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The Effect of Tuning Stimulus Vibrato, Timbre, and Frequency on Tuning Accuracy of University, High School, and Junior High School Instrumentalists.

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THE EFFECT OF TUNING STIMULUS VIBRATO, TIMBRE, AND FREQUENCY ON TUNING ACCURACY OF UNIVERSITY, HIGH SCHOOL, AND JUNIOR HIGH SCHOOL INSTRUMENTALISTS

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ABSTRACT

The purpose of this study was to examine intonation in response to a variety of conventional stimuli. Specifically, the tuning accuracy of university, high school, and junior high school woodwind, brass, and string instrumentalists was compared when responding to taped stimuli of A = 440 Hz played on oboe non-vibrato and oboe with vibrato; and pitches produced electronically on a Korg™ tuner of A = 430 Hz; A = 435 Hz; and A = 445 Hz. In question were the effects of vibrato, timbre, and frequency on tuning accuracy. Subjects ($\underline{N}$ = 198) were university music students ($\underline{n}$ = 85), high school students ($\underline{n}$ = 55) and junior high school students ($\underline{n}$ = 58). Subjects were individually recorded tuning to each of the five stimuli. Responses were analyzed through a computer system using MacRecorder™ software. These digitized pitches were analyzed for absolute and directional cent deviation with a Korg™ Auto Chromatic Tuner.

Results demonstrated significant differences in absolute cent deviation scores among educational levels, among instrumental groups, and among tuning stimuli. University students deviated less from tuning stimuli; junior high school deviated most. String players were most accurate in tuning; brass players were least accurate. Students tuned most accurately to the oboe vibrato, A = 440 Hz stimuli and least accurately to the oboe non-vibrato, A = 440 Hz.

Results regarding directional cent deviation analysis demonstrated a propensity toward flat responses. However,

while more flat responses occurred for strings and brass, there were more sharp responses for woodwinds. There were more flat responses to the higher tuning stimuli (A = 440 Hz and A = 445 Hz) and more sharp responses for the lower stimuli (A = 430 Hz and A = 435 Hz). Finally, while flat responses were dominant in response to the oboe stimuli, more sharp responses occurred in response to the Korg™.

INTRODUCTION AND REVIEW OF LITERATURE

Introduction and Need for Study

The fine art of instrumental performance is one in which a multitude of elements must continually and accurately blend in order to achieve an adequate and pleasing product. In any type of performance, certain elements are rehearsed in order to bring cohesion to the ensemble. Some such elements may include the production of correct rhythms played in a unified manner, a wide range of expressively executed dynamics, the implementation of musical styles which attempt to replicate the wishes of the composer, and tempos which are suitable to the work and historical period. These basic elements, studied thoroughly by a conductor, are related by that conductor to the ensemble through rehearsal. By the use of constructive and well planned rehearsal time, these elements may be mastered by the players and brought together as a unified whole. One element not yet mentioned which is as crucial, or perhaps more crucial to the quality of the performance, is not as directly under a conductor's control. This is the element of intonation.

The applicable definition of intonation for purposes of this study is found in the New Harvard Dictionary of Music:

> The degree to which pitch is accurately produced in performance, especially among the players in an ensemble. (Randel, 1986, 402)

This act of becoming "in-tune" with the rest of the ensemble begins rehearsal and performance situations with woodwind, brass, and string musicians asked to match a single,

unaccompanied pitch of predetermined frequency, usually from an oboe or electric tuner. During this process, the player is required to adjust the length of the instrument or the tension on the string manually in order to come to closest possible agreement with this predetermined reference frequency. It is thought that when an ensemble is able to achieve a consistently high degree of "intuneness" at the beginning of a rehearsal or performance, good overall intonation will have a better chance of occurring throughout the remainder of the rehearsal or performance.

The problem of intonation stands as a paradox in the field of music. While it can be scientifically demonstrated that performing exactly in tune is rare, good intonation is expected of any performer or performing ensemble. This dilemma is present not only for wind, string, percussion, and vocal performers, but for keyboard players as well. In the performance venue, intonation is most often left to the discretion and abilities of the performer. In most instances, a truly accomplished performer will adjust the intonation of each note carefully, attempting to match their intonational frequency to that of the rest of the ensemble. Most players of fixed-pitch instruments, however, turn the responsibility of tuning over to someone else (Palmer, 1958).

Intonation, and specifically the question of tuning instruments to a specific and common pitch, is a problem not easily approached or solved. External factors affecting intonation, such as room temperature or improperly adjusted instruments (Hofmeister, 1982; McAdow, 1952), and individual factors such as embouchure, breath support, and mouthpiece

selection (Hofmeister, 1982; McGinnis, 1962) show how individualized and complex the issue of intonation may become.

Few would deny the intricacy of the issue and the need for study involving tuning timbres and their effect on tuning accuracy. These tuning timbres may be as varied as oboe, commonly used for bands and orchestras, cello used for string quartets, or electronic tuners. These timbre differences range from a simple sine wave for the pure tones to the complex, harmonically rich tones of the oboe and cello.

In addition to the timbre of the tuning stimulus, another concern of research has been the frequency of the pitch which instrumental ensembles must match at the onset of any rehearsal or concert. Although A = 440 Hz was adopted as the international standard for tuning in 1938 by the British Standards Institution Conference and in 1955 by the International Organization for Standardization (Randel, 1986), some orchestras, such as the Berlin Philharmonic under Herbert von Karajan, tune to A = 448 Hz and others, such as the Boston Symphony Orchestra under Seiji Ozawa and the New York Philharmonic under Zubin Metha, tune to 442 Hz (Allman, 1989). The lack of a common standard among even high quality professional organizations only exacerbates the dilemma of tuning accuracy. Over the last 500 years, the frequency for an "A" has ranged from A = 360 Hz on an organ built in 1611 in Worchester Cathedral (Allman, 1989) to A = 567.3 Hz on an organ from 1619 in Northern Germany (Helmholz, 1954).

Intonation is often seen as a major flaw in ensemble performance (Bencriscutto, 1965; Kinyon, 1960; Klotman, 1957;

Miller, 1986; Walker, 1948; Wyand, 1973). An article by R.T. Scott (1960) has identified the problem of intonation as "the most common fault of all young instrumental groups" (pg. 28). Many authors have suggested ways of increasing sensitivity for and training in good intonation. Some of these have advocated training the group to listen for beats (Backus, 1977; Bencriscutto, 1965; Cassidy, 1988; Duke, 1985; Graves, 1963; Kinyon, 1960; Miles, 1972; Palmer, 1958; Walker, 1948). These beats are pulsations produced by an interference between two sound waves of simultaneously sounded pitches which are of slightly different frequency. Beats disappear when the frequencies are made identical (Randel, 1986). Others endorse the use of electronic tuners to reinforce the "correctness" of intonation (Hofmeister, 1982; Kinyon, 1960; McGinnis, 1962; Pottle, 1960; Stauffer, 1954; Wyand, 1973). When using the electronic tuners, performers are taught to bring the target pitch in tune so that the meters or wheels register that the pitch is exactly at the target pitch. Other approaches to training for accurate intonation have included such widely diverse practices as the use of electronic graphs for visual reinforcement (Heller, 1969) and the blindfolding of subjects in order to eliminate the effect of visual stimuli (Salzberg, 1980). Other practitioners see the problem of intonation as being one of poor attitude within the performance ensemble or simply a lack of care, concentration, or awareness on the part of the conductor and/or players (Klotman, 1957; McAdow, 1952; Miller, 1986; Scott, 1960).

Authors have written of myriad ways in which intonation may be improved through various teaching methods including modeling by an experienced player (Dowdy, 1973), singing target pitches and playing notes on instruments to try and match what was sung (Elliott, 1972, 1974; Smith, 1984), verbal inducements indicating the direction the pitch needs to be moved in order to match the target pitch (Madsen, 1966, 1974; Geringer, 1978) and the use of computer-assisted tuning instruction which makes use of of visual reinforcement (Codding, 1985,1987; Glass, 1989).

Many questions are raised by the preceding discussion. When attempting to tune, what are some of the basic factors that influence musicians? Does the "highness" or "lowness" of the target frequency influence overall tuning accuracy of an individual or an ensemble? Is the timbre of oboe or an electronic tuner of most benefit in matching the target pitch? Does the presence or the absence of vibrato in the target pitch affect tuning accuracy? Does age or instrument type play a part in tuning accuracy? In the search to provide some answers to these questions, the present study was designed.

The purpose of this study was to examine intonation under a variety of conventional stimuli. Specifically, the tuning accuracy of university, high school, and junior high school woodwind, brass, and string instrumentalists was compared when responding to a (1) taped stimulus of A = 440 Hz played on an oboe non-vibrato and oboe with vibrato; and (2) A = 430 Hz, A = 435 Hz, and A = 445 Hz sounded electronically on Korg™ tuners. Subjects were asked to match their instruments to each of the five stimuli. Responses

were recorded and analyzed for directional and non-directional cent deviations from each of the five stimuli and studied for possible effect of vibrato, timbre, and frequency on tuning accuracy.

The following null hypotheses were tested:

1. There will be no significant difference in the accuracy of tuning responses between the oboe stimuli and the Korg™ tuner stimuli;

2. There will be no significant difference in the accuracy of tuning responses between the oboe non-vibrato and oboe vibrato;

3. There will be no significant differences among tuning responses to the three Korg™ pitches of A = 430 Hz, A = 435 Hz, and A = 445 Hz;

4. There will be no significant differences among tuning responses of university, high school, and junior high school subjects; and

5. There will be no significant differences among tuning responses of woodwind, brass, and string instrumentalists.

Review of Literature

Intonation, according to the Randel edition (1986) of the Harvard Dictionary of Music is, "the degree to which pitch is accurately produced in performance, especially among the players in an ensemble (p. 402)." He states that tuning is "the art of adjusting the fundamental sounding frequency or frequencies of an instrument, usually in order to bring it or them into agreement with some predetermined pitch (p. 884)." The discrimination between these two elements, intonation and tuning, is often

unclear, and in common usage they may be applied interchangeably. In this study, intonation was regarded as playing correctly in tune with the stimulus pitches, and tuning was considered to be the process by which the instrument and/or embouchure is adjusted by the subject in order to match their responses to the stimuli.

The idea of a standard pitch level is a relatively new concept. The "A = 440 Hz" became a standard measure with the British Standards Institution Conference in May of 1938, and was adopted by the International Organization for Standardization in 1955 (Randel, 1986). Pitch level of an "A" had been very flexible, ranging from 360 Hz (Allman, 1989) to 567.3 Hz (Helmholz, 1954) during the middle of the seventeenth century in England and ranging, toward the end of the nineteenth century, as high as 455 Hz in England and 461 Hz in the United States (Backus, 1977). Due to the influence of temperature on instruments, the British Standards Institution Conference not only specified the pitch, but also the temperature (68 degrees Fahrenheit) at which this pitch should be measured (Young, 1956).

The accepted standards help to give some framework in which to study the intonational structure used today. Yet, as Mursell (1946) stated; "Any scale is a construct of the social mind, a phenomenon of social agreement (p. 565)." This idea of societal selection or choice may give insight as to why orchestras such as the Boston Symphony Orchestra and the Los Angeles Philharmonic use an A = 442 (Allman, 1989) as their tuning frequency for it is widely conjectured that upward

adjustments of pitch, although very small, give the orchestra a brighter sound.

Direction of Deviation: Sharp or Flat

The research literature regarding direction of deviation consists of both instrumental and vocal studies. Within each of these categories are studies regarding preference, perception/discrimination, and performance.

Scientific research in tuning preference for orchestral music has indicated that subjects prefer sharper over flatter sounds and, if given the opportunity, would raise the pitch (Geringer, 1976). This propensity toward sharp intonation preference has been well documented in other studies (Geringer, 1978; Madsen & Flowers, 1981/1982; Madsen & Geringer, 1976).

Geringer (1976) presented recorded orchestral music to 60 subjects, giving them an opportunity to change the pitch level of the excerpts by as much as an augmented fourth. He found that mean cent deviations for the group were 149.29 cents (approximately 1 1/2 semitones) for sharp tunings with mean deviation for flat tunings at 88.43 cents. The Madsen and Flowers (1981/1982) study of tuning in flute and oboe duets determined that subjects, when given the opportunity to adjust the frequency of the instruments in the recorded examples, had definite preferences for sharpness.

Another study where subjects were able to manipulate pitch frequency was by Madsen, Edmonson, & Madsen (1969) who found that elementary school students, when responding to

taped tones from an audio oscillator, tended to respond to the tonal stimulus incorrectly and sharp while older subjects responded with a tendency toward flatness. The investigators determined that auditory discrimination was partly a function of age as well as training. A subsequent study of trumpet tone quality versus intonation by Madsen and Geringer (1976) sought to determine any trends in perceptual judgments by asking subjects to determine whether a performance was good or bad for intonation and tone quality categories. Results showed 1) that music majors could discriminate more accurately between good and bad tone quality when the trumpet was not accompanied; 2) However, in a multiple variable condition created by the addition of accompaniment to trumpet excerpts, this was not the case; 3) Subjects were overwhelmingly influenced by intonation to the extent that when the tone quality was bad and intonation good, subjects judged the excerpt to be good. In other words, their perception was that both tone quality and intonation were of good quality; 4) Subjects showed preferences for sharp and in-tune accompaniment over flat.

