Order Number 9020146

Intonation tendencies of selected university flute, oboe, and clarinet players

Church, Ray Edward, Ed.D.

The University of North Carolina at Greensboro, 1989

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

INTONATION TENDENCIES OF SELECTED UNIVERSITY FLUTE, OBOE, AND CLARINET PLAYERS

by

Ray Edward Church

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

Greensboro
1989

Approved by

James W. Sherbon
Dissertation Adviser

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Dissertation Adviser ____________________

Committee Members ____________________

____

____

____

November 17, 1989
Date of Acceptance by Committee

November 6, 1989
Date of Final Oral Examination

CHURCH, RAY EDWARD, Ed.D. Intonation Tendencies of Selected University Flute, Oboe, and Clarinet Players. (1989) Directed by Dr. James W. Sherbon. 116 pp.

The purpose of this study was to investigate the intonation tendencies of flute, oboe, and clarinet players after accounting for the effects of instrument intonation deficiencies. Twenty-seven university students served as subjects in three groups ($n = 9$ per group). The subjects performed 15 scale tones of their respective instruments during pitch-matching trials involving a common set of sawtooth wave stimulus tones.

The research design was a mixed 3 (instrument) X 15 (scale tone) factorial analysis of covariance with a covariate (intonation deficiencies) changing across trials. The dependent variable was a measurement, in cent deviation, of intonation tendencies. The covariate was a measurement of the flat and sharp intonation deficiencies of instrument scale tones. The adjusted means of the dependent variable represented intonation tendencies after statistically controlling for possible effects of the covariate.

Significant differences of intonation tendencies occurred between groups due to instrument ($p = .01$). There were no significant differences due to scale tone selection ($p = .28$) or the interaction of instrument and scale tone ($p = .08$). The covariate effect on intonation tendencies was significant ($p < .0001$) for the interaction but not ($p > .05$) for between group differences. Based on the

results, the following conclusions were formulated.

1. There were significant differences in the intonation tendencies of flute, oboe, and clarinet players.

2. There was no significant difference in intonation tendencies for the different scale tones being performed.

Intonation tendencies of flute and clarinet players were sharper than oboe players and the sawtooth wave stimulus tones. Results of the study support speculation concerning apparent pitch differences associated with instrument timbre as a possible factor of intonation.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to Dr. James W. Sherbon for his guidance and assistance as director of this dissertation. Appreciation also is extended to other members of my committee, Drs. Hilary Apfelstadt, James Prodan, Patricia Sink, and David Soderquist, for their individual contributions related to their various areas of expertise.

Special thanks are extended to my family, friends, colleagues, students, and the administration at the North Carolina School of Science and Mathematics for their encouragement and cooperation. Most of all, I thank my parents, George and Elenoir Church, for their patience, understanding, and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Problem

Music educators and performing musicians generally agree that intonation problems in ensemble performance are a result of the lack of ability among individual performers to produce unified tonal precision. In addition to individual intonation performance tendencies, woodwind and brass musicians generally are confronted with compensating for the intonation deficiencies of their instruments, primarily attributed to variance in instrument construction (Pottle, 1962; Kohut, 1973; Sawhill and Grant, 1973). With a knowledge of these deficiencies, wind musicians generally attempt to improve intonation by adjusting the fundamental frequency and resulting pitch of certain tones with tone production techniques involving variation of embouchure lip pressure and air pressure, or the use of alternate fingerings.

The influence of timbre on pitch discrimination is a well established perceptual phenomenon also associated with ensemble intonation problems. Many musicians accept the premise that the pitch of a relatively "bright" tone is often perceived to have a higher pitch than a "darker" or less brilliant tone of the same fundamental frequency and overall intensity (Stauffer, 1954). The overall intonation of an instrumental ensemble is obviously improved when individual players of the same instrument type produce tones more similar in quality (Kohut, 1973).

Many musicians intentionally perform with sharp intonation. "Most people tend to play on the high side of pitch, preferring a bright tone that seems to project more" (Doane, 1987, p.71). When the tone qualities produced by individual performers within an instrument section of an ensemble are excessively bright, however, intonation and blend problems can occur due to the roughness produced by inharmonic partials (Kohut, 1973).

> On wind instruments, every tone has a center or focal point where maximum resonance can be achieved. Players who learn to play in the tonal center will play the majority of their notes in tune. (Kohut, 1973, p. 116).

According to Doane (1987), the "best" tone quality of an instrument is produced when the "pitch is most centered" (p. 71). Centering the pitch of tones produced on a wind instrument also allows a musician to have more flexibilty to alter the pitch upward or downward when needed to adjust for intonation.

Stauffer (1954) conducted an extensive study of the intonation deficiencies of wind instruments performed by professional musicians. He concluded that tuning an ensemble of wind instruments is subject to the apparent pitch associated with the timbre of an instrument.

> It is felt that special consideration should be given to the tone of the clarinet and the tuba in this respect. What quality of the clarinet tone justifies the fact that it has a mean pitch level of up to 30 cents higher than the flutes and oboes? Perhaps it is the peculiar hollow quality caused by significant lack of the lower even harmonics that gives an apparent pitch much lower than actual. Perhaps the clarinetist, naturally draws his hollow, vibratoless tone on the higher side to maintain psychologically an equal brilliance with the warm pulsating tone of the flutes and oboes (Stauffer, 1954, p. 161).

The pitch of a clarinet tuned to the same fundamental frequency of other musical instruments often appears to sound relatively "flat" (Meyer, 1964a; 1965; 1978b). Is this perceptual phenomenon, as advocated by Meyer, a factor of ensemble intonation?

Numerous studies provide evidence that timbre is an important factor of pitch discrimination and pitch-matching, but few researchers have investigated the timbre of a performer's instrument as a possible factor of intonation within a context of performance (Meyer, 1978b). The first published studies in this area of research (Greer, 1970; Jameson, 1980) involved tones performed on brass instruments during pitch-matching trials with various timbres as stimulus tones; but, the results of these studies were inconclusive when attempting to associate timbre with intonation tendencies of musicians.

Purpose of the Study

The purpose of this study was to investigate the intonation tendencies of flute, oboe, and clarinet players after accounting for inherent intonation deficiencies of their instruments. Based on speculation, any additional differences in the intonation tendencies of woodwind musicians could be related to the apparent pitch perceived as a result of instrument timbre. The characteristic timbres of these woodwind instruments are distinctly different and less homogeneous as an instrument group than those of the brass and string instrument groups. Perceptual biases concerning the apparent "flat" pitch of the clarinet illustrate the need for a study including factors of woodwind instrument timbre. After accounting for the intonation deficiencies of woodwind instruments, are there differences in the intonation tendencies between performers of flute, oboe, and clarinet across different scale tones?

Definitions of Concepts used in the Study

Timbre

Timbre is the tonal attribute of sound which describes perceptual differences between musical tones of equivalent frequency, intensity, and duration. Timbre perception is determined primarily by the waveform of a musical tone but also is dependent on the frequency, intensity, duration, and onset/decay of a sound envelope. The operational definition of instrument timbre for this study refers to the categorization of flute, oboe, and clarinet as three different instrument sounds produced with equal intensity and duration.

Pitch

The perception of pitch is a subjective judgment involving the placement of a sound on a low-to-high continuum. Although the pitch continuum primarily is related to the fundamental frequency of a tone, it is also dependent on the waveform and overall intensity of the sound (Radocy and Boyle, 1979). The discrimination of pitch differences involving timbre is associated with the relative number and intensities of low and high frequency harmonic spectral components of a sound's waveform (Fletcher, 1934; Wellek, 1934; Boring and Stevens, 1936).

Intonation

Intonation is a subjective judgment of the pitch accuracy of a performer's tones within a context of performance (Harvard Dictionary of Music, Second Edition, 1970).

> Intonation problems are pitch-matching problems; to say that someone is "out-of-tune" is to say that, in some observer's subjective judgment, a produced sound does not match a standard (Radocy and Boyle, 1979, p. 33).

Although pitch is a psychological factor, involving a subjective placement of a tone on a low-to-high continuum, the intonation of a performer's tone with regard to another tone as a pitch standard often is evaluated by an objective measurement of differences in the fundamental frequencies. When the fundamental frequencies are the same, the performer is objectively evaluated to be "in-tune."

Sharp/flat

When the fundamental frequency of a performer's tone is relatively higher than that of the standard tone used as a reference, the objective pitch of the tone is considered "sharp;" when the measured frequency of the performer's tone is relatively low, it is considered "flat." With regard to the subjective pitch of musical tones, the pitch of a tone may be perceived to be higher (sharp) or lower (flat) than the pitch of another tone with the same fundamental frequency.

Intonation tendencies

The intonation tendency of a musician is defined as the general tendency to perform with sharp or flat intonation compared to another musician or with reference to another source of sound used as a standard for intonation. Intonation tendencies for individual scale tones generally are measured, in cent deviation, as differences in the fundamental frequencies of a performer's tone and the tone used as the intonation standard. A positive cent deviation represents a "sharp" tendency, and a negative cent deviation represents a "flat" tendency.

Instrument intonation deficiencies

The concept of instrument intonation deficiencies refers to measurement, in cent deviation, of the inherent sharp and flat intonation for individual scale tones of a performer's musical instrument as compared to the equal-tempered scale (Stauffer, 1954, p. 2). Intonation deficiencies of woodwind instruments are attributed to variance in the construction of musical instruments, mouthpieces, and reeds.

Brightness

The timbral category of brightness is often used to describe pitch differences associated with waveform and overall intensity (Lichte, 1941; Bachem, 1948, 1950; Boring, 1950; Arment, 1960). Lichte (1941) defines timbral brightness as a function of the location for the midpoint of the energy distribution of a complex tone on the frequency continuum. Based on a survey of the literature, Hesse (1972) described three types of brightness continua.

(1) Brightness increases when the relative number and intensities of the harmonic components remain constant but the fundamental frequency increases (Revesz, 1913).

(2) Brightness increases when the fundamental frequency remains constant but higher

frequency spectral components of the harmonic structure are added (Hornbostel, 1926).

(3) Brightness increases when the formant of a musical tone is displaced to a higher frequency range (Stumpf, 1890; Hermann, 1890; Schumann, 1929).

Formant

A formant of a complex tone is a series of harmonic spectral components of a specific frequency range with relatively strong intensities. The formant theory has been applied to describe waveforms which represent various vowel qualities in singing and different timbres of musical instruments (Hermann, 1890; Aschoff, 1936; Jost, 1968; Meyer, 1978a). The frequency range of a formant generally remains constant regardless of the fundamental frequency. For example, the characteristic timbre associated with a formant generally remains consistent for a series of ascending scale tones performed on a musical instrument.

Justification for the Study

Timbre as a possible factor of intonation

Greer (1970) conducted one of the first published studies concerning the effect of timbre on intonation tendencies, specifically involving the intonation of brass players. He observed a significant difference ($p < .01$) in the intonation responses of subjects due to timbral differences of the recorded stimulus tones used in performance trials. In the *post-hoc* analysis, there was no significant difference ($p > .01$) in the intonation responses due to timbral differences of recorded stimulus tones produced on the subject's own brasswind instrument, piano, or organ (complex tones). There was, however, a significant difference ($p < .01$) in intonation tendencies within subjects for the "pure" (sinusoidal) tones produced by an oscillator in post-hoc comparisons with the complex tones. The intonation responses of brass players were objectively measured to be "flat" for the sinusoidal tone stimuli of the oscillator compared to the responses for the complex tone stimuli of musical instruments. This result confirms research evidence that subjects respond more accurately when presented with complex tone stimuli than with pure tone stimuli during pitch discrimination performance tasks (Henning and Grosberg, 1968; Houtsma, 1971; Sergeant, 1973; and Zeitlin, 1964).

A second part of the Greer study specifically involved timbral classifications of brasswind instruments as a possible factor of intonation. During the first of two performance trials, Greer found a significant difference ($p < .01$) between groups of trumpet, French horn, trombone, and tuba players with regard to intonation. During the second trial, the intonation responses of the subjects due to the effect of instrument were, however, not significantly different ($p > .01$).

Terhardt (1972a, 1972b) observed that subjects perceived the pitch of a sinusoidal tone to be higher than that of a complex tone consisting of only two or three consecutive harmonics. Terhardt concluded that an interaction between the fundamental and the second harmonic of a complex tone causes the pitch of the fundamental to be perceived as slightly lower than the pitch of a sinusoidal tone of equivalent frequency. This conclusion may have implications for the apparent pitch of flute timbre, which generally is described by a waveform consisting of primarily the fundamental and a few higher harmonics.

Swaffield (1974) conducted a study of the effects of contextual factors involving timbre, intensity, duration, and variable stimulation on the fine tuning responses of subjects. He concluded that the direction of fine tuning responses seemed dependent principally upon the frequency and intensity of the stimulus, but the accuracy of fine tuning appeared to be related primarily to timbre. Swaffield also concluded that some instrument timbres are more difficult to tune accurately than others.

Jameson (1980) studied the effects of different timbre conditions involving variation of the harmonic structure, intensity, and onset/decay transients of recorded trombone tones used as pitch stimuli. He concluded these variables did not have a significant effect on the pitch-matching performance of trombone players.

Wapnick and Freeman (1980) produced pairs of relatively dark versus bright clarinet tones by altering previously recorded clarinet tones (judged to be equivalent in brightness before alteration) with the use of an audio frequency band equalizer. They concluded that subjects associated flatness of pitch with relatively dark clarinet tones preceded by bright clarinet tones and associated sharpness of pitch with relatively bright clarinet tones preceded by dark clarinet tones.

According to Madsen and Geringer (1978), musicians were not able to judge good versus bad trumpet quality within a context of performance. They also concluded that musicians have a preference for sharp intonation regardless of the tone quality. In a related study involving unaccompanied flute and oboe duets, Madsen and Geringer (1981) reported that when subjects indicated a preference for good or bad tone quality they were actually responding to intonation variables. For both studies, they concluded that the vast amount of time musicians spend on the development of an acceptable tone may be best used in the development of good intonation.

Results of these studies, often contradictory, justify the need for further research concerning timbre as a possible factor of intonation. Further justification for a study of intonation tendencies of flute, oboe, and clarinet players is based on the results of acoustical research which describe timbral differences of the three instruments.

Timbral characteristics of flute, oboe, and clarinet

Meyer (1978a) states that flute tone is characterized by a very smooth harmonic spectrum with the fundamental having the greatest relative intensity, except for the lowest tones from c_4 (262 Hz) to e^{b}_4. "On no other orchestral instrument is this feature so pronounced" (p. 49). In contrast, the oboe has a timbre with a completely different harmonic structure from that of the flute as a result of differences in vibration production and differences of inner bore shapes of the instruments (p.51).

An oboe tone consists of many harmonic spectral components and, theoretically by definition, would have a "brighter" quality than flute tone. For oboe tone, the spectral harmonic components with the greatest relative intensities are in the frequency range of 1100 Hz. The relatively strong harmonics of formants in frequency ranges of approximatly 2700 Hz and 4500 Hz, particularly, give the oboe a marked brilliance (Meyer, 1978a, p. 51). For the present study, this raises the question regarding a possible difference in the intonation tendencies of flute and oboe players associated with theoretical brightness differences of the two timbres.

Clarinet timbre has a waveform in which the odd-numbered harmonics are predominant over even-numbered ones.

Meyer (1964a; 1965) concluded that well known generalizations about the characteristically "flat" pitch associated with the "hollow" quality of clarinet tones may be associated with the relative weakness in the intensities of the even-numbered spectral components. In a later study, Meyer (1978b) observed that most musicians perceived tones with a complete series of harmonics (sawtooth wave tones) to have a higher pitch than tones containing only the odd-numbered harmonics (square wave tones). Are the intonation tendencies of clarinet players influenced by the characteristic timbre of their instruments?

Timbre also varies for individual scale tones throughout the performance range of a musical instrument, as described by Meyer (1978a). For the lowest tones of the flute (with b-$flat_4$ as the lowest tone), the fundamental is weaker than the second harmonic. For flute tones in the very high register, from about f_6 and above, the odd-numbered harmonics have greater relative intensities than the even-numbered ones, decreasing the perceived brilliance of the tone. Flute timbre also becomes increasingly brilliant with increased loudness (Meyer, 1978a, p. 50).

The relative intensity of the fundamental harmonic of tones in the the lower register of the oboe is relatively weak; harmonics in the formant of between 500-550 Hz have the greatest relative intensities of the spectrum. Above e_5 the influence of the formants decreases and is accompanied by the perception of decreased brilliance. For b-flat$_5$, the fundamental and octave components are approximately equal. From d$_6$ upward, the fundamental predominates (Meyer, 1978a, p. 52).

The clarinet has basically three registers which have different characteristics with regard to the harmonic spectrum and perceived timbre. For tones in the lower octave (d$_3$ to d$_4$), the odd-numbered harmonics are stronger in relative intensity than the even-numbered ones, resulting in a dark and hollow sound (Meyer, 1978a, p.54). For tones in the "throat register" (e^{b}_4 to g$_5$), the intensities of the first and third harmonics are greater than the octave harmonic; the result is a somewhat dull quality. Above g#$_5$ the fundamental is strongest accompanied by a sloping harmonic envelope. Clarinet timbre in this register is similar to the timbre of a flute (p.55).

Additional Research Considerations and Limitations of the Study

Two areas of research well known to instrumental musicians and music educators also represent external factors of intonation performance which were considered in the study. These are beat elimination, as a method of tuning perfect unison and octave harmonic intervals, and loudness variation of a performer's tone involving intensity as a factor of intonation and tone quality variation.

Beats of interference

Pulsations or beats of amplitude variation can be observed when the frequency ratios of two tones in harmonic intervals of perfect unisons, octaves, and often fifths are slightly mistuned (Cotton, 1935; Corso, 1954; Cochelle and Firestone, 1957). The observance and elimination of interference beats (beat elimination method) commonly is an accepted technique used when tuning musical instruments and as a method for teaching the concept of intonation and improving the intonation accuracy of musicians (Graves, 1964; Miles, 1972). The present study was limited to pitch-matching trials involving melodic rather than harmonic unison intervals; as a consequence, the phenomenon of beats was not an external factor of intonation which could represent a possible contamination factor for the results of the experiment.

