any particular frequency among individuals and even differs for the same individual at multifarious frequencies. The degree of sensitivity to pitch changes depends on the frequency, intensity, duration, and suddenness of the change (1, p. 128). Moreover, the differences in pitch perception and discrimination between individuals are in part a function of musical training. Finally, the assessment of pitch discrimination depends heavily on the method of measurement (1, p. 129).

Some frequency resolution tasks involve the use of a pure tone of constant intensity whose frequency is continuously modulated. For the average individual, a change of 10 Hz around a mean of 2,000 Hz can be detected;

even smaller differences can be detected when the changes in frequency occur suddenly (22). Another means of measuring a person's ability to detect changes in frequency is the use of simultaneous tones. When simultaneously sounding tones are used, the two tones must lie outside a critical bandwidth to be discriminated. For example, at 2,000 Hz, the two tones must be at least 200 Hz apart before the auditor can distinguish two separate tones (22). These two methods of detecting pitch discrimination illustrate the point that even at the same frequency level, the results can vary according to the method of measurement.

A third means of measuring pitch discrimination abilities involves the successive sounding of two tones, and subjects must indicate whether the second tone is higher, lower, or the same as the first tone. Using this procedure, Wier, Jesteadt, and Green (20) determined that the average difference limen at 1,000 Hz for their five untrained subjects was 1.8 Hz.

The three methods of measuring pitch discrimination discussed above have isolated a single threshold of pitch discrimination; however, a study by Stevens (14) investigated the hypothesis that there are two critical threshold values for pitch discrimination: (1) a frequency increment below which a change in pitch is never detected, that was termed by Stevens as the "neural quantum" of pitch detection; and (2) a frequency increment above which a change in pitch is always detected, whose value is approximately twice that of the "neural quantum."

As a result of (a) different methods of measurement, (b) the fact that the degree of sensitivity to pitch change depends upon the frequency, intensity, duration, and suddenness of change, and (c) differing theories of pitch discrimination, the concept of just noticeable difference in frequency has not been clearly defined. The sensitivity of the ear to small pitch changes is still the subject of considerable research.

Many studies have employed sine tones, or single frequency tones, to investigate the problems of pitch perception. Because musical tones are for the most part not sine tones, the central question should logically be: how does an individual make judgments regarding complex musical tones?

The pitch range of musical instruments was found by Snow (12) to be approximately 17-4200 Hz (the frequency of the lowest note of the piano is about 27.5 Hz). Studies of the range of "musical pitch" by Zeitlin (21) and Henning and Grosberg (5) have shown that when the reference signal is less than 4,000 Hz, smaller differences can be detected for a complex tone than for a sinusoidal tone. These studies suggest that detection of pitch changes using musical instrument tones may result in a smaller difference limen than in a setting in which the stimuli are sine tones.

The research by acousticians and sensory psychologists which has been cited generally has not been concerned with music in performance. As a result, those investigations of pitch typically have not examined the more "musically" contextual aspects of pitch discrimination, such as intonation.

No matter what the criteria of "good" intonation is, the process by which people make judgments of intonation is still a matter of speculation. The concept of what is in-tune or out-of-tune extends beyond mere accuracy of simultaneous unisons or successive matching of a few selected pitches. Music in performance provides different circumstances in which a variety of tuning practices may be incorporated to achieve what can be considered good intonation. The circumstances may include a melodic content (a series of successive tones) for which the succession of "melodic intervals" may be the basis for intonation judgment. The performance material may include the presence of simultaneous, differing pitches, or "harmonic intervals," which may also be a basis for intonation judgment. A combination of melodic and harmonic lines taking place concurrently should also be considered a possibility. Finally, the presence of soloistic, small ensemble, or large group effects may need to be taken into account as well. Because of the preceding variables for music in performance, the purely objective method of psychoacoustical investigation (measuring people's perceptual capabilities) is inappropriate for determining intonational judgments.

Because music is a subjective human phenomenon, research which belongs to the second category of psychophysical investigation of pitch perception has also been conducted to determine how a person characteristically responds to sound stimuli. The investigation of perceived intonation of musical intervals in isolation has received the attention of several researchers. Sundberg and Lindqvist (15), and Cohen (2), among others, have studied pitch and musical octaves for which intervals slightly exceeded a 2:1 frequency ratio. Vos (17, 18) investigated the perception of pure and mistuned fifths and major thirds. Hall and Hess (4) extended their investigation to include all intervals from a unison to the the octave plus major tenths and twelfths. The subjects in these studies were asked to make judgments on degrees of mistuning. These studies have indicated that certain degrees of mistuning of intervals are indeed tolerated and even preferred in some instances. Terhardt and Zick (16) found differences in acceptable intonation relative to whether sounds were played in sequence (melodically) or harmonically. They concluded that "ideal" intonation has to be flexible, adaptable to the psychoacoustic requirements of the musical sound at each moment.

Although numerous studies in both categories of psychophysical determination of pitch perception have been conducted, the problem of how to transfer the findings of these studies into a musical setting is not often addressed. In fact, findings based upon nonmusical tones, or musical tones and intervals in isolation, may not be valid for music in performance. As a consequence of the problem of applying the results of these studies to music in performance, investigations of perception and judgment of intonation in the context of a musical setting have also been conducted. Madsen and Geringer (8) undertook a study in which a melodic line was performed by a trumpet and accompanied by an electronic keyboard. The accompaniment consisted of open triadic harmony in octaves. Two tuning adjustments of 25 cents flat and 50 cents sharp relative to equal temperament were made in the accompaniment while an additional accompaniment was calibrated for "in-tune" performances.

Madsen and Geringer observed that subjects demonstrated an ability to discriminate between sharp, flat, and in-tune intonation. Subjects appeared to prefer sharp and in-tune accompaniment significantly more than flat accompaniment. The authors suggested that deviations in intonation can be as great as 50 cents (1/4 tone) between soloist and accompanist in a musical context and be preferred to the same or greater extent than theoretically correct intonation. The rank order for preferences of intonation were sharp, in-tune, and flat. The investigators emphasized that the accompaniment of 25 cents sharp was not found to be significantly different from the in-tune accompaniment and that the tendency of preference appeared to operate only for deviations on the sharp side. Much smaller deviations toward flatness (25 cents flat as opposed to 50 cents sharp) were judged as out-of-tune.

Another study by Madsen and Geringer (7) also placed tuning deviation in a musical context. This investigation used unaccompanied flute and oboe duets. Recordings were made so that all pitches were either close to equal temperament or purposefully sharpened 50 cents. Flatted examples were omitted. Subjects were asked to judge the intonation for each example and judge tone quality as "good" or "bad." They found that when either of the instruments was mistuned, subjects responses evidenced no particular pattern relative to timbral considerations. Consequently, this resulted in determining no significant differences between correct and incorrect judgments. Madsen and Geringer suggested that in a musical context, deviations in intonation can be as large as 50 cents between two performers and be confused with other considerations, such as tone quality.

Rasch (10) conducted a study using two-part musical fragments wherein both harmonic and melodic intonations were manipulated. In the standard condition of intonation, the melody parts were tuned according to equal temperament, whereas the bass notes (forming a harmony part) were chosen in such a way that they formed a just-intonation interval with the simultaneous melody note. Deviations from the standard of intonation varied according to specific harmonic intervals. Minor thirds were adjusted 0, -10.4, -26.0, and -51.9 cents. Major thirds were altered by +6.9, +17.3, and +34.6 cents. Fifths were changed by -3.5, -8.7, and -17.3 cents. Minor sixths were deviated by -6.9, -17.3, and -34.6 cents. Major sixths were re-tuned by +10.4, +26.0, and +51.9 cents. Octaves were left unchanged through all conditions. Complex tones which served as stimuli were generated by a computer. The subjects were asked to judge the quality of intonation on a scale from 1 to 7, with 7 for perfect intonation and 1 for the poorest intonation. Stimuli with mistunings up to 10.4 cents deviation were judged a little better than those with standard intonation (equal temperament in melody; just intonation in harmony). Generally, the results indicated that with increasingly larger amounts of mistuning, intonation was correspondingly judged to be poorer. Deviations of 26 cents or greater seriously degraded the perceived quality of intonation.

All of the previously cited studies and others in this field provide a valuable base toward a better understanding of perceived pitch and intonation. Weaknesses, however, appear in some studies as a result of design and inadequate control of variables. Other concerns about the results of prior investigations eminate from the use of sounds which were not always typical of true musical instruments (e.g., use of pure (sinusoidal) tones versus musical (complex) tones). In addition, the presentations of tones, pitches, and melodic lines or harmonic material were not always characteristic of a common practice musical setting. The few studies that do judge intonation in a contextual musical setting seldom address the issue of estimating the point in pitch deviation at which a performance is considered to be out-of-tune. In light of these concerns, further study of intonational judgments in the context of musical performance is needed.

Purpose of the Study

The purpose of the study was to determine judgments of trained musicians regarding the intonation of complex tones in the context of synthesized three-part woodwind ensemble performances.

Research Problems

Problems included in the study were:

1. Estimation of the point in pitch deviation at which complex sounds were judged to be out-of-tune;
2. Investigation of effects of homogeneous and heterogeneous timbral combinations on judged intonation;
3. Investigation of effects of mistuning within differential voices relative to the judgments examined in Problems One and Two.

Definition of Terms

1. Homogeneous refers to combinations of like instruments. For this study, it included:
   (a) flute - flute- flute
   (b) oboe - oboe - oboe
   (c) clarinet - clarinet - clarinet
2. Heterogeneous refers to combinations of different instruments. For this study, it included:
   (a) flute - oboe - clarinet
   (b) flute - clarinet - oboe
   (c) oboe - flute - clarinet
   (d) oboe - clarinet - flute

(e) clarinet - flute - oboe

(f) clarinet - oboe - flute

Limitations

1. The study was limited to selected woodwind timbres (flute, oboe, B-flat soprano clarinet) as generated by a Kurzweil 250 synthesizer.

2. The study was limited to the range in pitches for the above instrumental timbres of concert D_4 (293.66 Hz) to concert D-$flat_6$ (1110.6 Hz).

3. Findings cannot be generalized to other timbres or combinations of timbres nor to any pitch ranges outside D_4 to D-$flat_6$.

4. Subjects were limited to volunteer undergraduate and graduate music majors at two selected universities in the Midwest and Southwest United States.

5. Results of the study may not be generalized to other populations and may not be totally applicable to live performance situations.

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CHAPTER II

RELATED LITERATURE

The study of pitch perception and intonation has been approached in diverse ways by investigators from a variety of disciplines including physics, psychology and music education. The review of literature has been categorized into four areas: (1) Intonational Variables in Performance, (2) Performed Intonation Versus Perceived Intonation, (3) Psychophysical Considerations, and (4) Context of Pitch Discrimination and Intonational Judgments. Except as noted, the investigations reviewed used equal temperament as the standard of intonation.

Intonational Variables in Performance

Included in the literature regarding performed intonation are investigations that have observed performances of scalar and intervallic musical material. Some of the following studies in this area have also investigated possible relationships between major performance area and/or amount of training of subjects and their intonational discrimination abilities, an area of secondary interest to the present study.

Madsen (21) undertook an investigation to determine the possibility of greater pitch acuity with respect to ascending or descending scale performance. The purposes of the study were to determine if there were consistent patterns of intonational deviation with regard to sharpness and flatness in scalar vocal performance and if there were differences among individuals or different groups of subjects.

As hypothesized by Madsen, it was found that all subjects (N=40) performed with greater pitch acuity when singing descending lines. In fact, the total cent deviation for ascending scales was approximately four times as great as the total cent deviation for descending patterns. It was predicted that subjects with greater formal training would perform more accurately than untrained subjects and that pitch differences between ascending and descending patterns would be less for those subjects with more training. There was a significant difference in accuracy of the performances of both ascending and descending patterns when pre-college subjects were compared with college level subjects with more musical training, suggesting that training does affect performed intonational accuracy.

There was not a progressive sharpening or flattening of pitch as students proceeded through the scales. Based on the widely varied performances, no pitch patterns surfaced which were consistent for individuals or different groups, either by performance area or according to musical experience level. Much speculation and conjecture has arisen concerning how a scale should be performed. Many are of the opinion that the placement of each note in a scale has its own distinct physiological and psychological properties, such as raising the seventh degree of the scale, slightly lowering the third, and so forth. Madsen's study indicated that there was not a statistically significant difference between any degrees of the scale and that all degrees of the scale were performed without significant sharp or flat pitch deviations.

In a study isolating the pitch variable of ascending scales, Geringer (10) divided undergraduate and graduate music student subjects (N=96) into four groups: string instrumentalists, wind instrumentalists, keyboard instrumentalists, and vocalists. String and wind players performed on their instruments; vocalists and keyboardists used their singing voices. Subjects performed ascending scalar patterns, one in the mixolydian mode unaccompanied and the other with piano accompaniment. Analysis of results indicated a tendency toward sharp intonation which remained consistent throughout the study for both unaccompanied and accompanied performances. Overall deviations in terms of cents were over twice the amount in a sharp direction as in a flat direction.

In a comparison of the unaccompanied and accompanied performances, analyses indicated that accompanied scales were performed with significantly less absolute deviation and a tendency (though statistically nonsignificant) to be less sharp than unaccompanied scales. An interaction was observed between accompaniment and scale degree.

String musicians performed with significantly less deviation than all other groups. The vocal and keyboard groups tended to be more inaccurate in a sharp direction than both the string and wind groups. Overall comparison with regard to direction of pitch deviation, however, was not statistically significant. The comparison of intonational performance with intonational perception, the area of primary interest to Geringer's study, will be discussed in greater detail in a succeeding section.

Research concerning the performed intonation of musical intervals has indicated a general lack of pitch conformity on the part of instrumental musicians to any one tuning system (14, 25, 28). In one study by Mason (25), few consistent patterns of differences in intonation were observed between solo and ensemble performances. Consequential differences, however, existed between the intervals performed in these two situations, leading Mason to conclude that "woodwind quintet performances are significantly affected by the harmonic structure of music" (25, p. 38). In a study of performances by seventeen string instrumentalists (four violinists, four violists, four cellists, and five double bassists), Papich and Rainbow (30) compared solo performances of each musician with an ensemble performance by the same person. It was observed that solos tended to be slightly sharper in pitch with a tendency for adjustments in ensemble performance to be in a downward pitch direction (30, p. 33). Also reported was an effect of melodic direction in which the size of ascending intervals, in general, tended to be overestimated (expanded) in performance. This finding supported the results of a related study by Nickerson (28).

Several investigations have centered on the effect of interval direction on performed intonation. Edmonson (8) sought to determine whether interval direction made a significant difference in the intonation of the unaccompanied solo voice, and whether there were any consistent patterns of intonational differences among performing individuals and groups. Forty undergraduate students participated. Eight subjects were chosen from each of five categories which included vocalists, string instrumentalists, pianists, brass instrumentalists, and woodwind instrumentalists. Edmonson hypothesized that subjects would perform ascending intervals with greater pitch acuity than descending intervals. The results, which supported his hypothesis, directly conflicted with the findings of Madsen (21). The significant interaction between intervals and directions implied that both variables strongly influenced each other.

Other findings by Edmonson revealed highly significant differences in performed accuracy of intervals between subjects, although there were no consistent patterns of those differences among individuals or groups. The data indicated that vocalists were more accurate than instrumentalists in solo vocal performance of both the ascending and descending intervals. Using the mean cent deviation of each group for comparisons, it was found that vocalists performed with the least amount of pitch deviation. The woodwind group evidenced the greatest mean cent deviation. Since the performance task was vocally oriented, it could be argued that the vocalist subjects may have had some innate advantage. Although the results of Edmonson's study conflict with Madsen's finding (21) regarding group differences between vocalists and intrumentalists performing vocally, the possiblility of bias may account for the conflict.

Duke (7) examined the relative consistency of intonation accuracy of forty-eight wind instrumentalists among several forms of melodic and harmonic intervals. Comparisons of melodic intervals performed in both ascending and descending directions were made with performances of harmonic intervals. Results of the absolute deviation analysis indicated that subjects' overall intonation accuracy did not differ significantly among the observed interval distances which supported earlier findings with regard to string and wind instrument performances (14; 25). Duke's findings for instrumental performances conflict with the findings of Edmonson (8) in his study of vocal interval performance. Duke's evidence also indicated that melodic intervals were generally expanded when performed in a descending direction and contracted when performed in an ascending direction. These tendencies of directional deviation were opposite those noted in previous studies concerning interval performance by string instrumentalists (30), and studies of vocal and instrumental scalar performance (21, 24) in which there was a tendency toward sharpness of pitch in performed ascending patterns.

Pikler and Harris (33) studied the hierarchy of cues which allows a trained musician to create a progression of musical intervals with consistent precision and speed. When subjects were asked to perform, one at a time, the different intervals of a major scale, results were commonly in error by as much as a quarter-tone (50 cents). The octave was found to be significantly sharp. Next, intervals were performed simultaneously with a series of pitches. It was found that even a primitive musical line provided a distinct cue for pitch intonation. When fixed tonics and octaves were provided, improvement continued. It was hypothesized by Pikler and Harris that cues from full harmony might bring intonation errors within the limits of a difference limen for the particular musical situation.

Hypothesizing a probability that the presence of some cue in a performance situation improves intonation, Small (37) conducted a study regarding intonation of vocal performances in an ensemble setting. The main purpose of the investigation was to determine whether individuals (college altos, tenors, and basses) sang a harmony part more in-tune when hearing a simultaneously sung soprano melody than when singing that same part without hearing the melody. Among several secondary purposes was the investigation of possible differences between vocalists and instrumentalists.

Results indicated that subjects (N=40: twenty vocalists, twenty instrumentalists) sang a harmony part more accurately with the in-tune melody than without it. Determination of this was accomplished by the use of analysis of variance according to absolute deviations. The findings evidenced a propensity among all subjects to perform in a flat direction. These results parallel the findings of Duke's (7) study of instrumental performances of intervals. These results are, however, still in conflict with most extant intonation research which indicates propensities toward sharp performances. While the comparison of the vocal performances of the twenty vocalists with the twenty instrumentalists revealed no significant difference between mean intonation scores for each group, these results could possibly have been influenced by the fact that all subjects, including the instrumentalists, were concurrently singing in a regularly scheduled choral group. In other words, even the instrumentalists had some vocal experience and training which may have diminished possible differences between the two groups.

Performed Intonation Versus Perceived Intonation

The discussion which follows concentrates on perceptual aspects of intonation and findings in the literature which suggest that performed intonation and perceived intonation may not be synonymous. For this study, performed intonation refers to the intonations used by musicians in performances. Perceived intonation refers to an auditor's judgment of intonation in a performance.