Madsen and Geringer (1981) investigated similar factors by asking subjects to determine whether there existed bad tone quality or bad intonation (sharp or flat) for a series of oboe/flute duets. Results showed that more intonation errors were perceived than tone quality errors when in fact the study was designed to have twice the number of tone quality errors as intonation errors. A significant difference occurred in

correct discrimination of intonation performance between 38% correct to sharp stimuli and 62% correct to flat stimuli. A subsequent study of pitch and tempo discrimination in recorded orchestral music by Geringer and Madsen (1984) determined that subjects could identify the presence of an error, but not the element change (pitch or tempo) which was the reason for the error.

Brown (1991), conducted a study which had 30 musicians and 30 non-musicians manipulate an electronically generated tone to match a simultaneously generated musical tone. The musical tones were from recordings of trumpet, trombone, violin, viola, voice and flute. The attacks and decays of the musical tones were removed. He found that responses for musicians placed the electronically generated tone above the musical tone stimulus ($\underline{M}$ = 10.53) while non-musicians placed the electronically generated tone below the musical tone stimulus ($\underline{M}$ = -7.76).

A question closely tied to the topics discussed above is that of the actual performance practice of beginning through advanced musicians. Several studies (Geringer and Witt, 1985; Nickerson, 1949; Sogin, 1989; Yarbrough and Ballard, 1989) demonstrated a propensity to perform sharp to given stimuli.

These studies related that most subjects performed tones sharp in relationship to A = 440 Hz; however, Geringer and Witt, in their 1985 study with string players responding to oboe stimuli, discovered that subjects tended to perform flat to the sharp stimulus (A = 440 Hz + 25 cents), and sharp to the

in-tune (A = 440) and flat stimuli (A = 440 Hz -15 cents). College and professional subjects were found to play sharper to the sharp and flat stimuli than high school subjects. A study by Nickerson (1949) stated that solo and ensemble performers tended to play consistently sharp when compared to equi-tempered tunings, sharp to Pythagorean on the intervals of perfect fourths, perfect fifths and major sixths, flat to Pythagorean tunings of major seconds, and ensembles flat with solos sharp to Pythagorean tunings of major thirds.

A study that sought to determine if visual stimuli affected intonational performance was designed by Salzberg (1980). She had subjects perform the musical tasks of a scale, arpeggio, double stops, and a melody with and without blindfolds. Results demonstrated no significant differences between visual conditions. Salzberg found that, as much research shows, the subjects played sharp to the stimuli.

Yarbrough, Karrick, and Morrison (in press) determined that instrumentalists performed more flat responses in the first year of instruction and more sharp responses in the fourth year. Treatments were: (1) subjects knew that the tuning knob on a variable pitch keyboard was mistuned in the sharp direction; (2) subjects knew the tuning knob was mistuned in the flat direction; and (3) subjects had no information on mistuning. Data showed that approaching the target pitch from above resulted in more sharp responses, from below, more flat responses, and those having no knowledge of mistuning direction responding equally flat and sharp. Tuning accuracy

was determined to be affected by years of experience and not by treatment. Accuracy consistently improved from the first to the fourth year.

Intervallic direction has been found to have a distinct effect on the performance of intonation. String players stated there was some difference between the production of ascending versus descending intervals with the ascending intervals sharper than equal temperament and the descending flatter (Greene, 1937). Of the five intervals tested, three had median scores that were flat with regards to equal temperament and two sharp of equal temperament. Greene's results indicated that the direction of musical interval performance exerts little influence on the overall intonational accuracy. A more recent study by Yarbrough & Ballard (1989) revealed the propensity of string players to play sharp; the interval direction did not greatly affect this sharpness. It should be noted, however, that of thirty-nine subjects in the study, thirteen subjects stated in a written survey that a flatted fifth of a pattern should be played flat and performed them flat.

In a study by Kantorski (1986), overall string intonation direction stayed consistently sharp. It was discovered, however, that the string players used as subjects performed with greater sharpness in the higher registers of their instruments than in the lower registers when both were played with computer-generated accompaniment.

Karrick, in a 1994 dissertation, presented subjects with a taped melody line to which they added a bass line and taped a

bass line to which they added a melody line. Performances were taped and analyzed for responses to 24 intervals from each playing (melody/harmony). Results demonstrated that university and professional performers' responses were closest to equal temperament and furthest from just tuning. Placement of the stimulus either above or below the response affected response accuracy. University subjects tended to perform less sharp than professional players when performing the bass line and less in-tune when playing the melody.

Another study which sought to determine the effects of duration on intonation deviation, added the elements of pitch deviation due to string instrument types, the presence or absence of vibrato, the effect of ascending versus descending pitches, and pitch differences among individual tones (Sogin, 1989). In this study, Sogin asked subjects to perform a four note ascending and descending scalar pattern. This pattern was played with and without vibrato. Sogin found that the instrument type and the presence or absence of vibrato made no significant difference in tuning accuracy. He also discovered that string instrumentalists tended to perform sharper at the end of the pitch than at the beginning, and that scalar material tends to be played sharp regardless of the melodic direction.

A study by Duke (1985) of wind instrumentalists seems to disagree with some of the findings of Sogin. Duke found that a significant, if musically inconsequential, difference in pitch sharpness appeared when direction was involved. Subjects were found to perform intervals slightly flatter when

ascending and slightly sharper when descending. The study observed that junior high school subjects tended to perform with a slight propensity to sharp intonation while college subjects demonstrated a propensity for flat intonation.

Some research has examined combinations of the elements of preference, discrimination, and performance. Yarbrough and Ballard (1989) found that when subjects play out-of-tune, they most often play sharp in spite of direction (ascending or descending). Subject opinion of the function of a note, that is, a sharped note functioning as a leading tone, that same note functioning as the third of an ascending or descending scale, and as a flatted fifth in a descending scale, showed that only 15 of 39 subjects performed the leading tones in agreement with their opinion that it should be sharper, six subjects sharped the third ascending, eight sharped the third descending, and thirteen played a flatted fifth in the descending scale.

Research shows that there is a tendency to prefer sharp pitches when subjects are given the ability to adjust the stimuli, it has been found, however, that there is greater sensitivity to, and accuracy in discriminating pitch flatness (Geringer, 1978; Geringer & Madsen, 1984; Geringer & Witt, 1985; Madsen, Edmonson & Madsen, 1969; Madsen & Geringer, 1976, 1981; Salzberg, 1980; Siegel & Siegel, 1977). In a study by Geringer (1978), the elements of perception in performance and perception of taped stimuli were combined. Instrumentalists and vocalists performed scalar patterns,

accompanied by piano and unaccompanied, with an opportunity afterwards to adjust their own recordings to a pre-recorded accompaniment. Results showed that accompanied scales were performed and perceived with significantly less absolute deviation and a tendency (though non-significant) to be less sharp than unaccompanied scales. The perceived intonation of performed and recorded unaccompanied scales was significantly less accurate. Vocal and keyboard players tended to respond with a sharper deviation from the stimuli than string and wind groups (String 2.7 cents; wind 3.5 cents; voice 11.0 cents; keyboard 10.7 cents), however, analysis differences disregarding direction were not significant.

Geringer and Witt (1985), in a study of preference for tuning stimuli and performed tuning accuracy, asked string subjects to tune to tape-recorded oboe pitches. One stimulus was at A = 440 Hz, one at A = 440 Hz + 25 cents, and one at A = 440 Hz - 15 cents. They discovered a significant difference in tuning accuracy to the three stimuli and to age groups (university and high school). Subjects were found to tune below the sharp pitch and above the in-tune and flat stimuli. High school subjects were found to tune lower for the sharp and flat stimuli than the college level subjects. All subjects, however, prefered a tuning sharp to A = 440. Actual performance responses were more flat than sharp and more sharp than in-tune.

Instrumental research presented here shows that although there is a tendency toward sharp performance, this is

not always the case. Direction (ascending/descending), previous note position, degree of deviation from a pitch standard, instrument group, and age have all been shown to affect results. A definitive answer regarding the effects of these influences has not been found . Preference, research clearly demonstrates preferences for sharp over flat intonation. Finally, instrumental studies of intonation perception/ discrimination, show better detection of flatness than sharpness.

Results of vocal research concerning the effects of direction on pitch discrimination and production are similar to that of instrumental research. Although the overall tendency is for sharp performance, as shown in the instrumental research, this tendency does not always hold true.

Discrimination research in the vocal field shows that pitch accuracy may be connected to timbre factors. A series of related studies makes apparent the effect of stimuli timbre on the pitch discrimination abilities of elementary students. The first study by Green (1990) sought to determine the effects of an adult female model, an adult male model, and a child model. It was discovered that vocal modeling did have an effect on response accuracy with children (grades 1 to 6). Responses were most correct in response to the child model followed by the adult female and then the adult male. Incorrect responses were more often sharp to the child model and flat to the adults. The highest degree of flat responses was produced by the first graders.

The second study of the set (Yarbrough, Green, Benson, and Bowers, 1991) explored the variables affecting pitch discrimination of a descending minor third sung by an adult female and an adult male. The variables studied consisted of (1) the use of Curwen hand signals as the students sang, (2) the use of solfege syllables of sol-mi, and (3) the pitches sung on a "la." Results demonstrated that no significant difference occurred for response mode, but a significant difference did occur for the male versus female model. Students were able to perform more accurately in response to the female stimuli.

The next study in the set (Yarbrough, Bowers, and Benson, 1992) sought to determine the effect of vibrato on pitch discrimination. Three stimuli were used, one a child without vibrato, one a female with vibrato, and the third, a female without vibrato. More correct responses were achieved in response to the female without vibrato than to the female with vibrato or the child. Presentation order was found to have an effect, with the greatest number of correct responses to the child when it was presented first and to the vibrato model when it was presented last. Responses to the non-vibrato adult model were most consistent across positions.

Price, Yarbrough, Jones, and Moore (in press) examined the effect of male timbre and falsetto and sine wave models on interval discrimination. Subjects were asked to vocally match a tenor and a bass vocalist who produced stimuli in their regular octaves and then in falsetto. Two sine waves, one in each octave, were also presented. Results showed more

accurate responses to the voices than to the sine waves. Girls responded more accurately to the higher pitches with boys more accurate to the low. The use of falsetto or regular voice also affected the size of the interval sung with the higher stimuli (falsetto) producing responses at or above middle C and the lower stimuli (regular voice) producing responses (6 of 8) in the lower octave when the stimuli was below C_4. The most recent study (Yarbrough, Morrison, Karrick, and Dunn, in press) tested the effect of male falsetto on pitch discrimination accuracy of uncertain boy singers in grades K - 8. This article, a replication and extension of the Price, Yarbrough, Jones and Moore (in press) article, used a different measurement system and examined only uncertain singers. It was found that significant differences did occur among octave models with the higher models eliciting more time spent on the correct pitch than the lower models.

A similar study by Small and McCachern (1983) which sought to determine differences in responses to male and female models found that before practicing with the models, subjects who could match one model could usually match the other. After a practice period with each model, no significant difference was discovered between responses. The female model grand mean was only slightly higher than that for the male.

Three studies, Elliott (1974), Cassidy (1985), and Smith (1984) joined instrumental and vocal experiences of band students in order to determine if vocalization could help to

develop more accurate pitch discrimination skills. Elliott (1974) used daily vocalization practice in beginning band classes to try to improve accuracy on aural acuity tests. Treatment consisted of the experimental groups singing selected exercises from the class literature in addition to their regular instrumental practice. He found that vocalization had a significant effect on post-test scores of the experimental group over the control group. Brass and woodwind players were affected equally by the treatments. Smith (1984), conducted a study in which treatment conditions of either playing the material or singing and playing the material were examined. Smith found that vocalization did not significantly affect the intonation of college wind players performances. A significant difference did occur, however, in responses by instrument group. Woodwinds tended to perform with less deviation ($\underline{M}$ = 30.86) than brass players ($\underline{M}$ = 38.03). Brass showed a higher mean score in the sing/play condition ($\underline{M}$ = 43.10) and woodwinds a lower mean ($\underline{M}$ = 30.30).

In a study which included both singing and playing for all subjects, Cassidy (1985) found, in a study of the effect of a sing-play and a play-sing condition on second year band students, that the condition order had a significant effect on the performance level. Play-sing groups showed more accurate overall intonation. She found that there was little correlation between vocal and instrumental intonation. Instrumental performance was, however, superior in intonation to vocal performance.

Research by Madsen, Wolfe, and Madsen (1969) sought to determine if intonational improvement could be affected with differential training in ascending and descending scales, and if improvement could be affected by behavior modification. In this study, subjects were pre-tested by singing a B and C# major scale. They were then assigned to one of eight treatment groups. The treatment groups consisted of practice in only ascending scales, only descending scales, both ascending and descending, and practice of selected songs. These four conditions were then treated with reinforcement or non reinforcement. After the period of treatment, the groups were then post-tested using the same scales. Results indicated that a significant difference occurred in cent deviation of scale accuracy with greater changes occurring in the accuracy of ascending scales. This study found that no significant difference occurred for scale direction or reinforcement versus non reinforcement groups. The group which showed the greatest improvement was the one with reinforcement and singing selected songs. The idea is put forth that singing songs improves intonation of scales if "motivation is high (p.29)."

The previous vocal studies have looked at a condition where a treatment has been implemented in order to help improve intonation over time. In addition to these discrimination and perception studies, many of which included a performance element, several studies have been done which looked only at performance tasks. Some of these include Edmonson (1972), Madsen (1966), and Vorce (1964).