Intensity variation

The second additional consideration for the study was intensity variation of the subjects' response tones as a factor of intonation. Timbral research provides evidence that the relative intensities of the spectral harmonic components of various instrument timbres vary with extreme differences in the overall intensity of a tone (Schumann, 1929; Jost, 1967; White, 1981). The change in the harmonic structure is accompanied by a perceptible change in timbre, including a possible change in the brightness of the sound quality. In addition, pitch differences associated with intensity variation of tones produced on wind instruments are also a result of an increase or decrease of the fundamental frequency due to increased blowing pressure or embouchure adjustments. For these reasons, the present study was limited to observations of the intonation tendencies of flute, oboe, and clarinet players during the performance of response tones with a loudness they perceived to be mezzo-forte (moderately loud).

Research Hypotheses

Three null hypotheses were treated in accordance with the stated purpose of this study.

1. There is no significant difference in the intonation tendencies between groups of flute, oboe, and clarinet players after accounting for instrument intonation deficiencies.

2. There is no significant difference in the intonation tendencies within subjects for the different scale tones being performed after accounting for instrument intonation deficiencies.

3. There is no significant difference in the intonation tendencies of subjects due to an interaction of instrument and scale tone.

Importance of the Study

Knowledge about the intonation tendencies for individual scale tones of one's instrument and of other performers' instruments is generally considered to be useful for predicting and preventing ensemble intonation problems. Such knowledge is also useful in the analysis of intonation problems among performers of various instrument types within a music class or rehearsal situation. Instrumental music educators recognize that the sharp and flat intonation tendencies of wind players for specific scale tones are often associated with intonation deficiencies of musical instruments. Investigation of the intonation tendencies of flute, oboe, and clarinet players after accounting for instrument intonation deficiencies may provide additional information which may be used to improve ensemble intonation. Such information also may be applied to instrumental music pedagogy with regard to the development of tone production methods which improve intonation.

CHAPTER II

REVIEW OF LITERATURE

As stated by Plomp (1970), timbre (commonly referred to as tone quality) is a multidimensional attribute of sound. The definition of timbre in the broadest sense refers to a category of sound perception involving identification of the distinctive tone qualities of the human voice and individual musical instruments. In a narrower sense, timbre is a qualitative attribute of sound which describes a perceptible difference in two tones of equivalent frequency, intensity, and duration.

Many early studies in the area of timbral research were focused on measurement of the relative intensities of the harmonic spectral components which describe the physical characteristics of individual instrument timbres. More recent studies provide evidence that the onset (or "attack") portion of a sound envelope is also a primary physical factor involved in the recognition and discrimination of different musical instrument timbres (Winckel, 1967; Elliot, 1975). Research investigating brightness as a category of timbre perception in a narrower sense is, however, generally limited to studies involving samples of the steady state portion of the sound envelope. The following review of the literature is a summary of pertinent information concerning the concept of brightness; timbral differences of flute, oboe, and clarinet tones; and the apparent brightness differences of these instrument timbres as a possible factor of intonation.

Brightness

The concept of brightness represents a dimension of tone quality perception often associated with the perception of pitch differences between musical tones of equivalent fundamental frequency and intensity (Stauffer, 1954; Meyer, 1978a). Stumpf (1914) first introduced the contrasting paired adjectives of dark-bright, dull-sharp (or smooth-rough), and full-empty (or broad-thin) to describe three distinctive qualitative dimensions of hearing perception which are not fully explained by the Helmholtz (1863) theory concerning the sensation of sound phenomenon. According to Helmholtz, pitch, tone quality, and loudness are the primary subjective attributes of sound and have direct one-to-one relationships with the physical characteristics of frequency, harmonic structure, and intensity, respectively. Experimental and Gestalt psychologists of the early twentieth century also disagreed with Helmholtz concerning the number of distinct qualitative attributes of sound but could not support their theories with scientific evidence. Revesz (1913) proposed a two component theory of pitch which divided pitch perception into two dimensions, including the perception of pitch on a low to high continuum related to a measurable increase of fundamental frequency (chroma) and also the perceptual phenomenon involving the similarity of complex tones produced in different octaves (octave similarity).

According to the Hornbostel (1926) theory concerning the psychology of hearing phenomena, the perception of pitch is a function of the brightness of a musical tone. Hornbostel stated that the tone quality of a complex tone is relatively brighter than the tone quality of a pure tone. For example, the pitch quality or brightness of the tone a_4 (440 Hz) produced on a piano sounds higher than a tone of equivalent fundamental frequency produced with a tuning fork.

Wellek (1934) compared the theories of Hornbostel and Revesz with the consonance theory of Krueger (1903). Wellek proposed a theory of the multidimensionality of pitch as the key to the systemization of musical phenomena. He concluded that brightness as a dimension of tone quality also represents a dimension of pitch.

Stevens (1934) described the dimensions of pure tones as pitch, loudness, volume, and density. Comparing complex tones of equal intensity and fundamental frequency, Lichte (1941) described three characteristics of timbre important in the study of musical tones.

1. brightness--being a function of the location of the midpoint of the energy distribution on the frequency continuum

2. roughness--being present in tones containing consecutive high partials above the 6th harmonic

3. fullness--being a function of the relative presence of odd- and even-numbered harmonics of a tone

Both Stevens (1934) and Lichte (1941) concluded that each subjective attribute of sound is related to more than one of the physical attributes frequency, harmonic structure, and intensity. Related research concerning the dependency of pitch perception on the harmonic structure of a musical tone includes studies of periodicity pitch and residual pitch (Seebeck, 1841, 1843, 1844a, and 1844b; Ohm, 1843, 1844; Helmholtz, 1857; Kranz, 1923; Fletcher, 1924, 1934; Shower and Biddulph, 1931; Stevens, Volkman and Newman, 1937; Schouten, 1940a). Periodicity pitch involves the retention of a pitch sensation related to the fundamental frequency of a musical tone when the fundamental harmonic is eliminated (Licklider, 1954; Lichte and Gray, 1955; Houtsma and Goldstein, 1972). Residual pitch is a type of periodicity pitch involving only the eighth and higher harmonics which constitute what is referred to as the "residue" (Schouten, 1940a).

Other related research concerns the theory of spectral dominance. According to this theory, the perception of pitch on a consistent basis is dependent on the relative dominance of harmonics in the most sensitive frequency range of human hearing (Lichte and Gray, 1955; Ritsma, 1967; Plomp, 1967a, 1967b; Bilsen, 1973).

Based on an extensive review of the literature concerning the relationship of pitch and tone quality, Hesse (1972) summarized that there are actually three brightness continua which are respectively related to variations of frequency, harmonic structure, and intensity.

1. One brightness continuum occurs when the relative number and intensities of the harmonic components remain constant but the fundamental frequency increases (Revesz, 1913).

2. A second brightness continuum occurs when the fundamental frequency remains constant but higher frequency spectral components of the harmonic structure are added (Hornbostel, 1926).

3. A third brightness continuum occurs when the formant of a musical tone is displaced to a lower or higher frequency range. This can also be described as a change of brightness due to a relative decrease or increase in the intensities of higher harmonics (Stumpf, 1890; Hermann, 1890; Schumann, 1929).

Timbral Differences of Flute, Oboe, and Clarinet Tones

Formant theory

The characteristic tone qualities of flute, oboe, and clarinet are distinctly different and are physically described by specific differences in the harmonic structures of their respective tones. Numerous studies describe the harmonic structures that characterize the timbral differences of tones produced on various orchestral instruments. The earliest studies (Stumpf, 1890; Hermann, 1890) described general differences of harmonic structures of instrument timbres involving an application of the formant theory.

A formant is described as a set of consecutive harmonics which are consistently strong in relative intensities within a distinct frequency range (formant region) of the harmonic structure of a musical tone. According to the formant theory, the presence of formants in various frequency ranges provides each instrument with its characteristic timbre. The existence of one or more formants is a result of the reinforcement of specific harmonics due to the particular resonance properties of the instrument. For example, tones of equivalent fundamental frequency performed on the violin and viola have slightly different timbres because the resonance properties of the viola are in a lower frequency range than those of the violin (James, 1937).

Hermann (1890) concluded that the formant region of dominant spectral components for each instrument is independent of the fundamental frequency of the tone. Schumann (1929) investigated the general phenomenon of formant regions that appear with instrument tones and concluded, however, that the position of an instrument formant is also dependent on the intensity with which a tone is played. Consequently, the intensity and resulting loudness of a musical tone as factors of woodwind tone production may have an effect on the relative brightness of instrument timbre. For example, the displacement of a formant to a higher frequency range due to an increase in the air pressure used to produce a tone on a woodwind instrument may result in a relative increase in brightness. Jost (1967) confirmed Schumann's conclusions in a study of clarinet tone quality and intonation. He stated that the harmonic structure, most notably the formants, of clarinet timbre varies with loudness variation.

Spectral analysis of instrument timbre

The first published studies involving the scientific systematic measurements of the relative intensities of the harmonic spectral components which characterize instrument timbres (Miller, 1922; Richardson, 1929; Meyer and Buchman, 1931) were verified by later studies which utilized more sophisticated measurement equipment (Hague, 1947; Benade, 1970). Although the tone quality of a woodwind instrument type may vary somewhat between performers of different national and regional schools of playing (Bate, 1975), distinct differences in the general timbres of each instrument type are described by general differences in the harmonic structures of their tones. The following documentation describes the general harmonic structures of flute, oboe, and clarinet timbres which provide evidence for the apparent brightness qualities of these instruments.

Flute. According to Seashore (1938), "The flute gives the purest and thinnest tone of all orchestral instruments. The fundamental contains 100 per cent of the energy in the highest tones and there are only five partials in each of the lowest two" (p. 189). In a more recent comprehensive study of timbral variation of tones produced on five brands of professional model flutes (White, 1981) concluded that the number of harmonic spectral components gradually decreases systematically with an increase in the fundamental frequency (low to high continua of scale tones). White also observed that an increase in the loudness of a flute tone is also accompanied by an increase in the number of consecutive harmonics.

Oboe. Helmholtz (1890) stated that the general "nasal" quality of oboe timbre is related to the presence of many harmonic spectral components. According to Bate (1956, Third Edition 1975), the tone quality of the oboe varies, somewhat, between successive tones and becomes progressively thinner in a performance of an ascending scale throughout the playing range of the instrument. Bate also summarized generalizations of Hague (1947) about differences in the harmonic structure of oboe tones in the low, middle, and high registers of a typical French oboe used by many American and European performers.

1. There appear to be no important overtones of a greater frequency than 7,000 cycles per second in any of the notes investigated.

2. The low and middle registers are rich in overtones up to about the sixteenth harmonic.

3. In the low register the first five overtones appear as nearly equal in strength to the fundamental. The fundamental becomes more prominent in the harmonic array as we descend (Bate, 1957, p. 126).

Clarinet. The timbre and related harmonic structure of clarinet tones have been investigated extensively in a series of studies published in the Journal of the Acoustical Society of America. From an early study in this series, Voxman (1936) formulated the following conclusions.

1. There is no evidence of a fixed formant as the determinate of clarinet timbre.

2. There is no consistent concentration of energy in any specific harmonic.

3. Both odd- and even-numbered harmonics exist but the odd-numbered harmonics predominate throughout. This predominance decreases with an increase of the fundamental frequency.

4. The acoustic spectrum for a tone of a given frequency is definitely a function of the intensity level; the louder the tone played, the more extended is the series of overtones and the greater their intensity relative to the fundamental.

Meyer (1964a; 1965) concluded that well known generalizations about the characteristically "flat" pitch quality of clarinet tones may be associated with the relative weakness in the intensities of the even harmonic spectral components.

Jost (1967) conducted a study concerning differences in the tone quality of three classifications of clarinet players: a member of a major professional symphony orchestra, a member of a amateur community orchestra, and a member of a popular dance band. Subjects in the experiment described distinct timbral differences, including brightness differences, associated with the tones produced by the three clarinet players. In general, the clarinet tones produced by the professional player were relatively dark compared to the tones produced by the other two clarinetists. The tones produced by the dance band clarinetist were relatively bright compared to the tones of the other two clarinetists.

Jost found that the harmonic structures of the clarinet tones also varied with different levels of loudness. He concluded that an increase of blowing pressure needed to produce relatively loud tones resulted in an increase in the relative number and intensities of higher harmonic components. Relatively soft tones were darker than relatively loud tones, particularly for the amateur clarinetist. The harmonic structure of tones produced by the professional orchestral clarinetist was more consistent for tones of different loudness.

Jost concluded that the harmonic structures of clarinet tones produced by performers of different playing ability and experience were a result of differences in the methods of tone production involving the amount of blowing pressure needed to produce tones of equivalent loudness. Jost stated, with an increase in the blowing pressure required for an increase in loudness of a clarinet tone, the formants are displaced to higher frequency regions. The result was an increase of relative brightness of clarinet tone.

According to Jost, the pitch of a clarinet tone is primarily dependent on the fundamental frequency but is also affected by its harmonic structure. The harmonic structure of a clarinet tone varies throughout the playing range of the instrument (involving selection of the fundamental frequency) and according to the blowing pressure required for loudness variation (intensity variation). In general, the pitch, tone quality, and loudness of clarinet tones are interrelated subjective attributes of sound and each are dependent on three physical attributes of sound: fundamental frequency, harmonic structure, and intensity.

Brightness Preferences of Individual Performers

The relative brightness of a musical tone also represents an area of tone quality evaluation involving the pedagogy of woodwind and brasswind tone production. Although the characteristic timbre of an instrument may be quite distinct to a listener, the timbral quality may vary for tones produced by different performers of the same instrument type. The evaluation of tone quality is, however, subjective; and judgments about the acceptability of a performer's tone quality vary among musicians. Madsen and Geringer (1976; 1981) state that in studies concerning preferences for tone quality and intonation, subjects were unable to discriminate "good" versus "bad" tone quality within a musical context. The researchers recommended that the vast amount of time that many instrumental musicians devote to the search for the ultimate tone quality may be more profitably spent on the development of good intonation.

The characteristic tone quality of a woodwind instrument also varies among performers in different countries and different schools of playing within a single country. Research evidence suggests a possible reason many musicians, particularly in the United States and Germany, prefer a relatively dark tone quality. Such a preference may, however, actually be a preference for tones with a minimum of "roughness." According to Helmholtz (1863),

> 1. simple tones sound sweet and pleasant without any roughness, but dull at low frequencies;
>
> 2. complex tones with moderately loud lower harmonics up to the 6th sound more musical and rich than do simple tones, but they are still sweet and pleasant if the higher harmonics are absent;
>
> 3. complex tones with strong harmonics beyond the 6th or 7th sound sharp, rough, and penetrating (pp. 118-119).

Lichte (1941) defined roughness as being present in tones containing consecutive high harmonics above the 6th. Plomp and Levelt (1965) stated that roughness effects of higher harmonics are due to the number of critical bands for frequency detection in hearing. According to Levelt et al. (1966), tone pairs containing many harmonics sound generally more dissonant than tone pairs containing only a few harmonics. Terhardt (1974b) described the tonal dissonance of roughness as an historical origin of the Western musical scale.

Based on the above statements, an acceptable and pleasing tone quality appears to be a result of a predominance of the lower 6 harmonics. If true, this would account for the desire of many instrumental musicians to produce a relatively dark sound. For example, tone production factors which would diminish the predominance of the higher frequency harmonic components of oboe tones would result in a relatively darker oboe tone quality. Consequently, a relatively darker oboe tone quality would be more similar to the brightness quality of many other instrument timbres.

Numerous pedagogical articles in music education journals describe various other physical factors of woodwind tone production which may have an effect on the brightness quality of a performer's tone. These include primary aspects such as variation in the quality of instrument; mechanical condition of the instrument (leaking pads, for example); physical dimensions of the mouthpiece; and, density and thickness of reeds.

Summary of Apparent Brightness Differences of Flute, Oboe, and Clarinet Tones

The following statements summarize apparent brightness characteristics and differences of flute, oboe, and clarinet timbres.

1. Flute tones are relatively dark consisting of five or fewer consecutive harmonics in which the fundamental harmonic is strongly predominant.

2. Oboe tones are relatively bright consisting of many lower and higher harmonics but the lower harmonics are predominant in relative intensities.

3. Although clarinet tones consist of many harmonics, tones produced in the lower register of the instrument are relatively dark due to the prominance of the fundamental and third harmonics and the relative weakness in the intensities of the even-numbered harmonics.

4. The harmonic structures of woodwind instrument timbre varies somewhat for tones throughout the frequency range of performance.

5. The harmonic structures of flute, oboe, and clarinet tones become more similar in the upper registers of each instrument.

6. The brightness quality of flute, oboe, and clarinet timbres vary among individual musicians due to variables involving methods of tone production.

CHAPTER III

RESEARCH METHOD AND PROCEDURES

Research Design

The study was designed to determine the intonation tendencies of flute, oboe, and clarinet players. The research design for the study was a mixed 3 (instrument) X 15 (scale tone) factorial analysis of covariance with a covariate changing across trials. The three levels of the between subjects factor represent the three woodwind instruments involved in the study (flute, oboe, and clarinet). The 15 levels of the within subjects factor, which is nested in the between subjects factor, represent the 15 scale tones performed by subjects on their respective instruments. The dependent variable was the measurement, in cent deviations, of intonation tendencies of subjects during pitch-matching trials involving the 15 scale tones. The covariate (intonation deficiencies) was the measurement of the instrument intonation deficiencies occurring across the 15 scale tones performed by each subject.

The covariate of the research design was a concomitant variable which represented a possible contamination factor of the dependent variable. The analysis of covariance permitted a post-hoc statistical control for one or more concomitant variables and reduced their influences on the dependent variable for the comparison of group means. The result of the analysis provided a set of adjusted means for the dependent variable which described additional group differences not attributed to the covariate factor (Winer, 1971).

Subjects

The subjects for the study were undergraduate and graduate music majors at the University of North Carolina at Greensboro ($\underline{n}$ =9 per instrument group). Flute, oboe, or clarinet was the major instrument of each subject. Music instructors of the three instruments asked their students to voluntarily participate in a study of woodwind intonation characteristics. Volunteers were accepted until a total of nine subjects per instrument group was acquired.

After possible contamination factors involving between group differences of age, education, and experience were examined, the subject selection process was determined to be valid. As shown in Table 1 below, the three experimental groups were similar with regard to chronological age, education (years of college study), and musical experience (years of playing experience and years of private study on the instrument). Complete data concerning the chronological age, education, and musical experience of individual subjects are shown in Appendix A.

TABLE 1

Group means for chronological age, education, and experience of subjects.