Ward and Martin (45) investigated discrimination of melodic sequences with adjusted tunings. Scales were used wherein each had a form of pitch alteration from equal temperament. Three scale tones were flatted (the third, sixth, and seventh degrees) by -6 cents to -30 cents. The subjects (N=20) were asked to indicate whether the third scale in a group of three sounded like the first or the second scale presentation. Upon completion of the task, subjects remarked that the first two scales in each group of three often sounded quite different but that it was difficult to decide whether the third scale was like the first or the second. Consequently, the task was repeated using only two scales within a grouping. For this administration, subjects were requested to judge whether the three adjusted scale steps (third, sixth, and seventh) of the second scale were sharper or flatter than the corresponding tones of the first scale. In the first study design, the results ranged from 54 percent correct for examples with deviations of 6 cents flat, to 88 percent correct on items containing mistunings of 30 cents flat. An increase in correct responses was found in the second design, with a range of 58 percent to 95 per cent correct for the respective deviations (45, p. 587). No mention was made of statistical testing for significance of results.

A third form of the task was constructed in which deviations from equal temperament in the altered scales (third, sixth, and seventh degrees) were sharp as well as flat. The researchers presented the results of the scoring of only two subjects, one of whom scored very high and one of who scored very low. They reported that neither subject had much difficulty in discriminating flat deviations and that both made errors on some large sharp deviations. In fact, the one subject considered to be the most able observer based on an earlier task was completely unable to decide whether departures of 25 cents sharp were sharp or flat, although he had met a 75 percent criterion of accuracy when mistunings were only ten cents. The authors suggested that the complexity of the task (listening critically to only three of eight notes) may have been responsible for the erratic results and that if a subject was not prepared for this type of test, scales involving the sharping of 25 cents in the three notes may have given the impression that the first and fourth scale degree steps were flat (45, p. 588).

The last task of Ward and Martin's study involved the rating of single scales as either "too sharp" or "too flat" based on the three adjusted notes (third, sixth, and seventh scale steps); in essence, the subjects were asked to give an "absolute" judgment of relative pitch. Scales with sharp, flat, and no deviations from equal temperament were presented in random order. Subjects were asked to indicate whether they preferred the adjustments in the three pitches that were sharp or flat. Again, examples containing large sharp deviations were often judged as "too flat," perhaps because of the difficulty in maintaining the judgmental criterion as in the previous test. A summation of results, in spite of noted problems, indicated that the discrimination of sharp mistunings was less accurate than that of flat mistunings.

Portions of a study by Madsen, Edmonson, and Madsen (22) also present findings relevant to the present study. The purpose of the study was to test auditory discrimination using a modulated frequency (369.99 Hz) of constant intensity (70 dB). Two hundred subjects participated in the study, twenty-five each in eight different groups. Included were second graders, fifth graders, eighth graders, eleventh graders, college juniors (non-music majors), college junior music majors, graduate music students, and music faculty.

The stimulus tone chosen was concert F# (369.99 Hz) which was taped from an audio oscillator. Subjects heard fifteen stimulus-tone presentations each of thirty seconds duration. The stimulus frequency was held constant for five seconds and then tones either ascended at a rate of two cents per second, descended at the same rate, or stayed the same (no frequency alteration). The maximum frequency deviation was fifty cents in either direction. Subjects were given a switch to trigger at the moment they perceived any change in a stimulus tone. Subjects were then instructed to mark an answer sheet whether they thought the tone went up, down, or stayed the same. Results of statistical tests of significance led to the following conclusions: (1) comparatively, younger subjects responded to tonal stimuli "incorrectly and sharp," and older subjects evidenced better acuity while demonstrating a propensity toward "flatness;" and (2) auditory discrimination is partially a function of age as well as of musical training (22, p. 1471).

In another study, Geringer (11) sought to determine: (1) whether musicians prefer to hear familiar orchestral excerpts in-tune, flat, or sharp relative to their recorded pitch levels; (2) what would be the direction and magnitude of preferred tunings; and (3) what would be the effect of initial pitch presentation levels. Sixty undergraduate and graduate musically trained subjects were asked to modulate a variable speed tape recorder to preferred pitch levels of ten recorded orchestral excerpts, each in a different key. Data consisted of cent deviation scores relative to A=440.

Geringer's results indicated that subjects demonstrated a marked propensity to tune excerpts sharp rather than flat relative to recorded pitch level. Analysis by total and mean cent deviations indicated that subjects preferred sharp pitch presentations more than three times as much as flat presentations. Further analyses indicated a greater percentage (70 percent) of sharp responses in categories of more than 100 cents deviation, while 62 percent of the flat responses occurred between zero and 100 cents deviation (11, p. 173). The authors concluded that the magnitude of sharp tuning preferences suggests that subjects are more sensitive to flatness than sharpness. In addition, they found that pitch preferences were significantly affected by the initial pitch presentation. After subjects first heard an excerpt, they would raise or lower the pitch and often seemed to return to an approximation of the initial pitch level.

Most of the studies of performance practices suggest the tendency of performers to play sharp (10, 21, 25, 30, 37). On the other hand, there seems to be a greater proclivity toward perception of flatness than sharpness (10, 22, 24, 45). Questions have been posed regarding reasons for these seemingly related, but apparently opposite phenomena.

Several studies have compared differences between performed intonation and perceived intonation. One such investigation was by Geringer (10), who studied the relationship between performed intonation and perceived intonation using ascending scalar patterns. The performance aspect of the study was discussed earlier wherein results indicated that a tendency toward sharp intonation in performance was consistent throughout the study for both unaccompanied and accompanied performances. Following the subjects' (N=96) performances, the perception aspect of the study was conducted using the subjects' own recorded scale performances as stimuli. Subjects were requested to make desired adjustments in the intonation of the recorded stimuli using a variable speed tape player. Comparisons of subjects' performances with their adjustments to the recordings of those performances were then made.

Analysis of variance procedures and Newman-Keuls multiple-comparison tests provided the basis for interpretation of results. Both directional (sharp and flat) and absolute deviation analyses revealed significant differences between perception of intonation and performed intonation. Results indicated that perception of intonation in unaccompanied scales was less accurate than the performed intonation of unaccompanied scales. The direction of deviation was not consistently more sharp or flat in subjects' perception of intonation in unaccompanied scales, but rather less accurate than when they performed a scale. Performed intonation and perception of intonation in accompanied scales were not significantly different.

Another performance/perception study by Geringer and Witt (13) investigated the relationship between the perception of tuning stimuli and performed tuning accuracy of string instrumentalists. Subjects consisted of sixty high school and sixty college students/professionals. Subjects, performing on their instruments, were asked to tune to tape-recorded tones which had been recorded by a professional oboist with levels of 440 Hz., twenty-five cents sharp relative to 440 Hz., and fifteen cents flat to 440 Hz. After recording the tuning process of a subject, each was asked to judge the relative placement of the pitch of the "A" on the tape through verbal response. The responses were coded into one of three categories: (1) sharp/a little sharp, (2) in tune, or (3) a little flat/flat.

Data were analyzed three ways: (1) performance data (relative to the stimulus pitch and relative to 440 Hz.), (2) verbal responses (perception data), and (3) a comparison of verbal responses with performances. Results of the performance data derived through a two-way analysis of variance indicated significant differences between cent deviations relative to the placement of the pitch stimuli. Subjects performed below the sharp stimulus, and above the in-tune and flat stimuli, suggesting a preference for sharp tuning relative to A=440. The college/professional subjects tuned sharper (approximately 10 cents) in pitch to both the sharp and the flat (approximately 5 cents) stimuli. Verbal responses concerning the judged intonation of the stimuli were similar for both groups. Chi-square analysis of responses indicated that subjects made significantly more "flat" judgments than either "sharp" or "in-tune" determinations.

With regard to the main interest of the study, it was found that the agreement between performed intonation and perceived intonation was 62 percent for the college/professional group, while the agreement between performance and perception for high school subjects was only 43 percent (13, pp. 95-96). These percentages seem to indicate a limited degree of association between perceptual judgment and performed intonation. The investigators suggested that the relative maturation and training of the college/professional group may have been responsible for the higher percent of agreement in their results than in the high school group (13, p. 97).

As evidenced by the results of the last two studies (10, 13), there appear to be differences between performed intonation and perception of intonation when only listening. The causes of this discrepancy are still undetermined and worthy of further investigation.

Psychophysical Considerations

Another approach to the investigation of intonation is to manipulate the tuning of synthesized musical fragments in order to discover effects of the altered variables on perceived intonation. Observing that perhaps the human ear may prefer "stretched" scales to theoretically correct scales, Sundberg and Lindqvist (38) studied musical octaves and pitch for which octave intervals in stretched scales would slightly exceed a 2:1 frequency ratio. Stretching is the uniform expansion of the logarithmic frequency ratios between the fundamental frequencies of tones in a scale and/or between each fundamental and its overtones. The investigators distinguished between the physical octave (PO) which is defined as a 2:1 frequency ratio, and the subjective (musical) octave (MO) that is perceived as pure. The parameter under study was the physical interval between two successive tones constituting a perceived pure octave. This interval was then referred to as the physical musical octave (PMO). Among the purposes of the study were (1) to establish how the PMO varied with the fundamental frequency of a lower complex tone which preceded a higher complex tone, and (2) to examine how the PMO compared with deviations from the equal-tempered scale derived from performed music.

Musically trained subjects (N=4) were instructed to adjust the frequency of a number of variable test tones so that each formed an upper octave interval (MO) with a preceding reference tone. Both signals were complex tones. Results indicated that the physical size of the perceptually pure musical octave (PMO) generally exceeded a 2:1 frequency ratio. Additionally, it was found that a stretched scale derived from the experimentally established average PMO at different frequencies showed similarities with scales derived from musical performances. These findings, though based on musically trained subjects' responses, should be considered with some caution because of the small number of subjects (one violinist, one pianist, one organist, and one vocalist). Futhermore, only octave tone-pairs were investigated, yet the comparison was made between a performed musical scale and one constructed of the average of individual PMO tones extracted from manipulated intervals.

Using six musical test sounds, each tuned in normal, stretched, and contracted tempered intonation, Terhardt and Zick (40) asked twenty-five musicians and twenty-five non-musicians to subjectively evaluate stimuli in paired-comparison tasks. The investigators concluded that (1) if the constituent complex tones of a musical sound cannot interact strongly in the auditory system because they are played in sequence (melodically) or because they are widely apart in frequency, stretched intonation was desirable ("high melody plus low accompaniment"); (2) if the musical sound is such that some interaction of spectral components may give rise to beats and roughness, normal intonation was considered best (medium spectral complexity); and (3) in musical chords of high spectral complexity (giving rise to strong interactions in the auditory system), even contracted intonation may be suitable (40, p. 273). These results suggest that there is no optimum intonation for every situation because the judgment of good intonation is subjective; that is, it depends on the structure of the musical sound. Summarily, Terhardt and Zick conluded that "ideal" intonation has to be flexible to adapt to the psychoacoustic requirements of the musical sound at each moment.

Rasch (34) attempted to determine if differences existed between melodic and harmonic influences on judged intonation. In order to investigate possible differences between melodic and harmonic influences, Rasch used synthesized two-part musical fragments in which both harmonic and melodic intonations were manipulated. Mistuning was applied to the harmonic intervals between simultaneous tones in the melody and bass lines (harmonic mistuning), which, at the same time, caused a mistuning of the melodic intervals between successive tones in each of the two parts. The fragments were presented to fifty music students for judgments of perceived quality of intonation. Results indicated that melodic mistuning of the melody parts had the greatest perceived effects on the quality of intonation, followed closely by harmonic mistunings. Based on the findings, Rasch reasoned (with reservations) that the deviating interval size was probably of more importance in the perception of harmonic mistuning than the presence of beats. He had, however, no method of quantification for extracting positive indications for this hypothesis (34, p. 465).

In this basal exploration of the intricacies of judgments regarding melodic and harmonic intonation, Rasch used only a series of single two-note intervals. Moreover, although the stimuli were constructed using complex tones, they were produced by a computer and were not characteristic of any commonly recognized musical instrument.

Context of Pitch Discrimination and Intonational Judgments

While some studies have focused on certain intonational variables of performance (scalar and intervallic musical material and directionality) in a generalized reference to musical context, others have specifically isolated various contextual characteristics of tonal stimuli relative to pitch discrimination. Leonard (20) conducted an investigation on the context of intonation by examining several variables in relation to pitch discrimination. Included were register, intensity, timbre, and duration. In separate discrimination tests for each variable, sixty-four subjects (elementary education majors enrolled in a music education class) were asked to listen to pairs of tones. They were instructed to indicate whether the second tone appeared to be higher or lower in pitch than the first tone. The stimuli were always different pitches with the second tone being either ten cents sharper or flatter than the first.

Among the selected findings was that the harmonic context affected the ability to discriminate pitch differences. Also, when intensity and loudness were constant, timbre did not significantly affect pitch discrimination. Although the study indicated that pitch discrimination was related to many variables, no conclusions regarding the specific relationships of some of the variables to pitch discrimination were drawn. Because associations of variables were analyzed one at a time, very irregular patterns of pitch discrimination resulted. Explanations for these irregularities were not possible because of this univariate analysis. Another problem with the interpretation of results arose from the fact that several statistical analyses indicated the ratio of right to wrong answers to be worse than expected of chance. Leonard concluded that " . . . more errors than that of chance must be interpreted as no discrimination at all; i. e., the same as chance" (20, p. 50).

Another problem in determining the validity of Leonard's results is the limited amount of explanation and description of procedures in the development of the tests. In addition, there was no evidence of test reliability. In spite of these problems, the study appears to indicate that contextual factors may affect the perception of intonation.

In another study of contextual influences on intonation, Greer (15) sought to determine the specific effects of timbre on brass-wind external intonation (tuning to another sound source). Thirty-two undergraduate and graduate brass majors took part, eight each in four categories: tuba, trombone, horn, and trumpet. The subjects were asked to perform in unison with a series of pitches sounded in four different timbres. The timbres were electronic oscillator, organ with a flute stop, piano, and the subject's own instrument. Data consisted of the differences in cents between the pitches of each stimulus tone and the corresponding subject performance of that pitch.

From the results of the study, Greer concluded that timbre differences rather than pitch differences were the main causes of difficulty in achieving acceptable intonation. There was a significant overall difference at the .01 level in subjects' abilities to perform "in-tune" with pitches sounded in the four different timbres. Greer also found that subjects performed more easily in-tune with pitches sounded in the timbre of their own instruments. The order of difficulty for in-tune performance progressed to piano, organ, and finally, the electronic oscillator. Prior to the testing, Greer hypothesized that familiarity may be a major cause for the timbre effect, and to some extent, the hypothesis was supported by the fact that tuning to the timbre of each subject's own instrument proved easiest. Greer asserted that familiarity was not the major cause for the timbre effect, however. This opinion was based on the consideration that the oscillator timbre should have been more familiar than the organ timbre because the oscillator is used in the tuning practices of various performing organizations. Greer attributed the erratic responses to performing with the oscillator to the lack of overtones in its timbre.

Other findings included were that scale direction was not a significant factor for external intonation (it may be recalled that Madsen (21) and Edmonson (8) found that direction was a significant factor in internal intonation but that Duke (7) found no effect of direction in internal intonation); that subjects playing low range instruments performed with better intonation than high range instruments; and that with intervening practice, subjects improved considerably on the second trials. Timbre differences, however, remained statistically significant for both trials.

Variables including timbre, intensity, duration, and relative frequency were investigated in a study of fine tuning by Swaffield (39). Subjects consisted of twenty-five undergraduate music students who were requested to respond to 108 recorded items, each of which consisted of a scale fragment (the fourth to seventh degrees of an A major scale). The fragments were presented in one of four timbres at one of three intensity levels and at one of three duration values. Upon hearing each item, subjects were given two seconds to tune a given tone to the tonic of the melodic fragment. The given tone was presented at exactly A=440, or twenty cents in either a flat or sharp direction.

Based on an analysis of covariance, Swaffield concluded that each of the four contextual factors had a highly significant effect upon fine tuning. He reported that the relative frequency of the tuning tone with respect to 440 Hz. had the greatest effect upon tuning while duration had the least effect. Close investigation of the statistical figures in the summary table, however, indicated that timbre had the least effect. It cannot be determined if the figures were placed incorrectly in the table or if the investigator misreported the findings. Interaction effects among all contextual factors were also found, with the exception of timbre/duration and intensity/relative frequency (39, p. 308).

Another part of the study tested the accuracy of tuning each timbre relative to the 440 Hz. standard. According to a summary table of the most accurate and most inaccurate tuning means of the four timbres (flute, clarinet, horn, and violin), the most accurate tunings involved the horn while the most inaccurate were associated with the violin. Caution should be exercised, however, in drawing any conclusions from the figures in the table because the violin also had the second highest number of most accurate means. Problems in the presentation of findings and incomplete data information also warrant prudence in accepting Swaffield's conclusions. Aside from these criticisms, the study indicates that some instrumental timbres may be more difficult to tune accurately than others.

Several investigations have suggested that familiarity of timbres may have some influence on perceptual discrimination (1, 9, 15, 19, 31). Such a study relative to intonation was conducted by Beyer (2). The main objective was to determine whether subjects could discriminate pitches produced only in timbres of their own instruments better than pitches produced by timbres of their own instruments combined with other instruments. Thirty high school students, each with no fewer than three years experience performing in ensemble on his instrument, served as subjects. Six subjects were selected in five categories: flute, clarinet, trumpet, French horn, and trombone. Subjects were asked to listen to twelve sets of successive paired tones produced by an instrument from their own timbral category. They were instructed to determine whether the pitches of the tones were the same or different. Subjects were then asked to do the same with tones produced by a like instrument and several different instruments. A 3 Hz. difference in frequency, either sharp or flat, was chosen for the interval of mistuning. No mention was made of specific frequencies used for stimuli.

Results of the testing indicated that subjects were able to discriminate pitches produced by timbres of their own instruments significantly better than pitches produced by like instruments with other instruments. The study also reported that (though not statistically based) subjects who played high-pitched instruments discriminated pitches produced by timbres of their own instruments better than subjects who played lower-pitched instruments. Beyer failed to explain the almost opposite results with regard to accuracy of pitch perception for like instrument with other instrument comparisons which was also indicated. The last findings are not surprising because of physiological reasons. For example, it has been found that at low frequencies, up to about 400 Hz, the ear can hear a modulated frequency when the range of modulation is greater than approximately 3 Hz (46). At higher frequency ranges which fall in the normal playing range of musical instruments, however, frequency discrimination becomes more acute (46). These facts suggest that a 3 Hz discrimination task in the pitch range of a flute, for example, may be easier physiologically than a 3 Hz discrimination task in the frequency range of a tuba. Other concerns toward Beyer's study center on the lack of information or discussion of the directional variables (sharp, flat) and that no comparisons were made between or among timbres of individual instruments.

Based on the idea that good intonation may be more difficult to achieve on certain instruments, Tunks (41) sought to determine what effect a particular combination of instruments being tuned in unison or octaves had on the accuracy of tuning long tones. Also, he desired to determine what instrument combinations could be identified as particularly difficult to tune. The task was limited to simultaneous long tones. Subjects were thirty-two music education majors of sophomore or junior standing. Stimuli consisted of tape recorded instrument tones presented in pairs and produced by seven wind instruments: oboe, flute, clarinet, trumpet, horn, trombone, and tuba.