Madsen (1966) found that there was a significant difference between vocal pitch acuity for ascending and descending scales. The intonation of descending scales was superior to that of ascending. Results demonstrated that the total cent deviation of ascending scales was approximately four times that of descending (23,921 cents - ascending, 6058 cents - descending). Edmonson (1972), followed with a study to test three hypotheses: 1) all subjects perform ascending intervals more accurately than descending; 2) there is no consistent pattern of intonation differences among individuals or groups; and 3) the relative difference between ascending and descending patterns remains constant regardless of treatments. The study involved the vocal performance of four selected intervals by vocal and instrumental subjects. Conclusions were that a significant difference occurred between the vocal performance and interval direction with ascending intervals highly superior to descending. Edmonson found no consistent pattern of group or individual differences, and the relative difference between ascending and descending patterns remained constant regardless of instruction. As is true in instrumental research, conflicting results are also present in the vocal area.

The consideration of simultaneous presentation by a model during subject response versus the subject independently has been shown to effect the accuracy of pitch (Vorce, 1964). In vocal performances, accompanied responses had a highly superior accuracy level. Brass, keyboard and woodwind players

were found to perform with a tendency toward flatness when compared to the stimulus while vocal performers tended to be sharp to the stimuli.

Instructional Methods for Intonation and Tuning

One of the more popular ideas regarding tuning or adjusting the pitch is that of tuning by elimination of beats (Backus, 1977; Cassidy, 1988; Corso, 1954; Graves, 1963; Miles, 1972; Tunks, 1982; Walker, 1948;). According to Wagner (1978), beats are, "the periodic reinforcement and cancellation of two waves due to a difference in frequency (p. 79)." The number of beats produced between two pitches sounded simultaneously is represented as variations in loudness due to the differences in the speed and length of the sine waves, or frequency, of the sounding pitches. This difference in frequency between the two instruments, determines the number of beats heard per second. Although this beating or "chorus effect" is desired in ensembles for added richness and power in the tone, it is a problem when trying to tune one single pitch to another in that one must first discriminate which pitch is the stimulus or target pitch. This problem of tuning is, in practice, inherent in all instruments with the exception of electronic instruments which may maintain the same frequencies over long periods of time (Campbell & Greated, 1987).

Subsequent studies such as the one by Miles (1972) demonstrated that even young students can be taught to use beat elimination in order to achieve correct intonation. In this

study, Miles worked with beginning band students in six sessions which became progressively more difficult in the task of beat elimination. These began with a demonstration of the beat elimination process through the use of the Intonation Trainer, an electronic pitch matching device which is capable of producing two pure tone frequencies. One frequency, adjusted by a dial, is held constant while the other frequency can be manipulated by another dial in order to bring the two pitches produced to the same frequency. Subjects (N = 118) attempted to eliminate beats with the Trainer. They then progressed to attempts to match their instrument to the trainer, the investigator, another subject, and major thirds and perfect fifths with the investigator. Three subjects then performed a major triad and attempted eliminate the beats. Subjects were taught to use the trainer in each of the conditions. Miles found that young students could be taught to perceive the presence and absence of beats.

A study by Cassidy (1988), examined the effect of beat elimination through the use of a Johnson Intonation Trainer and the use of lip flexibility exercises to help build better physical manipulation skills. The high school and middle school trumpet players used as subjects were divided into an experimental and a control groups. The control groups rehearsed without corrective feedback while the experimental group used the intonation trainer and received information from the researcher on pitch manipulation through the use of embouchure changes. Results indicated at a significant improvement of the

middle school for the experimental group over the control group. High school subjects demonstrated no significant gain.

The development of intonational and tuning skills is a process through which many roads may be taken to try to reach the same end. One of the techniques devised by string players involves the internalization of the pitch "A." This ability is often developed to the point that string players can vocalize or tune the instrument to this pitch without outside assistance (Farnsworth, 1969). Internalization of this type does have a counterpart in the brass world. It is conjectured that many trombonists, as well as string players, develop a kinesthetic sense for pitch and tuning, not by what is heard, but by what is felt (Parker, 1983). Salzburg (1980) approached the topic of internalization in a study of the visual aspect of string playing. University string players played a scale, an arpeggio, double stops, and a melody with normal visual stimulus (i.e. with their eyes open), and then played while blindfolded. It was found that the visual condition did not affect the accuracy of intonation.

Heller (1969) conducted a study to determine if visual-auditory feedback was superior to auditory feedback alone in regards to intonational accuracy. To accomplish this, subjects played or sang 16 phrases which were then used as models for each subject. Subjects were then asked to match their own pitches. The models were presented aurally and as computer generated graphs. These graphs detailed note attacks, releases, duration, and frequency fluctuation. Results stated that the

dual method of feedback was superior to the auditory feedback alone in increasing intonational accuracy.

Another study which supported dual feedback was one by Albert (1967) with instrumentalists. The effects of differential treatments on pitch accuracy of performance of an A = 440 Hz, incorporated several inducements to improve. These included oral inducement (lecture), visual inducement (stroboscope), aural inducement (hearing pitch through earphones), and aural inducement plus corrective instruction (told if flat or sharp). He found that the combination of aural inducement and corrective instruction produced the greatest improvement in pitch discrimination.

Graves (1963) included three approaches to tuning in his study. These were: (1) the use of the Stroboconn as a visual reference; (2) the playing of a pitch and tuning it to the playing of the same pitch on a fixed pitch instrument as an aural method; and (3) the "conventional" method, according to Graves, by which a student learns the basics of music theory so that an understanding of the function of notes and their relationships to each other may help to develop intonational accuracy. A significant difference was observed among the three methods of testing in different musical areas. None of the methods was consistently superior to the others; however, the conventional method appeared to be more effective generally than did the aural or visual method. Another study involved the use of the Stroboconn as a visual method (Lader, 1977). In comparing the methods of visual, aural, corrective

feedback, and combinations thereof, it was found that none of the treatments caused significant improvement. One interesting result of this study was that the subjects tended to play flat as opposed to sharp which is contrary to most other research.

The advent of computers has added an entirely new aspect to the teaching of intonation. The use of computer teaching programs to help students learn to match pitch and to discriminate pitch differences has produced interesting results. One such study incorporated the use of a "Tuning Tutor" which gave students instant feedback, and turned the learning of intonation into a game (Glass, 1989). The game allowed for aural or aural/visual usage in the Tutor Mode and was designed for individual, systematic development of discrimination skills of pitch difference, error direction, and development of the ability to bring an out-of-tune note into tune. Results revealed no significant difference among mean test scores, yet significant differences occurred in comparison of pretest/posttest game points and pretest/posttest time/score indices with posttest game point scores increasing significantly and time/scores decreasing significantly.

Another computer-assisted learning situation involved a mixture of computer and class/teacher situations. In this case, an experimental group received instruction in guitar tuning directly from the instructor which was reinforced through the use of a computer program (Codding, 1985). This multi-sensory treatment, visual/aural then verbal/aural feedback with the

experimental group was found to make no significant difference in the overall tuning accuracy of experimental versus control subjects. However, in a comparison of treatments, the study found that the students were significantly better at tuning when presented with immediate visual-aural computer feedback of the tuning pitches, but the improvement did not transfer into testing away from the computer. Another study by Codding (1987) using visual versus verbal instruction on beginning guitar student's tuning accuracy found that subjects in the visual treatment, which used computer graphics to relate pitch discrepancies between guitarists pitch and the stimulus pitch, were more accurate than subjects in the verbal condition during treatment. The verbal condition group, however, proved to be more accurate than the visual in the final posttest trial. Results suggested that the visual was more immediately effective, yet, was less effective once treatment was removed.

As the computer generation comes of age, one is apt to re-evaluate a more traditional information presentation method, that of modeling. Modeling has long been used and found to be a good way of presenting information (Hofmeister, 1982). Models may be live or electronically produced. Dowdy (1973) presented a study using 34 clarinet players from high school and college levels. In this study, a control group received a set of recorded pitch models to match, while an experimental group received a tape of their own playing and could raise or lower the pitch of the tape using a variable pitch recorder. It was found that the variable pitch method of teaching tuning was

more effective overall with the more mature, experienced university subjects benefiting most from this teaching methodology.

Relationship of Timbre to Intonation

The relationship between timbre and intonational responses is not yet well understood. Extant research covers several different areas including the effects of bright/dark timbres on pitch and comparisons of the timbres of multiple stimuli. Wapnick and Freeman (1980) conducted a study where 50 subjects heard 48 pairs of clarinet tones which differed in register (high or low) and timbre (dark or bright). Subjects responded on an answer sheet by telling if the second pitch was sharper, flatter, or the same as the first of the pair. Results demonstrated that subject responses were more flat than sharp when a bright-dark condition was presented, while a dark-bright condition produced more sharp errors than flat. Bright-bright conditions produced no significant difference and the dark-dark condition produced more flat than sharp errors. Significantly more pitch discrimination errors were made when the timbre changed and subjects were more accurate when the second tone was flat to the first of the pair.

Another study which linked timbre and intonation was conducted by Madsen and Geringer (1981). Two hundred and forty music majors and two hundred and forty non-music majors listened to 24 duet performances. The subjects were asked to respond to the tone quality (good or bad) and intonation (sharp, flat, or in-tune). This study showed that

subjects were able to detect errors without being able to identify whether the error was one of intonation or tone quality. Intonation differences of as much as 50 cents between soloists were identified as incorrect without correctly labeling the specific error (i.e.; intonation or tone quality). It appeared that, in this study, subjects were reacting more to intonation variables than to tone quality.

Ely (1992), in a study of college woodwind players, found that timbre did have an effect on perception and performance. Written responses of correct or incorrect for taped in- or out-of-tune stimuli as well as performance data were taken. Results showed that timbre had a significant effect on the detection of intonation problems, but not on the subjects' playing in tune. More flat responses than sharp or in-tune were found, and subjects tended to match their own instrument stimuli (flute, saxophone, or clarinet) slightly better.

Often studies look at a combination of factors concurrently. One such study incorporated timbre, intensity, duration, and relative frequency of 440 Hz - 20 cents, 440 Hz, or 440 Hz + 20 cents (Swaffield, 1974). After hearing an ascending pattern played, the subjects were asked to tune to the fundamental of that pattern. Results indicated that all four factors had a significant effect on tuning, with one of the strongest factors being the frequency of the initial tone. Additionally, the timbre of the French horn was found to be easier to tune to than the timbre of the violin. The other two timbres used in the four-factor design were clarinet and flute.

Another study which combined factors was one in which Leonard (1967) sought to measure pitch discrimination, through the use of taped examples. These examples were used to present differences in register-frequency, intensity, timbre, context, and duration of inter-stimulus time interval. Elementary education majors responded to taped stimuli. Significant differences were found in the effect of intensity with a difference in this pattern associated with register. Accuracy among the intensity levels was inconsistent with 40 db having the fewest errors and 45 db having the most. At a level of 125 Hz, discrimination improved as the intensity increased, while at 250 Hz the accuracy decreased as intensity increased. Register - frequencies around 125 Hz appeared to be more accurate. Contextual accuracy was most effective as the third or fifth of a chord with duration of inter-stimulus time interval also having significance. Intensity and timbre were found not to be significant factors.

Corso (1954), in a study including five instrumentalists, showed that the harmonic structure of the reference tone or stimuli made no difference in tuning accuracy and that the unison tuning of instruments is dependent on pitch-matching judgments of the performers rather than the discrimination of beats. In this study, stimuli were presented using a square wave generator, a sawtooth generator, a sine wave generator, a half-wave rectifier, and a piano. According to the results found from this small sample, the wave form presented did not have an appreciable effect on tuning accuracy.

A study by Cassidy (1989), examined the accuracy of tuning to timbres and octave displacements of nine electronically produced pitches from a Moog Synthesizer. Nine pitches from the chromatic scale, excluding a Bb, E and F, were selected. Octave displacement of one octave above the reference pitch were assigned to three pitches, and one octave below the reference pitches were selected for three pitches. Within each of the displacement categories, one pitch was assigned to each of the categories of sine wave, sawtooth wave, and square wave. The other three were presented from the regular tuning frequency. An interaction was found to be present between the stimulus timbre and octave displacement. Clarinet players ($\underline{M}$ = 27.42) were found to tune slightly more accurately than flute players ($\underline{M}$ = 33.02).

Taylor and Pembrook (1987) conducted a study in which subjects were to match the discrimination hierarchy of melodic intervals to determine if there be any difference in correct responses among aurally presented tone pairs as a function of frequency difference, timbre (wave form), register, or direction of the second pitch. Findings from this study stated that the obtained hierarchy moderately matched the standard hierarchy, that pitch discrimination was better at 1.5%, or 18 cents, than at 1%, or 12 cents, timbre was not a significant factor in discrimination, register was significant with the highest registers better matched, and the second stimulus tone lower than the first producing better discrimination.

Cassidy (1989) also studied the effect of wave form and tuning stimuli timbre. Subjects were flute and clarinet players who tuned to nine taped stimuli of various timbre, wave forms, and octave displacements. Results demonstrated an interaction among the timbre and octave displacements. A significant difference was found between the instruments with the clarinet players (M = 27.42) tuning more accurately than the flute players (M = 33.02).

Timbre variables in many previous research studies have included the presence or absence of the initial attack and final decay of the sound envelope. In a study of wind instruments, subjects were asked to identify what instrument was playing. They were presented two prepared tapes. One tape had the attack and decay of each pitch while the other removed the attack and decay of the sound envelope (Bergee, 1987). Results demonstrated a significant difference in the number of correct responses of the subjects who listened to pitches which had been unaltered (including the beginning and end of the envelope) as compared to correct responses of those who heard an abbreviated envelope. Familiarity with the sound of the instruments was also a significant factor. Wind and percussion players scored more accurately than those who were not wind or percussion players (Bergee, 1987). Greer (1970), in a study of brass intonation, showed that the highest agreement of pitch intonation came with like instruments and the lowest agreement was with a pitch oscillator. The higher accuracy of subjects in response to the timbre of instruments is a result

contrary that found by Tunks (1982). Tunks found that performed responses to pairs of like instruments, tuned to themselves, were not different from responses to unlike instruments.