	Age of Subjects	Years of College Study	Years of Playing Instrument	Years of Private Study
Instrument Group:				
Flute	19.87	2.44	8.67	6.00
Oboe	21.00	3.33	7.45	5.56
Clarinet	20.56	2.89	8.00	5.89
All Subjects:				
Mean	20.48	2.89	8.41	5.82
Median	20.00	2.00	8.00	6.00
Minimum	18.00	1.00	2.00	1.00
Maximum	28.00	10.00	15.00	14.00

Description of the Study

The study involved two tests of intonation performance. The Intonation Deficiencies Test (IDT) was designed to determine the characteristic "sharp" and "flat" intonation deficiencies for individual scale tones across each subject's instrument; these data served as the covariate. During the IDT, subjects performed two trials for each of the 15 scale tones with their respective instruments, resulting in a total of 30 trials. Subjects were instructed not to adjust for the characteristic "sharp" or "flat" intonation of each tone resulting from instrument construction. Subjects were also asked to perform each response tone with the "best" possible tone quality and with a loudness they perceived to be typicallly mezzo-forte for their instruments. The requested duration of each response tone was approximately three to four seconds.

The Intonation Tendencies Test (ITT) was designed to determine the intonation tendencies of subjects when they performed a scale tone and attempted to match the pitch of recorded stimulus tone. Subjects performed two trials for each of the 15 scale tones. For each of the 30 trials of the ITT, the subjects listened to a recorded stimulus tone; and immediately after its conclusion, performed a response tone of equivalent pitch with a duration of approximately three to four seconds. Subjects also performed each response tone in the ITT with the "best" possible tone quality and with a loudness they perceived to be mezzo-forte.

The test administrator specifically asked the subjects to perform tones in each test with the same perceived loudness, but the sound pressure level during performance trials were not measured. The variance in loudness across subjects may suggest a weakness in the study, but loudness studies indicate that musicians are capable of making far more subtle loudness judgments than traditional dynamic markings such as mezzo-forte suggest (Radocy and Boyle, 1979, p. 47).

The two tests for the study were administered individually to each subject. For each test, subjects performed two test trials for each of the 15 scale tones. The nine subjects in each group performed the 30 trials for each test in a different random order arrangement of scale tones. Subjects used individualized test sheets which included trial numbers and appropriate musical notation for the order of scale tones performed in each test. For the ITT, the musical notation for the order of scale tones corresponded to the recorded tones used as pitch stimuli during the pitch-matching trials.

In an attempt to administer the tests efficiently and to prevent decreased reliability due to fatique, the duration of each test was limited to approximately six minutes. The duration of each test trial for both the IDT and the ITT was approximately twelve seconds. Each test trial of the IDT included an announcement of test trial number (approximately three seconds), the subject's response tone (three to four seconds), and a rest period between trials (approximately five to six seconds). The test administrator measured the response of the subject for each trial and recorded the measurement data on a copy of the test sheet used by the subject.

Each test trial of the ITT included an announcement of test trial number (approximately three seconds), presentation of a stimulus test tone of three seconds duration, the subject's response tone (three to four seconds), and a rest period between trials (approximately two to three seconds) during which the test administrator recorded the measurement data. The total duration of the 30 trials for each test (with 12 seconds per trial) was approximately 360 seconds (six minutes).

The total duration of the individual test administration for each subject was approximately 25 minutes. The complete procedure for each subject included a brief description of the study by the administrator, verbal announcement of initial test instructions, additional instrument warmup and tuning, presentation of recorded instructions for each test, and two practice trials prior to each test.

Selection of Scale Tones

The tests were limited to the study of 15 scale tones (within subjects factor). This decision allowed for an appropriate duration of each test which limited any fatique factor which might reduce the test reliability. Musical notation of the scale tones selected for use in the study are shown in Figure 1 below.

Two criteria were used for selection of the specific scale tones involved in the experiment. The two octave range of scale tones from d_4 to d_6 was selected to

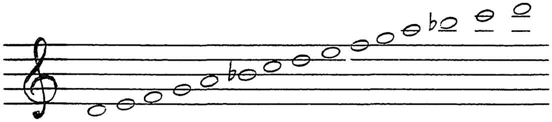


FIGURE 1. Scale tones involved in the study.

represent a performance range common to flute, oboe, and clarinet. The specific 15 scale tones within the two octave range were selected to include a minimum of key signature flats and sharps for each instrument type. Test sheets used by clarinet players as subjects included the appropriate musical notation of transposition for B-flat clarinet.

Test Materials and Equipment

Test sheets

Test sheets were used during the administration of the two tests to provide subjects with a visual stimulus of the musical notation for the scale tone performed during each test trial. Copies of the test sheets also were used by the test administrator as score sheets to manually record measurement observations of the subjects' responses. A copy of the test sheet used as a score sheet for subject F1 was included in Appendix C.

Nine equivalent test form sheets were designed and randomly assigned to the nine subjects within each group for each test. Each test form included 30 trials (two for each scale tone) arranged in a different random order to eliminate the possible effects of trial order of the 15 scale tones.

Test equipment

The following audio equipment was used to produce master cassette tapes of recorded audio test stimuli.

Ensoniq ESQ1 digital wave synthesizer with on-board eight-track sequencer

Aiwa stereo cassette recorder

Yamaha Model MTX four track cassette recorder with variable pitch control

Yamaha Professional Series Model P2100 power amplifier

JBL Model 4312 control monitor (loudspeaker)

6 Maxell XLII 90 high bias chromium oxide audio cassettes

Stereo headphones and assorted audio cables

The Yamaha recorder, amplifier, and loudspeaker also were used to present the audio test stimuli during the administration of two tests. The cent deviation meter of a Korg Model WT-12 audio tuner was used by the test administrator to measure cent deviations of the fundamental frequencies of response tones during the tests. Additional equipment used in the experiment included a music stand, two chairs, and a table.

Cassette tapes of audio test stimuli

Audio cassette tapes were used to present the audio test stimuli. For both the IDT and ITT, the audio test stimuli included recorded verbal test instructions, pitch reference tones of a_4 (440 Hz) for instrument tuning and announcement of test trial numbers. For the ITT only, the audio test stimuli also included the stimulus tones for each performance trial.

The tapes were recorded in the Electronic Music Laboratory at the North Carolina School of Science and Mathematics (Durham). The 15 stimulus tones used in the ITT and the reference tone used for tuning were produced with an Ensoniq ESQ1 digital wave synthesizer using a programmed cartridge sound labeled by the manufacturer as "BASIC." The timbre of the BASIC sound of the synthesizer is similar to that of a sawtooth waveform.

The stimulus tones were recorded initially with a digital sequencer of the synthesizer. The stimulus tones for each of the 30 test trials of the ITT were produced and recorded digitally with equivalent intensity and duration. Equivalent intensity was achieved by utilization of the velocity sensitive controls for the synthesizer keyboard. Equivalent duration of three seconds was controlled by the sequencer by recording each tone as a whole note of four beats (one measure of the sequencer) at a tempo of 80 beats per minute.

Using the "Create Sequence" function of the digital sequencer, 15 "sequences" were recorded, including one sequence for each of the 15 scale tones. For example, sequence one included only scale tone d_4, and sequence two included scale tone e_4. Each sequence included four measures (with 4 beats per measure) at a tempo of 80 beats per minute. The first measure of each sequence consisted of a stimulus tone of three seconds and was followed by three measures of the sequence which did not contain an audio stimulus from the synthesizer. The tuning reference tone of a_4 (440 Hz) with a duration of 30 seconds was produced on the synthesizer with the "BASIC" programmed sound and recorded as sequence number 16 on the digital sequencer.

Using the "Create Song" function of the sequencer, two series of the 15 sequences were "chained" into a "song" for each of the nine test sheets. The nine songs recorded on the sequencer were designated as Songs A through I. The unique random arrangement of the scale tones of the 30 sequences for each song corresponded to the musical notation for the 30 test trials of the appropriate test form sheet used in the experiment.

Using an Aiwa stereo cassette recorder, a set of verbal test instructions and announcements of trial numbers 1-30 (at twelve second intervals) were recorded on an audio cassette tape (cassette 1). The master cassette tapes including instruction, trial numbers, tuning reference tone, and audio test stimuli for each trial were transferred to master cassette tapes for each of the test forms by using multitrack recording techniques.

Testing Procedure

Test facility and physical arrangement of test equipment

The experiment was conducted in a classroom of the School of Music at the University of North Carolina at Greensboro. The physical dimension of the test room was approximately 15 feet by 30 feet with a ceiling height of approximately 12 feet.

The audio equipment used to present the recorded audio test stimuli included Yamaha four track tape deck used to record the test tapes, a Yamaha Professional Series Model P2100 power amplifier, and a JBL Model 4312 control monitor (loudspeaker). The Yamaha tape deck also was used to record the audio stimuli. The equipment was placed in one corner of the room with a table and chair for the test administrator. A music stand and chair for subjects were placed in the center of the test room.

Test administration

Tests were administered to each subject on an individual basis during one of two test days. The test administrator contacted each subject at least one week prior to the administration of the tests to schedule date and time for participation in the study. Upon arrival, subjects prepared for the tests by playing their instruments with their usual warmup procedures. Each subject was allowed at least 15 minutes to perform the warmup in one of several practice rooms adjacent to the testing room.

Before each subject entered the testing room, the test administrator conducted an equipment check and calibrated the frequency of the cent deviation meter used for data collection. The test tape was played to ensure that the test form number of the test tape corresponded with the test sheet being used. The tape was also played to calibrate the test tape with the cent deviation meter. The playback speed of the test tape was adjusted using the variable pitch control of the cassette recorder to calibrate tuning reference tone of the master cassette tape with a fundamental frequency of a_4 (440 Hz). The test sheet of the preassigned test form for each subject was placed on the music stand prior to each individual testing session.

After a subject entered the test room, the test administrator introduced himself and asked the subject to be seated. Following a brief description of the experiment, the test administrator asked the subject questions concerning chronological age, educational background, and performance experience. The test administrator then asked the subject to play the instrument for several minutes to become accustomed to the acoustical conditions of the test room. The subject was allowed the option to sit or stand during the remainder of the test administration.

When a subject was ready to begin, the test administrator presented the recorded instructions for the Intonation Deficiencies Test. Following the instructions, the test administrator asked if the subject needed clarification of the test procedure. After discussion of the instructions, the subject listened to the 30 second tuning reference tone and made tuning adjustments of the instrument. The tuning process repeated as needed until the subject determined that the instrument was in tune.

After the subject finished tuning the instrument, the test administrator asked if the subject was ready to begin the test or had any other questions. When the subject was ready to begin, the test administrator started the audio playback of the cassette tape with recorded announcements of test trial numbers for the IDT. The subject performed the response tones for each of the 30 performance trials using the randomly preassigned test sheet.

A similar procedure was used for the administration of the Intonation Tendencies Test. The cassette tape for the ITT also included the audio stimuli for the pitch matching trials. After completing the ITT, the test administrator thanked subjects for participating in the experiment and stated that they would be notified of the results of the experiment.

Data collection

During the administration of the IDT, the test administrator used the cent deviation meter of a Korg Model WT-12 Audio Tuner to measure the direction and magnitude of cent deviations for each trial. A positive cent deviation for an IDT test trial represented a characteristically "sharp" intonation deficiency of a specific scale tone of a subject's instrument relative to equal tempered tuning. A negative cent deviation represented a characteristically "flat" intonation deficiency of a specific scale tone of an instrument.

During the administration of the ITT, the test administrator measured cent deviations for differences in the fundamental frequency of a response tone with a corresponding stimulus tone in each performance trial. Stimulus tones were tuned to the equal-tempered chromatic scale based on a_4 (440 Hz) as a reference for tuning. The positive or negative cent deviations for the ITT test trials indicated the respectively "sharp" or "flat" intonation tendencies of each subject. A "sharp" intonation tendency corresponded to a response tone produced with a fundamental frequency which was higher than the fundamental frequency of its corresponding stimulus tone. A "flat" intonation tendency indicated a response tone produced with a fundamental frequency which was lower than the fundamental frequency of the corresponding stimulus tone.

Data for each subject's 30 performance trials in each test were transferred from the individual test score sheets to master score sheets. The complete data for the IDT and the ITT are shown in tables of Appendix D and Appendix E, respectively.

Statistical Analysis Procedures

Test reliability

To determine intrasubject and intersubject test reliability and to obtain accurate test data, each subject participated in two test trials for each of the fifteen scale tones performed in each of the two tests. Test reliability coefficients were calculated using the Pearson Product Moment Correlation procedure of the MINITAB computer program, (Ryan, Joiner and Ryan, 1985).

The method used to determine the intrasubject test reliability for the IDT and ITT involved the correlation of the two sets of cent deviations for the 15 scale tones of a test (test-retest reliability). This method resulted in the calculation of 27 reliability coefficients for each test to determine which of the subjects had consistent cent deviation scores.

The method used to determine intersubject test reliability for each test involved the correlation of the two sets of cent deviation scores produced by all subjects for each scale tone. This method resulted in the calculation of 15 intersubject reliability coefficients per test and determined the consistency of cent deviation scores for each of the 15 scale tones.

Relationships of age, education, and musical experience with the overall intonation tendencies of each subject

The mean of the 30 test trial cent deviations for each subject during the IDT (Appendix H) was calculated as a measure of the overall intonation deficiencies of each subject's instrument. The mean of the 30 test trial cent deviations for each subject during the ITT (Appendix H) was calculated as a measure of the overall intonation tendency of the subject. The resultant means for each subject in each test were used to study chronological age, education, private study, and experience as possible factors of contamination. The Pearson Product Moment Correlation procedure of the MINITAB computer program was used to analyze possible contamination relationships.

Tests of the null hypotheses

The mean of each subject's two cent deviation scores for the same scale tone of a test sheet was calculated for for both the IDT and the ITT. The resultant 15 mean cent deviation scores for each test (Appendix I) were used in the statistical analysis. The statistical design was a 3 (instrument) by 15 (scale tone) analysis of covariance with repeated measures on the second factor. The Greenhouse-Geisser test with corrected degrees of freedom for a repeated measures design was used to determine the probability of significant effects for the within subjects factor scale tone and the interaction of instrument and scale tone (Muller and Barton, 1988). The statistical analysis procedure for tests of the null hypotheses involved use of the BMDP-P2V Statistical Analysis computer program (Dixon and Brown, 1989). The program provided cell means of the dependent variable and covariate in addition to the inferential statistics used for tests of the null hypotheses.

Line graphs and regression lines of group cell means

The Chart-Master computer program, Version 6.1 (n.d.) was used to produce line graphs and regression lines of the group cell means. The line graphs and regression lines were plotted to illustrate group differences for each scale tone for both tests and to illustrate similarities of the dependent variable and the covariate for scale tones within each group.

Post-hoc analyses

The Bonferroni *t* test was used in the *post-hoc* analyses to determine significant differences between levels of the main effects or interaction effects involving repeated measures research designs. The Bonferroni test adjusts the overall alpha level for the number of comparisons being performed. The test is considered as a test which is not overly conservative nor too liberal involving alpha error (Miller, 1966; Winer, 1971).

CHAPTER IV

RESULTS AND STATISTICAL ANALYSIS

Data for the Intonation Deficiencies Test (IDT) and Intonation Tendencies Test (ITT) were included in Appendix D and Appendix E, respectively. The raw data consisted of cent deviation measurements for each subject's response tones for the 30 trials of each test, including two trials for each of the fifteen scale tones performed on each subject's instrument.

Test Reliability

Intrasubject test reliability

The intrasubject reliability was analyzed for the IDT and ITT with the Pearson Product Moment Correlation. The procedure involved a correlation of each cent deviation measurement for the first trials of the 15 scale tones with those of the second trials. The intrasubject reliability coefficients for each subject were included in Appendix F.

In general, the cent deviation scores of most subjects were consistent. For the IDT, seventy-four percent of the intrasubject reliability coefficients were in the range of r = .65 to .95. For the ITT, ninety-six percent of the intrasubject reliability coefficients (n = 27) were in the range of r = .65 to .95.

Intersubject test reliability

The intersubject reliability of the method and procedure for each test also was analyzed for each scale tone with the Pearson Product Moment Correlation. The analysis involved the correlation of the corresponding pairs of cent deviation measurements for all subjects (n = 27) for each of the fifteen scale tones involved in the study. The intersubject reliability coefficients for each scale tone were included in Appendix G.

The range of intersubject reliability coefficients for all of the fifteen scale tones of the IDT was r = .82 to .97 with a median coefficient of r = .93. The range of intersubject reliability coefficients for the IDT was r = .52 to .90 with a median coefficient of r = .79. Ninety-three percent of the intersubject reliability coefficients for the ITT were in the range of r = .65 to .90. The range of coefficients for twelve of the fifteen scale tones of the ITT was r = .75 to .90. The scores of subjects were less consistent in the ITT for scale tones c_5 (r = .52), d_5 (r = .65), and e_5 (r = .66).

Apparently, the intonation deficiencies for scale tones of flute, oboe, and clarinet were very consistent for test trials of the IDT. Subjects were, however, less consistent in their intonation tendencies during the ITT, particularly for scale tones c_5, d_5, and e_5.

Relationships of Age, Education, and Experience with Overall Intonation Deficiencies and Intonation Tendencies of Subjects

The correlation coefficients for relationships between the overall intonation deficiencies and intonation tendencies of subjects with the chronological age, education (years of college study), years of playing experience with the instrument, or years of private study are included in Table 2 below.

TABLE 2

Correlation coefficients for relationships of age, education, and musical experience of subjects with overall intonation deficiencies and with overall intonation tendencies.

	Intonation Deficiencies	Intonation Tendencies
Chronological Age	-.12	-.09
Years of College Study	-.26	-.15
Years on Instrument	-.36*	.07
Years of Private Study	-.30	.06

* $p = .05$

Based on the above correlation coefficients for the IDT, there is weak evidence to suggest possible inverse relationships of various types of musical performance experience with the overall instrument intonation deficiencies. According to the *t* test of significance for correlation coefficents, the relationship ($\underline{r}$ = −.363) of intonation deficiencies with years of playing experience with the instrument was significant ($\underline{p}$ = .05). In general, the instrument intonation deficiencies of scale tones for less experienced woodwind players tended to be "sharp" relative to those for more experienced players.