Subjects were asked to tune seven tape loops (variable tones), one at a time, to seven different fifteen-second tone segments (reference tones). Forty-nine different instrument combinations resulted. Instructions regarding tuning strategy (e.g., beat elimination, etc.) were not given but subjects were informed that the reference tones were each fifteen seconds in duration. Analysis of the data documented the difference in terms of cents between the variable tone and the reference tone for each combination. Tunks concluded that instrument combination affected the accuracy of long-tone tuning. This finding conflicts with the findings of Leonard (20) but does concur with the findings of Greer (15) and Swaffield (39). Tunks also found that eleven instrument combinations within both homogeneous and heterogeneous categories appeared to be more difficult to tune than various other combinations. Direction of error (sharp or flat) was approximately equally distributed and demonstrated no particular pattern.

An interest in timbral effect on pitch perception led to a study by Wapnick and Freeman (44). Fifty undergraduate music majors listened to forty-eight pairs of clarinet tones. Their task was to indicate whether the pitch of the second tone sounded sharp, flat, or the same as the first pitch. The second tone was either twelve cents sharp or flat, or was left the same. All tones had been altered by an audio equalizer so that they were either "bright" or "dark" relative to the original recorded source. Sequences consisted of bright/bright, dark/dark, bright/dark, and dark/bright.

Relative to timbral sequence accuracy, Wapnick and Freeman found that (1) subjects made significantly more errors in trials involving change of timbre than they did in trials involving no timbral change, regardless of whether low pitches or high pitches were heard; (2) subjects made significantly more errors of flat responses than errors of sharp responses when the timbral sequence was bright/dark; (3) when the sequence was dark/bright, significantly more errors of sharp responses were made than errors of flat responses; (4) no difference was found between the number of sharp and flat response errors in the bright/bright sequence; and (5) when the timbral sequence was dark/dark, subjects made significantly more errors of flat responses than errors of sharp responses (44, pp. 179-181). These patterns suggest that subjects associated dark tone quality with flatness of pitch and bright tone quality with sharpness of pitch.

In determining accuracy of judgments as a function of intonation, Wapnick and Freeman concluded that subjects' responses were more accurate when the second tone of each trial was flatter than the first, as compared to when it was the same as or sharper than the first. This finding is consistent with other research which indicates that the perception of flatness is generally better than the perception of sharpness (10, 13, 22, 24, 35, 45).

Madsen and Geringer (24) also examined timbral effects in relation to perceived intonation. The purpose of the study was to investigate aural discriminations and preferences of tone quality and intonation for the trumpet. Fifty undergraduate and graduate music students were asked to discriminate between "good" and "bad" tone quality and to rank-order eight sets of accompanied trumpet excerpts. There were three performance versions per set, each of which version varied in trumpet tone quality (good, bad) and intonation of the accompaniment relative to the trumpet (in-tune, 25 cents flat, and 50 cents sharp). Accompaniments consisting of open triadic harmony in octaves were played on an electronic keyboard. Subjects were initially asked only to discriminate between good and bad tone quality of two examples without accompaniment. All fifty subjects correctly categorized the examples. The main test was then administered.

Analysis of data revealed a tendency for subjects to prefer sharp and in-tune accompaniment over flat accompaniment regardless of tone quality. In terms of intonation analyses, subjects discriminated between sharp, flat, and in-tune. In the analysis regarding good versus bad tone quality, however, no significant difference in judgments of tone quality was found within the accompanied context. The last finding is noteworthy considering that in the pre-test, subjects exhibited accurate discrimination of tone quality in an unaccompanied context. Evaluation of the responses corresponding to tone quality indicated that responses to the category "tone quality" varied when intonation was changed, but subjects did not significantly differentiate when tone quality itself was changed. There was, however, the indication of a slight tendency to prefer good tone quality. Madsen and Geringer concluded that musically trained listeners apparently exercise a minimum degree of tone quality discrimination in an accompanied context. They also concluded that even when subjects responded categorically to the tone quality index, they were actually responding to intonational variables rather than quality variables (24, p. 19).

The preceding results, conclusions, and methodology present several points worthy of further consideration. Recall the association of bright and dark timbres with differences in pitch perception found by Wapnick and Freeman (44). The findings of Madsen and Geringer may be indicative of the reciprocal effect. Just as tone quality affects pitch perception, pitch may likewise affect tone quality perception; but that consideration was not within the scope of the Madsen and Geringer study. Also, Tunks' (41) finding that intonation of some instrument combinations were more difficult than others may be applicable to the combination of the trumpet with the electronic keyboard. No mention was made of the timbre used in the keyboard accompaniment, another possible source of influence.

A second concern arises from the comparisons of sharp and flat mistunings. In light of the research which has shown that perception of flat mistuning is better than perception of sharp mistuning, Madsen and Geringer exaggerated the difference in the direction of mistuning by making the sharp accompaniment 50 cents out-of-tune and the flat accompaniment only 25 cents out-of-tune. In response, subjects may have used different listening strategies in making their judgments of intonation. Depending upon the method of listening used, subjects may have (1) listened specifically for the intonation of the accompaniment, which was implied in the summary of findings which stated that "subjects preferred sharp and in-tune accompaniment significantly more than flat accompaniment" (24, p. 19), or (2) they may have focused more on the intonation of the melody, in which case the melody would have been exaggerated in the flat direction by 50 cents (using the sharp accompaniment) but by only 25 cents sharp relative to the flat accompaniment. If the second possibility were the case, then the reported analyses and conclusions should be reconsidered. If the subjects focused on the accompaniment, then a discrepency arises; that is, judgments of intonation were made according to parameters of the accompaniment, whereas judgments of tone quality were made in relation to the melodic line. In other words, two different entities required judgments to be made separately rather than interactively. As reported earlier, Rasch (34) found in his study of perception of melodic and harmonic intonation that melodic mistuning of melody parts had the greatest perceived effects on the quality of intonation. If this were true for Madsen and Geringer's study as well, then the sharp/flat data should definitely be reexamined in light of that consideration.

In a later study, Madsen and Geringer (23) again investigated discrimination between tone quality and intonation in unaccompanied flute and oboe duets. A total of 480 subjects took part, 240 of whom were musicians and 240 of whom were considered to be non-musicians. Subjects listened to twenty-four duet performances and were asked to respond to each according to intonation and tone quality aspects for both the flute and the oboe. Seven response categories were available for each of the twenty-four melodies: (oboe)--sharp, flat, bad tone quality; (flute)--sharp, flat, bad tone quality; and, "nothing." Subjects were free to indicate as many categories of error as were deemed appropriate for each performance. Recordings were made so that all pitches were either close to equal temperament or purposefully sharpened fifty cents. Flatted examples were omitted.

Generalized results were that, as might be expected, music majors discriminated correctly more often than did non-majors. There were 38 percent "sharp" responses compared to 62 percent "flat" responses. Also, both groups indicated the flute to have poor tone quality more often than the oboe, although the music majors made fewer errors of tone quality judgments. In the intonation trials, it was found that when either the flute or oboe was sharp relative to the other, there was no difference between correct and incorrect judgments. Subjects exhibited varied responses and at times, incorrectly attributed some intonation errors to tone quality errors.

The structure of the task may have contributed to the preceding results. The form on which subjects recorded their responses included a category for flat intonation, but only in-tune and sharp performances were used, which may have biased the responses. Moreover, in a two-part musical performance, it would have been difficult to determine without additional pitch reference which part was sharp or flat relative to the other. It could have easily been perceived that one part was flat, when, in fact, the other part was sharp. The interval distance would be exactly the same.*

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*This effect was noted by this writer in a pilot study for the present investigation. In studying intonational perception within three-part and four-part ensemble performances, subjects many times responded to a particular voice as being out-of-tune in one direction (sharp or flat) when a neighboring voice was actually out-of-tune in the opposite direction. The interval distance was perceived correctly, but responses were incorrect as to which voice contained the deviation (18).

Results of the tone quality trials in Madsen and Geringer's study were mixed. When the flute was played with poor tone quality, all subjects discriminated correctly. When the oboe was played with poor tone quality, however, subjects' responses were varied; some identified tone quality errors as intonation errors. When both the flute and oboe were played with bad tone quality, subjects' discriminations were correct more often than incorrect, and they identified more tone quality errors than intonation errors. Poor flute tone quality was identified approximately ten times more frequently than poor oboe tone quality.

The analysis of quality versus intonation revealed that subjects were equally correct in both the quality and intonation trials. Analysis of incorrect responses, however, revealed that the intonation response categories contained a significantly greater proportion of errors. These findings conflicted with those of their previous study (24), perhaps due in part to the previously mentioned possible effect of directional deviation in one part relative to the other. It is also possible that some differences may be attributable to the use of sound sources (oboe and flute) different from those used in the first study (trumpet and electronic keyboard). Many of the same concerns expressed about Madsen and Geringer's first study (24) regarding the timbre variable, subject listening strategy, and directionality are applicable to the last study as well.

It appears that some sort of timbral effect had taken place in both studies by Madsen and Geringer. Perhaps the determination of "good" or "bad" tone quality effects on judged intonation is not as important an issue as the effect of differing combinations of instruments, or as those combinations of instruments may account for a masking effect in pitch discriminations.

Instrument combination raises another point for consideration. The assignment of melody or harmony to an instrument and the order of assignment may have contributed to the conflicting results of Madsen and Geringer's two studies. Helmholtz noted this problem in several experiments conducted using instrument combinations of clarinet/violin, clarinet/oboe, and clarinet/harmonium, placing the instruments in differing positions (top or bottom note) of chords (17). He concluded that the use of tone qualities unique to different instruments "will affect the order of agreeableness" (17, p. 211) with respect to their relative positions. The duet study of Madsen and Geringer did not address this issue.

In an attempt to replicate and extend the findings of their two previous studies, Geringer and Madsen (23, 24) again used the flute/oboe duet stimuli materials from the 1981 study (12). The study tested forty-five music majors' and forty-five non-music majors' responses to performance conditions of tone quality and intonation. Both subject groups were further divided into three verbal instruction groups: "(1) listen to the better performance, (2) listen to the performance with the better intonation, and (3) listen to the performance with the better tone quality" (12, p. 27).

For both the music and non-music categories, the three verbal instruction groups within each evidenced little ability to correctly identify or listen to specific performance conditions. All subjects seemed to identify and listen to what was considered to be the better overall performance rather than identifying specific elements of intonation or tone quality. Madsen and Geringer again proffered that subjects who indicated a preference for tone quality were often actually responding to intonation variables. In this study, however, subjects tended to prefer some mistunings to poor flute quality. As with Madsen and Geringer's other two studies, results of this study even more strongly indicated that variables get confused within a contextual setting. Again, the concerns and considerations posed regarding Madsen and Geringer's other two studies (23, 24) are warranted for the last study.

Summary

The study of intonation has taken on many facets. Several investigations have focused on variables such as scalar and intervallic musical material and/or directionality in hopes of detecting possible patterns related to the specific variables. Other studies have sought to determine relationships between musicians' intonation in performance and their perception of intonation strictly as listeners. Although slight to moderate correlations between performed and perceived intonation have been found in some studies, there also appear to be substantial differences. Focusing on isolated psychophysical phenomena, researchers have uncovered many findings of interest regarding perception and preference of intonational variables in isolated contexts, which have yielded varied interpretations. The effect of timbre on intonational perception has received increasing attention. Finally, more studies are being conducted in which intonation is studied in contexts more characteristic of common practice musical settings.

Much of the literature reviewed investigated pitch perception and differential sensitivity to pitch changes using stimuli (sinusoidal tones) not usually present in musical situations. Some investigations, using complex tones, or even musical instrument tones, have treated pitch discrimination phenomena only in isolated contexts. While results of these studies have offered a great amount of information concerning perceptual behavior toward pitch and intonation variables, the transfer of these findings to the realm of musical performance is questionable.

There have been, and probably will continue to be, contradictions in research findings regarding intonational variables. The findings and the problems of earlier works have been of great value in arriving at the present topic. Many of the conclusions of those investigations have been incorporated into the methodology of this study and their problems helped to formulate the basis of the research problems for this study. It is hoped that the present investigation will help clarify some of the issues and perhaps extend and bring to light others for future consideration.

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CHAPTER III

METHODOLOGY

Pilot Studies

In order to estimate the point in pitch deviation at which complex sounds are judged to be out-of-tune, the first research problem of this study, it was necessary that parameters of mistuning be established. Previous investigations dealing with the subject provided the basis for a pilot study to determine subjects' judgments of intonation in ensemble performances.

The review of literature noted that Ward and Martin (17) had used mistunings ranging from 6 cents flat to 30 cents flat. Subjects were asked to make judgments of intonation wherein the third, sixth, and seventh scale degrees were deviated in an equal-tempered scale. The study left open the questions of what subjects' responses might be for sharp mistunings as well as what a more musically contextual setting would evoke. Rasch (12) chose short, two-part musical fragments using both sharp and flat mistunings of intervals between the melody and bass voice. The amount of mistuning ranged from 3.5 cents to 51.9 cents with no particular incremental values to help determine the point or interval at which judgments of bad intonation were made.

While Rasch's study used a setting more nearly approximating a musical performance than did the study of Ward and Martin, it involved only two voices, which limited the findings regarding effects of intonation within differential voices, another of the research problems of this study. Madsen and Geringer (9) used mistunings of a keyboard accompaniment relative to solo trumpet of 25 cents flat and 50 cents sharp, which also provided no determination of the point in mistuning at which judgments of bad intonation were made. A second study by the same investigators (8) used flute and oboe duets and mistunings only of 50 cents sharp. As in the study by Rasch (12), the use of only two voices limited possible findings related to differential voices.

Based upon the information and results gathered from previous studies, mistunings of ±12 cents, ±25 cents, and ±50 cents were arbitrarily selected for use in a pilot study. These deviations were selected in anticipation that they would help establish specific increments of deviation and result in responses which would clearly indicate the appropriateness of the method of gathering data.

In order to make a stimulus tape with precisely controlled pitch deviations for the pilot study, timbres generated on a Synclavier II synthesizer manufactured by New England Digital Corporation were used. The Synclavier system consists of a keyboard unit, a 16-bit Able computer, and an 8-megabyte Winchester drive. The software used was the Release I (compiler) and the Release R (resynthesis package).

The question of using synthesized tones versus truly acoustical musical sounds for investigations of discrimination has long been argued. The search for ways to give electronic sounds a "natural," realistic, musical quality of an instrument has been considered very important among many researchers. Most methods for doing so were quite cumbersome until Chowning's (2) discovery that natural sounding tones could be produced in a simple manner by the use of frequency modulation to generate complex, time-varying spectra. The character of the temporal evolution of spectral components is of critical importance in the determination of timbre. This is the premise of frequency modulation synthesis. From studies of the physical properties of actual musical instrument tones and their perceptual implications, both Chowning (2) and Grey (4) submit that the perception of timbre is a very complex subject, and that it is critically dependent upon temporal change. By simulating certain changing properties of a musical instrument tone, the illusion of the timbre of an instrument can be created without duplicating its exact waveform.

Using frequency modulation sound synthesis, Moorer (10) compared resynthesized tones to tones of corresponding original instruments. Among the several instruments compared were the three timbres used in this study (flute, oboe, and clarinet). Moorer found that the synthetic tones were very similar to the originals and that when some white noise was added to simulate the effect of tape recorder hiss, most of the synthetic tones were almost indistinguishable from the originals. Because the present state of computer technology makes possible the synthesis of extremely accurate representations of musical timbres, the stimuli for this study were generated by this method. The Synclavier II is one system which effects accurate sound resynthesis.

To accomplish the resynthesis of a trumpet timbre, a doctoral trumpet major performed numerous trumpet tones of different pitches, attacks and duration. The tones were digitally recorded and stored in the computer. In order to select the best target tone for resynthesis, the various trial tones were played back, judged aurally by the three musically trained judges, and analyzed visually via spectral analysis provided on the computer view-screen. Concert B-flat in the treble staff (466.16 Hz.) was selected as the target tone for resynthesis and its waveform was divided into components, from the initial onset of sound into its steady state. The components of the waveform were then labeled at the exact zero crossing point of the waveform for "framing." A total of thirteen frames were identified and stored. The last frame was looped in order to have a tone capable of infinite length. Decay was added to complete the tonal resynthesis.

Five three-voice ensemble examples (Appendix A) and five four-voice ensemble examples (Appendix B) were selected for inclusion in the observation instrument. The examples were in different keys, tempos, and/or meter signatures. Each of the intonational treatments for examples was then entered into the computer. Those included in-tune (equal temperament), ±12 cents, ±25 cents, and ±50 cents. Twenty-one three-voice examples were grouped together in Part I of the task, and twenty-eight four-voice examples were grouped together in Part II. Examples and treatments were randomly assigned to positions in the stimulus tape using the table of random numbers method.

The examples were recorded directly from the Synclavier II to a TEAC X-10 half-track stereo reel-to-reel tape deck using Ampex 1/4-inch, 1.5 mil precision magnetic tape. The announcement of the number for each example was recorded onto the tape using a Shure SM58 unidirectional dynamic microphone. An interstimulus time of six seconds of 1000 Hz white noise at an amplitude of 20 decibels was placed between items as an aural buffer. The use of white noise of this duration and amplitude level provided the necessary separation of performances in an auditory discrimination task while avoiding an unpleasant or painful distraction for subjects. The possibility of using a more potent distractor, such as segments of recorded orchestral music unrelated to the test items, was evaluated. This option was discarded because of the possibility that such a distractor might confuse subjects about the task, and/or affect the perceptual judgments of subjects on items following the buffer.

The administration of the first pilot instrument took place over two days in the Fall Semester of 1984. Thirty-eight subjects (N=38) were selected on a voluntary basis from undergraduate music majors enrolled at North Texas State University.

Groups consisting of eight to twelve subjects were presented with the task in a room acoustically controlled for external noise interference. Discussions regarding the relative advantages of free-field conditions versus fixed-field conditions (using a headset) have yielded mixed reactions and it seems that preference for one or the other varies with the purpose of the investigation. Sergeant (14, p. 15) found in a test of free-field conditions versus fixed-field conditions that differences in a pitch discrimination task were nonsignificant. The most accurate judgments in terms of absolute scores were observed in controlled, free-field conditions, although it was observed that the headset tests had a slightly smaller standard deviation, which suggested a somewhat higher level of consistency. Several of Sergeant's subjects, however, reported that reception of the stimuli through a headset seemed artificial.

In light of the preceding findings and considerations, the pilot study was conducted in a controlled, free-field environment. Subjects were given printed instructions (Appendix C) which outlined the procedures to be followed in completing the task. They were requested to read the instructions carefully, then ask any questions that might arise. If the subjects had no questions, they were then asked to respond to two recorded trial examples, one of which was considered to be in-tune and one of which was out-of-tune. If the subjects considered an example to be in-tune, they were instructed to mark blank "A" for the appropriate example number on the response form (see Appendix C for sample response format) and wait for the next example to be played. If they considered an example to be out-of-tune, subjects were to mark blank "B" and, on another part of the answer sheet, mark the appropriate blank that identified which voice they thought contained the tuning deviation. Finally, subjects were instructed to mark a blank indicating whether they thought the deviation was sharp or flat.