In addition to discriminate pitch with like and unlike instruments, the question of the ability to identify the kind of instrument being played, without the presence of the attack and decay of the sound envelope, has been studied. In a study by Elliott (1975), the beginning and end of the sound envelope was edited out on one of two stimulus tapes. Instruments used were flute, clarinet, oboe, bassoon, alto saxophone, trumpet, trombone, violin, and cello. Subjects, all graduate music students, responded by written identification of instrument to both the altered and unaltered tapes. Elliott found that, when presented with the tape of tones with the attacks and releases removed, only the clarinet, oboe, and trumpet were correctly identified a significant number of times. In the unaltered tape, all instruments were correctly identified a significant number of times with the violin and cello most often confused. Mean scores for both tapes indicated a significantly higher accuracy score for the unaltered pitches.

Vibrato Effects on Intonation and Tuning

Carl Seashore (1936) stated that vibrato is the most important of all ornamentation and that, "A good vibrato is a pulsation of pitch, usually accompanied with synchronous pulsations of loudness and timbre, of such extent and rate as to give a pleasing flexibility, tenderness, and richness to the

tone" (p. 7). Use of vibrato in the professional music field is a largely accepted fact with performances *senza* vibrato often found to be unpleasing and strained in sound. Goodwin (1977) reported that the ear fuses the oscillations heard into a single, unmodulated tone in a way similar to what the eyes do to give a single visual image. This idea of fusion may extend beyond single line or solo performance into the perception of ensemble performance (Brown, 1991). Winckel (1967) shows that in a section of like instruments, no two instruments begin on exactly the same frequency or oscillate with exactly the same rate or range. This action adds to the complexity of the sound achieved by an ensemble. Shonle and Horan (1980), in a perception and discrimination study, showed that the perceived pitch of vibrato corresponded to the mean of the oscillation. Most research shows that performers tend to vibrate above mean of the stimuli and that the target frequencies usually fall at or near the bottom of the oscillation (Fletcher, Blackman & Geersten, 1965; Goodwin, 1977; Papich & Rainbow, 1974). Harold Seashore (1932) related that while the pitch of the vibrato is slightly below the mean frequency, the amount of flatting is roughly equal to the range of the vibrato. When the range increases to as much as .75 to 1.00 step the target pitch is often very far from the mean frequency with some results above the mean, and some below.

Brown (1991) sought to determine the pitch perception of musicians and non - musicians when presented with a tone with vibrato. This was accomplished by using a tone-matching task

in which a subject attempted to match a non-modulating tone from a tone generator to recorded pitches. Results showed that a significant difference appeared among the two groups. Musicians were found to perceive pitches at a higher frequency than non - musicians and were sharp to the geometric mean while non - musicians tended to perceive the pitch slightly below the mean.

Papich & Rainbow (1974) studied the use of vibrato on string instruments. Results demonstrated that 1) vibrato was present in the attack of all notes; 2) the width and speed of vibrato were the same in both solo and ensemble situations; and 3) oscillation of vibrato did not tend to be both above and below the target pitch, but rather only in an upward direction from the target pitch. Geringer and Sogin (1988), in a study to test the intonational deviation of tones among woodwind, brass, and string players, discovered that sharpness in performance was consistent. In addition to these data, Geringer and Sogin collected data on string instrumentalists performance with and without vibrato. Results demonstrated that the accuracy of pitch was not significantly different when played with and without vibrato. In a later study, Sogin (1989) supported these results with string players, showing that the tuning accuracy of pitches played with and without vibrato was not significantly different.

Yarbrough, Bowers, & Benson (1992) studied the accuracy of vocal responses in elementary aged children. A minor third was presented by a child model and a female vocal model with

vibrato present, then absent. Measurements were taken on length of time spent on each of the target pitches. Findings showed that uncertain singers more successfully matched a female voice with non-vibrato and were least successful matching a female voice with vibrato. The non-vibrato stimuli elicited greater accuracy and consistent pitch discrimination across both genders and all age levels. Children classified as certain singers were not greatly affected by the introduction of vibrato.

Purpose of Study

Many existing studies have approached the question of intonation and tuning concerning the direction of response, the effects of timbre on performance or perception, the effect of vibrato on performance or perception, and instructional methods of improving intonational performance. However, the question of pure tuning to one reference frequency as one would do at the beginning of a rehearsal or performance, and the accuracy of that act has not been widely investigated. The purpose of this study was to examine the accuracy of responses to five stimuli. The selected stimuli were used to make one more small step in the search for answers to the question of the effect vibrato, stimuli timbre, and stimuli frequency have on tuning accuracy of instrumentalists. In order to accomplish this task, subjects were presented with each of five stimuli. Audio recordings were made of their responses. The responses were then transferred to digital data through a computer

system and analyzed for absolute and directional pitch deviation from the stimuli. Specific questions addressed were:

1. Does the timbre of a tuning stimuli have an effect on the tuning accuracy of instrumentalists?
2. Does the presence or absence of vibrato effect accuracy?
3. Does the pitch level or frequency of the stimuli effect accuracy?
4. Are there tuning accuracy differences which occur among educational levels?
5. Does the type of instrument have an influence on performance accuracy?
6. Do instrumentalists tend to tune flat, in-tune, or sharp to stimuli?

Terminology Used in Study

Absolute Deviation - The magnitude of cent deviation disregarding the direction of mistuning.

Cent - The unit of measurement which represents 1/100 of an equal tempered semitone where there are 12 equal semitones in an octave.

Cent Deviation - The difference in cents between a performed pitch and the stimulus pitch.

Directional Deviation - The direction, flat or sharp, of deviation from the stimulus pitch disregarding the octave displacement.

In-tune - The performance of a pitch whose cent deviation falls between ± 6 cents of the frequency of the stimulus pitch.[1]

Intonation - The process by pitches are produced which are correctly in-tune with the stimuli.

Stimulus and Stimulus Pitch - One or all five of the pitches used in this study. They are: 1. oboe vibrato; 2. oboe non-vibrato; 3. Korg™ A = 430 Hz; 4. Korg™ A = 435 Hz; and 5. Korg™ A = 445 Hz.

Timbre - The tone color or quality of a sound. The quality of a sound that distinguishes one instrument from another.

Tuning - The process by which an instrument and/or embouchure is adjusted in order to match the produced pitch to the stimuli.

Vibrato - The slight fluctuation in frequency used by performers to enrich or intensify a sound.

Footnote

[1]Just Noticeable Difference, or JND is defined as the amount by which a stimulus must be changed in order for an observer to detect a difference. A criterion is usually set for the percentage of times a correct response must occur in order for a JND to be set (Radocy & Boyle, 1979). The JND is different at different frequency levels with smaller JND at lower frequencies.

Backus, in The Acoustical Foundations of Music (1977), stated that in frequencies up to about 400 Hz, with frequency

modulation or vibrato at the rate of four oscillations per second, a modulation could be perceived if the frequency range were greater than about 3 Hz or approximately 13 cents (Young, 1956). Backus then states that considerably smaller changes could be heard if the changes were more sudden and that a "good ear" could hear a change as small as 3 cents at a frequency of about 500 Hz. Madsen, Edmonson, & Madsen, (1969) suggested that people can discriminate within ± 10 cents, while Parker (1983) suggested the discrimination point was around 20 cents. Williamson (1942) found that trained listeners can distinguish differences as small as 2 cents.

A study by Rodman (1981), in which test tapes of pure, electronically produced tones were played for subjects, showed that adult musicians were able to distinguish variances at about 4 cents with high school students able to distinguish differences at 5 cents and junior high school students at 12 to 15 cents. A 2 cent variance proved too small for even adult musicians to distinguish above a 34% degree of accuracy. This was only slightly above pure chance. In 18 of 20 comparisons among subject groups, subjects were more accurate in identifying flatness than sharpness. This study showed that adults were accurate on 90.74% of flat responses (15 ± cents) and 68.51% of sharp responses (15 ± cents). Students proved to be correct on 53.988% of flat responses (15 ± cents) and correct on 30.596% of sharp responses. Analysis for differences of 10, 5, and 2 cents was consistent with this

directional response but did not have as wide a percentile range.

For purposes of this study, based upon existing research, the cent deviation considered accurate was ± 6 cents. This was derived by taking an average of the three cent variances from the Rodman study (4 cents, 5 cents, and 12 cents), the results of Madsen, et. al. (10 cents), Williamson study (2 cents), and findings of Backus (3 cents).

METHODOLOGY

The purpose of this study was to examine intonation under a variety of conventional stimuli. Specifically, the tuning accuracy of university, high school, and junior high school woodwind, brass, and string instrumentalists was compared when responding to taped stimulus of A = 440 Hz played on an oboe non-vibrato and an oboe with vibrato; and pitches produced electronically on a Korg™ tuner of A = 430 Hz; A = 435 Hz; and A = 445 Hz. Subjects were asked to tune their instruments to match each of the five stimuli. Responses were recorded and analyzed for directional and non-directional cent deviations from each of the five stimuli and studied for possible effect of vibrato, timbre, and frequency on tuning accuracy.

Subjects

Subjects ($\underline{N}$ = 198) for this study were university, high school or junior high school string, woodwind or brass players. University subjects ($\underline{n}$ = 85) were enrolled as undergraduate or graduate music students at a major southern university with academic majors of applied music, music education, composition, music theory, or music history. Classifications ranged from freshmen through doctoral students. Other subjects were from existing band classes at a university affiliated laboratory school (high school $\underline{n}$ = 27; junior high school $\underline{n}$ = 49) and string students from a public high school and junior high school (high school $\underline{n}$ = 28; junior high school $\underline{n}$ = 9) in a major southern city. High school students were in grades nine through twelve with junior

high school students in grades seven and eight. Subjects were drawn from existing classes. The band students included all students in the junior high and high school bands. The high school string class was also a full class. Due to unscheduled and unannounced student absences and scheduling in the junior high strings, the full class was not available to participate.

Subjects were grouped not only by educational level, but also by instrumental groups of woodwinds (university, n = 29; high school, n = 11; junior high school, n = 21; total woodwind, n = 61), brass (university, n = 30; high school, n = 16; junior high school, n = 28; total brass, n = 74), and strings (university, n = 26; high school, n = 28; junior high school, n = 9; total strings, n = 63).

Tuning Stimulus Selection

A total of five tuning stimuli were presented to each subject:

1. A = 430 Hz played by a Korg™ Digital Tuner Metronome DTM-12
2. A = 435 Hz played by a Korg™ At-12 Chromatic Tuner
3. A = 445 Hz played by a Korg™ At-12 Chromatic Tuner
4. A = 440 Hz played by an oboe, non-vibrato
5. A = 440 Hz played by an oboe, vibrato

Three Korg™ tuners were used to present stimuli numbers 1, 2, and 3. Three tuners were used in order to avoid the necessity of recalibrating the tuners for each electronic stimulus presentation. Oboe stimuli were presented via audio taped recordings.

The "A" was chosen as the tuning stimulus in an attempt to keep the experiment in a controlled setting which would, as closely as possible, simulate the tuning situation of a symphony orchestra. The A = 440 Hz is the pitch level which has been considered standard since its adoption by the British Standards Institution Conference in 1938, and by the International Organization of Standardization in 1955 (Randel, 1986; Backus, 1977). The A = 430, 435, and 445 Hz pitches were selected as pitches outside the normal tuning realm in order to determine how well subjects could match tuning pitches beyond usual tuning frequencies.

A counterbalanced design was developed to avoid order effect (See Table 1). The twelve order design balanced the presentation of the electronic stimuli and inserted the non-vibrato versus vibrato oboe stimuli between the electronic stimuli in an alternating pattern. The design was also balanced among string and wind players to insure that similar numbers of winds and strings performed in each order (See Table 2). The design was replicated for each education level.

Experimental Environment

University data were gathered in a large, well-ventilated, well-lighted, temperature controlled research laboratory with a minimum of environmental noise. Laboratory school data were gathered in a large, well-ventilated, well-lighted, temperature controlled ensemble practice room situated off

Table 1

Counterbalanced Design for Oboe Stimuli of Non-vibrato and Vibrato and Korg™ Stimuli of A = 430 Hz, A = 435 Hz, and A = 445 Hz

Legend: N = Oboe non-vibrato at 440 Hz
V = Oboe with vibrato at 440 Hz
1 = 445 Hz
2 = 435 Hz
3 = 430 Hz

Order					
1	1	N	2	V	3
2	1	V	2	N	3
3	1	N	3	V	2
4	1	V	3	N	2
5	2	N	1	V	3
6	2	V	1	N	3
7	2	N	3	V	1
8	2	V	3	N	1
9	3	N	1	V	2
10	3	V	1	N	2
11	3	N	2	V	1
12	3	V	2	N	1

the main band hall. This room provided an environment with a minimum of external noise. String data, at both the high school and junior high school, were collected in a large, well-ventilated, well-lighted, temperature controlled ensemble practice room off the regular orchestra rooms. These rooms provided a minimum of external noise.