Despite the apparent relationships of a subject's overall instrument intonation deficiencies with the subject's musical experience levels, the relationships of intonation tendencies with chronological age, education, and various types of musical experience were negligible. The values of the correlation coefficients for these relationships were close to zero, in a range of $\underline{r}$ = −.153 to .073. In particular, the values of the coefficients were closest to zero for years of musical experience playing the instrument and private study.

As seen in Appendix A, each of the subjects performed on professional model brand name instruments such that the brand of instrument was not an apparent factor. Experience did appear to be a factor of intonation deficiencies. More experienced woodwind performers may have developed more advanced tone production techniques which improved the general intonation characteristics throughout the performance range of an instrument. Consequently, the more experienced players required fewer intonation adjustments involving embouchure and other physical factors of tone production during intonation tendencies performance tasks. The overall intonation tendencies of a subject apparently were not related, however, to musical experience.

Results of the Analysis of Covariance

Statistical design and null hypotheses

The mean of the two cent deviation scores for each of the 15 scale tones was calculated for each subject's responses in the IDT and the ITT. The resultant 15 mean cent deviations for each test (Appendix H) were used in the statistical analysis. The statistical design was a two factor 3 (instrument) by 15 (scale tone) analysis of covariance with repeated measures on the second factor. Results of the analysis of covariance (ANCOVA) with repeated measures procedure using the BMDP-P2V Statistical Analysis program are included in Table 3.

The first null hypothesis involved the between subjects factor of instrument with three levels and concerned the effects of timbral differences of flute, oboe, and clarinet tones on the intonation tendencies of a woodwind performer. The second null hypothesis examined the effects of scale tone (within subjects factor with 15 levels), and the third null hypothesis involved the possible interaction between instrument and scale tone. The stated level of probability used for the treatment of the null hypotheses was $p = .05$.

TABLE 3

Results of Analysis of Covariance with Repeated Measures.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Probability	Greenhouse Geisser Probability	Regression Coefficients
Instrument (I)	2157.42	2	1078.71	5.62	0.0103		
Covariate	783.38	1	783.38	4.08	0.0551		0.1463
1 Error	4412.59	23	191.85				
Scale tone (S)	365.78	14	26.13	1.25	0.2402	0.2811	
SI interaction	960.77	28	34.31	1.64	0.0243	0.0753	
Covariate	2671.05	1	2671.05	127.38	0.0000		0.4220
2 Error	7024.43	335	20.97				

Epsilon Factor for Greenhouse-Geisser degrees of freedom adjustment in Error Term 2 = 0.4927

Covariate effect

The ANCOVA revealed a significant effect of instrument intonation deficiency on instrument intonation tendency across individual scale tones ($p < .0001$, $F = 127.28$). These results support the assumption that the covariate instrument intonation deficiency was a significant concomitant factor of contamination for the dependent variable and that an analysis of covariance procedure was appropriate.

The cell means, in cent deviation, for the instrument intonation deficiencies and intonation tendencies are included in Tables 4 and 5, respectively. Figures 2, 3, and 4 illustrate the influence of instrument intonation deficiencies on the intonation tendencies of subjects according to instrument group and scale tone.

TABLE 4

Cell means, in cent deviation, for test of instrument intonation deficiencies (covariate).

	Scale tone														
Group	d_4	e_4	f_4	g_4	a_4	$b^{\flat}_4$	c_5	d_5	e_5	f_5	g_5	a_5	$b^{\flat}_5$	c_6	d_6
Flute	1.06	0.33	3.33	4.44	5.28	4.28	10.33	13.22	5.11	6.44	6.61	9.56	8.89	11.50	7.33
Oboe	3.11	7.06	3.39	12.50	5.22	4.11	12.78	15.17	16.33	4.11	14.72	-6.22	-12.61	11.17	19.06
Clarinet	-2.39	-0.83	2.00	8.17	0.78	1.94	1.61	1.28	1.83	5.06	7.44	8.89	8.22	3.06	4.56

TABLE 5

Cell means, in cent deviation, for test of intonation tendencies (dependent variable).

	Scale tone														
Group	d_4	e_4	f_4	g_4	a_4	$b^{\flat}_4$	c_5	d_5	e_5	f_5	g_5	a_5	$b^{\flat}_5$	c_6	d_6
Flute	2.28	4.00	5.17	6.00	7.89	8.50	6.83	10.33	5.17	5.61	5.28	5.06	6.17	6.28	5.22
Oboe	-0.83	1.39	-2.11	1.06	-0.11	0.72	-0.06	6.61	10.83	-1.50	3.28	-2.50	-6.39	0.61	4.00
Clarinet	2.17	1.33	3.89	8.06	3.00	3.83	2.83	3.11	2.72	4.83	7.89	10.11	9.61	6.72	4.78

Flute. The line graphs of the cell means of the IDT and ITT for the flute group (Figure 4) are similar, illustrating the effect of instrument intonation deficiencies on the intonation tendencies of the flute players. The slopes of the two regression lines are quite different.

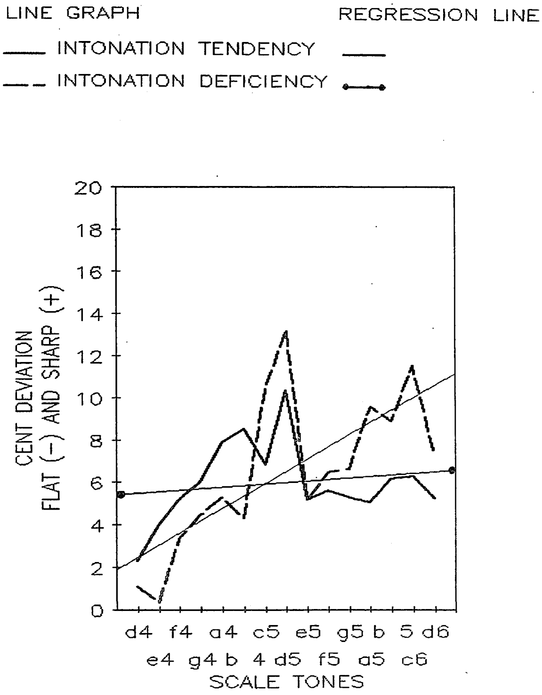


FIGURE 2. Instrument intonation deficiencies and intonation tendencies for the flute group.

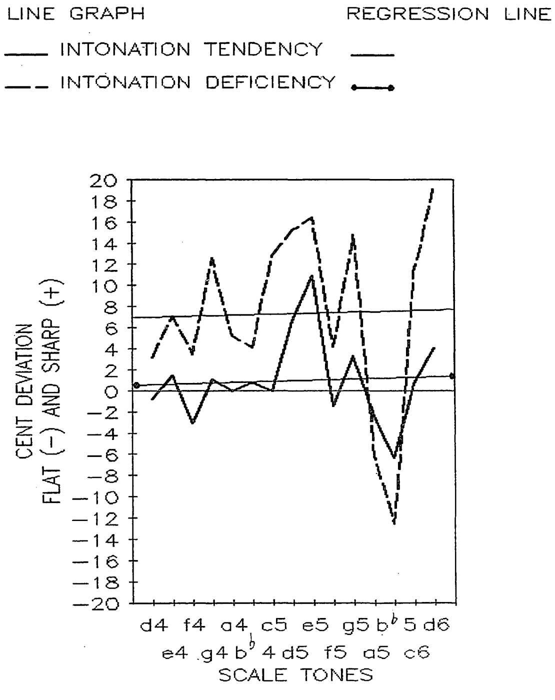


FIGURE 3. Instrument intonation deficiencies and intonation tendencies for the oboe group.

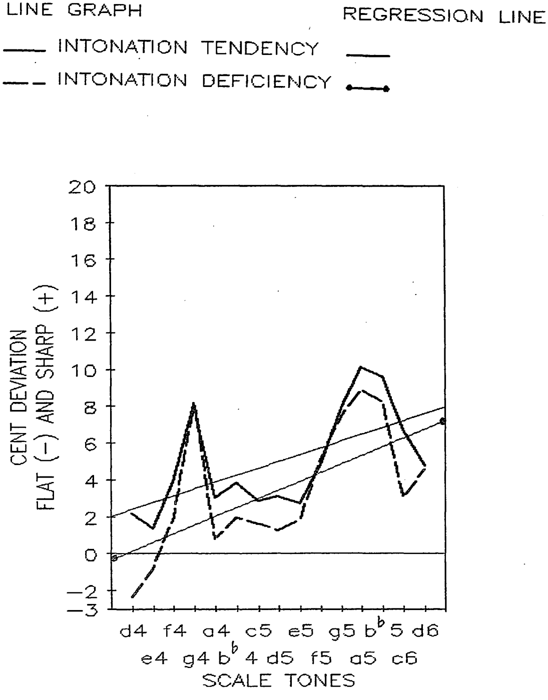


FIGURE 4. Instrument intonation deficiencies and intonation tendencies for the clarinet group.

The cent deviations for the 15 scale tones performed by flute players in the IDT were positive values, indicating sharp intonation deficiencies of the flute throughout the two octave range. The cent deviations for the ITT also indicated sharp intonation during the pitch-matching trials; however, flute players increased the sharp intonation of scale tones in the lower octave of the instrument but decreased the sharp intonation for scale tones in the higher octave. The resultant slope of the regression line for cell means of the dependent variable was approximately zero, indicating a general intonation tendencies cent deviation of six cents for scale tones performed by the flute group.

Oboe. The general shapes of the line graphs for the instrument intonation deficiencies and intonation tendencies for the oboe group were also similar, indicating the effect of the covariate. The slopes of the regression lines were also similar, but the regression line of the cell means for the intonation deficiencies test is approximately five cents higher than the regression line for the intonation tendencies test. Although the general intonation deficiencies were sharp for the majority of scale tones, the intonation tendencies of oboe players for these tones were in an approximate range of -2.0 to 2.0 cents. However, the intonation tendencies of the oboe group were approximately 8.0 cents sharp for d_5 and e_5 and

-6.0 cents flat for b^{b}_5, apparently due to the extremely sharp and flat instrument intonation deficiencies of the oboe for these scale tones.

Clarinet. In general, the greatest similarity of cell means of the cent deviation scores for the two tests appeared in the clarinet group. The line graphs of the cell means for the two tests illustrate relatively small differences in the intonation tendencies of clarinet subjects as a group and the intonation deficiencies of the instrument. The slopes of the regression lines for cell means of the clarinet group are also similar for the two tests and only differ by approximately one to two cents throughout the two octave range of scale tones.

Based on these observations, the intonation tendencies of clarinet players as subjects appear to be strongly related to the instrument intonation deficiencies of the clarinet. However, subjects in the clarinet group appeared to have a general tendency to perform with increased sharpness during pitch-matching trials, particularly for consecutive scale tones a4 to e5 and consecutive scale tones a_5 to d_6.

Tests of the null hypotheses

Main effect of instrument. The value of the *F* test statistic for the between groups factor of instrument was *F* = 5.62 and indicated a significant difference (*p* = .0103). Therefore, the first null hypothesis was rejected. There was a significant difference in the intonation tendencies between instrument groups of flute, oboe, and clarinet players after statistically controlling for the effects of intonation deficiencies.

Main effect of scale tone. The value of the F test statistic for the within subjects factor of scale tone was $F = 1.25$. The probability of significance was $p = 0.24$ for the uncorrected F statistic and $p = .28$ for the Greenhouse-Geisser F correction test statistic. As noted in Chapter III, the Greenhouse-Geisser test is used to adjust the degrees of freedom correction for within subjects factors in research designs involving repeated measures. There was no significant difference in the intonation tendencies of subjects for the main effect of scale tone. Retention of the null hypothesis indicates that the intonation tendencies of subjects did not vary significantly due to the selection of scale tones performed in the study.

Interaction effects of instrument and scale tone

The value of the F statistic for the interaction effect was $F = 1.64$. The probability for the uncorrected F test was $p = .02$. However, the probability for the Greenhouse-Geisser test with corrected degrees of freedom for the F statistic was $p = .08$, not significant at the .05 level. Therefore, the null hypotheses for the interaction effects of instrument and scale tone was not rejected. There was no significant interaction effect of instrument and scale tone.

Post-hoc Analysis of Instrument Main Effect

The adjusted means, in cent deviation, for each level of the instrument main effect associated with timbral differences of instruments are shown in Table 6.

TABLE 6

Adjusted group means for main effect of instrument.

Instrument	Mean of adjusted cell means
Flute	5.72
Oboe	0.37
Clarinet	5.83

The Bonferroni *t* test was used to determine which differences of the main effect of instrument were significant. The Bonferroni critical value calculated to determine a significant difference between two instruments was $t = 4.40$, involving three comparisons with 23 df at the .05 level of probability.

The difference in the adjusted means for flute (5.72 cents) and clarinet (5.83 cents) was .11 cents, smaller than the Bonferroni critical value for significant differences. There was no significant difference ($p > .05$) of intonation tendencies between flute and clarinet players.

The difference in adjusted means for the flute (5.72) and oboe (0.37 cents) was 5.35 cents, which exceeded the Bonferonni critical value. There was a significant difference ($p < .05$) in the intonation tendencies of flute and oboe players.

The difference in the adjusted means for clarinet (5.82 cents) and oboe (0.37 cents) was 5.46 cents, which also exceeded the critical value. There were significant differences ($p < .05$) in the intonation tendencies of clarinet and oboe players.

The adjusted means for the dependent variable reflect a significant difference in the intonation tendencies between the oboe and flute groups and between the oboe and clarinet groups. These general differences were also observed in comparisons of the adjusted cell means for the dependent variable with the exception of e_5.

The adjusted cell means of the dependent variable for individual scale tones of each instrument represent the differences in the intonation tendencies of groups for each scale tone when the covariate effect of instrument intonation deficiencies is statistically controlled. The adjusted cell means for the dependent variable are shown in Table 7.

The line graphs of adjusted cell means for the dependent variable (Figure 5) illustrate the significant differences (p < .05) between flute and oboe groups and between clarinet and oboe groups.

TABLE 7

Adjusted cell means, in cent deviation, for the dependent variable.

	Scale tone														
Group	d_4	e_4	f_4	g_4	a_4	b^{b}_{4}	c_5	d_5	e_5	f_5	g_5	a_5	b^{b}_{5}	c_6	d_6
Flute	4.0	6.0	6.1	6.5	8.1	9.0	5.2	7.6	5.4	5.4	5.0	3.7	5.0	4.2	4.6
Oboe	0.1	0.9	-2.2	-1.4	0.1	1.3	-2.6	3.2	7.0	-0.9	0.0	1.9	0.3	-1.4	-0.8
Clarinet	5.1	3.7	5.3	7.2	4.8	5.2	4.3	4.7	4.2	5.1	7.3	9.0	8.7	7.7	5.2

With the exception of scale tone e_5, the adjusted cell means for the oboe were consistently closer to zero cent deviation than those for flute and clarinet. The values of the adjusted cell means for the other fourteen scale tones of the oboe were in a range of -2.2 to +3.2 cents.

Although the adjusted means for flute and clarinet were not significantly different, the cent deviation values of adjusted cell means for flute were slightly greater ("sharper") than those for clarinet in the lower and middle ranges of scale tones. In contrast, the cent deviation values of adjusted cell means for clarinet were slightly larger positive values than those for flute in the upper range of scale tones.

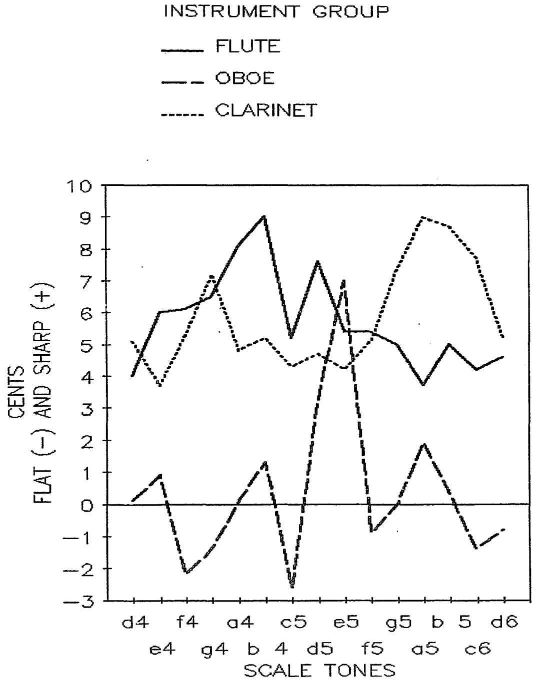


FIGURE 5. Line graphs of the adjusted cell means of the dependent variable for flute, oboe, and clarinet.

CHAPTER V

DISCUSSION

Summary

The purpose of this study was to investigate the intonation tendencies of flute, oboe, and clarinet players. The study focused on two factors of intonation: (1) the performer's instrument and (2) different scale tones performed with the instrument. After accounting for the influence of instrument intonation deficiencies, are there differences in the intonation tendencies of flute, oboe, and clarinet players across 15 different scale tones?

In accordance with the purpose of the study, three null hypotheses were treated.

1. There is no significant difference in the intonation tendencies between groups of flute, oboe, and clarinet players after accounting for instrument intonation deficiencies.
2. There is no significant difference in the intonation tendencies within subjects for the different scale tones being performed after accounting for instrument intonation deficiencies.
3. There is no significant difference in the intonation tendencies of subjects due to an interaction of instrument and scale tone.

The research design for the study was a mixed factor 3 (instrument type) X 15 (scale tone) analysis of covariance with a covariate changing across trials. The dependent variable was a measurement, in cent deviation, of the intonation tendencies of flute, oboe, and clarinet players during pitch-matching trials of the Intonation Tendencies Test (ITT). The stimuli for trials of the ITT consisted of saw-tooth wave tones produced on a electronic synthesizer with equal-tempered tuning (a_4 = 440 Hz). The covariate was a measurement of the sharp and flat instrument intonation deficiencies of instruments with regard to equal tempered tuning during trials of the Intonation Deficiencies Test (IDT).

Based on results of the analysis of covariance, the effects of the covariate factor of instrument intonation deficiencies were significant ($p < .0001$). After statistically controlling for the effects of the covariate, there were significant differences ($p = .01$) in the intonation tendencies between groups of flute, oboe, and clarinet players. According to results of the Bonferonni t test for post-hoc analysis, general intonation tendencies were significantly different ($p = .05$) between groups of flute and oboe players and between groups of clarinet and oboe players. There was no significant effect of scale tones ($p = .28$) on the intonation tendencies of subjects. There was also no significant interaction effect of instrument and scale tone (p = .08) on the intonation tendencies of subjects.