Following the trial examples, correct responses were given and subjects were again offered an opportunity to ask questions. If there were none, the stimulus tape was played. If questions were raised or the task seemed unclear, further explanation was provided. Subjects were instructed to avoid conversation during the time of administration unless a problem developed which would preclude finishing the task. Such a problem did not occur during any of the sessions. The main portion of the task took twenty-four minutes. A short discussion/reaction period followed each administration in order to obtain criticisms of the task and to solicit suggestions for improvement.

The tape recorder used (TEAC X-10) for playback was the same recorder employed in setting intensity levels on the stimulus tape. Amplitude levels on the recorder were maintained at a constant level during each administration. The speed of the recorder was tested electronically and found to be within specifications for maintaining accurate pitch. The machine was checked before and after each administration because the recorder contained a speed control device. Throughout all procedures, no variation was noted, which ensured that pitch levels were constantly accurate. Other playback equipment included a Technics SU-Z1 stereo integrated amplifier and AVS stereo loudspeakers.

The primary goal of the evaluation of results for the pilot study was to assess the number of correct and incorrect answers according to the established criteria of intonation. An item analysis (Appendix D) was conducted for this purpose. Percentages of "correct" responses were determined by the difficulty indices ($\underline{p}$). Part I (three-voice examples), mean $\underline{p} = .72$; Part II (four-voice examples), mean $\underline{p} = .76$; cumulative mean $\underline{p} = .74$. In other words, there was a 72 percent correspondence of responses with item treatments in Part I of the observation, 76 percent correspondence in the second half, and an overall correspondence of 74 percent.

For three of the seven in-tune items, approximately three-fourths of the subjects responded that they considered the items to be in-tune as indicated in the grouped-item index (Appendix E). For four of the in-tune items, however, the correspondence of responses was much lower, ranging from 37 percent to 53 percent. In view of the discrimination indices, these low percentages of correspondence may indicate that some responses were guesses. Responses in correspondence with tuning deviations of ±12 cents ranged from 16 percent to 95 percent. This wide range of correspondence coupled with some low discrimination indices for a few items (in one case, negative $\underline{D}$) again raised the question of a guess factor. Eighty-two percent of the subjects judged that items containing deviations of ±25 cents were out-of-tune. With the exception of one subject incorrectly answering one item in the ±50 cent category, all items in that category were judged as being out-of-tune.

The Kuder-Richardson Formula 20 (KR20) was used to determine the reliability estimate of the pilot study. The KR20 procedure is based on item statistics and is appropriate for estimating the reliability of a measurement containing dichotomous item responses. Reliability was estimated to be .69 for the cumulative test. The relatively low estimate could have been attributed to the following: (a) the relative simplicity of task (mean $p = .74$) created by the wide differences between mistuning treatments (±12 cents, ±25 cents, ±50 cents); and/or (b) the possibility of guessing as indicated by several low item discrimination indices.

Based upon the item analysis, subjects' criticisms and suggestions, and discussions with faculty advisors, a second pilot study was developed to simplify the task, improve reliability, and establish exacting parameters of mistunings to be used in the main study. A set of thirty-four new examples was constructed in the same manner as before using the same equipment and procedures. Treatments of in-tune, ±9 cents, ±12 cents, ±15 cents, ±18 cents, ± 25 cents, or ±50 cents were assigned to each of the examples. As in the first set of examples, only one voice per example was mistuned.

Subjects for Pilot Two (N=26) consisted of volunteer undergraduate music majors at North Texas State University. The two administrations of Pilot Two again took place in a room controlled for outside noise interference using the same procedures and equipment as in Pilot One.

The subjects' task was simplified by requiring that they only make a judgment of in-tune or out-of-tune for each example played. The charge of specifying which voice contained the tuning deviation and in what direction, sharp or flat, was eliminated. Because responses were limited to judgments of intonation, printed scores of each example were not included as in Pilot One. Data were recorded on five-response optical scanner sheets (Appendix F) on which subjects were asked to mark column 1 for "in-tune" or column 2 for "out-of-tune."

Item analysis was accomplished through the use of a computer program from the North Texas State University Statistical Library (16). Item difficulty (correspondence of responses with treatments of items) and discrimination indices (Appendix G) were again consulted to help in the determination of items or types of items to be included in the main study.

A primary objective of Pilot Two was to establish firm parameters of tuning deviations for use in the main study in order to address the first research problem, that of estimating the point in pitch deviation at which complex sounds were judged to be out-of-tune. To select specific mistunings, data were examined using the Chi-square test. When research data are in frequencies rather than scores and are in discrete categories (either nominal or ordinal), then the Chi-square test is useful for determining the significance of the differences among <u>k</u> independent samples (15, pp. 175, 193). The Chi-square test at the .05 level of significance was used to analyze the results of the second pilot study.

For the three-voice examples, out-of-tune judgments were made significantly more at each progressive 6 cent interval below the ±25 cent deviation category. Those occurred in comparisons for ±9 cent versus ±15 cent deviations (χ^2=11.53), ±12 cents versus ±18 cents (χ^2=37.98), and, ±18 cents versus ±25 cents (χ^2=7.83). There was a significant difference of judgments at a 3 cent interval between ±9 cents versus ±12 cents (χ^2=9.76), but not between ±12 cents versus ±15 cents (χ^2=1.49) nor between ±15 cents versus ±18 cents (χ^2=3.06).

As in the three-voice examples, subjects' responses to the four-voice examples evidenced a noted tendency for significant differences in judgments at progressive 6 cent intervals. Significant differences were observed for ±9 cents versus ±15 cents (χ^2=6.42), ±12 cents versus ±18 cents (χ^2=3.91), and for ±18 cents versus ±25 cents (χ^2=16.54). Also, there was a significant difference for ±9 cents versus ±12 cents (χ^2=20.67), but at none of the other 3 cent interval comparisons: ±12 cents versus ±15 cents (χ^2=1.88), and ±15 cents versus ±18 cents (χ^2=.49). Examples in both the three-voice and four-voice categories which contained deviations of ±25 cents were judged as out-of-tune 90 percent of the time. Mistunings of ±50 cents in any example were judged 100 percent of the time as being out-of-tune.

Based upon the item analyses and results of the two pilot investigations, conditions of in-tune, and mistunings in one voice of ±6 cents, ±12 cents, ±18 cents, ±24 cents, or ±50 cents were selected for stimulus examples for the main study. The decision to use ±24 cents rather than ±25 cents as in the pilot studies was made to maintain the 6 cent interval throughout the majority of conditions. A limited number of items containing ±50 cent deviations were included as reliability checks. These deviations were considered appropriate for addressing the issue of estimating the point in pitch deviation at which out-of-tune judgments are made.

Another of the research problems for the main study was to investigate the effects of mistunings within differential voices. This problem was addressed in Pilot Two in preparation for the the main study. Chi-square analysis conducted regarding differential voices led to the following findings: (a) in the three-voice examples, there was no significant difference (χ^2=6.55) of judgments found, indicating that mistunings in any one particular voice did not effect more out-of-tune responses than in any other voice; but (b) in the four-voice examples, judgments of bad intonation were made significantly less often (χ^2=32.40) when deviations were in voice 1 than in any of the other three voices.

Analysis was also undertaken for sharp versus flat deviations. No significant difference in judgments was found in overall sharp versus flat deviations for both the three-voice and four-voice examples. In the three-voice examples, sharp deviations were detected slightly more often, though not significantly, in voice 1 than in voices 2 or 3. Flat deviations were detected slightly more often, but not significantly, in voice 2 than in voices 1 or 3. In the four-voice examples, sharp deviations were detected significantly more often in voice 3 (χ^2=8.83) than in any other voice. Flat deviations were detected significantly more often (χ^2=29.97) in voices 2 and 4 than in voices 1 and 3. The method of analysis regarding the investigation of possible effects of mistunings within differential voices was determined to be appropriate for use in the main study.

A reliability index of .82 for the second study was derived using Cronbach's Alpha method. This reliability index was an improvement over Pilot One and is considered to be acceptable for group testing (7, p. 398).

Main Study

Results of both pilot studies were expected to provide a basis for the final study, and to point out areas of weakness in the administration and evaluation process. Based upon an assessment of the pilot investigations, it appeared that the method of gathering data would be acceptable for the main study. No major problems were noted in the administration of the second pilot instrument, nor did subjects have difficulty understanding the instructions. The findings of the pilot studies also firmly established specific tuning deviations to be used in the main study to address the first stated research problem: estimation of the point in pitch deviation at which complex sounds are judged to be out-of-tune.

To investigate timbral effects on judged intonation, the second research problem, timbres of contrast were selected. Consequently, the trumpet timbre used in the pilot investigations was dropped in favor of using synthesized flute, oboe, and clarinet timbres in homogeneous and heterogeneous combinations. To prevent the main study from becoming too long and cumbersome, the four-voice examples were eliminated, leaving only three-voice examples.

The process of analysis was also reevaluated in consideration of the results of both pilot studies. Analyses made using the Chi-square test to determine the significance of differences among the independent samples were found to be appropriate for use in the main study.

Materials and Equipment

The flute, oboe, and clarinet timbres used in the main study were produced on a Kurzweil 250 Synthesizer. Like the Synclavier II which was used in the pilot studies, the Kurzweil 250 is an advanced digital sampling keyboard instrument.

Prior to making the stimulus tape for the main study, several trial examples were made using each of the three timbres (flute, oboe, and clarinet) in solo performance and in various ensemble settings. The trial examples were then submitted to a panel of six judges, consisting of applied instrumental faculty members and graduate teaching assistants at Texas Tech University. Three were from the woodwind area, two from the brass area, and one from the percussion area. The members of the panel were asked to make judgments regarding the synthesized timbres relative to characteristic qualities of sound for each. A nine-point Likert-type scale (Appendix H) ranging from "Very Bad" (1) to "Very Good" (9) was used for each trial example. Assessment of the timbres by the six judges are as follows:

flute timbre (solo): 8.17
flute timbre (trio): 8.33
oboe timbre (solo): 6.16
oboe timbre (trio): 6.16
clarinet timbre (solo): 7.50
clarinet timbre (trio): 7.33
mixed timbres (trio--flute, oboe, clarinet): 8.17

Based on the panel's judgments, the synthesized timbres were deemed suitable for the study. While some timbres were judged to be better than others, the general consensus of the panel was that the advantages of absolute control over tuning deviations far outweighed any reservations concerning the timbres.

Examples for the main study were recorded at the Broadway Recording Studios, Lubbock, Texas. To ensure separation of sounds, individual voices in each of the three different timbres were recorded on a different track of the master tape (2" Ampex 456 Grand Master recording tape) with a blank track separating them. A Sound Workshop Series 30 twenty-four track mixing console directed to a Sound Craft SCM 380/760 tape recording machine was used for this process.

Once each individual part had been recorded onto separate tracks, the stimuli examples were constructed by mixing the separate tracks in all nine possible timbral combinations for voices 1, 2, and 3:

(1) flute - flute - flute
(2) oboe - oboe - oboe
(3) clarinet - clarinet - clarinet
(4) flute - oboe - clarinet
(5) flute - clarinet - oboe
(6) oboe - flute - clarinet
(7) oboe - clarinet - flute
(8) clarinet - flute - oboe
(9) clarinet - oboe - flute

Deviation in a particular voice was accomplished by directing the recorded track of the desired voice through an Eventide Harmonizer model H949 during mixing. The Harmonizer is a digital processing device and is capable of extremely accurate pitch control in terms of microcents. Unlike the variable speed control found on many tape recorders which changes the overall pitch of a recording, the Harmonizer can isolate an individual voice and alter its relative pitch without varying the speed of the performance or the pitch of other voices. This allowed the altered voice to be mixed with unchanged voices.

Mixing was done in stereo to simulate the effect of the typical seating arrangement of the three instruments in a small ensemble situation. An Ursa Major 8X32-Mk II unit was used to provide a small amount of reverberation during recording to prevent the examples from having a perceptual flat response, thereby creating the effect of spatial room ambience. Final mastering of the stimulus tapes was done on an Otari 5050 half-track stereo reel-to-reel tape recorder using 1/4" Ampex 456 Grand Master recording tape.

Three musical examples (Appendix I) of four bar phrases each were chosen from those used in the pilot studies. The examples were presented in their original keys and transposed to another key. A total of six differing keys were represented: C, G, D, F, E-flat, and A-flat. These transpositions were selected to provide additional tonal areas while keeping the examples within the practical playing range of the three woodwind timbres of the study. A few individual voices were slightly rewritten from their original form to eliminate voice crossing and/or crucially exposed unisons or octaves. All examples were presented at M.M.=88 for the quarter note.

Two hundred fifty-two intonation/timbral combinations could have been included as items in the study. Based on the results of the pilot investigations, however, the number of examples containing mistunings of ±50 cents and ±24 cents was reduced. This was determined by the magnitude of subjects' judgments of bad intonation for items containing a deviation of ±50 cents and the fact that no statistically significant differences were found between judgments toward items containing either ±25 cent or ±50 cent deviations. After selected eliminations, 146 items remained in the available pool. Two response forms were used with each form containing seventy-three items. The total number of subjects (N=200) yielded a satisfactory number of responses per item for reliable analysis.

An equal number of similar items were assigned to each of the two forms (Appendix J) to ensure equivalency of forms. Within each form, items were arranged in a two-tiered block random fashion to control for order effects. This two-tiered arrangement made it possible to place harder items (as determined in the pilot studies) in positions so that subjects would not encounter them until they were completely comfortable with the task. Items from the first tier were initially assigned positions one through ten within each form. As Sergeant states:

> [Strict] randomization may mean that difficult items occur at the beginning of a test, with the result that a subject has no chance to acclimatize himself to the test before critical judgments are demanded of him. Scores derived from difficult items placed early in the test may show unreliability that even the provision of sample or trial items cannot prevent. In a pitch discrimination test, one is dealing with measurements along a sensory scale and attempting to discover at what point along that scale a subject ceases to be capable of accurate judgment. Thus, the placing of difficult items early in the test might be considered a hazard to test validity (14, p. 15).

Therefore, items determined as most difficult through item analyses of the two pilot studies were placed in the second of the two randomized tiers.

Reliability estimates for the two forms were derived through the computer statistical software package (11) used in item analysis and was a modified KR20 procedure. Form A was estimated at .86 and Form B at .87. According to the literature on research procedures, these levels were considered to be acceptable for group testing (5).

Subjects

The subject sample (N=200) was composed of volunteer undergraduate and graduate music majors at Texas Tech University and Oklahoma State University. Of the total, there were sixty-three freshmen, forty-one sophomores, twenty-nine juniors, thirty-three seniors, and thirty-four graduate students. Represented were all modes of performance concentration areas. Subjects grouped by performance area included vocal (62), keyboard (34), string (19), woodwind (34), brass (32), percussion (16), conducting/ composition (3). Of the subjects, 115 were female and 84 were male. One subject did not indicate gender.

Procedures

Administration of the main study took place during the Fall Semester of 1986 in a manner similar to Pilot Two. Subjects, in small groups, listened to the taped stimuli in a room controlled for external noise distraction. They were asked to respond to each item on the stimulus tape by judging whether the item seemed to them to be in-tune or out-of-tune. Optical scanner forms (Appendix K) were used to gather subjects' responses.

Playback equipment included a ReVox B77 Mk II half-track tape deck, a Luxman L-480 stereo integrated amplifier, and ReVox BR530 stereo speakers. Amplitude was maintained at a constant level for the duration of each period of administration. Playback equipment was checked for accuracy of speed and pitch prior to and after each session.

Analysis of Data

Analyses of obtained data using Chi-square (13) were directed toward arriving at results which would address the three research problems of the main study:

1. Estimation of the point in pitch deviation at which complex sounds were judged to be out-of-tune;
2. Investigation of effects of homogeneous and heterogeneous timbral combinations on judged intonation;
3. Investigation of effects of mistuning within differential voices relative to the judgments examined in Problems One and Two.

Additional analyses not related to any stated research problem were also made. Those analyses compared overall responses of subjects by area of performance concentration, by academic classification, by gender, and by participating schools.

Results of the analyses and discussion are contained in the following chapter.

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CHAPTER IV

RESULTS OF THE MAIN STUDY

The purpose of this study was to determine judgments of trained musicians regarding the intonation of complex tones in the context of synthesized three-part woodwind ensemble performances. Research problems developed for the investigation toward the purpose of determining those judgments of intonation included (1) estimation of the point in pitch deviation at which complex sounds were judged to be out-of-tune, (2) investigation of effects of homogeneous and heterogeneous timbral combinations on judged intonation, and (3) investigation of effects of mistuning within differential voices relative to the judgments examined in problems 1 and 2.

In order to address the issues presented in the three research problems of the main study, the Statistical Analysis System (SAS) computer program which provided Chi-square statistical procedures was employed in the analysis of data. The confidence level for significance of differences in intonational judgments of subjects was set at $p \leq .01$. All analyses were based on the responses of the total subject sample (N=200) and were grouped for presentation with the relevant research problem.

Research Problem One

Tables I-IV represent analyses of data grouped in differing manners to address the problem of estimating the point in pitch deviation at which out-of-tune judgments were made. Table I presents percentages of individuals making the judgment that a perceived pitch treatment was out-of-tune. The percentages are graphically depicted in Figure 1.

TABLE I

PERCENTAGES OF OUT-OF-TUNE RESPONSES
GROUPED BY CENT DEVIATIONS

Cent Deviation	0	±6	±12	±18	±24	±50
Percentage of Out-of-Tune Judgments	.203	.332	.465	.694	.835	.992

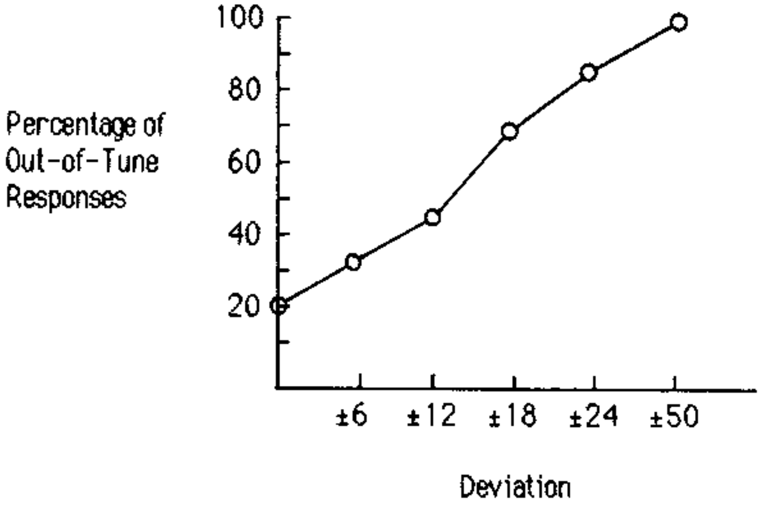

Fig. 1--Out-of-tune responses by deviation

The table indicates that 20 percent of the responses judged that examples were out-of-tune when, in fact, they were in-tune according to the standard of equal temperament. When examples contained mistunings of ±6 cents in any one voice, one-third of the responses were out-of-tune judgments and two-thirds were in-tune judgments. Over half of the responses toward examples which contained deviations of ±12 cents indicated determinations of good intonation. Deviations of ±18 cents effected a majority of out-of-tune responses from subjects.