Table 2

Example of String/Wind Order for Twenty-five Subjects

	Stimulus Presentation and Control Orders		
Random Subject	Instrument	String	Winds
1	Wind		1
2	String	1	
3	String	2	
4	Wind		2
5	Wind		3
6	Wind		4
7	String	3	
8	String	4	
9	Wind		5
10	Wind		6
11	String	5	
12	Wind		7
13	Wind		8
14	String	6	
15	Wind		9
16	String	7	
17	Wind		10
18	Wind		11
19	Wind		12
20	Wind		1
21	String	8	
22	Wind		2
23	String	9	
24	Wind		3
25	Wind		4

Procedure

University subjects were scheduled at convenient times during the day with the junior high school and high school

subjects scheduled during their regular band or orchestra classes. Subjects were asked to warm-up before coming to the testing sight. Upon arrival at the sight, subjects were called into the room individually and asked to sit or stand in front of a Sony ECM-939LT Electret Condenser Microphone mounted on a microphone stand. The researcher was seated facing the subjects at a table which held a JVC JR-S100 Stereo Receiver, a Pioneer CT30 Stereo Cassette Tape Deck, a Marantz Stereo Cassette Recorder PMD 430, and a JVC PC-W35 Dual Cassette Recorder. A pair of Advent/3 speakers were placed on the floor, next to the table, facing the subjects. Data were recorded on the Marantz recorder using Sony HF 60 cassette tapes.

Oboe stimuli were played through the stereo apparatus using the Pioneer CT30 Stereo Cassette Tape Deck, JVC JR-S100 Stereo Receiver and Advent/3 speakers. Electronic stimuli were sounded directly from two Korg™ Auto Chromatic Tuners AT-12 and one Korg™ Digital Tuner Metronome DTM-12. A JVC PC-W35 cassette player was used to play distracter music between experimental responses.

Selections of distracter music used for the university students were short sections from the London cast recording of the musical, <u>Les Misérables</u> with music by Claude-Michel Schönberg. Distracter music for the high school and junior high school were selections from the Dan Fogelberg tape, <u>The</u>

Innocent Age. All selections were screened in order to avoid works in the keys of A major or a minor.

University subjects were scheduled at 15 minute intervals by the researcher. Five minutes were allowed for warm-up, however, actual time used was determined by the individual subject up to the five minute interval. Subjects had been asked at the time of scheduling to warm-up before arriving at the test sight. High school and junior high school students were warmed-up as a group by their regular teacher. They were then sent into the experimental setting individually.

Subjects were asked to move close to the microphone which was then adjusted to height optimum for the recording of each instrument. The subject's number was spoken and recorded by the researcher. University students were then asked to play a D major scale followed by an Eb major scale in order to insure that the equipment was reading and recording each instrument. High school and junior high school band students were asked to play a Bb concert scale; string players were asked to play a D major scale to insure recording levels. Levels were adjusted for best possible recording quality.

All subjects were told that they would hear five different "A's." Each would be presented three times and they should play along the first two times the stimulus was heard and to match what they heard as closely as possible. During this time they should make any adjustments they wished to make. The words pitch and tuning were not used in order to avoid drawing the

subjects attention to these elements. In the third presentation, subjects were asked to begin with the stimulus and to sustain their sound after the stimulus was stopped. When the stimulus was stopped, the subject's response was recorded. This set of instructions, "play along the first two times, then play with the stimulus the third time and sustain your sound after the stimulus is stopped," was repeated. The researcher dictated the end of the recorded response. The length of the recorded response was approximately four seconds. Five to ten seconds of distracter music was played between each of the stimuli-responses. The process of stimuli-response-distracter was continued through the five stimuli. This procedure was repeated for each subject.

Data Analysis

Audio-taped responses to the five stimuli were converted to digitized sound using MacRecorder™ 2.0. The recordings were sampled at the monaural rate of 22 KHz for high pitch and timbre resolution, and therefore, accuracy. After stimuli and responses were digitized, they were analyzed for pitch cent deviation. Using MacRecorder™ software, the most stable portion of each stimulus and response was looped to create a continuous pitch for subsequent measurement; this, of course, excluded initial attack and final decay. Responses tended to be inherently unstable, so the most stable portion of each one (generally the middle third) was selected and looped for assessment. After the best loop points were selected, the

pitch was measured using a Korg™ Model AT-12 Auto Chromatic Tuner, which is accurate to within ± 1 cent (Korg, 1987).

Absolute cent deviations from "0" for the stimuli were analyzed from the digitized pitches. The results were; (1) oboe non-vibrato, A = 440 Hz plus 7 cents; (2) oboe vibrato A = 440 minus 17 cents; (3) Korg™ A Hz = 430 minus 5 cents; (4) Korg™ A = 435 Hz minus 4 cents; and Korg™ A = 445 Hz minus 4 cents.

Some response pitches on the tapes were unable to be analyzed due to poor audio quality, experimenter error in using equipment, or sound interference from external sources. This resulted in the loss of data on seven subjects. These seven are not considered in the N of 198.

Reliability

A total of 5 stimuli and 990 subject responses were analyzed. The analysis procedure was completed on 280, or 28% of the responses by a highly qualified independent observer. Disagreement occurred when the cent deviations differed by ± 6 cents (see Footnote, pg. 39). Reliability was calculated by dividing the total number of agreements by agreements plus disagreements (Madsen & Madsen, 1983). Agreement between analyses was .91%.

Variables

The independent measures of this study were:

1. Timbre: Oboe or electronic;

2. The presence or absence of vibrato for the oboe stimuli;
3. Frequency level: Oboes at Hz 440, Korg™ at Hz 430, 435, or 445;
4. Education level: university, high school, or junior high school; and
5. Instrument group: woodwind, brass, or strings

The dependent measures were:

1. Absolute and directional cent deviation from each stimuli; and
2. Flat, in-tune, or sharp responses to each stimuli.

RESULTS

The purpose of this study was to examine intonation responses to a variety of conventional stimuli. Specifically, the tuning accuracy of university, high school, and junior high school woodwind, brass, and string instrumentalists was compared when responding to a (1) taped stimulus of A = 440 Hz played on an oboe non-vibrato and oboe with vibrato; and (2) A = 430 Hz, A = 435 Hz, and A = 445 Hz sounded electronically on Korg™ tuners. Subjects were asked to match their instruments to each of the five stimuli. Responses were recorded and analyzed for directional and non-directional cent deviations from each of the five stimuli and studied for possible effect of vibrato, timbre, and frequency on tuning accuracy.

Two hundred and five subjects were randomly assigned to one of twelve experimental orders. Seven subjects were removed from the total sample. Four because of equipment/recording problems and three for ambient noise. The mean number of remaining subjects per order was 17 with the actual numbers of subjects per order ranging from 14 to 19. Two hundred and one complete data sets were gathered with three of these removed from the study because of ambient noise. The total number of subjects used in the study analysis was one hundred and ninety-eight.

Data used for statistical analysis consisted of cent deviations from each of the five tuning stimuli and were derived

Table 3

Frequency Distribution of Subjects Among the Orders of Stimuli Presentation

Order	Subjects per order
1	16
2	16
3	18
4	18
5	16
6	19
7	16
8	16
9	16
10	17
11	16
12	14
Total	198

using the MacRecorder™ program for Macintosh to digitize the data. Information gathered was then fed directly from the computer into a Korg™ AT -12 Auto Chromatic Tuner. Directional pitch deviation was recorded in cents flat (-) or sharp (+) from the stimulus pitch. All pitches were adjusted to the deviation of the stimulus pitches. All stimuli and data responses were brought to a common "0." A pitch was considered accurate if, after adjustment, it was within ± 6 cents of the stimulus (see Footnote, pg. 39). Absolute deviations were those disregarding direction.

Magnitude of Absolute Cent Deviation Data

A three-way analysis of variance with repeated measures using the dependent measure, absolute cent deviations, compared education level and instrument group with repeated measures on the third factor, tuning stimuli (See Table 4). Results demonstrated:

1. A significant difference among the three educational levels, $F_{2, 189} = 15.10$, $p < .05$. A post - hoc means analysis using Sheffé's S test demonstrated significant differences among all possible pairs of means. As expected, university students deviated least from the tuning stimuli ($M = 12.65$ cents), high school students were the second most accurate group ($M = 17.14$ cents), and junior high school students deviated most from the models ($M = 20.95$ cents);
2. A significant difference among the three instrumental groups, $F_{2, 189} = 8.57$, $p < .05$. A post hoc means analysis using Sheffé's S test demonstrated significant differences between strings and woodwinds and between strings and brass, and no significant difference between woodwinds and brass. Absolute deviation means analysis showed that strings deviated least from the stimuli ($M = 12.49$ cents), followed by woodwinds ($M = 17.58$ cents), and brass students deviated most from the models ($M = 18.57$ cents);

3. A significant difference was reported for the repeated measure of tuning stimuli, $F_{2, 756} = 19.58$, $p < .05$. The absolute cent deviation means for the five tuning stimuli were:

   A. Oboe - Non-vibrato - $M = 21.28$

   B. Oboe - Vibrato - $M = 12.50$

   C. Korg ™ A = 430 Hz - $M = 19.50$

   D. Korg™ A = 435 Hz - $M = 12.53$

   E. Korg™ A = 445 Hz - $M = 15.83$.

   As can be seen, the greatest deviation occurred from the oboe, non-vibrato, and the Korg™ A = 430 Hz stimuli; the least deviation was from the oboe, vibrato, and the Korg™ A = 435 Hz stimuli.

4. Significant interactions occurred among the tuning stimuli, educational level, and instrumental group. Two-way interactions occurred among the tuning stimuli by educational level, and tuning stimuli by instrumental group. A three-way interaction occurred among tuning stimuli by educational level by instrumental group. No significant interaction occurred for educational level by instrumental group.

To examine the interactions further, a table was developed illustrating the mean absolute cent deviations for educational level by instrument group by tuning stimuli (See Table 5).

The mean absolute cent deviations table, Table 5, shows that the group with the least deviation was the university

Table 4

Analysis of Variance: Educational Level x Instrumental Group x Tuning Stimuli

Source	df	SS	MS	F	p
Educational Level	2	9787.33	4893.66	15.10	<.01
Instrument Group	2	5551.61	2775.81	8.57	<.01
Educational Level x Instrumental Group	4	507.16	126.79	.39	.81
Subject (Group)	189	61244.63	324.05		
Tuning Stimuli	4	10727.64	2681.91	19.58	<.01
Tuning Stimuli x Educational Level	8	3437.43	429.68	3.14	<.01
Tuning Stimuli x Instrumental Group	8	2965.70	370.71	2.71	<.01
Tuning Stimuli x Educational Level x Instrumental Group	16	4996.85	312.30	2.28	<.01
Tuning Stimuli x Subject (Group)	756	103553.62	136.98		

strings, while the group with the greatest deviation was the high school woodwinds. All of the lowest deviations for each of the instrumental and educational subgroups fall within the vibrato and A = 435 Hz stimuli. The highest deviations fall in the non-vibrato and A = 430 Hz stimuli. Twelve of the fifteen lowest deviations fall in the university category. These include all of the university means for vibrato, A = 430, 435, and 445 Hz. The lowest means for the non-vibrato fell to the high school woodwinds, junior high brass, and junior high strings. The highest deviations for each subgroup were scattered throughout the high school and junior high school with 6 in the high school section and 9 in the junior high school section.

It should be noted that although the majority of the means were significantly different, the standard deviations for twelve of the forty-five cells (educational level by instrumental group by tuning stimuli) were greater than the mean. With the exception of two cells (university brass to oboe non-vibrato and high school strings to non-vibrato) the remainder of the cells contained standard deviations which indicate a very high degree of variability among subjects. This result shows that, for most response groups, the results did not fall within the framework of a normal bell curve. This gives some cause for suspicion of validity in statistical analysis comparing means in this type of research. This was the reason that non-parametric statistics comparing direction of responses were used.

Directional Deviation Analysis

The frequency of flat, in-tune, and sharp responses was determined for each of the 5 tuning stimuli, for each of the three educational levels, and for the three instrument groups. To be considered as in-tune, the responses must be ±6 cents from the stimulus. Chi-square analyses demonstrated (see Table 6):

1. A significant difference among flat, in-tune, and sharp responses for educational levels of high school [X^2 (2, N = 560) = 17.92, $p < .05$] junior high school [X^2 (2, N = 570) = 26.02, $p < .05$]. More flat responses than sharp occurred for both groups. No significant difference occurred for university responses [X^2 (2, N = 850) = 2.05, $p < .30$]. More flat responses than sharp and more sharp than in-tune were recorded for the high school and junior high. More flat responses than in-tune, and more in-tune than sharp responses for the university;
2. A significant difference among flat, in-tune, and sharp responses for the three instrumental groups of woodwinds [X^2 (2, N = 610) = 15.35, $p < .05$], brass [X^2 (2, N = 740) = 37.71, $p < .05$], and strings [X^2 (2, N = 630) = 12.02, $p < .05$]. More flat responses than in-tune, and more in-tune than sharp occurred for strings; more flat responses than sharp, and more sharp than in-tune occurred for brass; and more sharp

responses than flat, and more flat than in-tune for woodwinds;

3. A significant difference among flat, in-tune, and sharp responses for the five tuning stimuli of oboe non-vibrato [$\underline{X}^2$ (2, $\underline{N}$ = 396) = 242.39, $\underline{p}$ < .05], oboe vibrato [$\underline{X}^2$ (2, $\underline{N}$ = 396) = 8.39, $\underline{p}$ < .05], A = 430 Hz [$\underline{X}^2$ (2, $\underline{N}$ = 396) = 69.12, $\underline{p}$ < .05], A = 435 Hz [$\underline{X}^2$ (2, $\underline{N}$ = 396) = 53.55, $\underline{p}$ < .05], and A = 445 Hz [$\underline{X}^2$ (2, $\underline{N}$ = 396) = 24.64, $\underline{p}$ < .05]. A greater number of flat responses than in-tune, and in-tune than sharp occurred for stimuli of oboe non-vibrato, oboe vibrato, and A = 445 Hz. A greater number of sharp responses than in-tune, and in-tune than flat occurred for A = 430 Hz and A = 435 Hz;
4. A significant difference occurred among flat, in-tune, and sharp responses for the total data set [$\underline{X}^2$ (2, $\underline{N}$ = 1980) = 26.37, $\underline{p}$ < .05]. More flat responses than sharp, and more sharp than in-tune were recorded;
5. A significant difference occurred among flat, in-tune, and sharp responses for the oboe stimuli [$\underline{X}^2$ (2, $\underline{N}$ = 792) = 156.04, $\underline{p}$ < .05]. Flat responses were dominant, followed by in-tune, and sharp responses; and
6. A significant difference occurred among the flat, in-tune, and sharp responses for the Korg™ stimuli [$\underline{X}^2$ (2, $\underline{N}$ = 1188) = 36.25, $\underline{p}$ < .05]. More sharp responses occurred than in-tune, and more in-tune than flat.