Conclusions

Conclusions for this study were based on a statistical analysis of test data involving 27 university woodwind musicians. Although the analysis of covariance procedure was justified because of identified instrument intonation deficiencies, conclusions based on tests of the null hypotheses were presented with caution due to the limitations of the subject selection. A more comprehensive and possibly unbiased sample is necessary to satisfy research assumptions for the hypothesis tests to derive generalizations about the intonation tendencies of flute, oboe, and clarinet players.

1. There were significant differences in the intonation tendencies of flute, oboe, and clarinet players.

2. There was no significant difference in intonation tendencies for the different scale tones being performed.

With regard to the covariate effect, intonation tendencies were strongly associated with instrument intonation deficiencies. After accounting for the effects of instrument intonation deficiencies, the intonation tendencies of flute and clarinet players were sharp compared to those of oboe players and sharp compared to the sawtooth wave tones.

Specifically, the adjusted group means for both the flute and clarinet players were approximately six cents sharp relative to saw-tooth wave tones used as pitch stimuli. The adjusted group mean for the oboe players was less than one cent sharp relative to the saw-tooth wave tones. This finding may explain ensemble intonation problems which occur between flute and oboe players and between clarinet and oboe players.

The general intonation tendencies of flute and clarinet players were not clearly different. The tendency of the flute group was, however, toward sharp intonation when compared with the clarinet group for the series of lower octave scale tones, a_4 through e_5. In contrast, the general tendency of the clarinet group was toward sharp intonation when compared to the flute group for higher octave scale tones, g_5 through d_6. Perhaps, ensemble intonation problems among flute and clarinet players may occur due to a reversal of the comparative sharp and flat intonation tendencies for each octave of scale tones.

Results of the study support previous speculation concerning apparent pitch differences associated with instrument timbre as a possible source of ensemble intonation problems (Stauffer, 1954; Meyer, 1978b). Based on the results, the general intonation tendencies of a woodwind musician may be associated with both the intonation deficiencies and timbre of a performer's instrument.

Implications of the Study

Instrumental music educators are aware that differences in the intonation tendencies of individual performers of wind instruments contribute to ensemble intonation problems. Results of this study indicate that the sharp and flat intonation tendencies of selected university woodwind musicians are strongly influenced by the intonation deficiencies for individual scale tones of their instruments. The study also provides evidence concerning additional differences in the intonation tendencies of wind players after accounting for the effects of instrument intonation deficiencies. An awareness by performers and teachers concerning both factors of intonation tendencies may be applied to the improvement of ensemble intonation.

With reference to the intonation of symphony orchestras, a commonly used procedure for orchestral ensemble tuning involves the presentation of a tuning reference tone performed by an oboe player. The tuning reference tone generally is performed several times to allow the separate tuning of woodwind, brass, and string sections. Flute and clarinet players in this study tended to tune their instruments and perform with sharp intonation. This tendency would appear to be a possible source of intonation problems among players within the woodwind section and possibly among woodwind, brass, and string sections.

In concert bands, tuning procedures also generally involve the presentation of a tuning reference tone. However, the source of the reference tone may differ among various ensembles, based on the decision of the conductor. For example, the tuning reference tone often is performed by a clarinet player or a trumpet player. Based on speculation concerning the possible effects of instrument timbre on intonation tendencies, ensemble tuning and intonation may also be dependent on the apparent pitch associated with the timbre of a tuning reference tone. Further speculation on the possible effects of timbre on ensemble tuning and intonation would require additional research.

Recommendations for Further Research

Conclusions concerning the results of this study were limited to generalizations about the intonation tendencies of selected subjects from the School of Music at the University of North Carolina at Greensboro. Similar studies at other universities may provide different results. This study should be replicated involving a larger sample of the population of flute, oboe, and clarinet players with various levels of musical experience and from different schools of woodwind performance.

Further research should include studies involving comparisons of various woodwind, brasswind, and string instruments. Studying the use of various instrument timbres as pitch-matching stimuli also could provide information concerning the possible influence of instrument timbre on the tuning of musical instruments and the intonation tendencies of musicians within a context of performance.

BIBLIOGRAPHY

Abeles, H. (1979). Verbal timbre descriptors of isolated clarinet tones. Bulletin of the Council for Research in Music Education, 59, 1-7.

Ahrens, A. (1947). Characteristic limitations of the internal tuning of selected wind instruments as played by amateurs (Doctoral dissertation, The University of Wisconsin).

Apel, W. (Ed.) (1970). Harvard Dictionary of Music, Second Edition. Revised and enlarged by Willi Apel. Cambridge, Mass.: The Belknap Press of Harvard University Press, 1944, 1969, Second Printing 1970.

Arment, H. (1960). A study by means of spectrographic analysis of the brightness and darkness qualities of vowel tones in women's voices (Doctoral dissertation, Indiana University). Dissertation Abstracts International, 21(03), 2989, 60-02989.

Aschoff, V. (1936). Experimentelle Untersuchungen an einer Klarinette. Akustische Zeitschrift, 1, 77-93.

Averitt, F. (1974). An intonation method for flutists (non-exclusive of other instrumentalists and singers) based on the use of difference tones as a practical guide to the achievement of perfectly tuned intervals (Doctoral dissertation, Florida State University).

Bachelder, D. (1977). An investigation of trombone "tone center" (Doctoral dissertation, Brigham Young University, 1976). Dissertation Abstracts International, 37(08-A), 4681, DCJ77-02174.

Bachem, A. (1948). Chroma fixation at the ends of the musical frequency scale. Journal of the Acoustical Society of America, 20, 704-705.

Bachem, A. (1950). Tone height and tone chroma as two different pitch qualities. Acta Psycholgica, 7, 80-88.

Backus, J. (1964). Effect of wall material on the steady-state tone quality of woodwind instruments. Journal of the Acoustical Society of America, 36, 1881-1887.

Backus, J. (1969). The Acoustical Foundations of Music. New York: W. W. Norton & Company, Inc.

Bate, P. (1975). The Oboe, 1956, Third Edition 1975. London/New York: W. W. Norton & Company, Inc.

Bekesy, G. and Rosenblith, W. (1948). The early history of hearing--observations and theories. Journal of the Acoustical Society of America, 20, 727-748.

Benade, A. (1960). Horns, Strings, and Harmony. New York.

Benade, A. (1970). On the tone color of wind instruments. Selmer Bandwagon, Spring issue.

Bergan, J. (1966). Factors affecting pitch discrimination. Bulletin of the Council for Research in Music, 8, 15-21.

Bernier, J. and Stafford, R. (1972). The relationship of musical instrument preference to timbre discrimination. Journal of Research in Music Education, 20, 283-285.

Bilsen, F. (1966). Repetition pitch. Monaural interaction of a sound with the repetition of the same, but phase shifted sound. Acustica, 17, 63-73.

Bilsen, F. (1973). On the influence of the number and the phase of harmonics on the perceptibility of thepitch of complex signals. Acustica, 28, 60-65.

Bilsen, F. and Ritsma, R. (1969/70). Repetition pitch and its implications for hearing theory. Acustica, 22, 63-73.

Blaikley, D. (1890). Acoustics in relation to wind instruments, London.

Boer, E. de. (1956). On the "Residue" in hearing. Academic Thesis Amsterdam.

Boring, E. (1942). Sensation and Perception in the History of Experimental Psychology. New York: Irvington Publishing, 1977. Reprint from History of Experimental Psychology, 1942, 15, 644.

Boring, E. and Stevens, S. (1936). The nature of tonal brightness. Proceeding of the National Academy of Science (Washington), 22, 514-521.

Bosanquant, R. (1881). On the beats of consonances of the form h : 1. Philosophy Magazine 5th Series, 11, 420-436, 492-506.

Boulton, J. (1975). A performance test of flute tone production, intonation and dexterity (Doctoral dissertation , University of Kansas, 1974). Dissertation Abstracts International, 35(09-A), 6177, DCJ75-06158.

Branning, H. (1968). Audition preferences of trained and untrained ears on hearing melodic and harmonic intervals when tuned in just intonation of Pythagorean ratios (Doctoral dissertation, The University of Texas at Austin, 1967). Dissertation Abstracts International, 28(10A), 4197, 68-04242.

Brick, J. (1984). An exploratory study of the effects of a self-instructional programme utilizing the Pitch Master on pitch discrimination and pitch accuracy in performance of young trombonists. Psychology of Music, 12(2), 119-125.

Brown, A. (1973). A comprehensive performance project in oboe literature with a cinefluorographic pilot study of the throat while vibrato tones are played on flute and oboe (Doctoral dissertation, The University of Iowa). Dissertation Abstracts International, 34(06A), 3449, DCJ73-31002.

Brown, H. (1978). The pitch of complex tones: A new method for assessing the existence region (Doctoral dissertation, Northwestern University, 1977). Dissertation Abstracts International, 38(09B), 4498, DDK78-00690.

Buttram, J. (1969). The influence of selected factors on interval identification. Journal of Research in Music Education, 17, 309-315.

Carroll, R. (1971). A comparison of college freshman and senior music majors in their ability to discriminate between pitches of less than a semitone. Ed.D 1970 Northeast Louisiana University, 1970). Dissertation Abstracts International, 32(01A), 473, 71-12521.

Chandler, J. (1981). Intonation: A source of information for the university wind ensemble conductor (Doctoral dissertation, Ball State University). Dissertation Abstracts International, 42(05A), 1843, DEN81-23540.

Chart-Master User's Manual (n.d.). Westport, Connecticutt: Decision Resources, Inc.

Chevallard, P. (1983). Intonational performance as predicted by subject-related variables (Doctoral dissertation, The University of Iowa, 1982). Dissertation Abstracts International, 43(12A), 3747, DEP83-10040.

Chochelle, R. and Firestone, F. (1957). About the sensation of beats between two tones whose frequencies are nearly in a simple ratio. Journal of the Acoustical Society of America, 29, 750.

Church, R. (1984). The effects of elimination and replacement of individual harmonics on the pitch perception of oboe tone. Proceeding of the 1984 Southeastern Music Education Symposium, J. Braswell (Ed.). Athens, Georgia: University of Georgia, 34-40.

Church, R., High, L., Moss, B., and Jeffries, H. (1984). Effects of dark versus bright clarinet timbres on the perception of intonation. The North Carolina Music Educator, 33(1), 22-23.

Corso, J. (1954). Unison tuning of musical instruments. Journal of the Acoustical Society of America, 26, 746-750.

Cotton, J. (1935). Beats and combination tones at intervals between the unison and the octave. Journal of the Acoustical Society of America, 7, 44-50.

Das, P. (1931). Theory of the clarinet. Indian Journal of Physics, 6, 225-240.

Dickreiter, M. (1977). Der Klang der Musikinstrumente: Klangstructur und Klangerlebnis. Muenchen: TR-Verlagsunion.

Dixon, W. and Brown, M. (Eds.) (1979). BMDP-79. Los Angeles: University of California Press.

Doane, C. (1987). Intonation on brass instruments. The Instrumentalist, 41(10), 62-72.

Dowdy, R. (1973). Selection of pitch models for intonation training on the B-flat soprano clarinet: A comparison between the use of initially accurate pitches and the use of controlled corrected examples of the player's own pitches (Doctoral dissertation, University of

Mississippi). Dissertation Abstracts International, 34L(04), 1950A, DCJ73-23648.

Duke, R. (1983/84). Wind instrumentalists' intonational performance of selected musical intervals (Doctoral dissertation, Florida State University, 1983). Dissertation Abstracts International, 44(07), 2079-A, DA83-25403.

Edmondson, F. (1968). The effect of interval direction on pitch acuity in solo vocal performance (Doctoral dissertation, The Florida State University, 1967). Dissertation Abstracts International, 28(07A), 2710, 68-00349.

Edmondson, F. (1972). Effect of interval direction on pitch acuity in solo vocal performance,. The Journal of Research in Music Education, 20, 246-254.

Elliot, C. (1974). Effect of vocalization on the sense of pitch of beginning band class students. The Journal of Research in Music Education, 22, 120-128.

Elliot, C. (1975). Attacks and releases as factors in instrument identification. Journal of the Acoustical Society of America, 34, 35-40.

Eriksen, K. (1974). A comparison of three teaching procedures used in the development of improving intonation in clarinet performance (Doctoral dissertation, Utah State University). Dissertation Abstracts International, 34(12), 7805A, DCJ74-13214.

Feldtkeller, R. and Zwicker, E. (1956). Das Ohr als Nachrichtenempfaenger. Band VI, Monographien der Elektrischen Nachrichtentechnik, R. Feldtkeller (Ed.). Stuttgart: S. Hirzel Verlag.

Figgs, L. (1979). Qualitative differences in trumpet tones as perceived by listeners and by acoustical analysis (Doctoral dissertation, University of Kansas, 1978). Dissertation Abstracts International, 39(11A), 6616, DEL79-10614.

Fletcher, H. (1924). The physical criterion for determining pitch of a musical tone. Physical Review, 23, 427.

Fletcher, H. (1934). Loudness, pitch, and the timbre of musical tones and their relation to intensity, the frequency, and the overtone structure. Journal of the Acoustical Society of America, 6, 59-69.

Fletcher, H. and Munsen, W. (1933). Loudness, its definition, measurement and calculation. Journal of the Acoustical Society of America, 5, 82-108.

Folts, M. (1973). The relative effect of two procedures, as followed by flute, clarinet, and trumpet students while practicing, on the development of tone quality and on selected performance skills: An experiment in student use of sound-recorded practice material (Doctoral dissertation, New York University). Dissertation Abstracts International, 34(03A), 1312, DCJ73-19457.

Fourier, J. (1822). Theorie analytique de la chaleur, English translation, 1878.

Galileo, G. (1638). Discorsi e dimostrazioni mathematiche intorno a due nuove scienze. English translation, Mathematical Discourses Concerning Two New Sciences Relating to Mechanicks and Local Motion, 1730 and 1914.

Geringer, J. (1978). Intonational performance and perception of ascending scales. Journal of Research in Music Education, 26, 32-40.

Geringer, J. and Madsen, C. K. (1981). Verbal and operant discrimination--preference for tome quality and intonation. Psychology of Music, 9, 26-30.

Glass, G. and Stanley, J. (1970). Statistical Methods in Education and Psychology. Englewood Cliffs, New Jersey: Prentice Hall, Inc.

Gosh, R. (1938). Theory of the clarinet. Journal of the Acoustical Society of America, 9, 255-264.

Graves, W. (1963). Improving intonation. The Instrumentalist, 18, 46-47.

Graves, W. (1964). A comparison of three methods for improving intonation in the performance of instrumental music (Doctoral dissertation, University of Colorado, 1963). Dissertation Abstracts International, 24(09), 3590, 64-01921.

Greene, P. (1937). Violin intonation. Journal of the Acoustical Society of America, 1937, 9, 43-46.

Greenhouse, S. and Geisser, S. (1959). On methods in the analysis of profile data. Psychometrika, 24, 95-112.

Greer, R. (1970). The effect of timbre on brasswind intonation. Experimental Research in the Psychology of Music, E. Gorden (Ed.), 6. Iowa City, Iowa: University of Iowa Press.

Hague, B. (1947). The tonal spectra of wind instruments. Proceedings of the Royal Musical Association, 73, 72.

Hahn, J. (1981). A model of octave stretch with implications for the subjective representation of pitch (Doctoral dissertation, The Ohio State University, 1980). Dissertation Abstracts International, 41(10B), 3919, DEN81-07334.

Hallquist, R. (1979). A comparative study of the effect of various mouthpieces on the harmonic context of trumpet tones (Doctoral dissertation, University of Minnesota). Dissertation Abstracts International, 40(02A), 731, DEL79-18339.

Harris, J. (1952). Pitch discrimination. Journal of the Acoustical Society of America, 24, 750-755.

Harris, T. (1978). An investigation of the effectiveness of an intonation training program upon junior and senior high school wind instrumentalists (Doctoral dissertation, University of Illinois). Dissertation Abstracts International, 38(10), 5980-A, 78-04015.

Hays, W. (1973). Statistics for the Social Sciences, Second Edition. London: Holt, Rinehart, and Winston, Inc.

Helmholtz, H. von (1857). Ueber die Vocale. Archiv Holaendische Beitrag Nationale Heilkunst, 1, 354f.

Helmholtz, H. von (1859). Ueber die Klangfarbe der Vocale. Annalen der Physik und Chemie, 99, 1618-1627.

Helmholtz, H. von (1863). Die Lehre von den Tonempfindungen als physiologische Grundlage fuer die Theorie der Musik. F. Vieweg & Sohn, Braunschweig. English translation by A. J. Ellis, On the Sensation of Tone as a Basis for the Theory of Music, 1914, reprinted by Dover Publications, New York, 1954.

Henning, G. and Grosberg, S. (1968). Effects of harmonic components on frequency discrimination. Journal of the Acoustical Society of America, 44, 1386-1389.

Herkner, W. (1969). Der Ausdruck der Klangfarben von Musikinstrumenten (Doctoral dissertation, Universitaet Wien).

Hermann, L. (1889). Phonophotographische Untersuchungen. Archiv ges. Physiologie, 45, 582-620.

Hermann, L. (1890). Phonophotographische Untersuchungen. III. Archiv ges. Physiologie, 47, 347-391.

Hermann, L. (1892). Untersuchungen mittels des neuen Edison'schen Phonographes. Archiv ges. Physiologie, 530, 1-51.

Hermann, L. (1894). Nachtrag zur Untersuchung der Vocalcurven. Archiv ges. Physiologie, 58, 264-279.

Hesse, H.-P. (1972). Die Wahrnehmung von Tonhoehe und Klangfarbe. Koeln (Cologne, West Germany): Staatlisches Institut fuer Musikforschung Preussisch Kulturbesitz, Band VI.

Hesse, H.-P. (1980). Experimente zur Tonhoehenwahrnehmung. Bericht ueber den Internationalen Musikwissenschaftlichen Kongress Berlin 1974. Kassel: Baerenreiter.

Hiigel, L. (1968). The relationship of syllables to pitch and tonguing in brass instrument playing (Doctoral dissertation, University of California at Los Angeles, 1967). Dissertation Abstracts International, 28(09-A), 3700, 68-03263.

Hindsley, M. (1962). Wind instrument guides. Published in an appendix to Tuning the school band and orchestra by R. Pottle (1962). Hammond, Louisiana: Southeastern Louisiana College.