The Chi-square test was used to compare responses to examples grouped according to specific mistunings to determine if significant differences existed between cent deviation levels. Table II contains those comparisons with their Chi-square values. Points of significance ($\underline{p}<.01$) are indicated by a asterisk.

TABLE II

COMPARISONS OF INTONATIONAL JUDGMENTS BASED UPON GROUPED ITEMS BY CENT DEVIATION

Cent Deviations	χ^2
0 vs. ±6	30.89*
±6 vs. ±12	38.77*
±12 vs. ±18	583.08*
±18 vs. ±24	135.33*
±24 vs. ±50	82.50*

*$\underline{p}<.01$

Significant differences of out-of-tune judgments were found in every comparison between each of the six cent deviation categories and for the comparison of ±24 cents versus ±50 cents. These results indicate that a statistically significant greater number of out-of-tune judgments were progressively made at every ±6 cent deviation interval along a pitch continuum. It took, however, deviations of ±18 cents or greater to effect a majority of out-of-tune responses from subjects. The greatest amount of difference in intonational judgments came at the interval between ±12 cents and ±18 cents.

In an analysis of overall sharp versus flat deviations, out-of-tune responses were made significantly more (χ^2=98.26, $\underline{p}$<.01) for examples containing sharp deviations (66 percent) than for those containing flat deviations (58 percent). In the interest of determining differences in judgments caused by sharp or flat mistunings for specific cent deviations, data were grouped accordingly for further analysis. Table III presents percentages of out-of-tune responses grouped by cent deviation and by the respective direction (sharp or flat) of mistuning. The percentages are graphically depicted in Figure 2.

TABLE III

PERCENTAGES OF OUT-OF-TUNE RESPONSES
GROUPED BY CENT DEVIATION AND
DIRECTION OF MISTUNING

Deviation	+6 vs.-6		+12 vs.-12		+18 vs.-18		+24 vs.-24		+50 vs.-50	
Percentage	.341	.324	.522	.406	.718	.670	.879	.790	.990	.995

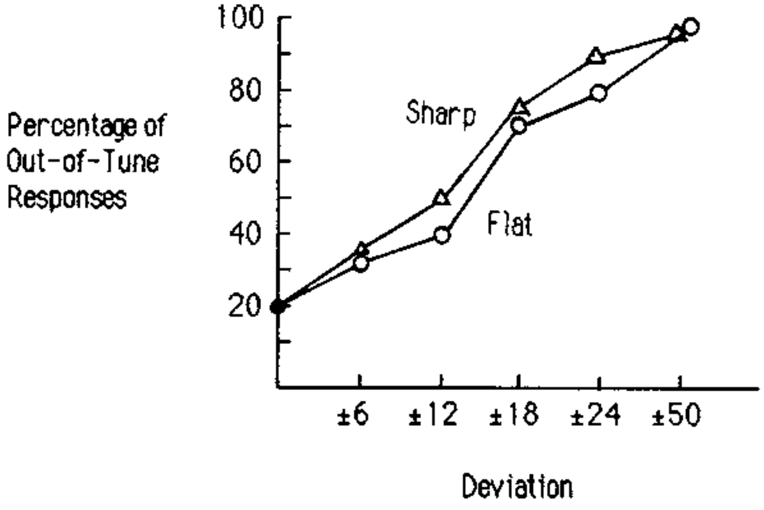

Fig. 2--Sharp versus flat by deviation

As Table III indicates, sharp deviations evoked a higher percentage of judgments of bad intonation at each incremental value of deviation except in the 50 cent category. Table IV presents results of the testing for significant differences in judgments between sharp and flat mistunings for each incremental value of cents deviation.

TABLE IV

COMPARISONS OF INTONATIONAL JUDGMENTS
BASED UPON GROUPED ITEMS BY CENT
AND DIRECTIONAL DEVIATION

Cent Deviations	χ^2
+6 vs. -6	0.12
+12 vs. -12	72.47*
+18 vs. -18	14.73*
+24 vs. -24	25.74*
+50 vs. -50	1.01

*$p < .01$

Table IV indicates that sharp mistunings caused significantly more out-of-tune responses in the 12 cent, 18 cent, and 24 cent deviation categories. No significant difference was found between responses to direction of deviation for 6 cent and 50 cent mistunings.

To summarize the results as they relate to the first research problem, it was found that: (a) twenty percent of the responses toward "in-tune" examples (equal temperament) were judged as poor intonation, (b) a statistically significant greater number of out-of-tune judgments were progressively made at every ±6 cents deviation interval along a pitch continuum, (c) deviations of ±18 cents or greater effected a majority of out-of-tune judgments from subjects, (d) sharp deviations caused significantly more out-of-tune judgments than flat deviations, and (e) sharp deviations which caused significantly more judgments of bad intonation occurred in the 12 cent, 18 cent and 24 cent deviation categories with no significant differences found at either the 6 cent or the 50 cent deviation levels.

Research Problem Two

Data obtained from responses of the subject sample (N=200) were regrouped to investigate timbral effects on judged intonation. Tables V-VIII present the results of those analyses relative to the second research problem. Table V contains percentages of responses identifying mistunings of items grouped according to each timbral combination.

TABLE V

PERCENTAGES OF RESPONSES GROUPED BY TIMBRAL COMBINATION

	Homogeneous			Heterogeneous					
Voice 1	F*	O**	C***	F	F	O	O	C	C
Voice 2	F	O	C	O	C	F	C	F	O
Voice 3	F	O	C	C	O	C	F	O	F
Percentage	.567	.612	.667	.529	.645	.677	.581	.694	.577

*Flute **Oboe ***Clarinet

Table V indicates that the flute-oboe-clarinet combination resulted in the lowest percentage of out-of-tune responses. Interestingly, this is the most common voicing (flute=voice 1, oboe=voice 2, clarinet=voice 3) of parts in the literature for this particular timbral combination. The greatest percentage of out-of-tune responses was found in the clarinet-flute-oboe combination.

For homogeneous timbral combinations, the flute trio effected the lowest percentage of out-of-tune judgments, whereas the clarinet trio resulted in the highest percentage. To determine if significant differences in judgments relative to timbral combinations existed, comparisons of the responses grouped by the various timbral arrangements were made. The comparisons were of homogeneous combinations are presented in Table VI.

TABLE VI

COMPARISONS OF RESPONSES GROUPED BY HOMOGENEOUS TIMBRAL COMBINATIONS

Timbral Combination	χ^2
FFF vs. OOO	7.08*
FFF vs. CCC	35.95*
OOO vs. CCC	11.26*

*$p<.01$

As noted in Table VI, the various homogeneous timbral combinations demonstrated significant differences in responses toward perceived intonation. The combination of three clarinet timbres resulted in a significantly greater number of judgments of poor intonation than did the other two homogeneous combinations. The combination of three flute timbres generated the least number of out-of-tune responses within the homogeneous category.

An analysis for significant differences in judgments based on timbral considerations was conducted for heterogeneous combinations. All six possible heterogeneous timbral combinations using the three different timbres were included in the study. The results of heterogeneous combination comparisons are presented in Table VII.

TABLE VII

COMPARISONS OF RESPONSES GROUPED BY HETEROGENEOUS TIMBRAL COMBINATIONS

Timbral Combination	χ^2
FOC vs. FCO	44.75*
FOC vs. OFC	75.61*

TABLE VII--Continued

Timbral Combination	χ^2
FOC vs. OCF	8.38*
FOC vs. CFO	92.67*
FOC vs. COF	7.46*
FCO vs. OFC	3.43
FCO vs. OCF	13.27*
FCO vs. CFO	8.22*
FCO vs. COF	15.29*
OFC vs. OCF	30.69*
OFC vs. CFO	1.11
OFC vs. COF	33.54*
OCF vs. CFO	42.67*
OCF vs. COF	0.04
CFO vs. COF	45.97*

*$\underline{p}<.01$

Of the heterogeneous timbral combinations, only three comparisons yielded nonsignificant differences. The combination of flute-oboe-clarinet resulted in significantly fewer judgments of poor intonation than any other combination. This was followed in order by the combinations of clarinet-flute-oboe and oboe-flute-clarinet. No significant difference was found between the last two timbral combinations. The remaining combinations, progressing toward greater percentages of out-of-tune responses, were flute-clarinet-oboe, oboe-flute-clarinet, and clarinet-flute-oboe.

The last set of results indicate that mistunings in the timbral combination of flute-oboe-clarinet were tolerated significantly more, (or detected less) by subjects than for any other combination. All other heterogeneous combinations caused progressively more judgments of poor intonation. Mistunings in the timbral combination of clarinet-flute-oboe were judged to be out-of-tune more than any other combination.

Following the segregated analyses of intonational responses for homogeneous and heterogeneous combinations, the judgments within the two categories were compared with each other according to timbral arrangements. Table VIII contains the Chi-square values of differences in judgments for homogeneous versus heterogeneous timbral combinations.

TABLE VIII

COMPARISONS OF RESPONSES GROUPED AS HOMOGENEOUS VERSUS HETEROGENEOUS TIMBRAL COMBINATIONS

Timbral Combination	χ^2
FFF vs. FOC	4.96
FFF vs. FCO	21.43*
FFF vs. OFC	43.09*
FFF vs. OCF	0.61
FFF vs. CFO	56.77*
FFF vs. COF	0.32
OOO vs. FOC	23.30*
OOO vs. FCO	4.07
OOO vs. OFC	15.46*
OOO vs. OCF	3.00
OOO vs. CFO	24.50*
OOO vs. COF	4.03
CCC vs. FOC	65.97*
CCC vs. FCO	1.77
CCC vs. OFC	0.36
CCC vs. OCF	25.17*
CCC vs. CFO	2.73
CCC vs. COF	27.79*

*$\underline{p}$<.01

One-half of the comparisons of responses grouped as homogeneous versus heterogeneous indicated significant differences in judgments of intonation. Those differences, however, evidenced no particular pattern related to whether homogeneous combinations were any more or less present within examples for which judgments of poor intonation were made than were heterogeneous combinations. As stated before, the heterogeneous timbral combination of clarinet-flute-oboe generated the highest percentage of out-of-tune responses. The heterogeneous category also contained the flute-oboe-clarinet combination, which generated the lowest percentage of judgments of poor intonation.

To summarize the results of the last set of analyses related to research problem two, it was found that: (a) a timbral effect on judged intonation had taken place, (b) for homogeneous combinations in the study, the combination of three clarinet timbres effected the highest percentage of out-of-tune responses, whereas the combination of three flute timbres resulted in the lowest percentage of out-of-tune judgments, and (c) for heterogeneous combinations in the study, as well as in overall comparisons between homogeneous and heterogeneous combinations, the clarinet-flute-oboe combination yielded the greatest percentage of judgments of poor intontation, while the flute-oboe-clarinet combination yielded the lowest percentage of out-of-tune judgments.

Research Problem Three

The third research problem was to determine effects of mistuning within differential voices relative to the judgments of intonation investigated in the two previous research problems dealing with pitch and timbre, respectively. Tables IX through XVII present information derived from analyses of subjects' (N=200) responses pertaining to differential voices.

The first sub-set of analyses conducted for research problem three was directed toward the effect of pitch deviation within differential voices. Percentages of out-of-tune responses grouped according to voice and corresponding absolute cent deviation are presented in Table IX. For example, 1±6 means that voice 1 contained mistunings of 6 cents (sharp and flat combined).

TABLE IX

PERCENTAGES OF OUT-OF-TUNE RESPONSES
GROUPED BY VOICE AND CENTS DEVIATION

Voice and Deviation	1±6	1±12	1±18	1±24	1±50
% of Responses	.311	.434	.672	.869	.995
Voice and Deviation	2±6	2±12	2±18	2±24	2±50
% of Responses	.330	.421	.680	.847	.995
Voice and Deviation	3±6	3±12	3±18	3±24	3±50
% of Responses	.340	.498	.712	.786	.979

By comparing the figures in Table IX grouped by voices (horizontally), it can be seen that percentages of correspondent assessments toward mistunings increased for every deviation category. Data was grouped by voice for comparisons between mistunings to test for significance of differences in judgments between the cent deviation categories. Results of the comparisons are found in Table X.

TABLE X

COMPARISONS OF RESPONSES BETWEEN
CENT DEVIATIONS GROUPED BY VOICE

Voice and Deviation	χ^2
1±0 vs. 1±6	6.21
1±6 vs. 1±12	5.89
1±0 vs. 1±12	139.71*
1±12 vs. 1±18	207.16*
1±18 vs. 1±24	88.24*
1±24 vs. 2±50	28.53*
2±0 vs. 2±6	14.79*
2±6 vs. 2±12	6.19
2±6 vs. 2±18	95.81*
2±12 vs. 2±18	245.02*
2±18 vs. 2±24	62.23*
2±24 vs. 2±50	29.75*
3±0 vs. 3±6	23.14*
3±6 vs. 3±12	25.80*
3±12 vs. 3±18	170.78*
3±18 vs. 3±24	12.48*
3±24 vs. 3±50	20.46*

*$\underline{p}<.01$

The results above indicate that differences in judgments between cent deviations, grouped according to individual voices, were significant in all but three instances. Those results which evidenced no significant differences suggest that in order for subjects to have made significantly more judgments of poor intonation in those three cases, the amount of deviation would have had to exceed six cents. Those comparisons evidencing no statistical differences between intonational treatments were found in voice 1 comparisons of 0 versus ±6 cents deviation and ±6 cents versus ±12 cents. Also, no significant difference of intonational judgments was found in the voice 2 comparison of ±6 cents versus ±12 cents. Based on these findings, it appears that an effect of pitch mistuning within differential voices was present, but minimal. Thus, it was concluded that pitch deviation was the main effect regarding differences in judgments of intonation regardless of which voice contained the pitch deviation.

Analysis of data grouped according to cent deviations (vertical grouping of Table IX) was undertaken next to determine if significant differences existed between judgments corresponding to which voice contained deviations. In observing the percentages of Table IX grouped vertically by cent deviations, no apparent pattern can be found in the specific ordering of voices in terms of highest to lowest percentage of out-of-tune responses for any particular mistuning. For ±6 cent deviations, the order for voices from highest to lowest percentage of out-of-tune responses was 3-2-1; for ±12 cent mistunings, the order was 3-1-2; for ±18 cent deviations, it was 3-2-1; the order for ±24 cent mistunings was 1-2-3; and for ±50 cent deviations, the percentages for voices 1 and 2 were identical followed by voice 3. Table XI presents results of the comparisons between voices with the data grouped by cent deviations.

TABLE XI

COMPARISONS OF RESPONSES BETWEEN VOICES GROUPED BY CENTS DEVIATION

Voice and Deviation	χ^2
1±6 vs. 2±6	0.07
1±6 vs. 3±6	0.23
2±6 vs. 3±6	0.04
1±12 vs. 2±12	0.66
1±12 vs. 3±12	14.56*
2±12 vs. 3±12	21.93*
1±18 vs. 2±18	0.24
1±18 vs. 3±18	6.75*
2±18 vs. 3±18	4.44
1±24 vs. 2±24	1.33
1±24 vs. 3±24	14.65*
2±24 vs. 3±24	7.29*
1±50 vs. 2±50	0.01
1±50 vs. 3±50	1.51
2±50 vs. 3±50	1.52

*$p < .01$

In Table XI, those results which reflect significant differences in out-of-tune responses indicate that a greater effect of pitch deviation within differential voices was present within categories of grouped deviation levels, whereas limited effects were found for comparisons between categories of cent deviation levels presented in Table X. As Table XI indicates, no significant difference in judgments was found in comparisons between voices 1 and 2 for all cent deviation categories. Significant differences in judgments were, however, found in all other two-voice comparisons at some point.

Comparisons of out-of-tune responses for sharp and flat deviations were made similar to the analysis reported in Table IV, but were further grouped by voice. Table XII contains percentages of out-of-tune responses grouped by voice and directional cents deviation.

TABLE XII

PERCENTAGES OF OUT-OF-TUNE RESPONSES
GROUPED BY VOICE AND CENTS DEVIATION

Deviation	+6 vs.-6		+12 vs.-12		+18 vs.-18		+24 vs.-24		+50 vs.-50	
Voice 1 %	.311	---	.470	.398	.730	.615	.814	.925	.991	1.00
Voice 2 %	.404	.255	.473	.370	.677	.683	.895	.796	1.00	.989
Voice 3 %	.309	.354	.543	.452	.713	.711	.932	.643	.979	---

The percentages in Table XII indicate that responses to mistunings varied relative to sharp versus flat direction with no particular pattern noted. For example, within the 24 cent category, judgments of poor intonation were made more often for flat mistunings in voice 1 than for sharp mistunings (horizontal comparison); but for voices 2 and 3, out-of-tune responses were made more often when mistunings were sharp. In the same 24 cent category, the order for sharp deviations from highest to lowest percentage of out-of-tune responses according to voice (vertical comparison) is 3-2-1, whereas for flat deviations, the order is 1-2-3.

Sharp versus flat data (horizontal comparisons) for each deviation level grouped by voice were tested for significance of differences in out-of-tune responses. Results of those comparisons appear contained in Table XIII.

TABLE XIII

COMPARISONS OF RESPONSES FOR SHARP VERSUS FLAT ACCORDING TO CENT DEVIATIONS GROUPED BY VOICE

Voice and Deviation	χ^2
1+6 vs. 1-6	no information available
1+12 vs. 1-12	9.26*
1+18 vs. 1-18	27.08*
1+24 vs. 1-24	16.64*
1+50 vs. 1-50	1.01
2+6 vs. 2-6	4.72
2+12 vs. 2-12	20.01*
2+18 vs. 2-18	0.08
2+24 vs. 2-24	11.56*
2+50 vs. 2-50	1.01
3+6 vs. 3-6	0.62
3+12 vs. 3-12	15.04*
3+18 vs. 3-18	0.00
3+24 vs. 3-24	71.73*
3+50 vs. 3-50	no information available

*$p < .01$

The figures in Table XIII indicate that several comparisons of sharp versus flat for different deviation categories evidenced an effect of direction of mistuning within differential voices. These findings can be compared to the results of the overall sharp versus flat analysis presented in Table IV. It should be recalled that in overall sharp versus flat comparisons (grouped by cent deviation), sharp mistunings effected significantly more judgments of poor intonation in the 12 cent, 18 cent, and 24 cent deviation categories. For the analysis presented in Table XIII above, all comparisons in the 12 cent deviation category indicate that sharp deviations prompted significantly more out-of-tune responses for all voices, thereby demonstrating no effect of direction of mistuning within differential voices.