Table 5

Mean Absolute Cent Deviations: Educational Level x Instrumental Group x Tuning Stimuli

	University			High School			Junior High School		
	WWind	Brass	String	WWind	Brass	String	WWind	Brass	String
Nonvibrato	15.55	24.77	18.15	15.00	26.50	24.29	27.14	20.40	15.22
N =	29	30	26	11	16	28	21	28	9
S.D.	9.55	12.29	9.58	12.55	17.07	10.81	20.09	15.10	9.43
Vibrato	9.14	9.23	8.81	13.36	14.50	13.32	18.62	15.93	12.78
N =	29	30	26	11	16	28	21	28	9
S.D.	7.27	7.29	9.74	10.05	11.18	10.36	26.52	14.69	8.90
A = 430 Hz	17.17	15.67	8.81	35.09	26.25	10.82	26.81	28.54	21.56
N =	29	30	26	11	16	28	21	28	9
S.D.	11.81	11.83	10.85	18.62	16.42	9.25	14.76	17.35	13.76
A = 435 Hz	14.21	11.87	6.31	15.82	16.12	9.00	15.09	15.18	13.67
N =	29	30	26	11	16	28	21	28	9
S.D.	9.37	12.16	4.01	14.83	11.46	10.74	15.59	16.55	13.76
A = 445 Hz	10.21	10.47	7.73	20.18	22.25	11.50	24.05	27.86	15.44
N =	29	30	26	11	16	28	21	28	9
S.D.	8.81	12.22	11.33	16.48	15.73	12.96	16.29	18.10	15.98

Table 6

Directional Data: Flat/In-tune/Sharp Educational Level x Instrumental Group x Tuning Stimuli

		UNIVERSITY			HIGH SCHOOL			JUNIOR HIGH SCHOOL			TOTAL
		WWIND	BRASS	STRING	WWIND	BRASS	STRING	WWIND	BRASS	STRING	
		N = 29	N = 30	N = 26	N = 11	N = 16	N = 28	N = 21	N = 28	N = 9	
NON-	F	24	27	22	8	15	27	17	23	6	169
VIBRATO	I	3	1	3	3	1	1	2	5	2	21
	S	2	2	1	0	0	0	2	0	1	8
VIBRATO	F	5	16	11	4	9	15	6	9	3	78
	I	16	10	13	4	2	11	6	8	3	73
	S	8	4	2	3	5	2	9	11	3	47
KORG 430	F	3	10	3	0	4	9	0	3	3	35
	I	5	7	14	0	1	9	2	4	0	42
	S	21	13	9	11	11	10	19	21	6	121
KORG 435	F	2	4	3	0	4	2	4	4	0	23
	I	4	11	12	5	3	16	6	7	4	68
	S	23	15	11	6	9	10	11	17	5	107
KORG 445	F	10	10	3	7	11	9	17	24	4	95
	I	12	14	18	3	1	10	1	3	3	65
	S	7	6	5	1	4	9	3	1	2	38
TOTALS		145	150	130	55	80	140	105	140	45	990

Flat = F; In-tune = I; Sharp = S

Summary of Results

Results for instrumental groups demonstrated the greatest mean absolute cent deviation for brass players was 28.54 cents in response to Korg™ A = 430 Hz; the least was 9.23 cents in response to oboe vibrato. For woodwinds, the greatest mean absolute cent deviation was 35.09 in response to Korg™ A = 430 Hz, and least absolute mean cent deviation was 9.14 in response to oboe vibrato. The mean absolute cent deviation for strings was greatest in response to oboe vibrato ($\underline{M}$ = 24.29 cents) and least in response to Korg™ A = 435 Hz ($\underline{M}$ = 6.31 cents).

Educational levels across instrumental groups demonstrated that junior high school brass players responded with the highest mean absolute cent deviation ($\underline{M}$ = 28.54 cents), and university brass players responding with the least mean absolute cent deviation ($\underline{M}$ = 9.23 cents). University woodwinds demonstrated the least mean absolute cent deviation ($\underline{M}$ = 9.14 cents) with high school woodwinds the most ($\underline{M}$ = 35.09 cents). String responses showed that university string players demonstrated the least mean absolute cent deviation ($\underline{M}$ = 6.31 cents) and the high school players the greatest ($\underline{M}$ = 24.29 cents).

Taking each of the categories into consideration (overall response; total university; total high school; total junior high school; total woodwinds; total brass; total strings; and each combination of educational level and instrument group as shown in Table 5), 9 showed the highest deviation to A = 430 Hz while 7 showed the highest deviation to the non-vibrato stimuli. The

lowest absolute deviations showed 8 responses to each of A = 435 Hz and vibrato.

The highest and lowest mean absolute cent deviations for each stimuli showed the greatest mean absolute cent deviation for the oboe non-vibrato stimulus played by the junior high school woodwinds (M = 27.14 cents) and the least deviation played by the high school woodwinds (M = 15.00 cents). Responses to oboe vibrato showed the junior high school woodwinds with the highest deviation (M = 18.62 cents) and university strings the lowest (M = 8.81 cents). Korg™ A = 430 Hz responses ranged from the high school woodwinds with the highest mean absolute cent deviation of 35.09 to the lowest mean absolute cent deviation of 8.81 played by the university strings. Responses to Korg™ A = 435 Hz showed the greatest mean absolute cent deviation performed by the high school woodwinds (M = 15.82 cents) and the lowest by university strings (M = 6.31 cents). Korg™ A = 445 Hz responses were greatest by the junior high school brass (M = 27.86 cents) and least by university strings (M = 7.73 cents).

Responses to all stimuli showed the university strings responded with the lowest mean absolute cent deviation to four of the five stimuli with the high school woodwinds lowest to the fifth stimuli. Junior high school woodwinds responded with the greatest mean absolute cent deviation to two stimuli, high school woodwinds greatest to two stimuli, and junior high school brass highest to one stimulus.

DISCUSSION

The purpose of this study was to examine intonation in response to a variety of conventional stimuli. Specifically, the tuning accuracy of university, high school, and junior high school woodwind, brass, and string instrumentalists was compared when responding to taped stimuli of A = 440 Hz played on oboe non-vibrato and oboe with vibrato; and pitches produced electronically on a Korg™ tuner of A = 430 Hz; A = 435 Hz; and A = 445 Hz. In question were the effects of vibrato, timbre, and frequency on tuning accuracy. Subjects (N = 198) were university music students (n = 85), high school students (n = 55) and junior high school students (n = 58). Subjects were individually recorded tuning to each of the five stimuli. Responses were analyzed through a computer system using MacRecorder™ software. These digitized pitches were analyzed for absolute and directional cent deviation with a Korg™ Auto Chromatic Tuner.

Results demonstrated significant differences in absolute cent deviation scores among educational levels, among instrumental groups, and among tuning stimuli. University students deviated less from tuning stimuli; junior high school deviated most. String players were most accurate in tuning; brass players were least accurate. Students tuned most accurately to the oboe vibrato, A = 440 Hz stimuli and least accurately to the oboe non-vibrato, A = 440 Hz.

Mean absolute cent deviation scores compared to standard deviations showed that in twelve of the forty-five cells, standard

deviations were greater than the means, and most other standard deviations were extremely high. This demonstrates that great variability in the tuning responses occurred. These results support the writings of authors who see intonation as a major problem in ensemble performance (Bencriscutto, 1965; Kinyon, 1960; Klotman, 1957; Miller, 1986; Scott, 1960; Walker, 1948; Wyand, 1973). The great variability of responses found in all groups highlights the fact that instrumentalists, as a group, do not tune accurately. One example of the variability in intonational responses gathered in this study can be seen in the responses from the junior high school woodwind players to the oboe non-vibrato stimuli. Data gathered showed responses that ranged from a high of 88 cents sharp to a low of 60 cents flat. This range is 148 cents, or almost a one and a half steps. This result is not unexpected in an intonational study, however, it does present further items for consideration. One such item may be a group that tunes sharp or flat to a stimulus together so that the entire group is the same number of cents flat or sharp. Should this be considered to be "in-tune" since the entire group is consistent?

Results regarding directional cent deviation analysis demonstrated a propensity toward flat responses. However, while more flat responses occurred for strings and brass, there were more sharp responses for woodwinds. There were more flat responses to the higher tuning stimuli (A = 440 Hz and A = 445 Hz) and more sharp responses for the lower stimuli (A = 430 Hz

and A = 435 Hz). Finally, while flat responses were dominant for the oboe stimuli, more sharp responses occurred for the Korg.

Data used for statistical analysis consisted of cent deviations from each of the five tuning stimuli and were derived using the MacRecorder™ program for Macintosh to digitize the data. Information gathered was then fed directly from the computer into a Korg™ AT -12 Auto Chromatic Tuner. Directional pitch deviation was recorded in cents flat or sharp from the stimulus pitch. A pitch was considered accurate if within ± 6 cents of the stimulus. Absolute deviations were those disregarding direction.

Direction of Deviation

Existing instrumental research dealing with tuning preference and/or performance demonstrated a marked propensity for sharp tunings (Brown, 1991; Geringer, 1976, 1978; Kantorski, 1986; Karrick, 1994; Madsen & Flowers, 1981/1982; Madsen & Geringer, 1976; Salzberg, 1980; Sogin, 1989; Yarbrough & Ballard, 1989). In this study, sharp responses were found for only a few groups: overall Korg™ responses, woodwind responses, and responses to Korg™ pitches of A = 430 and 435 Hz. Preference studies by Brown (1991), Geringer (1976), and Madsen & Flowers (1981/1982) demonstrated that when given a choice, or an opportunity to change a pitch, subjects tended to choose the higher frequency.

Although the greater share of existing instrumental research showed a marked propensity for sharp tunings, studies

by Duke (1985), Ely (1992), and Ladner (1977) demonstrated a greater tendency toward flat tunings. Duke found that wind performers tended to play slightly flatter when intervals were ascending. Ely found, in a study of college level woodwind players, more flat responses than sharp or in-tune with subjects able to tune slightly better to their own instrument stimuli. Ladner, in a study of instructional methods on string players, discovered that his subjects had a tendency to play flat to the stimuli of an A = 440 Hz on a Stroboconn.

Many of the existing instrumental performance studies deal with, not only the direction of response, but also the approach from above or below the target pitch as a factor affecting the direction of response. The tuning of an individual note, as opposed to one in an interval or phrase, may affect the direction of response due to the lack of a pitch with which to compare intonation. Performance studies by Kantorski (1986), Karrick (1994), Sogin (1989), and Yarbrough and Ballard (1989), demonstrated sharp responses to stimuli; however, all of these studies isolated individual pitches or intervals out of a specific set of pitches. The present study, in the choice of a single, unaccompanied pitch instead of one affected by the position in an ascending or descending line, may have influenced the direction of response.

It appears that the lowest of the stimulus frequencies drew the sharper responses. One influencing factor in this may have been the lack of familiarity with this range of frequencies. The

international standard for "A" of 440 Hz is widely used. Some groups may use a pitch which is close to this frequency, such as the A = 442 Hz used by the Boston Symphony and Los Angeles Philharmonic (Allman, 1989). Yet, close scrutiny of the actual cent deviations between the frequencies of A = 440 and 442 Hz, reveals only an eight cent difference. In this study, a difference of ± 6 cents was considered to be accurate (see Footnote, pg. 39). When one moves from an A = 440 Hz to an A = 430 Hz, the cent difference is 40 cents, while the cent difference to A = 435 Hz is 20 cents. The cent difference to the A = 445 Hz frequency from A = 440 Hz is 19 cents (Young, 1952). The oboe vibrato, the pitch most closely matched, was actually at an A = 440 Hz minus 17 cents. This brings that stimulus within three cents of the A = 435 Hz frequency. The A = 435 Hz was the next best matched stimulus and upon analysis was found to be only 4 cents flat.

The results of this study showed that overall pitch performance in response to the tuning stimuli was in the flat direction. Research states that better pitch discrimination occurs for flat intonation (Duke, 1985; Geringer, 1978; Geringer & Madsen, 1984; Geringer & Witt, 1985; Madsen, Edmonson, & Madsen, 1969; Madsen & Geringer, 1976, 1981; Salzberg, 1980; Siegel & Siegel, 1977). In studies where subjects could manipulate the frequency of the pitch through mechanical means (Geringer, 1978; Madsen, Edmonson, & Madsen, 1969; Geringer & Witt, 1985), it was found that older subjects responded more in the flat direction, while younger subjects responded more

accurately to sharp stimuli. This study found that in the performance of pitches, all three age groups responded with more flat responses that in-tune or sharp.

A finding by Geringer and Witt (1985) has been partly supported by this study. The researchers stated that string subjects responding to oboe stimuli were found to tune below sharp pitches (A = 440 Hz + 25 cents) and above the in-tune (A = 440 Hz) and flat pitches (A = 440 - 15 cents). This research supports these results in that subjects tuned above the flat pitches (A = 430 and 435 Hz) and below the sharp pitches (oboes at A = 440 Hz and Korg™ A = 445 Hz).