Hohn, R. (1959). A study of the relationship between vowel modification and changes in pitch in the male singing voice: A spectrographic analysis reinforced by the judgment of phonetics experts (Doctoral dissertation, Indiana University). Dissertation Abstracts International, 20(09), 3770, 59-05446.

Hornbostel, E. (1926). Psychologie der Gehoerserscheinungen. Handbuch der normaler und Pathologischer Physiologie, Band 11, 701-730. Berlin: Boethe und Becker.

Houtsma, A. (1971). What determines musical pitch? Journal of Music Therapy, 15, 138-157.

Houtsma, A. and Goldstein, J. (1972). The central origin of pitch of complex tomes: Evidence from musical interval recognition. Journal of the Acoustical Society of America, 51, 520-529.

Ish, R. (1958). Avoiding contest willies. The Instrumentalist, 12(8), 27.

Jameson, R. (1980). The effect of timbre conditions on the prompted and simultaneous pitch matching of three ability groups of trombone performers (Doctoral dissertation, Columbia University Teachers College). Dissertation Abstracts International, 41(01), 8015076.

Jeans, J. (1937). Science and Music. New York: Dover Publications, Inc., (1968 Edition).

Jenkins, R. (1961). Perception of pitch, timbre and loudness. Journal of the Acoustical Society of America, 33, 1550-1557.

Jost, E. (1967). Akustische und psychometrische Untersuchungen an KlarinettenKlaengen. Koeln (Cologne West Germany): Staatliches Institut fuer Musikforschung Preussisch Kulturbesitz, Band I.

Kohler, W. (1915). Akustische Untersuchungen III. Zeitschrift fuer Psychologie, 72, 1-192.

Kohut, D. (1973). Instrumental Music Pedagogy. Englewood Cliffs, N.J: Prentice-Hall, Inc.

Kranz, F. (1923). Sensitivity of the ear as a function of pitch. Physical Review, 22, 66-72.

Krueger, F. (1903). Differenztoene und Konsonanz. Archiv for die ges. Psychologie, 1, 205-275.

Lanier, J. (1960). An acoustical analysis of tones produced by clarinets constructed of various materials. Journal of Research in Music Education, 8, 16-22.

Lehman, P. (1964). The harmonic structure of the bassoon. Journal of the Acoustical Society of America, 36, 1649-1653.

Lehman, P. (1968). Tests and Measurements in Music. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Levelt, W., Geer, J. van de, and Plomp, R. (1966). Triadic comparisons of musical intervals. British Journal of Mathematical and Statistical Psychology, 19, 163-179.

Lewis, D. (1934). Studies in timbre (Doctoral dissertation, The University of Iowa).

Lewis, D. and Cowan, M. (1935). The influence of intensity on the pitch of Violin and Cello tones. Journal of the Acoustical Society of America, 8, 20-22.

Lichte, W. (1941). Attributes of complex tones. Journal of Experimental Psychology, 28, 455-480.

Lichte, W. and Gray, R. (1955). Influence of overtone structure on the pitch of complex tones. Journal of Experimental Psychology, 49, 431-436.

Licklider, J. (1954). Periodicity pitch and place pitch. Journal of the Acoustical Society of America, 26, 945.

Mackworth-Young, R. (1978). A new device for the measurement of pitch. Psychology of Music, 6(1), 65-67.

Madsen, C. K. (1966). The effect of scale direction on pitch acuity in solo vocal performance. Journal of Research in Music Education, 14, 266-265.

Madsen, C. K. (1974). Sharpness and flatness in scalar solo vocal performance. Sciences do l'Art Scientific Aesthetics, 9, 91-97.

Madsen, C. K., Edmondson, F. and Madsen, C. H., Jr. (1969). Modulated frequency discrimination in relationship to age and musical training. Journal of the Acoustical Society of America, 46, 1468-1472.

Madsen, C. K. and Geringer, J. (1976). Preference for trumpet tone quality versus intonation. Council for Research in Music Education, 46, 13-22.

Madsen, C. K. and Geringer, J. (1981). Discrimination between tone and intonation in unaccompanied flute/oboe duets. Journal of Research in Music Education, 29, 305-313.

Mason, J. (1960). Comparison of solo and ensemble performances with reference to Pythagorean, just and equi-tempered intonations. Journal of Research in Music Education, 8, 31-38.

McAdow, N. (1952). Intonation worries and remedies. The Instrumentalist, 7(2), 14-15, 40-41.

McGarry, R. (1968). A teaching experiment to measure the extent to which vocalization contributes to the development of selected instrumental music performance skills: A comparison of the effectiveness of two teaching techniques on instrumental music performance utilizing the Watkins-Farnum Performance Scale (Doctoral dissertation, New York University). Dissertation Abstracts International, 28(11/11-A), 4385, 68-04815.

McGinnis, C. and Gallagher, C. (1941). The mode of vibration of a clarinet reed. Journal of the Acoustical Society of America, 12, 529-536.

McGinnis, C., Hawkins, H., and Sher, N. (1943). An experimental study of the tone quality of the Boehm clarinet. Journal of the Acoustical Society of America, 14, 228-237.

McGinnis, C. and Pepper, R. (1945). Intonation of the Boehm clarinet. Journal of the Acoustical Society of America, 16, 188-193.

McQuerry, L. (1957). The improvement of sensitivity to interval intonation through training with a mechanical apparatus: An exploratory study (Doctoral dissertation, Indiana University). Dissertation Abstracts International, 18(01), 249, 00-24559.

Mersenne, M. (1636). Traitez de la nature des sons et des mouvemens de toute sortes de corps and Harmonie universelle, contenant la theorie et la practique di la musique, Italy.

Meyer, E. and Buchman, G. (1931). Die Klangspektren der Musikinstrumente. Commissioned by Walter de Gruyter. Berlin: Verlag der Akademie der Wissenschaften.

Meyer, J. (1964a). Die Klangspektren von Klarinetten. Das Musikinstrument, 2, 3.

Meyer, J. (1964b). Geraeuschante im Klangspektrum der Musikinstrumente. Das Musikinstrument, 8.

Meyer, J. (1965). Die Richtcharakteristiken von Klarinetten. Das Musikinstrument, 14.

Meyer, J. (1978a). Acoustics and the performance of music (English translation by the author). Frankfurt/Main: Verlag Das Musikinstument.

Meyer, J. (1978b). The dependence of pitch on harmonic sound spectra. Psychology of Music, 6(1), 3-12.

Meyer, J. (1979). Die Toenempfindung bei musikalischen Klaengen in Abhangigkeit vom Grad der Gehoerschulung. Braunschweig.

Meyer, M. (1914). Vorschlaege zur akustischen Terminologie. Zeitschrift fuer Psychologie, 68, 114-119.

Meyer-Eppler, W. (1957). Die dreifache Tonhoehenqualitaet. Dagmar Weise, (Ed.). Festchrift Joseph Schmidt-Goerg zur 60. Geburtstag, 202-212. Bonn: Verlag des Beethovenhauses Bonn.

Miles, E. (1972). Beat elimination as a means of teaching intonation to beginning wind instrumentalists. Journal of Research in Music Education, 20, 496-500.

Miller, D. (1922). The Science of Musical Sounds. New York: The McMillan Company.

Miller, J. (1956). A spectrum analysis of clarinet tones (Doctoral dissertation, The University of Wisconsin). Dissertation Abstracts International, 16(11), 2178, 00-10120.

Miller, R. (1966). Simultaneous Statistical Inference. New York: McGraw-Hill.

Minitab Reference Manual, Release 5.1 (1985). State College, Pennsylvania: Minitab, Inc.

Mooney, J. (1968). The effect of the oral cavity on the tone quality of the clarinet (Doctoral dissertation, Brigham Young University). Dissertation Abstracts International, 32(02A), 1002.

Morgan, C., Garner, W., and Galambros, R. (1951). Pitch and intensity. Journal of the Acoustical Society of America, 23, 658-663.

Muller, K. and Barton, C. (1988). Approximate power for repeated measures. An unpublished paper in the Department of Biostatistics at the University of North Carolina at Greensboro.

Nickerson, J. (1949). Intonation of solo and ensemble performance. Journal of the Acoustical Society of America, 21, 593-595.

Nitsche, P. (1978). Klangfarbe und Schwingungsform. Band XII, Berliner Musikwissenschaftliche Arbeiten, C. Dahlhaus and R. Stephen (Eds.). Muenchen-Salzberg: Musikverlag Emil Katzbichler.

Oddo, V. (1971). Pure-tone and complex-tone equal contours for pitch and loudness (Doctoral dissertation, Indiana University). Dissertation Abstracts International, 32/02A, 1002. 71-21291.

Ohm, G. (1843). Ueber die definition des Tones, nebst daran geknuepften Theorie der Sirene und Aehnlicher tonbildener Vorrichtunger. Poggendorfer's Annalen der Physik, 59, 513-565.

Ohm, G. (1844). Noch ein Paar Worte ueber die Definition des Tones. Poggendorfer's Annalen der Physik, 62, 1-18.

Ostoich, M. (1981). The influence of gouge and shape on pitch and tone quality of the oboe (Doctoral dissertation, The Louisiana State University of Agricultural and Mechanical College, 1980.

Palmer, D. (1958). Intonation: Music's problem child. The Instrumentalist, 13(1), 38-39.

Parker, O. (1983). Quantitative differences in frequency perceptions by Violinists, Pianists, and Trombonists. Council for Research in Music Education, 76, 49-58.

Parker, S. (1947). Analyses of the tones of wooden and metal clarinets. Journal of the Acoustical Society of America, 19, 415-429.

Pederson, E. (1951). Frequency detection and speech formants. Journal of the Acoustical Society of America, 23, 668-674.

Plomp, R. (1967a). Pitch of complex tones. Journal of Acoustical Society of America, 41, 1526-1533.

Plomp, R. (1967b). Beats of mistuned consonances. Journal of the Acoustical Society of America , 42, 464-474.

Plomp, R. (1970). Timbre as a multidimensional attribute of complex tones. Frequency Analysis and Periodicity

Detection in Hearing. R. Plomp and F. G. Smoorenberg (Eds.). Leiden: A. W. Suithoff.

Plomp, R. (1976). Aspects of Tone Sensation: A Psychological Study. London/New York: Academic Press.

Plomp, R. and Levelt, W. (1965). Tonal consonance and critical bandwidth. Journal of the Acoustical Society of America, 38, 548-560.

Pottle, R. (1943). Intonation problems in school bands (Doctoral dissertation, George Peabody College for Teachers).

Pottle, R. (1962). Tuning the School Band and Orchestra. Hammond, Lousiana: Southeastern Louisiana College.

Prodan, J. (1977). The effect of the intonation of the crow of the reed on the tone quality of the oboe (Doctoral dissertation, The Ohio State University, 1976). Dissertation Abstracts International, 37(11A), 6832, DCJ77-10478.

Radocy, R. (1978). Some unanswered questions in musical perception. Psychology of Music, 6(1), 47-54.

Radocy, R. and Boyle, J. (1979). Psychological Foundations of Musical Behavior. Springfield, Ill.: Charles C. Thomas Publisher.

Rahlfs, V. (1966). Psychometrische Untersuchungen zur Wahrnehmung musikalischer Klaenge (Doctoral dissertation, Universitaet Hamburg).

Revesz, G. (1913). Zur Grundlegung der Tonpsychologie, 84-90, Leipzig.

Revesz, G. (1953). Introduction to the Psychology of Music, translated by G. de Courcy, 1953. London/New York: Longmans, Green and Co. Original publication, Einfuehrung in die Musikpsychologie, Amsterdam, 1946.

Richardson, E. (1929). The Acoustics of Orchestral Instruments and of the Organ. London.

Ritsma, R. (1967). Frequencies dominant in the perception of the pitch of complex tones. Journal of the Acoustical Society of America, 42, 191-202.

Ritsma, R. and Bilsen, F. (1970). Spectral regions dominant in the perception of repetition pitch. Acustica, 23, 334-339.

Rizzolo, R. (1969). An experimental taped program to improve sensitivity to intonation (Doctoral dissertation, Arizona State Universities). Dissertation Abstracts International, 30(04A), 1591, 69-16482.

Ryan, F., Joiner, B, and Ryan, T. (1985). Minitab Handbook, Second Edition. Boston: PWS Publishers.

Saldhanha, E. and Corso, J. (1964). Timbre cues and the identification of musical instruments. Journal of the Acoustical Society of America, 36, 2021-2026.

Salzberg, R. (1980). The effects of visual stimulus and instruction on intonation accuracy of string instruments. Psychology of Music, 8(2), 42-49.

Saunders, F. (1946). Analyses of the tones of a few wind instruments. Journal of the Acoustical Society of America, 18, 395-408.

Saveur, J. (1700). Sur la determination d'un son fixe. Hist. Acad. Sci. Paris, 131-140.

Saveur, J. (1701). Des intervales des sons, et son application a tous les systemes et a tous les instrumens de musique. Hist. Acad. Sci. Paris, 299-366.

Sawhill, C. and Matthew, G. (1969). Intonation Manual for Wind Instruments. Ashland, Oregon: Byron-Douglas Publications.

Schimank, H. (1936). Fruehgeschichte der Akustik. Akustische Zeitschrift, 1(3).

Schouten, J. (1940a). The perception of pitch. Phillips Technical Review, 5, 286-294.

Schouten, J. (1940b). The residue, a new component in subjective sound analysis. Proceedings Koninlijke Nederlandsche Akademie van Vetenschappen te Amsterdam, 43, 356-365.

Schouten, J., Ritsma, R., and Cardozo, B. (1962). Pitch of the residue. Journal of the Acoustical Society of America, 34, 1418-1424.

Schulte, G. (1967). Untersuchungen zum Phaenomenon des tonhoeheneindurcks bei verschiedenen Vokalfarben. Koelner Beitrage zur Musikforschung, Band XLVI. Regensburg: Gustav Bosse verlag.

Schumann, E. (1929). Physik der Klangfarben. Berlin: Habilitations-Schrift.

Schumann, E. (1973). Zur Physik der Vokalklangfarben. Musicae Scientiae Colectanea, Festschrift K. G. Arno-Volk-Verlag.

Scott, C. (1960). A study of the effect of changes in vocal intensity upon the harmonic structure of selected singing tones produced by female singers (Doctoral dissertation, Indiana University). Dissertation Abstracts International, 21(07), 1964, 60-05325.

Seashore, C. (1938). Psychology of Music. New York/London: McGraw-Hill Book Company, Inc.

Seebeck, A. (1841). Beobachtungen ueber einige Bedingungen der Entstehung von Toenen. Annalen der Physik, 53, 417-435.

Seebeck, A. (1843). Ueber die Sirene. Annalen der Physik, 60, 449-482.

Seebeck, A. (1844a). Ueber die Definition des Tones. Annalen der Physik, 63, 353-368.

Seebeck, A. (1844b). Ueber die Erqeugung von Toenen durch getrennte Eindruecke mit Beziehung auf die Definition des Tones. Annalen der Physik, 63, 368-380.

Sergeant, D. (1973). Measurement of pitch discrimination. Journal of Research in Music Education, 21, 3-19.

Sergeant, D. and Boyle, D. (1980). Contextual influences on pitch judgement. Psychology of Music, 8(2), 3-15.

Seipp, L. (1976). Factors involved in clarinet intonation (Doctoral dissertation, The Florida State University).

Shackford, C. (1954). Intonation in ensemble string performance: An objective study (Doctoral dissertation, Harvard University).

Sherburne, E. (1982). An analysis of the blowing pressure used for trombone and euphonium tone production (Doctoral dissertation, University of Minnesota, 1981). Dissertation Abstracts International, 42(10A), 4197, DE082-06423.

Shinn, W., Jr. (1976). An investigation of the effects of supralaryngeal adjustments to clarinet tones (Doctoral dissertation, Louisiana State University and Agricultural and Mechanical College).

Shower, E. and Biddulph, R. (1931). Differential pitch sensitivity of the ear. Journal of the Acoustical Society of America, 2, 275-287.

Simmonds, M. (1978). Observations on the relativity of pitch perception. Psychology of Music, 6(2), 48-50.

Sisson, J. (1969). Pitch preference determination, a comparative study of tuning preferences of musician from the major performing areas with reference to just intonation, Pythagorean tuning, and equal temperament (Doctoral dissertation, The University of Oklahoma). Dissertation Abstracts International, 30(07A), 3048, 69-21990.

Small, A. (1937). An objective analysis of artistic violin performance. University of Iowa Studies in the Psychology of Music, 4, 217-231.

Small, T. (1967). The evaluation of clarinet tone quality through the use of oscilloscopic transparencies. Journal of the Acoustical Society of America, 15, 11-22.

Snitkin, H. (1976). The effects of reed type and player on the listener's ability to discriminate differences in oboe tone quality (Doctoral dissertation, The University of Connecticut, 1975). Dissertation Abstracts International, 36(11A), 7038, DCJ76-10284.

Snow, W. (1936). Change of pitch with loudness at low frequencies. Journal of the Acoustical Society of America, 8, 14-19.

Stauffer, D. (1954). Intonation Deficiencies of Wind Instruments. Washington, D. C.: Catholic University Press.

Stevens, S. (1933). The volume and intensity of tones. (Doctoral dissertation, Harvard University, Published 1977).

Stevens, S. (1934). The attributes of tones. Proceedings of the National Academy of Science, 20, 457-459. Washington.

Stevens, S. (1935). The relation of pitch to intensity. Journal of the Acoustical Society of America, 6, 150-154.

Stevens, S. (1955). The measurement of loudness. Journal of the Acoustical Society of America, 27, 523.

Stevens, S. and Davis, H. (1936). Psychophysiological acoustics: Pitch and Loudness. Journal of the Acoustical Society of America, 8(1).

Stevens, S. and Volkman, J. and Newman, E. (1937). A scale for the measurement of the psychological magnitude pitch. Journal of the Acoustical Society of America, 8, 185-190.

Stout, B. (1937). The harmonic structure of vowels in singing in relation to pitch and intensity (Doctoral dissertation, The University of Iowa).

Stubbins, W. (1954). The measurement of musical tone. Journal of Research in Music Education, 2, 135-145.

Stumpf, C. (1890). Tonpsychologie II, Leipzig.

Stumpf, C. (1914). Ueber neuere Untersuchungen zur Tonlehre. Bericht VI Kongress experimenteller Psychologie, 305-348.

Stumpf, C. (1915). Ueber neuere Untersuchungen zur Tonlehre. Akustik, 8, 51-56. Leipzig: Verlag von Johann Ambrosius Barth.