For the 18 cent deviation category, however, the only point of significant difference in out-of-tune responses was found for voice 1. Therefore, it can be said that the difference previously found for this category of mistuning is a result of an effect of direction of mistuning within differential voices. Mistunings in voice 1 of 18 cents sharp were singularly responsible for the significant difference in out-of-tune judgments for that deviation category found in the overall sharp versus flat analysis.

The deviation category of 24 cents yielded even more varied results. Comparisons of 24 cents sharp versus 24 cents flat in voices 2 and 3 concurred with previous findings relative to research problem one (sharp = significantly more out-of-tune responses). Results, however, were reversed for voice 1, with flat mistunings of 24 cents effecting more judgments of poor intonation than sharp mistunings of 24 cents. It can be concluded that an effect of direction of mistuning within differential voices was present in the 24 cent deviation category. The effect of direction of mistuning found in that one instance, however, was not great enough to supercede the overall effect of pitch deviation.

A summary of findings on effects of pitch deviation within differential voices is as follows: (a) limited effects of pitch deviation within differential voices were found between cent deviation categories; (b) a greater effect of pitch deviation within differential voices was found, although still somewhat limited, within the different cent deviation categories; (c) no effects of direction of mistuning within differential voices were found in the 6 cent, 12 cent and 50 cent deviation categories; and (d) effects of direction of mistuning within differential voices were found in the 18 cent and 24 cent deviation categories.

In addition to the investigation of effects on judged intonation of pitch mistuning within differential voices, research problem three was concerned with the investigation of effects of timbre within differential voices. A second sub-set of analyses was directed toward the effects of timbre within differential voices relative to judged intonation. Table XIV presents percentages of responses identifying mistunings present in each respective timbre and voice for examples of homogeneous timbral combination. The percentages are graphically depicted in Figure 3.

TABLE XIV

PERCENTAGES OF RESPONSES RELATED TO EXAMPLES
OF HOMOGENEOUS TIMBRAL COMBINATIONS
ACCORDING TO INDIVIDUAL TIMBRES
GROUPED BY VOICE

Timbre and Voice	F1	O1	C1	F2	O2	C2	F3	O3	C3
Percentage	.596	.643	.752	.430	.732	.601	.630	.603	.639

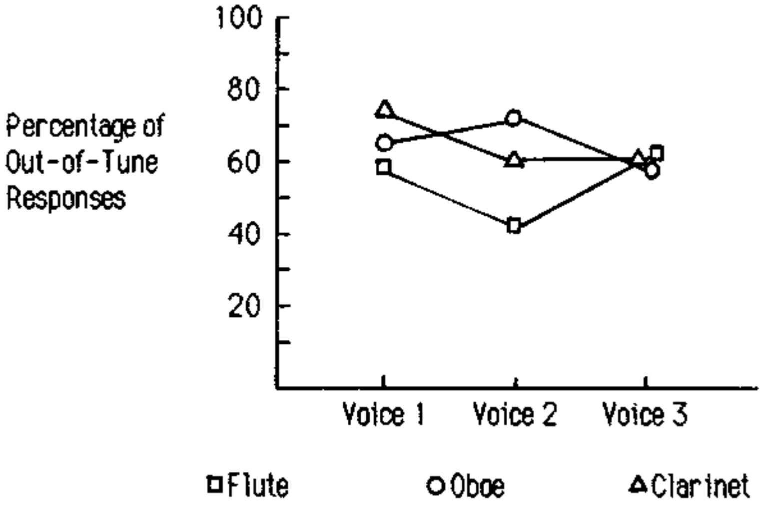

Fig. 3--Out-of-tune responses by timbre and voice: homogeneous

As can be seen in Table XIV, when a mistuning was present in voice 1 of a homogeneous timbral combination, the clarinet timbre was associated with the highest percentage of out-of-tune responses, followed by the oboe timbre, and the flute timbre. Voice 2 yielded a different ordering of highest to lowest percentages of judgments of poor intonation (oboe-clarinet-flute) as did voice 3 (clarinet-flute-oboe). To determine if significant differences in intonational judgments existed relative to possible effects of timbre, data were grouped according to voice for comparisons between timbres. Those results are presented in Table XV.

TABLE XV

COMPARISONS OF RESPONSES BETWEEN TIMBRES FROM HOMOGENEOUS COMBINATIONS GROUPED BY VOICE

Timbre and Voice	χ^2
F1 vs. O1	3.46
F1 vs. C1	38.24*
O1 vs. C1	16.89*

TABLE XV--Continued

Timbre and Voice	χ^2
F2 vs. O2	92.83*
F2 vs. C2	27.22*
O2 vs. C2	23.12*
F3 vs. O3	0.83
F3 vs. C3	0.06
O3 vs. C3	1.39

*$p < .01$

The analysis contained in Table XV indicates that significant differences found in earlier comparisons of homogeneous timbral combinations were also found to exist relative to differential voices. While none of the comparisons for voice 3 indicated any significant differences in judgments, all comparisons for voice 2 were found to contain significant differences in judgments. The oboe timbre was associated with the greatest number of out-of-tune responses followed in order by the clarinet and flute timbres. Two of the three comparisons within voice 1 also evidenced significant differences in judgments. The clarinet timbre was matched with judgments of poor intonation significantly more than either the flute or oboe timbres. No statistically significant difference in judgments was found between the flute and oboe timbres. An effect of timbre within differential voices relative to judged intonation was apparently present for specific homogeneous timbral combinations.

The same types of comparisons made for homogeneous combinations investigating possible effects of timbre within differential voices were also made for heterogeneous combinations. Table XVI presents percentages of responses identifying mistunings present in each respective timbre and voice for examples of heterogeneous timbral combinations. The percentages are graphically depicted in Figure 4.

TABLE XVI

PERCENTAGES OF RESPONSES RELATED TO EXAMPLES
OF HETEROGENEOUS TIMBRAL COMBINATIONS
ACCORDING TO INDIVIDUAL TIMBRES
GROUPED BY VOICE

Timbre and Voice	F1	O1	C1	F2	O2	C2	F3	O3	C3
Percentage	.636	.624	.666	.696	.474	.614	.678	.611	.627

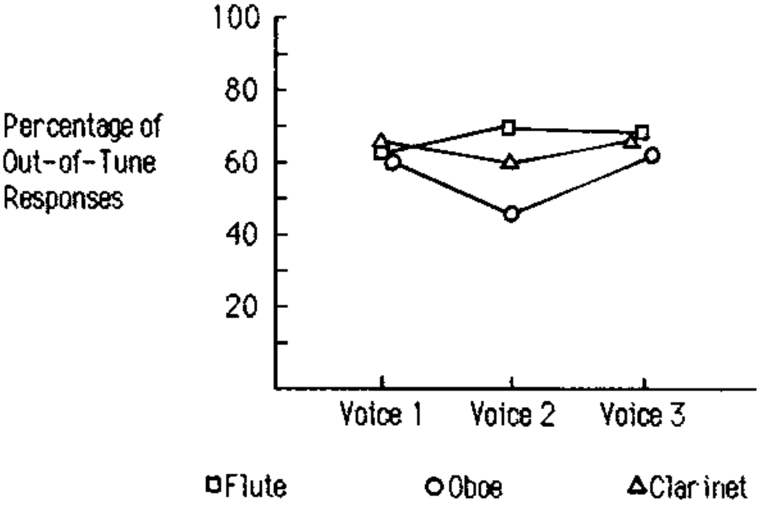

Fig. 4--Out-of-tune responses by timbre and voice: heterogeneous

As for examples of homogeneous timbral combinations, comparisons between timbres from heterogeneous timbral combinations grouped by voice were tested for possible significant differences in out-of-tune responses. Table XVII contains those results.

TABLE XVII

COMPARISONS OF RESPONSES BETWEEN TIMBRES FROM HETEROGENEOUS COMBINATIONS GROUPED BY VOICE

Timbre and Voice	χ^2
F1 vs. O1	0.38
F1 vs. C1	2.39
O1 vs. C1	4.29
F2 vs. O2	102.00*
F2 vs. C2	15.16*
O2 vs. C2	39.27*
F3 vs. O3	9.60*
F3 vs. C3	5.65
O3 vs. C3	0.63

*$\underline{p}$<.01

Within all six heterogeneous timbral combinations, no significant differences of intonational judgments were found between any individual timbres for voice 1, although the clarinet timbre indicated a slightly higher percentage of out-of-tune responses. This was followed by out-of-tune responses for the flute and oboe timbres respectively. No effects of timbre were found for voice 1.

Voice 2 evidenced the widest range of significant differences of judgments in comparisons between timbres according to voice. The flute timbre significantly effected the greatest number of out-of-tune responses followed, in order, by the clarinet and oboe timbres. Each of the timbral comparisons for voice 2 yielded significant differences of judgments, indicating a strong effect of timbre in voice 2.

Only one comparison within voice 3 indicated a significant difference of out-of-tune responses in the comparison between the flute and oboe timbres. The flute timbre had prompted significantly more judgments of poor intonation than the oboe timbre but not more than the clarinet timbre. The oboe and clarinet timbres in voice 3 evidenced no significant difference of judgments. A limited degree of effect of timbre was found for voice 3. Similar to the findings of the analyses presented in Tables IX-XIII regarding effects of pitch deviation within differential voices, no specific pattern was observed which was linked to timbral effects within differential voices.

To summarize the results of the analyses regarding investigation of the effects of timbre within differential voices, it was found that: (a) for homogeneous timbral combinations, an effect of timbre was present for voices 1 and 2 but not for voice 3; (b) for heterogeneous timbral combinations, no effect of timbre was found for voice 1, whereas a strong timbral effect was found for voice 2 and a limited timbral effect was found for voice 3; and (c) no specific pattern of responses was observed relative to any effects of timbre within differential voices.

Additional Analyses

Four additional analyses were conducted relative to demographical information provided by subjects in the study. The review of literature and results of the pilot studies raised the issues of (a) differences in intonational judgments based on area of performance concentration of subjects; (b) differences in intonational judgments attributable to academic classification of subjects; (c) differences in intonational judgments relative to gender of subjects; and (d) differences in intonational judgments of subjects associated with the school attended.

Questions were posed concerning the judgments of musicians whose area of performance concentration was similar to the timbres used in the study or whose area of performance concentration differed from the timbres used. Consideration was given to the possibility that musically trained subjects' judgments may differ when hearing musical examples from an area with which they may not normally perform. For this reason, determination of the area of performance concentration of subjects was made. Included were the areas of vocal (N=62), keyboard (N=34), string (N=19), woodwind (N=34), brass (N=32), percussion (N=16), and, other (conducting/composition N=3). Percentages of overall responses correspondent to the criteria of intonation (responses matching intonational treatments of examples) are listed below for each group in order from highest to lowest:

1. Other (.763)
2. Brass (.665)
3. String (.645)
4. Keyboard (.619)
5. Woodwind (.617)
6. Vocal (.602)
7. Percussion (.591)

The result that the category of "other" had the highest percentage of correspondence with the criteria of intonation may have been influenced by the small number of subjects (N=3) in the category and/or by the fact that all three were graduate students. The relative placement of the woodwind category (fifth) might suggest one of two things: (a) that familiarity of context does not make a difference in judgments of intonation, or (b) that persons in that category may have a different concept of intonation from that used in the study than subjects in the other performance area categories. The first of the two suggestions appears more likely to be the case. Judgments of intonation appeared to be based more on the actual intonation of pitches within a context than on familiarity with the context.

Comparisons of overall responses were made between each of the performance area groups to test for any significant differences of generalized intonational judgments. Table XVIII presents the results of those comparisons.

TABLE XVIII

COMPARISONS OF RESPONSES GROUPED BY AREA OF PERFORMANCE CONCENTRATION OF SUBJECTS

Area of Performance Concentration	χ^2
Vocal vs. Keyboard	1.90
Vocal vs. String	8.03*
Vocal vs. Woodwind	1.50
Vocal vs. Brass	26.01*
Vocal vs. Percussion	0.45
Vocal vs. Other	23.20*
Keyboard vs. String	2.55
Keyboard vs. Woodwind	0.02
Keyboard vs. Brass	10.93*
Keyboard vs. Percussion	2.56
Keyboard vs. Other	17.93*
String vs. Woodwind	3.00

TABLE XVIII--Continued

Area of Performance Concentration	χ^2
String vs. Brass	1.65
String vs. Percussion	7.73*
String vs. Other	11.44*
Woodwind vs. Brass	12.14*
Woodwind vs. Percussion	2.32
Woodwind vs. Other	17.92*
Brass vs. Percussion	18.76*
Brass vs. Other	9.05*
Percussion vs. Other	23.50*

*$p<.01$

It is evident from the figures in Table XVIII that several instances of significant differences in intonational judgments between performance concentration areas existed. The order of performance area groups is listed below from the highest to lowest percentage of correspondent judgments relative to intonational treatments of examples. The groups are also bracketed according to nonsignificant differences of intonational judgments.

1. Other
2. Brass
3. String
4. Keyboard
5. Woodwind
6. Vocal
7. Percussion

Consideration was also given to the possibility that musically trained subjects' judgments of intonation might differ according to academic classification. Subjects (N=200) grouped according to academic classification included freshmen (63), sophomores (41), juniors (29), seniors (33), and graduate students (34). Overall responses correspondent to the criteria of intonation are listed below in order of highest to lowest percentages according to classification:

1. Graduate (.683)
2. Junior (.645)
3. Senior (.638)
4. Sophomore (.611)
5. Freshman (.580)

The only exception to absolute ordering associating percentages of intonational judgment correspondence with classification was that juniors and seniors were reversed. As can be seen, however, the percentage difference was only very slight. Chi-square was used to determine if significant differences in intonational judgments existed according to academic classification, results of which are presented in Table XIX.

TABLE XIX

COMPARISONS OF RESPONSES GROUPED BY ACADEMIC CLASSIFICATION OF SUBJECTS

Academic Classification	χ^2
Freshman vs. Sophomore	7.16*
Freshman vs. Junior	24.88*
Freshman vs. Senior	21.34*
Freshman vs. Graduate	71.63*
Sophomore vs. Junior	5.79
Sophomore vs. Senior	3.92
Sophomore vs. Graduate	29.63*

TABLE XIX--Continued

Academic Classification	χ^2
Junior vs. Senior	0.24
Junior vs. Graduate	7.27*
Senior vs. Graduate	11.04*

*p<.01

As seen in Table XIX, comparisons of freshmen with all other academic classifications yielded significant differences of intonational judgments. Freshmen were significantly less "accurate" in their judgments according to the criteria of intonation used in the study. Comparisons of sophomores, juniors, and seniors showed no significant differences of generalized intonational judgment between or among those classifications. Comparisons of graduate level subjects with all other academic levels produced significant differences in overall intonational judgments. It appeared that academic classification contributed slightly, though not always significantly, to the ordering of those classifications relative to the intonational criteria of the study.

Comparison of overall intonational judgments according to gender indicated no significant difference (χ^2=1.73), with males (.630) obtaining only a slightly higher percentage of correspondence than females (.615). A comparison between subjects' intonational judgments according to institution of enrollment also indicated no significant difference (χ^2=1.07), although one institution did have a slightly higher percentage (.629) of concurrence with the criteria of intonation than the other (.621).

In summary, findings for research problem one were that (a) twenty percent of the subjects' responses to "in-tune" examples were out-of-tune determinations, (b) a statistically significant greater number of out-of-tune judgments were progressively made at every ±6 cents deviation interval along a pitch continuum, (c) deviations of ±18 cents or greater effected a majority of out-of-tune tune judgments from subjects, (d) sharp deviations caused significantly more out-of-tune judgments than flat deviations.

General findings relative to research problem two were that (a) a limited degree of timbral effect on judged intonation was present, and (b) the degree of effect varied depending upon particular timbral combinations.

Findings for research problem three can be summarized as follows: (a) an effect on judged intonation of pitch deviation within differential voices was found in some comparisons of intonational judgments but not in others, (b) an effect on judged intonation of timbre within differential voices was found in some comparisons of intonational judgments but not in others, and (c) the effect on judged intonation of pitch deviation within differential voices was greater than the effect of timbre within differential voices.

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CHAPTER V

SUMMARY AND CONCLUSIONS

Purpose and Rationale

The purpose of this study was to determine judgments of trained musicians regarding acceptable intonation of complex tones in a musical context using synthesized three-part woodwind ensemble performances. The primary objective of the study was to estimate the point in pitch deviation which would result in out-of-tune judgments of musical performances. Secondly, the investigation was concerned with timbral effects on judgments of intonation. Finally, the study sought to determine effects of mistuning within differential voices relative to intonational judgments.

The rationale for the study grew out of research dealing with pitch perception and intonation. While previous studies have provided a valuable base toward a better understanding of perceived pitch, many were limited in scope and contained results which were sometimes inconclusive and often contradictory. The review of literature raised the following concerns: (a) few studies addressed the issue of estimating the point in pitch deviation at which a musical performance is judged out-of-tune; (b) sound sources used as stimuli were not always typical of true musical instruments; (c) few investigations observed effects of mistuning within differential voices; and (d) presentations of tones, pitches, and melodic or harmonic material were not always characteristic of a common practice musical setting. In light of these concerns, further investigation of intonational judgments in the context of musical performances was deemed necessary.

Research Problems

Research problems included in the study were:

1. Estimation of the point in pitch deviation at which complex sounds were judged to be out-of-tune;
2. Investigation of effects of homogeneous and heterogeneous timbral combinations on judged intonation;
3. Investigation of effects of mistuning within differential voices relative to the judgments examined in problems one and two.

Methodology

Two pilot studies were conducted to (a) develop an acceptable method of gathering subjects' intonational response data, (b) establish parameters of variables to be used in the main study, and (c) define an appropriate method of analysis for determining if significant differences in intonational judgments existed relative to the variables of the study.

The method of gathering intonational response data in the second pilot study was found to be suitable for use in the main study. With the findings of both pilot studies serving as a guide, specific increments of tuning deviations were selected to address research problem one. In-tune examples and examples containing mistunings of ±6 cents, ±12 cents, ±18 cents, ±24, cents and ±50 cents were included. The use of three timbres (flute, oboe, and clarinet) in various homogeneous and heterogeneous combinations was considered to be propitious in addressing the issues presented by research problems two and three. Likewise, the use of Chi-Square for analyses of data was found to be appropriate for use in the main study.

Two hundred volunteer undergraduate and graduate music majors from two universities participated in the main study. Subjects, in small groups, were presented with one of two recorded sets (seventy-three examples per set) of synthesized three-part woodwind ensemble performances. Subjects were asked to judge each example as in-tune or out-of-tune.