Another element which must be considered, and is worthy of further research, is the question of the effect of physical limitations of the various instruments in reaching certain frequencies. When trying to match the A = 430 Hz stimulus, one clarinet player in the study, a highly proficient graduate performance major, actually changed from a Bb barrel to an A clarinet barrel. It is possible that accuracy by instrumental group was affected by this factor. The strings, which possess the greatest degree of frequency flexibility due to the physical make-up of their instruments, proved to be the instrumental group with the best tuning accuracy. They were followed by the woodwinds, and finally the brass. The closer accuracy of string responses supports the results of Geringer (1978) who found that string subjects responded more closely to the stimulus than did wind players.

Absolute Cent Deviations as Effected by Timbre and Vibrato

Timbre, the tone color or quality of a sound which helps the ear discriminate one instrument from another, proved to be a factor in the accuracy of tunings in this study. The effect of timbre was evident in the range of cent deviations for responses. Responses recorded for the oboe stimuli ranged from $\underline{M} = 8.81$ cents to 27.14 cents, while responses to the electronic stimuli ranged from $\underline{M} = 6.31$ cents to 35.09 cents. This matching of complex, overtone rich, sound waves, such as those produced by the oboe, with greater acuity than the simpler sound waves produced by an electronic tuner is not consistant with the findings of Corso (1954) and Taylor and Pembrook (1987) who found that differences in the type of waveform presented did not have a significant effect on subject responses. The findings of this study are supported, however, by research showing that subjects better matched pitches produced by the same instruments they played (Bergee, 1987; Cassidy, 1988; Ely, 1992; Greer, 1970; Tunks 1982). Sounds produced by any non-electronic musical instrument are complex sound waves by the very nature of the overtone series produced. The presence of this overtone series, as opposed to the lack of series in a simpler, electronic wave, may provide some insight as to the reasons behind the higher pitch matching acuity to the more complex sound waves of the oboe.

The effect of timbre among responses to the individual stimulus frequencies not as certain. Oboe responses proved to

have the least cent deviation (oboe vibrato) and the greatest deviation (oboe non-vibrato) from the stimulus pitch. The three Korg™ pitches, from most successfully matched overall to least successfully matched overall were, Korg™ A = 435 Hz, Korg™ A = 445 Hz, and Korg™ A = 430 Hz. The responses for all three fell between the responses for the two oboe stimuli. Isolation of the variables of vibrato, frequency, and timbre are in need of study to help determine to a more certain degree the reasons behind this layering of response timbre.

Vocal research supports the idea that timbre makes a difference in response accuracy. Studies which examined the effect of male models, female models, child models, and vibrato all point out that timbre does indeed affect response (Green, 1990; Small & McCachern, 1983; Yarbrough, et al., 1991, 1992).

Vibrato, as well as timbre may be found to have a profound effect on the tuning accuracy of subjects. In consideration of only the oboe stimuli, one with vibrato and one non-vibrato, it was found that the stimulus with vibrato was the stimulus most closely matched overall, while the oboe non-vibrato proved to be the worst matched of the five stimuli. The results of this study contradict the findings of research by Geringer and Sogin (1988), and Sogin (1989) who found that vibrato did not significantly affect pitch accuracy of string players. This also contradicted some of the findings of the vocal study by Yarbrough, Bowers, & Benson (1992) who found that a non-vibrato pitch was most closely matched vocally by elementary children who were

uncertain singers. Certain singers were not greatly affected by the presence or absence of vibrato.

The existing research cited was done within the context of a set of pitches, a minor third, as in the Yarbrough, et al. (1992) study, or in the context of a specific musical passage as in the Geringer and Sogin studies. It is possible that the tuning of response pitches to a stimulus with vibrato is a different type of task for the performer when there are no reference pitches other than the stimulus available. The tuning of only one pitch, the response, to only one other pitch, the stimulus, may prove to be a completely different type of tuning task when compared to the task of tuning in context of another pitch or in an ensemble situation. This idea needs additional investigation.

Possible answers to the accuracy of pitch matching to the vibrato stimuli in this study may lie in the research of Brown (1991) and Goodwin (1977). They reported a belief that the ear tends to fuse the oscillations of a vibrated pitch into a single unmodulated tone. It may be that subjects most closely matched, not necessarily, the "pitch" of the vibrated stimulus, but perhaps, the pitch range of the vibrato in that stimulus. This view is supported by the findings of Shonle and Horan (1980) who presented the idea that the perceived pitch of vibrato corresponded to the oscillation of the pitch.

While the question of pitch within the context of vibrato and an individual's perception thereof is still unanswered, further study in tuning accuracy to individual pitches and pitches in

musical context is warranted. Vibrato amplitude and variance from another frequency should be considered.

Conclusions and Recommendations for Further Research

Conclusions drawn from the results of this study indicated that frequency, timbre, and vibrato are all factors which can affect the tuning acuity of instrumentalists to some degree. Age and instrument played also appeared to be active factors in accuracy. As an overall group, the older the subject, the closer the response came to being accurate. In instrumental groups string players tended to be more accurate overall than woodwinds, and woodwinds more accurate than brass. An examination of string teaching techniques for intonational training may be useful in finding a way to help, not only the woodwinds and brass, but also more string performers to play in tune.

The teaching of better intonation, as shown in the review of literature, has taken on many faces throughout the years. This is an area in which much more research is needed in order to come to any kind of a definitive answer as to the validity and value of any one method of instruction.

Further study in the isolated act of tuning is needed to find the most advantageous situation for each age group and instrument. Results of this study support the idea that the pitch of A = 435 Hz for a string ensemble may produce a sound more in-tune with itself, whereas the pitch of A = 440 Hz produced by an oboe with vibrato may be most advantageous for a brass and

woodwind ensemble. In the situation of a full orchestra, the pitch which seems most beneficial to tuning accuracy appears to be the oboe with vibrato at A = 440 Hz. Further study is needed in each age level and instrumental group type to determine the reliability across groups of these results.

Elements for change in any replication of this study would include the addition of a tuning stimulus of Korg™ A = 440 Hz. It is felt that the inclusion of this frequency and timbre source would help to isolate the actual effect of oboe timbre as opposed to electronic timbre. The results found in this study show a wide discrepancy between the mean responses to the oboe generated pitches with and without vibrato. However, the lack of the same pitch frequency on an electronic tuner does not allow for direct comparison of vibrato, non-vibrato, and electronic source.

Another possible approach to evaluation of a study such as this is in the analyzation of data. Analysis could be approached not only as it directly relates to the stimulus frequency, but also for any pattern of relationship between the actual response frequencies compared to the given stimuli and other closely related frequencies. It is observed that many of the responses in this study to the frequency of oboe non-vibrato, A = 440 Hz plus 7 cents, were very close to the actual frequency of A = 435 Hz. The difference in cent deviation between A = 440 Hz plus 7 cents and A = 435 Hz is only 27 cents (20 cent deviation plus 7 cents sharp for the oboe stimulus). Many subjects were more than 27 cents

flat and may have actually been trying to match a different pitch. This approach needs further consideration and study.

The degree to which the factors of frequency, timbre, age, instrument type, and vibrato effect tuning are in need of further research. The experimental isolation of each factor in order to study its effect is warranted. If a definitive pitch and timbre for the most accurate tuning of a soloist or a group could be determined, it could help eliminate the guesswork used today to teach intonational skills to children and may, one day, be so incorporated into the normal teaching routine that intonational concerns may no longer be a factor.

REFERENCES

Albert, D.G. (1967). The effect of differential treatments on pitch acuity in solo instrumental performance. Unpublished master's thesis, The Florida State University, Tallahassee, FL.

Allman, W.F. (1989, June 26). A matter of imperfect pitch. U.S. News & World Report, pp. 55-56.

Backus, J. (1977). The Acoustical Foundations of Music (2nd ed.). New York: W.W. Norton & Company.

Bencriscutto, F. (1965). Intonation - A new approach. The Instrumentalist, 20 (4), pp. 66, 68.

Bergee, M.J. (1987, May). Attack and release transients as factors in identification of wind instrument tones. Paper presented a meeting of the Southern Division of the Music Educators National Conference, Orlando, FL.

Brown, S.F. (1991). Determination of location of pitch within a musical vibrato. Bulletin of the Council for Research in Music Eduation, 108, 15-30.

Campbell, M., & Greated, C. (1987). The musician's guide to acoustics. New York: Schirmer Books.

Cassidy, J.W. (1985). The relationship between second year band students' intonation on pitches played and sung in a melodic context. Unpublished master's thesis, The Florida State University, Tallahassee, FL.

Cassidy, J.W. (1988). The use of instruction in acoustical interference ("beats") and lip flexibility exercises to improve intonation accuracy. Unpublished paper, The Florida State University, Tallahassee, FL.

Cassidy, J.W. (1989). The effect of instrument type, stimulus timbre, and stimulus octave placement on tuning accuracy. Missouri Journal of Research in Music Education, 26, 7-23.

Codding, P.A. (1985). The effect of differential feedback on beginning guitar students' intonational performance in tuning strings. Unpublished dissertation, The Florida State University, Tallahassee, FL.

Codding, P.A. (1987). The effects of visual versus verbal instruction on beginning guitar students' tuning accuracy. In Madsen, C.K., Greer, R.D., & Madsen, C.H., Jr. (Eds.), Applications of research in music behavior (pp. 272-284). Tuscaloosa, Alabama: The University of Alabama Press.

Corso, J.F. (1954). Unison tuning of musical instruments. The Journal of the Acoustical Society of America, 26 (5), 746-750.

Dowdy, R.A. (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. Unpublished dissertation, The University of Mississippi, University, MS.

Duke, R.A. (1985). Wind instrumentalists' intonational performance of selected musical intervals. Journal of Research in Music Education, 33, 101-111.

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

Elliott, C.A. (1972). The effectiveness of singing in the beginning band class. Journal of Band Research, 9, 38-39.

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

Elliott, C.A. (1975). Attacks and releases as factors in instrument identification. Journal of Research in Music Education, 23, 35-40.

Ely, M.C. (1992). Effects of timbre on college woodwind players' intonational performance and perception. Journal of Research in Music Education, 40, 158-167.

Farnsworth, P.R. (1969). The Social Psychology of Music. Ames, IA: The Iowa State University Press.

Fletcher, H., Blackham, E.D., & Geersten, O.N. (1965). Quality of violin, viola, cello and bass-viol tones. Journal of the Acoustical Society of America, 37, 851-863.

Geringer, J.M. (1976). Tuning preferences in recorded orchestral music. Journal of Research in Music Education, 24, 169-176.

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

Geringer, J.M., & Madsen, C.K. (1984). Pitch and tempo discrimination in recorded orchestral music among musicians and non-musicians. Journal of Research in Music Education, 32, 195-204.

Geringer, J.M., & Sogin, D.W. (1988). An analysis of musicians' intonational adjustments within the duration of selected tones. Contributions to Music Education, 15 (Fall), 1-6.

Geringer, J.M., & Witt, A.C. (1985). An investigation of tuning performance and perception of string instrumentalists. Bulletin of the Council for Research in Music Education, 85, 90-101.

Glass, J.S. (1989, March). The effects of a microcomputer-assisted tuning program on junior high school students' pitch discrimination and pitch-matching abilities. Paper presented at the meeting of the Southern Division of the Music Educators National Conference, Nashville, TN.

Goodwin, A. (1977). An acoustical study of individual voices in a choral blend. Unpublished dissertation, North Texas State University, Denton, TX.

Graves, W. (1963). Improving intonation. The Instrumentalist, 18 (4), 46-47.

Green, G.A. (1990). The effect of vocal modeling on pitch-matching accuracy of children in grades one through six. Journal of Research in Music Education, 38, 225-232.

Greene, P.C. (1937). Violin intonation. Journal of the Acoustical Society of America, 9, 43-44.

Greer, R.D. (1970). The effect of timbre on brass-wind intonation. Experimental Research in the Psychology of Music, 6, 65-94.

Heller, J. (1969). Electronic graphs of musical performance: A pilot study in perception and learning. Journal of Research in Music Education, 17, 202-216.

Helmholtz, H.L.F. (1954). On the Sensations of Tone as a Physiological Basis for the Theory of Music. New York: Dover Publications, Inc.

Hofmeister, D. (1982). Elementary band intonation; Where it begins. The School Musician, 54 (3), 13-15.

Kantorski, V.J. (1986). String instrument intonation in upper and lower registers: The effects of accompaniment. Journal of Research in Music Education, 34, 200-210.

Karrick, B. (1994). An examination of the intonation tendencies of advanced wind instrumentalists based on their performance of selected musical intervals. Unpublished dissertation, Louisiana State University, Baton Rouge, LA.

Kinyon, J. (1960). Tuning the band. Music Journal, 18 (3), 30-31.

Klotman, R.H. (1957). Intonation and pitch discrimination. The Instrumentalist, 12 (2), 68-69.

Korg AT-12 Auto Chromatic Tuner Owner's Manual (1987). Tokyo, Japan: Korg Inc.

Lader, E.C. (1977). The effect of differential treatments on the intonation of string instrumentalists. Unpublished master's thesis, The Florida State University, Tallahassee, FL.

Leonard, N., Jr. (1967). The effect of certain intrinsic and contextural characteristics of the tone stimulus on pitch discrimination. Unpublished dissertation, West Virginia University, Morgantown, WV.

Madsen, C.K. (1966). The effect of scale direction on pitch acuity in solo vocal performance. Journal of Research in Music Education, 14, 266-275.