Swaffield, W. (1974). Effect of melodic parameters on ability to make fine-tuning responses in context. Journal of Research in Music Education, 22, 305-312.

Terhardt, E. (1970). Frequency analysis and periodicity detection int he sensations of roughness and periodicity pitch. Reprinted from Frequency Analysis and Periodicity Detection in Hearing. R. Plomp and G. F. Smoorenburg, (Eds.). A. W. Sigthoff: Lieden.

Terhardt, E. (1971a). Pitch shifts of harmonics, an explanation of the octave enlargement phenomenon. Paper read at the Seventh International Congress on Acoustics, Budapest.

Terhardt, E. (1971b). Die Tonhoehe Harmonischer Klaenge und das Oktavintervall. Acustica, 24, 126.

Terhardt, E. (1972a). Zur Tonhoehenwarnehmung von Klaengen. I. Psychoakustische Grundlagen. Acustica, 26, 173-186.

Terhardt, E. (1972b). Zur Tonhoehenwarnehmung von Klaengen. II. Ein Funktionsschema. Acustica, 26, 187-199.

Terhardt, E. (1974a). On the perception of periodic sound fluctuations (roughness). Acustica, 39(4), 201-213.

Terhardt, E. (1974b). Pitch, consonance, and harmony. Journal of the Acoustical Society of America, 55(5).

Terhardt, E. (1974c). Pitch of pure tones: Its relation to intensity. Preprint from Psychophysical Models and Physiological Facts in Hearing, E Zwicker and E. Terhardt (Eds.). Springer: Berlin/Heidelberg/New York.

Terhardt, E. (1975a). Die Stimmung von Tasteninstrumenten. Instrumentbau, 29(40), 361-362.

Terhardt, E. (1975b). Influence of intensity on the pitch of complex tones. Acustica, 33(5), 344-348.

Terhardt, E. (1976). Frequenz und Tonhoehe. Instrumentenbau, 30, 232-235.

Terhardt, E. (1976/77). Ein psychoakustisch begruendetes Konzept der Musikalischen Konsonanz. Acustica, 36, 121-137.

Terhardt, E. (1977). The two-component theory for musical consonance. Psychophysics and Physiology of Hearing, E. F. Evans and J. P. Wilson (Eds.). London: Academic Press.

Terhardt, E. and Zwick, M. (1975). Evaluation of the tempered tone scale in normal, stretched and contracted intonation. Acustica, 32(4), 268-274.

Todenhoft, C. (1967). The effect of humidity upon the intonation and response of wood clarinets (Doctoral dissertation, Indiana University, 1966). Dissertation Abstracts International, 28(01A), 254, 67-00351.

Tognozzi, O. (1977). A comparative study of the vocal principles which apply to the clarinet (Doctoral dissertation, University of Cincinnati).

Tromblee, M. (1973). An investigation of the effectiveness of programmed drill training in teaching intonation discrimination skills (Doctoral dissertation, University of Illinois at Urbana-Champaign, 1972). Dissertation Abstracts International, 33(10A), 5770, DCJ73-10071.

Voigt, W. (1980). Die Anwendungen der Schumannschen Klangfarbengesetze fuer die Elektroakustische Uebertragung von Sprache und Musik. Bericht ueber den Internationalen Musikwissenschaftlichen Kongress Berlin 1974. Kassel: Baerenreiter.

Voxman, H. (1936). The tone quality of the clarinet (Thesis, The University of Iowa Library, Iowa City).

Wapnick, J. and Freeman, P. (1980). Effects of dark-bright timbral variation on the perception of flatness and sharpness. Journal of Research in Music Education, 28, 176-185.

Ward, W. (1954). Subjective musical pitch. Journal of the Acoustical Society of America, 26, 369-380.

Ward, W. and Martin, D. (1961). Psychophysical comparison of just tuning and equal temperament in sequences of individual tones. Journal of the Acoustical Society of America, 33, 586-588.

Warnke, K. (1976). Experimentelle Untersuchung zur Tonhoehenwahrnehmung. Veroeffentlichungen des Staatlischen Instituts fuer Musikforschung Preussischer Kulturbesitz, Band VIII. H. P. Reinecke and D. Droysen, (Eds.). Koeln (Cologne, West Germany): Arno Volk Verlag Hans Gerig sk. G.

Warren, R. and Warren, R. (1968). Helmholtz on Perception: It's Physiology and Development. Wiley and Sons.

Wehner, W. (1961). The effect of interior shape and size of clarinet mouthpieces on intonation and tone quality (Doctoral dissertation, University of Kansas).

Wehner, W. (1963). An analysis of the French and German clarinet tone. National Association of College Wind and Percussion Instructors Bulletin, 11, 10-18.

Wellek, A. (1934). Die Aufspaltung der Tonhoehe in der Hornbostelschen Gerhoerpsychologie und die Konsanztheorien bon Hornbostel und Krueger. Zeitschrift fuer Musikwissenschaft, 16, 481-496, 537-533.

Wellek, A. (1935). Die Mehrseitigkeit der "Tonhoehe" als Schluessel zur Systematik der musikalischen Ersheinungen. Zeitschrift fuer Psychologie, 134, 302-348.

Wellek, A. (1942). Tonpsychologie und Typologie. Leipzig: Akademische Verlagsgesellschaft Becker & Erler Kom.-Ges.

Wellek, A. (1963). Musikpsychologie und Musikaesthetik. Frankfurt/M.: Akademische Verlagsgesellschaft.

Wever, E. (1949). Theory of Hearing. New York.

White, J. (1981). A spectral analysis of the tones of five flutes constructed of different materials Doctoral dissertation, The University of North Carolina at Greensboro). Dissertation Abstracts International, 42(01-A), 598, 8114886.

Wightman, F. and Green, D. (1974). The perception pitch. American Scientist, 62, 208-215.

Winckel, F. (1967). Music, Sound and Sensation. (T. Binkley, trans.) New York: Dover, 1967.

Winer, B. (1971). Statistical Principles in Experimental Design (2nd ed.). New York: McGraw-Hill.

Winston, E. (1976). A study of alterations to the baffle for the clarinet mouthpiece and how they affect tone quality, intonation, and response (Doctoral dissertation, The Louisiana State University and Agricultural and Mechanical College).

Wood, A. (1945). The Physics of Music, Third Edition. London.

Wyatt, R. (1954). The improvability of pitch discrimination. Psychological Monographs, 58.

Zeitlin, L. (1964). Frequency discrimination of pure and complex tones. Journal of the Acoustical Society of America, 36, 1927.

Zepp, R. (1954). Effects of four factors on clarinet tone quality (Doctoral dissertation, University of Kansas).

Zurmuehl, G. (1930). Abhaengigkeit der Tonhoehenempfindung von der Lautstaerke und ihre Beziehung zur Helmholtzschen Resonanztheorie des Hoerens. _Zeitschift fuer Sinnesphysiologie_, _61_, 40-86.

Zwicker, E. and Feldtkeller, R. (1967). _Das Ohr als Nachrichtenempfaenger_. Stuttgart: Hirzel-Verlag, Second Printing.

APPENDIX A

TABLE A. INSTRUMENT BRAND, CHRONOLOGICAL AGE, EDUCATION, AND EXPERIENCE LEVELS OF SUBJECTS.

TABLE A

Instrument brand, chronological age, education, and experience levels of individual subjects.

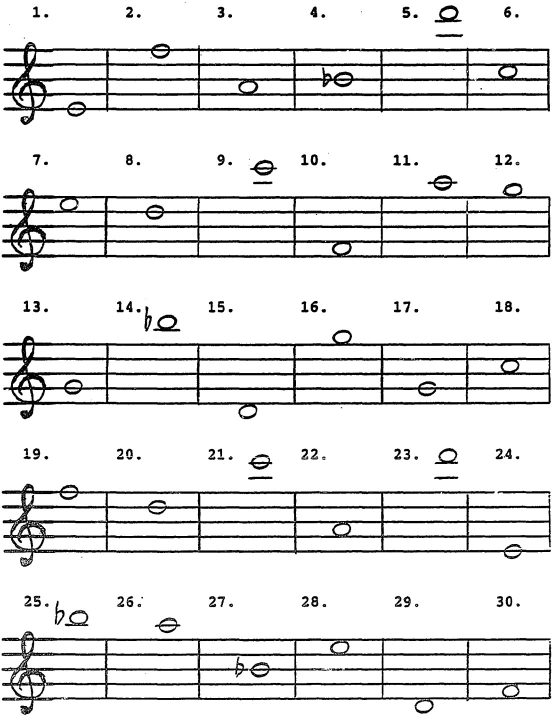
Subject No. and Brand of Instrument	Chrono-logical Age	Years of College Education	Years of Playing Instrument	Years of Private Study
F1 Miramatsu	20	3	10	8
F2 Armstrong	20	3	7	3
F3 Yamaha	19	1	7	7
F4 Prima Sankyo	18	1	9	6
F5 Prima Sankyo	23	5	11	5
F6 Yamaha	20	2	10	5
F7 Gemeinhardt	23	5	11	8
F8 Prima Sankyo	18	1	7	6
F9 Prima Sankyo	18	1	6	6
Flute group means	19.87	2.44	8.67	6.00
O1 Loree	22	4	12	8
O2 Loree	18	1	2 + 7 Flute	2
O3 Loree	21	2	6	3
O4 Loree	21	4	6 + 2 Clar	5
O5 Loree	20	3	9	7
O6 Loree	22	4	10	8
O7 Loree	18	1	4 + 3 Clar	1
O8 Loree	19	1	3 + 4 Sax	2
O9 Loree	28	10	15	14
Oboe group means	21.0	3.33	7.45	5.56
C1 Buffet	24	6	15	9
C2 Buffet	20	2	7	2
C3 Buffet	18	2	7	6
C4 Buffet	19	1	10	8
C5 Selmer Signet	18	1	8	4
C6 Buffet	19	1	7	4
C7 Selmer Signet	18	1	7	1
C8 SelmerSeries10	25	5	9	12
C9 Buffet	24	7	12	7
Clar. group means	20.56	2.89	8.00	5.89
Grand Mean	20.48	2.89	8.41	5.82
Grand Median	20.00	2.00	8.00	6.00
Grand Minimum	18.00	1.00	2.00	1.00
Grand Maximum	28.00	10.00	15.00	14.00

APPENDIX B

SAMPLE TEST SHEET

TEST OF INTONATION CHARACTERISTICS OF WOODWIND INSTRUMENTS

Test sheet/score sheet FORM A Subject No. F1

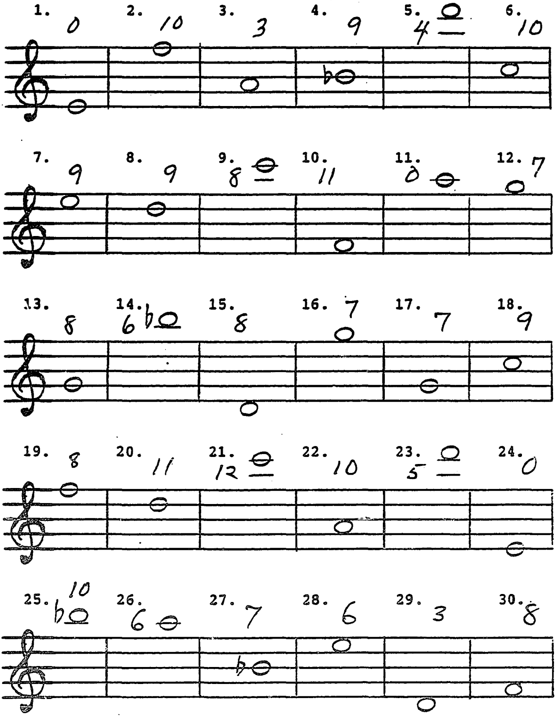


APPENDIX C

SAMPLE SCORE SHEET

TEST OF INTONATION CHARACTERISTICS OF WOODWIND INSTRUMENTS

Test sheet/score sheet FORM A   Subject No. F1



APPENDIX D

TABLE B. CENT DEVIATIONS FOR INTONATION DEFICIENCIES TEST

TABLE B

Cent deviation scores for Intonation Deficiencies Test.

Subject Number	Test Form	d_4	e_4	f_4	g_4	a_4	b^b_4	c_5	d_5	e_5	f_5	g_5	a_5	b^b_5	c_6	d_6
F 1	I1	0	-2	9	5	0	11	6	16	5	3	12	8	7	13	11
	I2	0	-5	5	7	-3	3	-3	15	0	9	0	10	8	13	11
F 2	A1	0	-1	-8	0	8	2	-2	4	-3	-1	3	12	4	2	0
	A2	-1	-1	-2	1	8	-1	4	4	0	-5	-1	12	7	2	0
F 3	B1	4	-1	6	4	7	5	7	12	4	2	10	22	21	16	0
	B2	4	4	5	8	4	15	13	12	5	8	12	16	24	20	17
F 4	C1	8	9	12	4	16	8	16	14	7	13	1	4	3	15	7
	C2	8	7	10	6	21	5	12	10	4	9	4	4	8	10	6
F 5	D1	9	8	12	28	35	23	30	30	15	23	25	15	17	12	13
	D2	8	13	13	20	25	34	23	28	9	15	12	12	15	30	8
F 6	E1	5	-2	0	14	4	-3	12	17	9	5	-3	10	0	3	2
	E2	8	3	7	18	7	3	13	18	5	7	5	8	3	-2	6
F 7	F1	-12	-7	-6	-12	-4	4	14	12	8	6	7	17	21	14	4
	F2	-11	-3	-4	-10	6	7	14	8	7	4	11	16	18	16	7
F 8	G1	3	-3	5	7	-6	-3	7	15	14	9	13	3	7	12	15
	G2	2	3	4	0	3	2	6	22	12	14	11	6	6	16	16
F 9	H1	-11	-14	-5	-15	-18	-20	7	-4	-6	-4	-4	0	-3	3	-1
	H2	-5	-2	-4	-5	-18	-8	7	5	-3	-1	1	-3	-6	12	10
O 1	I1	-5	-2	-14	-5	-4	0	-5	7	7	-8	0	-12	-21	-3	9
	I2	-4	-3	-15	-2	-6	2	-6	7	7	-8	-7	-12	-15	-8	-3
O 2	A1	14	2	17	28	22	22	44	39	32	32	30	18	6	40	32
	A2	14	10	18	27	36	25	34	40	30	35	30	8	-5	50	30
O 3	B1	12	22	0	24	27	7	26	8	25	6	30	22	10	25	47
	B2	7	21	20	25	20	15	30	20	35	21	22	16	24	30	47
O 4	C1	-3	-10	-11	-8	-22	-22	-17	-4	2	-20	-8	-42	-36	-9	9
	C2	-4	-3	-6	-6	-25	-13	-8	-3	2	-21	-13	-43	-44	-18	13

TABLE B (continued)

Subject Number	Test Form	Scale tone														
		d_4	e_4	f_4	g_4	a_4	b^b_4	c_5	d_5	e_5	f_5	g_5	a_5	b^b_5	c_6	d_6
O 5	D1	9	10	6	19	4	7	10	10	21	−3	8	−4	−25	−3	21
	D2	4	9	6	12	−6	0	4	13	19	−4	6	−9	−28	−14	9
O 6	E1	7	5	13	10	−3	−4	8	20	−13	6	12	−20	−35	0	−3
	E2	8	7	10	18	2	−3	8	23	−9	4	19	−20	−21	2	4
O 7	F1	0	7	−8	17	5	7	3	15	16	−3	20	−30	−23	−3	11
	F2	2	6	−1	17	−3	−6	1	15	8	−3	20	−20	−16	10	28
O 8	G1	9	25	18	27	30	34	50	35	40	28	42	34	15	50	48
	G2	7	26	28	27	32	20	50	27	50	30	40	27	7	50	50
O 9	H1	−10	0	−10	−5	−5	−10	−3	0	12	−8	8	−12	−10	2	20
	H2	−11	−5	−10	0	−10	−7	1	1	10	−10	6	−13	−10	0	15
C 1	I1	0	−7	−4	7	−4	−5	−3	0	1	4	7	8	6	4	8
	I2	6	−2	−1	7	−5	−4	−3	1	3	3	11	7	13	8	12
C 2	A1	11	−6	−5	−1	−2	−2	−2	−2	1	0	1	4	−1	6	1
	A2	15	0	−6	−1	1	4	−3	−1	4	2	1	5	2	7	2
C 3	B1	−17	−3	−5	1	0	−2	−3	−5	−6	−6	−9	−8	−9	−6	−6
	B2	−15	−7	−10	2	−1	−5	−1	−3	−5	−2	−6	−4	−7	−4	−8
C 4	C1	−12	−7	2	0	1	3	0	0	−5	−5	5	0	0	9	−2
	C2	−9	0	2	1	1	1	4	4	−2	1	4	5	2	12	3
C 5	D1	10	13	18	35	2	0	−1	−4	0	12	10	19	18	15	24
	D2	8	20	25	35	4	4	0	−2	3	11	16	21	22	15	23
C 6	E1	−5	4	4	12	0	2	4	3	3	2	9	11	4	−2	−10
	E2	−3	3	8	9	1	2	4	4	0	4	11	11	8	2	−9
C 7	F1	−16	−16	−14	0	6	10	3	−2	9	11	5	11	10	−14	5
	F2	−9	−13	−11	3	8	9	6	0	8	13	12	9	13	−11	−1
C 8	G1	−1	9	14	13	6	6	6	7	6	20	24	19	22	10	10
	G2	3	7	14	18	7	10	8	12	11	24	22	24	22	11	13
C 9	H1	−12	−10	1	9	−1	−2	5	6	4	0	4	11	12	−5	7
	H2	−1	0	4	7	1	4	5	5	−2	−3	7	7	11	−2	10

APPENDIX E

TABLE C. CENT DEVIATIONS FOR INTONATION TENDENCIES TEST

TABLE C

Cent deviation scores for Intonation Tendencies Test.