Analyses of data using Chi-square ($\underline{p}$<.01) were undertaken to address each of the three research problems to determine if differences in judgments of intonation existed relative to (1) a particular category of cent deviation, (2) timbral combinations, and (3) deviation of pitch within differential voices. Additional analyses were conducted to determine if differences in intonational judgments existed according to (a) area of performance concentration of subjects, (b) academic classification of subjects, (c) gender of subjects, and (d) institution the subjects attended. The last set of analyses were intended only to provide additional information and were not related to any stated research problem.

Findings of the Main Study

Research Problem One

The first research problem was the estimation of the point in pitch deviation at which complex sounds were judged to be out-of-tune in a musical performance. Comparisons of intonational judgments of examples were first made by grouping data according to specific cent deviation categories. Results indicated that deviations had to reach ±18 cents before a majority (69 percent) of out-of-tune responses were made. In-tune judgments continued to be made 16 percent of the time to mistunings of ±24 cents. Deviations of ±50 cents effected a 99 percent rate of judgment of poor intonation. Fifty-three percent of the responses toward deviations of ±12 cents and 67 percent of the responses toward deviations of ± 6 cents were judgments of acceptable intonation. Of particular note was that examples which were in-tune according to equal temperament were judged as out-of-tune in 20 percent of the cases. This suggests that a certain percentage of auditors have a concept of acceptable intonation which differs from the standard of equal temperament.

Previous research concerning the intonation of performers has indicated a general lack of conformity to any one tuning system (7, 18, 20, 21). Few studies, however, have investigated perceived intonation of musical performance by listeners not concurrently performing. Two investigations (17, 23) included in the last category found that deviations of intonation within a musical context may be preferred to the same or greater extent than the theoretically correct intonation of equal temperament. One of those studies was by Rasch (23) who concluded that mistunings of up to 10.4 cents between two instrumental voices were judged as being more acceptable than equal-tempered intonation between the voices. Another study by Madsen and Geringer (17) suggested that deviations in intonation could be as great as 50 cents between two voices in a musical context and, in some instances, be preferred to equal-tempered intonation.

It has long been noted that equal temperament is not a preferred standard of intonation to a percentage of musicians. Rasch's study indicated that, on a scale of one to seven with seven being the highest degree of acceptance, equal-tempered examples achieved a mean rating of only four.

Similar results were found in the present study. Even though 20 percent of the responses to "in-tune" examples were judged out-of-tune, the results of this study indicated that a statistically greater number of out-of-tune responses were made for every progressive ±6 cent deviation category beyond the "in-tune" category, placing this finding in conflict with the two previously cited studies. This conflict in findings could be attributed to one or many things including, but not limited to, (a) differences in sound sources, (b) differences in timbral combinations, (c) differences in musical material, (d) differences in specific pitch deviations, (e) differences in presentation of stimuli, and/or (f) differences in the methods of evaluating results.

Data were regrouped to determine if the direction of pitch mistuning (sharp or flat) had an effect on the judgments previously found. Analyses of responses grouped as sharp versus flat deviations revealed that significantly more out-of-tune judgments were made for examples containing sharp deviations (66 percent) than for examples containing flat deviations (58 percent). It follows that there was a 34 percent rate of in-tune response to examples which contained sharp deviations and a 42 percent rate of in-tune response to examples that contained flat deviations. Apparently, sharp mistunings were tolerated less or detected more often than flat mistunings.

The finding that sharp deviations effected a significantly greater number of judgments of poor intonation than flat deviations is contrary to some literature offering the opposite conclusions (6, 15, 16, 17, 30, 31). Tunks (27) and Vos (28), however, found in separate studies that direction of pitch mistuning had no statistically significant effect on judged intonation. The same possibilities of explanation which were posed for the varied conclusions of investigations of pitch deviation may also account for the different findings regarding direction of pitch deviation.

Research Problem Two

The second research problem was to investigate timbral effects on the judgments of intonation examined in research problem one. Timbral effects within homogeneous combinations were first analyzed. Comparisons of intonational responses were made with data grouped according to timbral combinations. Significant differences were found in all comparisons between homogeneous timbral combinations, indicating that timbre had an effect on judged intonation within this category. A significantly greater number of judgments of poor intonation (67 percent) were made for examples using three clarinet timbres than for the other two homogeneous groupings. The least number of out-of-tune responses (57 percent) was made for examples using three flute timbres. These findings suggest that of the homogeneous combinations included in this study, mistunings within the three flute timbres were either tolerated more or detected less. Conversely, tuning deviations within the three clarinet timbres were either detected significantly more often or tolerated the least.

Comparable comparisons were also made for heterogeneous combinations. Similar to the findings in the homogeneous category, a timbral effect on judged intonation was present within certain heterogeneous combinations. Only three of fifteen comparisons between heterogeneous timbral combinations evidenced nonsignificant differences in intonational judgments. Significantly fewer judgments of poor intonation were made for examples using the combination of flute-oboe-clarinet than for examples of any other heterogeneous combination, which may explain the fact that the flute-oboe-clarinet combination is the voicing most commonly found in the performance literature for this particular timbral combination. Mistunings in the combination of clarinet-flute-oboe were found to be the least tolerated by subjects, or perhaps detected most often.

Following the segregated analyses of intonational responses for homogeneous and heterogeneous timbral combinations, comparisons of judgments were made between the combinations within both categories. One-half of the comparisons of responses (grouped according to instrument combination) between timbral categories indicated significant differences in judgments of intonation. Those differences, however, evidenced no particular pattern related to whether homogeneous combinations were any more or less present within examples for which judgments of poor intonation were made than were heterogeneous combinations.

The finding that timbre had an effect on judged intonation concurs with several prior investigations (8, 16, 17, 25, 27, 30). Tunks' conclusion (27) that accepted intonation is more difficult to achieve for certain instrument combinations than for others may also apply to the perception of intonation relative to various timbral combinations. In the studies by Rasch (23) and Madsen and Geringer (16, 17), as well as this investigation, the differences in the amount of pitch deviation at which judgments of poor intonation were made could have been the result of the effects of different timbral combinations. Explanations of a determinant or of multiple causes for differences in intonational judgments relative to a timbral effect were not within the scope of the present study. It can, however, be proffered that physical properties of timbres interacting within the various instrument combinations are most likely responsible for a timbral effect which results in differences in judgments of intonation. Although timbral effects on judged intonation were found in this study, they were not as influential as the effect of pitch mistuning. Similar results were presented in previous investigations by Madsen and Geringer (16, 17).

Research Problem Three

The third research problem was to determine effects of mistuning within differential voices upon the judgments of intonation investigated in the previous research problems dealing with pitch and timbre. Three analyses of data were conducted to determine if an effect of mistuning within differential voices existed in relation to pitch deviation.

Intonational judgments were first grouped according to voice, and comparisons were made between cent deviation categories. The statistically significant differences in intonational judgments presented earlier between the deviation categories at 6 cent intervals remained intact for a majority of comparisons when the responses were divided into the appropriate voice categories. From this, it was concluded that a minimal effect of mistuning within differential voices was present between cent deviation categories.

Data were next grouped according to cent deviation categories for comparisons between voices. An effect of mistuning within differential voices was found within the categories of grouped cent deviations. While no significant differences in judgments were found as a result of the effect of mistuning within differential voices in all comparisons between voices 1 and 2, differences were found in all other two-voice comparisons. No apparent pattern was observed in the ordering of voices in terms of highest to lowest percentage of out-of-tune responses in relation to the amount of mistuning. In essence, it cannot be argued that pitch deviations in any particular voice are detected significantly more often or that mistunings in an individual voice effect a significantly greater number of judgments of poor intonation.

While Rasch (23) observed that mistuning of a melody part had the most significant effect on judgments of intonation for two-part musical examples, his findings can only be compared with those of this study, in which a few occurrences of statistically significant differences in judgments existed between two voices. The fact that the present study used three voices suggests that additional voices within an ensemble may diminish the effect of mistuning within differential voices.

Comparisons of out-of-tune responses to sharp and flat deviations were made by voice.. A significantly greater number of out-of-tune responses to sharp deviations in the ±12 cent deviation category were approximately evenly distributed among the three voices, thereby evidencing no effect of direction of mistuning within differential voices. An effect of direction of mistuning within differential voices was found to exist, however, in the ±18 cent deviation category. While no significant differences in judgments were made according to sharp versus flat deviations in voices 2 and 3, a statistically significant difference was found in voice 1. This finding indicated that the difference in judgments for the ±18 cents deviation category were singularly a result of responses to sharp deviations in voice 1.

Statistically significant differences in judgments in relation to direction of mistuning were also found in the ±24 cent deviation category. Out-of-tune responses to flat deviations were significantly higher than for sharp deviations in voice 1. This was the only comparison for which flat deviations were associated with a significantly greater number of judgments of poor intonation. Comparisons of responses within voices 2 and 3 indicated that sharp deviations effected significantly more out-of-tune responses than flat deviations. Although significantly more out-of-tune responses were made for flat deviations in voice 1, the differences found for voices 2 and 3 were great enough to result in the overall finding that sharp mistunings were associated with the greatest number of judgments of poor intonation for the category of ±24 cents. No effects of direction of mistuning were found in either the ±6 cent or ±50 cent deviation categories. This finding for the ±50 cent deviation category can be explained by the fact that nearly all of the responses to mistunings within that category were judgments of poor intonation. That no effect of direction of mistuning was found for the ±6 cent deviation category, however, may have been a result of subjects' guesses about examples containing pitch deviations.

The varied results of the analyses on the effect of direction of mistuning within differential voices suggest that differences in judgments associated with the direction of mistuning may, in some instances, diminish the overall effect of direction of mistuning; in other instances, they may not. Because no patterns of intonational judgments were noted for the direction of mistuning within differential voices, no definitive conclusions can be drawn for this portion of the investigation.

Research problem three was also concerned with the effect of mistuning within different voices relative to timbre and timbral combinations. In the homogeneous timbral category, results indicated that for voice 1 the clarinet timbre was associated with a significantly greater number of out-of-tune responses, but in voice 2, the oboe timbre was linked with the most occurrences of judgments of poor intonation. Voice 3 evidenced no statistically significant differences in responses in relation to timbral considerations.

Intonational responses to mistunings within differential voices relative to timbre within the heterogeneous category demonstrated similarities and differences with those in the homogeneous category. Whereas the clarinet timbre was associated with the greatest number of out-of-tune responses in the homogeneous category for voice 1, none of the three timbres in the heterogeneous category were. Another point of difference in the two timbral categories was present in voice 2. The flute timbre was associated with the greatest number of responses of poor intonation and the oboe with the least, an exact reversal of the findings for homogeneous combinations. The percentages of out-of-tune responses in the two timbral categories were very similar for voice 3. Percentages for the flute, oboe, and clarinet timbres in homogeneous combinations were .63, .60, and .64, respectively, while for heterogeneous combinations, the corresponding percentages were .67, .61, and .63.

No specific pattern of the effect of mistuning within differential voices was observed for any particular timbre or combination of timbres. Similar to the discussion on the effect of mistuning within differential voices in relation to pitch deviation, no conclusions can be drawn regarding timbral differences within differential voices and associated intonational judgments. A timbral effect was observed in some instances, but not consistently.

Additional Analyses

Four additonal analyses not associated with the research problems were conducted using demographic information provided by subjects in the study. Several investigations (2, 3, 5, 13) suggested that familiarity of timbres or area of performance concentration may influence perceptual discrimination or judgments of intonation. Comparisons of overall intonational responses were made to determine if significant differences in judgments existed according to subjects' area of performance concentration. Statistically significant differences in judgments were found between some categories but not between others. Subjects in the category of conducting/composition had a significantly higher percentage of correspondence of responses with intonational treatments of examples than all other categories. This was followed, in order, by subjects from the performance areas of brass, string, keyboard, woodwind, vocal, and percussion.

If familiarity of timbral context can be equated with area of performance concentration, then the possibility should be dismissed that familiarity with a context influences intonational judgments. This conclusion is based on the finding that the placement of the woodwind category was relatively low in terms of correspondence of judgments with intonational treatments of examples. Although Greer (7) found that the subjects in his study performed intonational tasks better with timbres of their own instruments, he also concluded that familiarity was not the major cause of the timbre effect found on intonation.

Other consideration was given to the possibility that musically trained subjects' intonational judgments might differ according to academic classification. The graduate category exhibited a significantly higher percentage of responses correspondent to intonational treatments of examples than all undergraduate categories. No significant differences in judgments were found among the sophomore, junior, and senior categories, although juniors and seniors reversed position in absolute ordering (graduate, junior, senior, sophomore, and freshman) by seven-tenths of one percent. The percentage of correspondence with intonational treatments of examples was significantly lower for freshmen than for all other classifications. These findings suggest that academic classification may have a limited degree of effect on judgments of intonation.

An analysis comparing overall responses by gender indicated no significant difference between the intonational judgments of males and females. The final comparison between subjects' intonational judgments according to institution of enrollment indicated no significant difference in judgments as well.

Conclusions

Improvements in the technology of sound synthesis through the use of digital computers have alleviated many of the criticisms of electronically generated stimuli representing musical instruments. At the same time, it has continued to provide the control over the physical properties of sound necessary to researchers in psychoacoustics. The importance of this study grows from the use of musical examples in the context of three-part woodwind ensemble performances. While previous efforts provided the basis for the present study, inferences drawn for application to a musical setting have not been made which allow for the psychological responses of the musician listener. It has been pointed out that psychophysical research is divided into two general categories: First, scientific investigation of the perceptual capabilities of an organism responding to sensory stimuli; and second, investigation of how an organism characteristically responds to sensory stimuli. The present study belongs in the second category, and it more closely approximates a setting characteristic of musical performance than prior investigations. Results of this study, then, should be viewed as extending rather than refuting the findings of previous studies. Because the stimuli used in this study were more representative of music in performance than those used in previous investigations, the findings of this study may more nearly approximate individuals' intonational judgments of musical performance.

The conclusion of prior studies that a certain percentage of listeners prefer musical performances which deviate somewhat from equal-tempered intonation is substantiated by this investigation. Aside from the arguments over what auditors consider acceptable intonation, the results of statistical analyses lead to the conclusion that the point in pitch deviation at which a majority of musically trained listeners make a judgment of poor intonation is between ±12 cents and ±18 cents deviation. It can also be concluded that significantly more out-of-tune responses are made for every additional ±6 cents deviation along a pitch continuum from a standard of "in-tune." The conflicts in research findings concerning the effect of direction of mistuning leads one to conclude that the effect will vary depending upon one or several of the following: differences in timbral sound sources and combinations, differences in musical performance material, differences in pitch deviations, differences in presentation of stimuli, or differences in the methods of evaluating results.

The results of this study also support that timbral differences have an effect on judged intonation. Different timbres and/or timbral combinations will result in diverse judgments of intonation of the same musical material. Some judgments will evidence no significant differences and some will. Moreover, it can be concluded that mistunings within differential voices will sometimes effect differences in judgments of intonation and at other times will not.

The last set of conclusions to be drawn from the study relate to demographic considerations regarding subjects. Differences in judged intonation existed relative to the area of performance concentration of subjects. Analysis, however, did not provide any explanation for the differences in intonational judgments. Such explanation was beyond the scope of this study. Results also suggest that training and/or experience has an effect on judged intonation. Finally, neither gender nor school of enrollment of subjects had any effect on intonational judgments.

Discussion

Interpretation of the results of studies such as this one must be based in the knowledge that the task was constructed in a somewhat artificial manner. Although closely approximating a true musical performance setting, synthesized examples cannot fully replace live musical performance.

It has been well documented that performers do not conform to any one system of intonation and that they continually vary specific pitches to suit the needs of each particular musical situation. The result that 20 percent of the subjects in this study judged "in-tune" examples (equal temperament) as out-of-tune demonstrates a parallel preference among listeners: equal temperament is not considered to be satisfactory intonation by a certain percentage of the musically trained listening population. The 20 percent of subjects who did not judge equally-tempered examples as satisfactory can, in part, be attributed to the intonational practices of performers. A precise determination of how much of the foregoing can actually be attributed to preferences and how much may be a result of guessing cannot be made. The results of this study have substantiated that listeners possess a tolerance of pitch deviation in the context of ensemble performances; in some instances, those could be an acceptance of a great degree of pitch deviation. The implication then, is that performers and/or musical organization conducters should not spend futile time with an electronic tuning device trying to achieve perfect intonation. Rather, it might be wiser to spend that time using the ear to make ongoing adjustments to intonation suitable to each performance situation.

Suggestions for Further Study

A great deal remains to be accomplished in the examination of intonation factors. Certainly, replication of this study would be in order. The construction and administration of a similar study using smaller increments of cent deviations and/or vibrato is also warranted. In addition, a study using a systematic method of variable tuning of individual notes for melodic and harmonic adjustments should be conducted. Advancements in technology may eventually make it possible to even more nearly simulate live musical performances than this study. Advances in technology may also make it possible to manipulate performances of live musicians to eliminate the many inconsistencies commonly found in live musical performances.

This study has dealt exclusively with specific timbral combinations of the woodwind family, leaving open to question whether the results would be similar if the study were made with different timbral combinations. Related to this concern is the consideration of the number of timbres included within ensemble combinations. Intonational judgments regarding a trio setting could possibly differ from those pertaining to a quartet, quintet, sextet, or other ensemble configuration.

An extension of this study might be to eliminate "in-tune" examples and ask subjects to indicate which voice is out-of-tune and the direction of the mistuning. An investigation such as this may reveal how individuals judge intonation by determining if subjects make their judgments by listening primarily to the melody voice, an inner voice, a bass voice, or some combination thereof.

While no implication of "correct" judgment of intonation was intended as a result of this investigation, the study offers some answers to a few previously unanswered questions regarding intonational judgments. It has also raised additional questions and issues worthy of investigation aimed toward a better understanding of the interactions between acoustics and psychology.

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APPENDICES

APPENDIX A

THREE-VOICE MUSICAL EXAMPLES FOR PILOT STUDIES


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APPENDIX B

FOUR-VOICE MUSICAL EXAMPLES FOR PILOT STUDIES


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APPENDIX C

INSTRUCTIONS AND TRIAL EXAMPLES FOR PILOT ONE

You will be listening to a series of short, recorded examples of trio and quartet ensemble performances. Following the playing of each example, you are to evaluate the example according to the criteria listed. If you consider the example to be "in-tune," check blank A and wait for the next example to be played. If you consider the example to be "out-of-tune," check blank B and continue further specification of which voice you think is out-of-tune and in what direction (sharp or flat).