Subject Number	Test Form	d_4	e_4	f_4	g_4	a_4	b^{b}_4	c_5	d_5	e_5	f_5	g_5	a_5	b^{b}_5	c_6	d_6
F 1	A1	8	0	11	0	3	9	10	9	9	10	7	0	6	8	4
	A2	3	0	8	7	10	7	9	11	6	8	7	6	10	12	5
F 2	B1	-4	3	0	6	18	10	8	8	-4	2	3	14	9	7	0
	B2	-1	2	-3	8	17	0	1	9	-4	-5	-2	14	8	6	0
F 3	C1	-1	6	7	0	8	12	4	8	4	7	12	10	21	6	8
	C2	0	7	4	3	5	18	8	10	3	3	6	5	14	6	4
F 4	D1	13	7	9	0	0	-4	3	14	7	1	3	-1	0	-1	9
	D2	4	4	9	10	4	-2	12	17	7	4	0	2	0	2	4
F 5	E1	17	13	16	24	19	23	7	18	3	12	9	1	-2	0	0
	E2	17	18	16	27	20	29	1	7	4	10	-3	-4	10	-1	3
F 6	F1	5	7	1	-2	9	0	5	7	8	3	1	3	-4	3	8
	F2	3	-2	3	6	7	2	12	10	0	-7	0	1	-3	0	-2
F 7	G1	-11	-11	-10	-5	-2	4	15	7	5	4	1	3	0	3	0
	G2	-16	-10	-10	-6	0	2	9	7	4	1	2	3	0	7	0
F 8	H1	4	10	0	18	12	11	9	15	22	16	12	11	12	19	15
	H2	2	12	18	12	12	16	5	16	15	20	18	7	13	14	18
F 9	I1	1	3	7	0	-2	6	2	6	2	6	10	6	8	10	10
	I2	-3	3	7	0	2	10	1	7	2	6	9	10	9	12	8
O 1	A1	-2	-4	-8	4	-3	3	5	8	10	-2	-5	-4	-5	8	7
	A2	-4	-1	-8	-1	0	4	6	5	10	-1	-5	-5	-11	5	3
O 2	B1	0	-10	-9	6	4	0	4	3	11	7	4	-4	0	3	4
	B2	3	8	-7	0	6	-7	-5	3	2	9	9	-7	-4	-4	6
O 3	C1	0	3	-2	5	8	10	3	7	13	-5	9	0	-6	-10	-3
	C2	-3	7	-2	3	8	9	7	9	10	1	5	-3	-4	-3	-3
O 4	D1	-6	0	-3	-5	-5	4	4	2	16	-10	-5	-4	-7	3	7
	D2	-4	-4	-6	-11	-12	3	-7	6	-3	-8	-2	-6	-5	3	9

TABLE C (continued)

Subject Number	Test Form	Scale tone d_4	e_4	f_4	g_4	a_4	$b^b{}_4$	c_5	d_5	e_5	f_5	g_5	a_5	$b^b{}_5$	c_6	d_6
O 5	E1	9	10	11	14	3	−1	4	1	12	4	7	0	−10	−13	8
	E2	1	4	−1	9	−8	5	−5	1	8	−7	−3	−1	−7	0	3
O 6	F1	11	3	1	6	−2	8	4	17	22	2	7	−2	−4	0	1
	F2	6	5	12	8	0	1	0	30	8	1	7	−4	−12	−1	0
O 7	G1	−1	4	−2	−7	0	−3	1	14	13	−6	−3	−16	−10	−2	9
	G2	−3	−2	−6	−2	0	1	−2	5	13	−6	−3	−5	−6	4	6
O 8	H1	−1	−8	−7	3	2	−2	−5	6	15	−8	4	5	−7	10	3
	H2	−10	−1	−10	−5	2	−8	0	0	10	2	8	5	−14	12	0
O 9	I1	−5	5	−7	−4	−2	−9	−10	0	10	−4	13	1	−1	−1	5
	I2	−6	6	−2	−4	−3	−3	−5	2	15	4	12	5	−2	−3	7
C 1	A1	2	−3	0	4	−5	−5	−3	14	−1	−4	7	10	10	8	10
	A2	3	−4	5	2	−5	−3	−3	3	0	6	7	10	12	7	8
C 2	B1	12	−2	−8	0	2	4	−2	0	4	3	3	4	4	10	7
	B2	11	−1	−7	−5	1	4	−1	0	5	2	3	0	6	12	6
C 3	C1	−6	−10	2	4	0	−3	−1	−10	−8	−8	−6	−5	−5	−4	−4
	C2	−6	−1	4	4	1	−1	−1	0	−4	−1	−2	−2	−3	−3	−1
C 4	D1	−8	−2	−2	6	2	3	4	1	−2	0	−3	1	5	12	2
	D2	−4	3	3	6	3	6	5	5	3	1	0	3	−4	14	4
C 5	E1	22	23	15	31	5	6	7	−2	4	17	18	30	24	6	24
	E2	16	22	19	32	8	7	4	4	5	14	16	29	19	13	8
C 6	F1	1	7	7	12	7	5	4	4	2	−1	8	9	7	0	−9
	F2	8	10	15	15	3	6	7	4	4	1	11	15	7	6	−9
C 7	G1	−11	−10	−6	1	6	13	6	2	8	16	9	19	19	1	3
	G2	−9	−10	−6	8	9	13	6	3	9	18	17	22	16	−2	−2
C 8	H1	−2	0	5	13	6	6	5	9	10	10	20	8	17	10	20
	H2	0	2	6	16	8	6	5	8	10	17	19	14	22	12	15
C 9	I1	4	−2	8	0	1	0	4	4	0	−2	8	6	7	7	6
	I2	6	2	10	−4	2	2	5	7	0	−2	7	9	10	12	2

APPENDIX F

TABLE D. INTRASUBJECT RELIABILITY COEFFICIENTS

TABLE D

Intrasubject reliability coefficients for Intonation Deficiencies Test (IDT) and Intonation Tendencies Test (ITT).

Subject	IDT	ITT
F 1	0.676	0.413
F 2	0.780	0.839
F 3	0.667	0.699
F 4	0.757	0.565
F 5	0.539	0.808
F 6	0.805	0.200
F 7	0.948	0.936
F 8	0.790	0.319
F 9	0.761	0.858
Flute Group Mean	0.747	0.626
O 1	0.850	0.888
O 2	0.865	0.288
O 3	0.690	0.853
O 4	0.936	0.527
O 5	0.934	0.454
O 6	0.952	0.684
O 7	0.827	0.785
O 8	0.894	0.683
O 9	0.944	0.882
Oboe Group Mean	0.877	0.672
C 1	0.895	0.744
C 2	0.887	0.925
C 3	0.774	0.642
C 4	0.854	0.707
C 5	0.964	0.841
C 6	0.921	0.864
C 7	0.950	0.941
C 8	0.935	0.889
C 9	0.743	0.751
Clarinet Group Mean	0.880	0.812
GRAND MEAN	0.835	0.703
GRAND MEDIAN	0.854	0.751

APPENDIX G

TABLE E. INTERSUBJECT RELIABILITY COEFFICIENTS

TABLE E

Intersubject reliability coefficients for each level of scale tone.

Scale tone	IDT	ITT
d_4	0.927	0.869
e_4	0.890	0.767
f_4	0.887	0.786
g_4	0.950	0.869
a_4	0.910	0.857
b-flat$_4$	0.822	0.842
c_5	0.956	0.516
d_5	0.943	0.646
e_5	0.939	0.660
f_5	0.933	0.753
g_5	0.894	0.789
a_5	0.970	0.899
b-flat$_5$	0.940	0.884
c_6	0.932	0.785
d_6	0.886	0.771
MEANS	0.919	0.780
MEDIANS	0.930	0.790

APPENDIX H

TABLE F. OVERALL INSTRUMENT INTONATION DEFICIENCIES AND OVERALL INTONATION TENDENCIES FOR SUBJECTS.

TABLE F

Overall instrument intonation deficiencies and overall intonation tendencies for subjects.

Subject	DEFICIENCIES	TENDENCIES
F 1	5.83	6.767
F 2	1.57	4.33
F 3	9.53	6.93
F 4	8.70	4.57
F 5	18.33	10.47
F 6	6.07	2.80
F 7	5.07	-0.07
F 8	7.37	12.80
F 9	-3.83	5.27
FLUTE GROUP MEANS	6.51	5.99
O 1	-4.30	0.30
O 2	25.33	1.17
O 3	21.47	2.43
O 4	-14.57	-1.87
O 5	3.70	1.93
O 6	1.83	4.43
O 7	3.07	-0.50
O 8	31.87	0.03
O 9	-2.47	0.47
OBOE GROUP MEANS	7.33	0.93
C 1	2.60	3.07
C 2	1.17	2.57
C 3	-5.20	-2.667
C 4	0.60	2.23
C 5	12.53	14.87
C 6	2.83	5.53
C 7	1.47	5.60
C 8	12.23	9.90
C 9	2.73	3.83
CLARINET GROUP MEANS	3.44	4.99
MEANS FOR ALL SUBJECTS	5.76	3.97

APPENDIX I

TABLE G. MEANS OF PAIRED CENT DEVIATIONS USED AS DATA FOR THE ANALYSIS OF COVARIANCE.

TABLE G

Means of cent deviations used as data for the analysis of covariance.

Data Label Key:
x1 = Means of cent deviations for Intonation Tendencies Test
x2 = Means of cent deviations for Intonation Deficiencies Test

Subject Number	Data Label	Scale Tone														
		d_4	e_4	f_4	g_4	a_4	$b^b{}_4$	c_5	d_5	e_5	f_5	g_5	a_5	$b^b{}_5$	c_6	d_6
F1	x1	5.5	0.0	9.5	3.5	6.5	8.0	9.5	10.0	7.5	9.0	7.0	3.0	8.0	10.0	4.5
	x2	0.0	-3.5	7.5	6.0	-1.5	7.0	1.5	15.5	2.5	6.0	6.0	9.0	7.5	13.0	11.0
F2	x1	-2.5	2.5	-1.5	7.0	17.5	5.0	4.5	8.5	-4.0	-1.5	0.5	14.0	8.5	6.5	0.0
	x2	-0.5	-1.0	-5.0	0.5	8.0	0.5	1.0	4.0	-1.5	-3.0	1.0	12.0	5.5	2.0	0.0
F3	x1	-0.5	6.5	5.5	1.5	6.5	15.0	6.0	9.0	3.5	5.0	9.0	7.5	17.5	6.0	6.0
	x2	4.0	1.5	5.5	6.0	5.5	10.0	10.0	12.0	4.5	5.0	11.0	19.0	22.5	18.0	8.5
F4	x1	8.5	5.5	9.0	5.0	2.0	-3.0	7.5	15.5	7.0	2.5	1.5	0.5	0.0	0.5	6.5
	x2	8.0	8.0	11.0	5.0	18.5	6.5	14.0	12.0	5.5	11.0	2.5	4.0	5.5	12.5	6.5
F5	x1	17.0	15.5	16.0	25.5	19.5	26.0	4.0	12.5	3.5	11.0	3.0	-1.5	4.0	-0.5	1.5
	x2	8.5	10.5	12.5	24.0	30.0	23.5	26.5	29.0	12.0	19.0	18.5	13.5	16.0	21.0	10.5
F6	x1	4.0	2.5	2.0	2.0	8.0	1.0	8.5	8.5	4.0	-2.0	0.5	2.0	-3.5	1.5	3.0
	x2	6.5	0.5	3.5	16.0	5.5	0.0	12.5	17.5	7.0	6.0	1.0	9.0	1.5	0.5	4.0
F7	x1	-13.5	-10.5	-10.0	-5.5	-1.0	3.0	13.0	7.0	4.5	2.5	1.5	3.0	0.0	5.0	0.0
	x2	-11.5	-5.0	-5.0	-11.0	1.0	5.5	14.0	10.0	7.5	5.0	9.0	16.5	19.5	15.0	5.5
F8	x1	3.0	11.0	9.0	15.0	12.0	13.5	7.0	15.5	18.5	18.0	15.0	9.0	12.5	16.5	16.5
	x2	2.5	0.0	4.5	3.5	-1.5	-0.5	6.5	18.5	13.0	11.5	12.0	4.5	6.5	14.0	15.5
F9	x1	-1.0	3.0	7.0	0.0	0.0	8.0	1.5	6.5	2.0	6.0	9.5	8.0	8.5	11.0	9.0
	x2	-8.0	-8.0	-4.5	-10.0	-18.0	-14.0	7.0	0.5	-4.5	-2.5	-1.5	-1.5	-4.5	7.5	4.5
01	x1	-3.0	-2.5	-8.0	1.5	-1.5	3.5	5.5	6.5	10.0	-1.5	-5.0	-4.5	-8.0	6.5	5.0
	x2	-4.5	-2.5	-14.5	-3.5	-5.0	1.0	-5.5	7.0	7.0	-8.0	-3.5	-12.0	-18.0	-5.5	3.0
02	x1	1.5	-1.0	-8.0	3.0	5.0	-3.5	-0.5	3.0	6.5	8.0	6.5	-5.5	-2.0	-0.5	5.0
	x2	14.0	6.0	17.5	27.5	29.0	23.5	39.0	39.5	31.0	33.5	30.0	13.0	0.5	45.0	31.0
03	x1	-1.5	5.0	-2.0	4.0	8.0	9.5	5.0	8.0	11.5	-2.0	7.0	-1.5	-5.0	-6.5	-3.0
	x2	9.5	21.5	10.0	24.5	23.5	11.0	28.0	14.0	30.0	13.5	26.0	19.0	17.0	27.5	47.0

TABLE G (continued)

Subject Number	Data Label	d_4	e_4	f_4	g_4	a_4	b^b_4	c_5	d_5	e_5	f_5	g_5	a_5	b^b_5	c_6	d_6
04	x1	-5.0	-2.0	-4.5	-8.0	-8.5	3.5	-1.5	4.0	6.5	-9.0	-3.5	-5.0	-6.0	3.0	8.0
	x2	-3.5	-6.5	-8.5	-7.0	-23.5	-17.5	-12.5	-3.5	2.0	-20.5	-10.5	-42.5	-40.0	-13.5	-11.0
05	x1	5.0	7.0	5.0	11.5	-2.5	2.0	-0.5	1.0	10.0	-1.5	2.0	-0.5	-8.5	-6.5	5.5
	x2	6.5	9.5	6.0	15.5	-1.0	3.5	7.0	11.5	20.0	-3.5	7.0	-6.5	-26.5	-8.5	15.0
06	x1	8.5	4.0	6.5	7.0	-1.0	3.5	2.0	23.5	15.0	1.5	7.0	-3.0	-8.0	-0.5	0.5
	x2	7.5	6.0	11.5	14.0	-0.5	-3.5	8.0	21.5	-11.0	5.0	15.5	-20.0	-28.0	1.0	0.5
07	x1	-2.0	1.0	-4.0	-4.5	0.0	-1.0	-0.5	9.5	13.0	-6.0	-3.0	-10.5	-8.0	1.0	7.5
	x2	1.0	6.5	-4.5	17.0	1.0	0.5	2.0	15.0	12.0	-3.0	20.0	-25.0	-19.5	3.5	19.5
08	x1	-5.5	-4.5	-8.5	-1.0	2.0	-5.0	-2.5	3.0	12.5	-3.0	6.0	5.0	-10.5	11.0	1.5
	x2	8.0	25.5	23.0	27.0	31.0	27.0	50.0	31.0	45.0	29.0	41.0	30.5	11.0	50.0	49.0
09	x1	-5.5	5.5	-4.5	-4.0	-2.5	-6.0	-7.5	1.0	12.5	0.0	12.5	3.0	-1.5	-2.0	6.0
	x2	-10.5	-2.5	-10.0	-2.5	-7.5	-8.5	-1.0	0.5	11.0	-9.0	7.0	-12.5	-10.0	1.0	17.5
C1	x1	2.5	-3.5	2.5	3.0	-5.0	-4.0	-3.0	8.5	-0.5	1.0	7.0	10.0	11.0	7.5	9.0
	x2	3.0	-4.5	-2.5	7.0	-4.5	-4.5	-3.0	0.5	2.0	3.5	9.0	7.5	9.5	6.0	10.0
C2	x1	11.5	-1.5	-7.5	-2.5	1.5	4.0	-1.5	0.0	4.5	2.5	3.0	2.0	5.0	11.0	6.5
	x2	13.0	-3.0	-5.5	-1.0	-0.5	1.0	-2.5	-1.5	2.5	1.0	1.0	4.5	0.5	6.5	1.5
C3	x1	-6.0	-5.5	3.0	4.0	0.5	-2.0	-1.0	-5.0	-6.0	-4.5	-4.0	-3.5	-4.0	-3.5	-2.5
	x2	-14.0	-5.0	-7.5	1.5	-0.5	-3.5	-2.0	-4.0	-5.5	-4.0	-7.5	-6.0	-8.0	-5.0	-7.0
C4	x1	-6.0	0.5	0.5	6.0	2.5	4.5	4.5	3.0	0.5	0.5	-1.5	2.0	0.5	13.0	3.0
	x2	-10.5	-3.5	2.0	0.5	1.0	2.0	2.0	2.0	-3.5	-2.0	4.5	2.5	1.0	10.5	0.5
C5	x1	19.0	22.5	17.0	31.5	6.5	6.5	5.5	1.0	4.5	15.5	17.0	29.5	21.5	9.5	16.0
	x2	9.0	16.5	21.5	35.0	3.0	2.0	-0.5	-3.0	1.5	11.5	13.0	20.0	20.0	15.0	23.5
C6	x1	4.5	8.5	11.0	13.5	5.0	5.5	5.5	4.0	3.0	0.0	9.5	12.0	7.0	3.0	-9.0
	x2	-4.0	3.5	6.0	10.5	-5.0	2.0	4.0	3.5	1.5	3.0	10.0	11.0	6.0	0.0	-9.5
C7	x1	-10.0	-10.0	-6.0	4.5	7.5	13.0	6.0	2.5	8.5	17.0	13.0	20.5	17.5	-0.5	0.5
	x2	-12.5	-14.5	-12.5	1.5	7.0	9.5	4.5	-1.0	8.5	12.0	8.5	10.0	11.5	-12.5	2.0
C8	x1	-1.0	1.0	5.5	14.5	7.0	6.0	5.0	8.5	10.0	13.5	19.5	11.0	19.5	11.0	17.5
	x2	1.0	8.0	14.0	10.5	6.5	8.0	7.0	9.5	8.5	22.0	23.0	21.5	22.0	10.5	11.5
C9	x1	5.0	0.0	9.0	-2.0	1.5	1.0	4.5	5.5	0.0	-2.0	7.5	7.5	8.5	9.5	2.0
	x2	-6.5	-5.0	2.5	8.0	0.0	1.0	5.0	5.5	1.0	-1.5	5.5	9.0	11.5	-3.5	8.5