TRIAL EXAMPLES:

(1)

A.____In-tune

B.____Out-of-tune

I. (check one only) II. (check one onl

____voice 1 ____sharp

____voice 2 ____flat

____voice 3

(2)

A.____In-tune

B.____Out-of-tune

I. (check one only) II. (check one onl

____voice 1 ____sharp

____voice 2 ____flat

____voice 3

____voice 4

STOP

====================

Please Do Not Turn To Next Page

Until Instructed To Do So

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Thank You

APPENDIX D

ITEM ANALYSIS FOR PILOT ONE

* = N answering correctly

PART I:

Item	Part, Treatment	A	B	item diffi-culty p	sub-test discrimination D	cumulative discrimination D
1.	N.W.	*30	8	.79	.10	.20
2.	1+25	5	*33	.87	.30	.20
3.	2+50	1	*37	.97	.10	.10
4.	2-12	28	*10	.26	.30	.10
5.	1+50	0	*38	1.00	.00	.00
6.	2-50	0	*38	1.00	.00	.00
7.	1+25	10	*28	.74	.40	.40
8.	3+12	32	* 6	.16	.20	-.10
9.	3+25	3	*35	.92	.30	.30
10.	3+50	0	*38	1.00	.00	.00
11.	1-50	0	*38	1.00	.00	.00
12.	2+12	14	*24	.63	.60	.50
13.	3-12	32	* 6	.16	.30	.30
14.	3-50	0	*38	1.00	.00	.00
15.	3-25	9	*29	.76	.60	.50
16.	N.W.	*20	18	.53	.20	-.10
17.	N.W.	*27	11	.71	.10	.20
18.	2-25	7	*31	.82	.20	.40
19.	1+12	15	*23	.61	.70	.60
20.	1-12	25	*13	.34	.20	.30
21.	2+25	3	*35	.92	.30	.30

mean p = .72

PART II:

22.	2-12	2	*36	.95	.20	.10
23.	3+12	3	*35	.92	.10	.00
24.	1-12	12	*26	.68	.60	.50
25.	4+50	0	*38	1.00	.00	.00
26.	3-12	19	*19	.50	.40	.20
27.	2+12	17	*21	.55	.70	.30
28.	N.W.	*29	9	.76	.10	.20
29.	2+25	2	*36	.95	.10	.10
30.	3-25	17	*21	.55	.50	.40
31.	1+12	26	*12	.32	.50	.10
32.	3-50	0	*38	1.00	.00	.00
33.	2-25	10	*28	.74	.60	.60
34.	N.W.	*16	22	.42	-.10	.20
35.	2-50	0	*38	1.00	.00	.00
36.	3+25	13	*25	.66	.20	.30
37.	4-12	22	*16	.42	.70	.50
38.	2+50	0	*38	1.00	.00	.00
39.	N.W.	*19	19	.50	-.10	.10
40.	4+12	26	*12	.32	.60	.70
41.	3+50	0	*38	1.00	.00	.00
42.	1-25	4	*34	.89	.10	.10
43.	4-50	0	*38	1.00	.00	.00
44.	N.W.	*14	24	.37	-.20	.00
45.	1+50	0	*38	1.00	.00	.00
46.	4-25	4	*34	.89	.30	.20
47.	4+25	3	*35	.92	.20	.20
48.	1-50	0	*38	1.00	.00	.00
49.	1+25	5	*33	.87	.10	.10

mean p = .76

cumulative mean p = .74

APPENDIX E

GROUPED-ITEM INDEX FOR PILOT ONE

		Item	p	Cumulative D
In-Tune		1.	.79	.20
		16.	.53	-.10
		17.	.71	.20
		28.	.76	.20
		34.	.42	.20
		39.	.50	.10
		44.	.37	.00
Sharp	+12	8.	.16	-.10
		12.	.63	.50
		19.	.61	.60
		23.	.92	.00
		27.	.55	.30
		31.	.32	.10
		40.	.32	.70
	+25	7.	.74	.40
		9.	.92	.30
		21.	.92	.30
		29.	.95	.10
		36.	.66	.30
		47.	.92	.20
		49.	.87	.10
	+50	3.	.97	.10
		5.	1.00	.00
		10.	1.00	.00
		25.	1.00	.00
		38.	1.00	.00
		41.	1.00	.00
		45.	1.00	.00
Flat	-12	4.	.26	.10
		13.	.16	.30
		20.	.34	.30
		22.	.95	.10
		24.	.68	.10
		26.	.50	.20
		37.	.42	.50
	-25	2.	.87	.20
		15.	.76	.50
		18.	.82	.40
		30.	.55	.40
		33.	.74	.60
		42.	.89	.10
		46.	.89	.20
	-50	6.	1.00	.00
		11.	1.00	.00
		14.	1.00	.00
		32.	1.00	.00
		35.	1.00	.00
		43.	1.00	.00
		48.	1.00	.00

APPENDIX F

RESPONSE FORM FOR PILOT TWO

GENERAL PURPOSE - NCS® - ANSWER SHEET

FOR USE WITH ALL NCS SENTRY OPTICAL MARK READING SYSTEMS
SEE IMPORTANT MARKING INSTRUCTIONS ON SIDE 2

NAME (Last, First, M.I.)

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Apr. ○	①	①	①	①	①	①	①	①	①	①	①	①	①	①	①	①	①	①	①	①
May ○	②	②	②	②	②	②	②	②	②	②	②	②	②	②	②	②	②	②	②	②
Jun. ○	③	③	③	③	③	③	③	③	③	③	③	③	③	③	③	③	③	③	③	③
Jul. ○		④	④	④	④	④	④	④	④	④	④	④	④	④	④	④	④	④	④	④
Aug. ○		⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤
Sep. ○		⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥
Oct. ○		⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦
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Dec. ○		⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨

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A B C D E
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41 ①②③④⑤
42 ①②③④⑤
43 ①②③④⑤
44 ①②③④⑤
45 ①②③④⑤
46 ①②③④⑤
47 ①②③④⑤
48 ①②③④⑤
49 ①②③④⑤
50 ①②③④⑤

A B C D E
51 ①②③④⑤
52 ①②③④⑤
53 ①②③④⑤
54 ①②③④⑤
55 ①②③④⑤
56 ①②③④⑤
57 ①②③④⑤
58 ①②③④⑤
59 ①②③④⑤
60 ①②③④⑤

A B C D E
61 ①②③④⑤
62 ①②③④⑤
63 ①②③④⑤
64 ①②③④⑤
65 ①②③④⑤
66 ①②③④⑤
67 ①②③④⑤
68 ①②③④⑤
69 ①②③④⑤
70 ①②③④⑤

A B C D E
71 ①②③④⑤
72 ①②③④⑤
73 ①②③④⑤
74 ①②③④⑤
75 ①②③④⑤
76 ①②③④⑤
77 ①②③④⑤
78 ①②③④⑤
79 ①②③④⑤
80 ①②③④⑤

A B C D E
81 ①②③④⑤
82 ①②③④⑤
83 ①②③④⑤
84 ①②③④⑤
85 ①②③④⑤
86 ①②③④⑤
87 ①②③④⑤
88 ①②③④⑤
89 ①②③④⑤
90 ①②③④⑤

A B C D E
91 ①②③④⑤
92 ①②③④⑤
93 ①②③④⑤
94 ①②③④⑤
95 ①②③④⑤
96 ①②③④⑤
97 ①②③④⑤
98 ①②③④⑤
99 ①②③④⑤
100 ①②③④⑤

APPENDIX G

ITEM ANALYSIS FOR PILOT TWO

```
   difficulty        discrimination
      (p)                 (D)
                                   ******************************************************************ITEM-TEST-HOMOGENEITY ANALYSIS

                                   MUSIC   PILOT  2

                                   ***********************************************************************************************

                                         PEARSON R'S  POINT BISERIALS FOR DICHOTOMOUS ITEMS

                                                             S.E.= 0.20
                                                           ITEM ANALYSIS

ITEM  MEAN    ST DEV    TOTAL*    VOICE and TREATMENT
  1   1.000   0.0       0.0   *   1+50
  2   0.192   0.402    -0.120*    2+18
  3   0.346   0.485     0.360*    1-18
  4   0.115   0.326     0.216*    3+15
  5   0.846   0.368     0.364*    1-25
  6   0.692   0.471     0.019*    2-15
  7   0.385   0.496     0.324*    1+15
  8   0.192   0.402     0.565*    1-9
  9   0.615   0.496    -0.165*    In-tune
 10   0.538   0.508     0.362*    1-15
 11   0.269   0.452     0.128*    2+9
 12   0.192   0.402     0.142*    3-9
 13   0.962   0.196     0.214*    3-18
 14   0.846   0.368     0.009*    In-tune
 15   0.769   0.430     0.224*    1+18
 16   0.192   0.402     0.115*    1+9
 17   0.885   0.326     0.234*    3+25
 18   0.808   0.402     0.148*    3+18
 19   0.962   0.196    -0.108*    2+25
 20   0.308   0.471     0.024*    1-9
 21   1.000   0.0       0.0   *   2-50
 22   0.615   0.496     0.358*    4-18
 23   0.269   0.452     0.201*    1+18
 24   0.769   0.430    -0.444*    In-tune
 25   0.500   0.510     0.427*    4+15
 26   0.385   0.496     0.233*    3-9
 27   0.500   0.510     0.094*    1+15
 28   0.500   0.510     0.137*    1-18
 29   0.577   0.504     0.584*    2-15
 30   0.423   0.504     0.204*    1+9
 31   0.692   0.471    -0.157*    In-tune
 32   0.192   0.402     0.391*    2+9
 33   0.462   0.508     0.094*    1-15
 34   0.923   0.272     0.235*    4-25

          COEFFICIENTS FOLLOWED BY ASTERISK (*) HAVE BEEN CORRECTED FOR SPURIOUS ITEM-TEST OVERLAP
```

APPENDIX H

ASSESSMENT FORM FOR TIMBRES IN MAIN STUDY

Please circle the number which most appropriately corresponds to your judgment of the characteristic tone quality for each example:

1. Solo Flute:

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

2. Flute Trio:

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

3. Solo Oboe:

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

4. Oboe Trio:

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

5. Solo Clarinet:

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

6. Clarinet Trio:

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

7. Mixed Trio (flute-oboe-clarinet)

Very Bad		Bad		Neutral	Good		Very Good	
1	2	3	4	5	6	7	8	9

APPENDIX I

MUSICAL EXAMPLES FOR MAIN STUDY

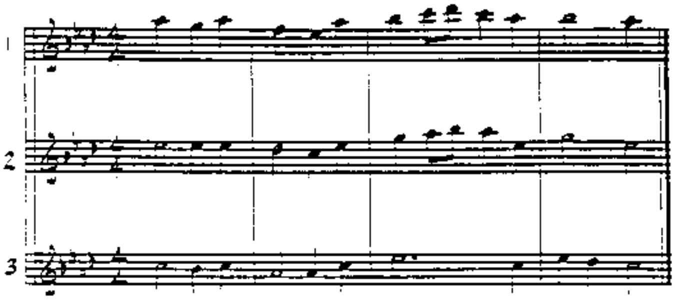
Example IA

Example IB

Example IIA

Example IIB

Example IIIA



Example IIIB

APPENDIX J

ITEMS LISTED WITH INTONATIONAL TREATMENTS OF MUSICAL EXAMPLES FOR MAIN STUDY FORMS "A" AND "B"

FORM A

Item	Example	Comb.	Trmt.
1.	IIIB	4	3-24
2.	IIIA	4	in-tune
3.	IB	3	1-50
4.	IIA	2	1-18
5.	IIIA	4	2+18
6.	IA	1	1-18
7.	IIB	7	2+24
8.	IB	4	1-18
9.	IA	9	2-24
10.	IIA	7	1+12
11.	IIB	2	2-12
12.	IIIA	7	3+12
13.	IIB	1	2+12
14.	IIIB	5	3-18
15.	IB	1	3-12
16.	IA	4	2-18
17.	IIIA	9	2-12
18.	IIA	4	1+24
19.	IIIB	8	3+18
20.	IIA	2	1-24
21.	IA	9	2+18
22.	IIB	6	in-tune
23.	IA	1	1-12
24.	IIIB	4	1-12
25.	IB	2	1+12
26.	IIIA	9	3+18
27.	IB	8	3-18
28.	IIB	2	3-18
29.	IIA	5	1-18
30.	IIIB	5	3-12
31.	IIA	1	1+6
32.	IIB	6	1+18
33.	IB	6	3+18
34.	IA	1	1+12
35.	IIIB	8	1+18
36.	IIIA	9	1+12
37.	IA	1	in-tune
38.	IIA	1	1+24
39.	IIIA	9	2+12
40.	IB	8	2-18
41.	IIIB	8	3-6
42.	IIB	7	2+12
43.	IA	6	2-12
44.	IIA	3	3+12
45.	IIIB	8	3+24
46.	IIIA	1	1+50
47.	IB	3	1-12
48.	IIB	3	2-18
49.	IIA	4	2-12
50.	IB	6	1-12
51.	IIB	5	in-tune
52.	IIIA	7	1+18
53.	IA	6	3+12
54.	IIIB	5	1-24
55.	IA	9	1+18
56.	IIIA	1	2-12
57.	IIB	3	1+18
58.	IB	2	3-6
59.	IIA	2	2+24
60.	IIIB	2	2+12
61.	IIA	9	2-18
62.	IIIB	2	3+18
63.	IA	8	1+12
64.	IB	4	3-12
65.	IIB	2	in-tune
66.	IIIA	1	3-18
67.	IA	5	3+12
68.	IIIB	3	1-18
69.	IIA	8	2-12
70.	IIIA	7	2+24
71.	IB	2	2+18
72.	IIA	9	3+12
73.	IIB	6	2-18

FORM B

Item	Example	Comb.	Trmt.
1.	IIIA	7	3-24
2.	IA	9	1-18
3.	IIA	7	1-18
4.	IIB	7	in-tune
5.	IB	2	1+18
6.	IIIB	6	2-50
7.	IIIB	3	2+18
8.	IIA	1	3-24
9.	IA	4	1+12
10.	IIIA	8	1-12
11.	IIB	8	3+12
12.	IB	5	2+12
13.	IA	1	2-18
14.	IIA	6	3-12
15.	IB	6	1-18
16.	IIIB	5	2-12
17.	IIB	4	3+18
18.	IIIA	3	2-24
19.	IA	8	1-18
20.	IIIB	5	3+18
21.	IIA	5	1-12
22.	IB	3	3-12
23.	IIB	3	1+12
24.	IIIA	8	2+18
25.	IIA	9	in-tune
26.	IIIB	6	3-18
27.	IB	3	2+6
28.	IIIA	2	2-18
29.	IA	9	3-18
30.	IIB	9	1+24
31.	IIIA	9	1-12
32.	IB	4	1+18
33.	IIIB	6	2+18
34.	IIB	6	1+12
35.	IA	2	2+50
36.	IIA	1	1+18
37.	IIIA	4	2+12
38.	IIA	6	3+24
39.	IIIB	8	in-tune
40.	IIB	8	2+12
41.	IB	5	2-18
42.	IA	2	3+12
43.	IA	7	2-12
44.	IIA	5	1+12
45.	IIB	3	3+24
46.	IIIA	7	1-12
47.	IB	3	3-18
48.	IIIB	4	2-6
49.	IIA	8	3-12
50.	IA	9	3-12
51.	IIIA	1	3+18
52.	IIB	1	3+12
53.	IIIB	8	1-24
54.	IB	5	1+18
55.	IIIA	5	3+50
56.	IIB	2	1-12
57.	IA	1	2+18
58.	IIIB	5	2+24
59.	IIA	3	in-tune
60.	IB	3	2+12
61.	IIIA	7	2-18
62.	IA	7	3+18
63.	IIB	6	2+12
64.	IIA	7	3-12
65.	IB	4	3-18
66.	IIIB	6	3+6
67.	IIIA	4	3+12
68.	IA	7	3-18
69.	IIIB	3	2-12
70.	IIB	6	2-24
71.	IB	3	3+18
72.	IIA	2	3-12
73.	IA	5	2+18

APPENDIX K

RESPONSE FORM FOR MAIN STUDY

TEST FORM ANSWER SHEET
TEXAS TECH UNIVERSITY

NAME (LAST) ____________ (FIRST) ____________ (INIT) ____

DEPT ____ COURSE ____ SECTION ____ TEST NO. ____ DATE ____ INSTRUCTOR ____

SOCIAL SECURITY NUMBER								
⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪
①	①	①	①	①	①	①	①	①
②	②	②	②	②	②	②	②	②
③	③	③	③	③	③	③	③	③
④	④	④	④	④	④	④	④	④
⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤
⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥
⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦
⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧
⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨

FORM ① ②

DO NOT WRITE BELOW THIS LINE

TEST NO	DEPT NO.				COURSE				SECTION		
⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪
①	①	①	①	①	①	①	①	①	①	①	①
②	②	②	②	②	②	②	②	②	②	②	②
③	③	③	③	③	③	③	③	③	③	③	③
④	④	④	④	④	④	④	④	④	④	④	④
⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤
⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥
⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦
⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧
⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨

OPTIONS Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ

FORM ① ② ③ ④ ⑤ ⑥ ⑦ ⑧

SHEET TYPE Ⓐ Ⓦ

USE BLACK LEAD PENCIL ONLY
(NO. 2½ OR SOFTER)

1 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	11 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	21 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	31 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	41 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	51 Ⓐ Ⓑ Ⓒ Ⓓ
2 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	12 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	22 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	32 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	42 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	52 Ⓐ Ⓑ Ⓒ Ⓓ
3 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	13 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	23 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	33 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	43 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	53 Ⓐ Ⓑ Ⓒ Ⓓ
4 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	14 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	24 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	34 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	44 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	54 Ⓐ Ⓑ Ⓒ Ⓓ
5 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	15 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	25 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	35 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	45 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	55 Ⓐ Ⓑ Ⓒ Ⓓ
6 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	16 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	26 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	36 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	46 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	56 Ⓐ Ⓑ Ⓒ Ⓓ
7 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	17 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	27 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	37 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	47 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	57 Ⓐ Ⓑ Ⓒ Ⓓ
8 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	18 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	28 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	38 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	48 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	58 Ⓐ Ⓑ Ⓒ Ⓓ
9 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	19 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	29 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	39 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	49 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	59 Ⓐ Ⓑ Ⓒ Ⓓ
10 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	20 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	30 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	40 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	50 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	60 Ⓐ Ⓑ Ⓒ Ⓓ

61 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	71 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	81 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	91 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	101 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	111 Ⓐ Ⓑ Ⓒ Ⓓ
62 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	72 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	82 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	92 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	102 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	112 Ⓐ Ⓑ Ⓒ Ⓓ
63 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	73 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	83 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	93 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	103 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	113 Ⓐ Ⓑ Ⓒ Ⓓ
64 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	74 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	84 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	94 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	104 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	114 Ⓐ Ⓑ Ⓒ Ⓓ
65 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	75 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	85 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	95 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	105 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	115 Ⓐ Ⓑ Ⓒ Ⓓ
66 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	76 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	86 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	96 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	106 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	116 Ⓐ Ⓑ Ⓒ Ⓓ
67 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	77 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	87 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	97 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	107 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	117 Ⓐ Ⓑ Ⓒ Ⓓ
68 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	78 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	88 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	98 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	108 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	118 Ⓐ Ⓑ Ⓒ Ⓓ
69 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	79 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	89 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	99 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	109 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	119 Ⓐ Ⓑ Ⓒ Ⓓ

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