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

Madsen, C.K., Edmonson, F.A., III., & 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., & Flowers, P.J. (1981-1982). Effect of tuning in an attempt to compensate for pitch/quality errors in flute/oboe duets. Contributions to Music Education, 5, 2-9.

Madsen, C.K., & Geringer, J.M. (1976). Preferences for trumpet tone quality versus intonation. Bulletin of the Council for Research in Music Education, 46, 13-22.

Madsen, C.K., & Geringer, J.M. (1981). Discrimination between tone quality and intonation in unaccompanied flute/oboe duets. Journal of Research in Music Education, 29, 305-315.

Madsen, C.H., & Madsen, C.K. (1983). Teaching/Discipline: A Positive Approach for Educational Development (3rd edition). Raleigh, NC: Contemporaty Publishing Company.

Madsen, C.K., Wolfe, C.H., & Madsen, C.H. (1969). The effect of reinforcement and directional scalar methodology on intonational improvement. Bulletin of the Council for Research in Music Education, 18, 22-23.

McAdow, M. (1952). Intonation worries and their remedies. The Instrumentalist, 7 (2), pp. 14, 15, 40, 41.

McGinnis, D.E. (1962). Good intonation and how to achieve it. The School Musician, 34 (3), pp. 44, 45, 51.

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

Miller, H. (1986). Now there's a tuning fork in my tuba. The School Musician, 58 (2), 4-6.

Mursell, J.L. (1946). Psychology and the problem of the scale. The Musical Quarterly, 32, 564-573.

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

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

Papich, G., & Rainbow, E. (1974). A pilot study of performance practices of twentieth-century musicians. Journal of Research in Music Education, 22, 24-34.

Parker, O. (1983). Quantitative differences in frequency perceptions by violinists, pianists, and trombonists. Bulletin of the Council for Research in Music Education, 76, 49-58.

Pottle, R.R. (1960). Tuning the school band and orchestra. 2nd edition. Hammond, Louisiana: Ralph R. Pottle.

Price, H.E., Yarbrough, C., Jones, M., & Moore, R.S. (in press). Effects of male timbre and falsetto, and sine wave models on interval matching by inaccurate boy and girl singers. Journal of Research in Music Education.

Radocy, R.E., & Boyle, J.D. (1979). Psychological Foundations of Musical Behavior. Springfield, IL: Charles C. Thomas Publisher.

Randel, D.M. (Ed.). (1986). The New Harvard Dictionary of Music. Cambridge, MA: The Belknap Press of Harvard University Press.

Rodman, M.E. (1981). Range distribution, timbre and cent calibration as factors in pitch discrimination capacities. Unpublished dissertation, Texas Tech University, Lubbock, TX.

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

Scott, R.T. (1960). Intonation equals concentration. The School Musician, 31 (5), pp. 28, 29, 60.

Seashore, C. (1936). Psychology of the vibrato in voice and instrument. Iowa Studies in the Psychology of Music, III.

Seashore, H. (1932). The hearing of the pitch and intensity in vibrato. In Seashore, C. (Ed.), Iowa Studies in the Psychology of Music, I.

Shonle, J., & Horan, K. (1980). The pitch of vibrato tones. Journal of the Acoustical Society of America, 67, 246-252.

Siegel, J.A., & Siegel, W. (1977). Absolute identification of notes and intervals by musicians. Perception & Psychophysics, 21, 143-152.

Small, A.R., & McCachren, F.L. (1983). The effect of male and female vocal modeling on pitch-matching accuracy of first-grade children. Journal of Research in Music Education, 31, 227-233.

Smith, E.R. (1984). The effects of vocalization on the intonation of college wind performers. Unpublished dissertation, The Florida State University, Tallahassee, FL.

Sogin, D.W. (1989). An analysis of string instrumentalists' performed intonational adjustments within an ascending and descending pitch set. Journal of Research in Music Education, 37, 104-111.

Stauffer, D.W. (1954). Intonation Deficiencies of Wind Instruments in Ensemble. Washington, D.C.: The Catholic University of America Press.

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

Taylor, J.A., & Pembrook, R.G. (1987, May). Pitch discrimination for melodic intervals and individual tones: Hierarchies and the influences of frequency, timbre, and register. Paper presented at the meeting of the Southern Division of the Music Educators National Conference, Orlando, FL.

Tunks, T.W. (1982). Defining tuning errors for simultaneous tones. Psychomusicology, 2, 14-20.

Vorce, F.W. (1964). The effect of simultaneous stimulus on vocal pitch accuracy. Unpublished dissertation, The Florida State University, Tallahassee, FL.

Wagner, M.J. (1978). Introductory musical acoustics. Raleigh, NC: Contemporary Publishing Company.

Walker, B.H. (1948). Does your band play in tune? Music Educators Journal, 35 (2), 26-27.

Wapnick, J., & Freeman, P. (1980). Effects of dark-bright timbral variation on the perception of flatness and sharpness. Journal of Research in Music Education, 28, 176-184.

Williamson, C. (1942). Intonation in musical performance. American Journal of Physics, 10, 172.

Winckel, F. (1967). Music, sound and sensation: A modern exposition. New York: Dover Publications.

Wyand, A. (1973). The pitch awareness program. The Instrumentalist, 27 (8), 80-81.

Yarbrough, C., & Ballard, D.L. (1989). The effect of accidentals, scale degrees, direction, and performer options on intonation. Update: Applications of Research in Music Education, Spring-Summer 1990, 19-22.

Yarbrough, C., Bowers, J., & Benson, W.L. (1992). The effect of vibrato on the pitch matching accuracy of certain and uncertain singers. Journal of Research in Music Education, 40, 30-38.

Yarbrough, C., Green, G.A., Benson, W., & Bowers, J. (1991). Inaccurate singers: An exploratory study of variables affecting pitch-matching. Bulletin of the Council for Research in Music Education, 107, 23-34.

Yarbrough, C., Karrick, B. & Morrison, S. (in press). The effect of knowledge of directional mistuning on the tuning accuracy of beginning and intermediate wind players. Journal of Research in Music Education.

Yarbrough, C., Morrison, S., Karrick, B. & Dunn, D. (in press). The effect of male falsetto on the pitch matching accuracy of uncertain boy singers, grades K-8. Update: Applications of Research in Music Education.

Young, P.M. (Ed.). (1956). A Guide to Musical Acoustics. London: Dennis Dobson, Ltd.

Young, R.W. (1952). A table relating frequency to cents (deviation from the equally timpered scale on A = 400 Hz). Elkhart, IN: C.G. Conn Limited.

APPENDICIES

APPENDIX A

Individual Data

Appendix A

Individual Data

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
1	University	Woodwind	7	13	23	19	11
2	University	String	-15	11	13	17	4
3	University	String	-14	0	8	7	-3
4	University	Woodwind	-10	0	30	-8	26
5	University	Woodwind	-13	10	7	11	-18
6	University	Woodwind	-12	5	12	-1	-14
7	University	Woodwind	-17	-3	12	19	22
8	University	Brass	-17	-18	-35	11	-49
9	University	Brass	-17	3	10	6	-4
10	University	Woodwind	-13	4	2	7	17
11	University	Brass	-50	-10	29	-9	-3
12	University	Brass	-32	0	18	17	1
13	University	Brass	-42	-15	-15	-3	-13
14	University	Woodwind	-38	-20	10	-3	-10
15	University	String	-32	-10	2	9	-3
16	University	Woodwind	-7	11	29	21	-13
17	University	Brass	-22	-9	-25	7	1
18	University	String	-23	-10	-6	-10	19
19	University	Woodwind	-14	-5	2	11	4
20	University	Woodwind	-7	-5	22	44	7

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
21	University	String	-18	0	-2	9	1
22	University	Woodwind	-14	14	39	14	-7
23	University	Brass	-32	-28	0	-3	13
24	University	Woodwind	-27	-15	0	-17	2
25	University	Brass	-20	0	-15	9	-9
26	University	Brass	10	10	33	38	39
27	University	Brass	-34	-10	-12	-1	33
28	University	Brass	-20	4	-13	18	1
29	University	String	5	2	3	4	1
30	University	String	-14	-6	2	1	2
31	University	Woodwind	0	15	13	16	4
32	University	Woodwind	-8	5	32	6	-14
33	University	Woodwind	-24	20	25	9	-6
34	University	Brass	-14	-5	2	9	-1
35	University	Brass	-4	0	-5	14	-1
36	University	String	7	-6	32	4	-53
37	University	Woodwind	-27	0	12	7	1
38	University	Brass	-49	4	-13	11	-8
39	University	Brass	-22	-10	8	11	-3
40	University	Woodwind	-26	4	12	9	9
41	University	Woodwind	-10	19	18	21	4
42	University	String	-5	0	5	8	11
43	University	Brass	36	30	35	34	27
44	University	String	0	19	12	14	17

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
45	University	String	-12	-3	-2	-3	6
46	University	String	-22	2	-52	11	1
47	University	Woodwind	-18	-3	-15	-19	0
48	University	Brass	-14	5	-2	6	1
49	University	Brass	-22	0	32	11	-14
50	University	Brass	-17	-8	5	1	4
51	University	Brass	-39	0	12	-33	2
52	University	Brass	-9	12	23	52	21
53	University	Woodwind	-13	2	3	11	1
54	University	Woodwind	-14	5	27	31	-9
55	University	Brass	-8	10	35	1	1
56	University	Brass	-14	-8	-7	-14	-1
57	University	String	-14	-21	8	1	-3
58	University	Brass	-41	-10	-2	8	-3
59	University	String	-20	0	5	4	-1
60	University	Woodwind	-35	-13	-10	-3	-3
61	University	String	-14	-11	0	7	-4
62	University	Woodwind	1	2	-13	14	-6
63	University	String	-22	0	2	-3	-1
64	University	Woodwind	-4	-16	1	8	1
65	University	Woodwind	10	30	48	27	27
66	University	String	-14	-13	-10	-9	-28
67	University	Brass	-27	-10	12	-1	-16
68	University	Brass	-19	-10	0	-6	-9

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
69	University	Brass	-19	-10	37	8	-13
70	University	Brass	-24	-18	-8	-3	-8
71	University	Brass	-30	-10	-10	-8	-8
72	University	Woodwind	-17	-11	30	11	-9
73	University	String	-22	-3	5	1	4
74	University	String	-41	-45	-12	-3	11
75	University	String	-25	-16	10	7	2
76	University	String	-25	-10	8	7	7
77	University	String	-27	-15	-5	-8	-9
78	University	Woodwind	-29	4	18	26	-36
79	University	String	-25	-10	8	-2	2
80	University	Woodwind	-22	5	18	9	-11
81	University	String	-10	-1	-2	7	-3
82	University	Woodwind	-14	-6	15	10	4
83	University	String	-34	-13	12	4	-3
84	University	Brass	-39	-10	17	-3	7
85	University	String	-12	2	-3	4	2
86	High School	Woodwind	-14	-8	12	-3	-6
87	High School	Woodwind	-32	-3	28	0	-33
88	High School	Woodwind	-10	4	35	22	-9
89	High School	Woodwind	-14	-28	18	-1	-53
90	High School	Woodwind	0	-8	42	31	11
91	High School	Woodwind	-2	24	65	31	-3
92	High School	Woodwind	1	29	60	37	-1

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
93	High School	Woodwind	-7	20	58	31	-14
94	High School	Woodwind	-34	-13	18	-3	-33
95	High School	Woodwind	-29	-6	23	1	-33
96	High School	Woodwind	-22	4	27	14	-26
97	High School	Brass	-30	24	38	46	-19
98	High School	Brass	-17	22	39	-18	-19
99	High School	Brass	3	-10	28	22	11
100	High School	Brass	-22	-20	33	9	-28
101	High School	Brass	-44	-20	-5	-6	-23
102	High School	Brass	-13	-10	23	8	-14
103	High School	Brass	-22	-8	17	11	7
104	High School	Brass	-69	-46	-38	-34	-64
105	High School	Brass	-37	-13	-25	14	0
106	High School	Brass	-9	10	-10	-16	11
107	High School	Brass	-16	7	17	22	-19
108	High School	Brass	-23	2	9	-3	26
109	High School	Brass	-20	-10	-71	4	-31
110	High School	Brass	-50	-23	8	-16	-49
111	High School	Brass	-39	0	28	7	-19
112	High School	Brass	-17	7	31	22	-16
113	High School	String	-40	-25	-8	-3	-9
114	High School	String	-32	-16	5	-6	-13
115	High School	String	-32	-13	-12	-6	-8
116	High School	String	-37	-6	28	44	-58

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
117	High School	String	-37	-26	-7	-9	0
118	High School	String	-22	-5	-13	-3	7
119	High School	String	-20	-5	8	1	6
120	High School	String	-30	-8	5	-3	7
121	High School	String	-29	-8	-8	7	-2
122	High School	String	-32	-20	0	9	-6
123	High School	String	-34	-27	2	-3	-9
124	High School	String	-32	-26	18	-11	4
125	High School	String	-7	-13	3	11	-3
126	High School	String	-17	-16	12	-3	-16
127	High School	String	-17	-6	-12	-3	-6
128	High School	String	-29	-6	-2	7	-1
129	High School	String	-20	-10	2	-3	-2
130	High School	String	-20	-1	8	-1	16
131	High School	String	-18	4	-2	11	4
132	High School	String	-14	5	10	4	9
133	High School	String	-4	10	13	-6	9
134	High School	String	-10	-6	28	11	14
135	High School	String	-34	-10	35	7	-39
136	High School	String	-10	4	-7	-6	11
137	High School	String	-9	40	-13	27	-8
138	High School	String	-42	-20	10	41	39
139	High School	String	-19	2	-2	-3	8
140	High School	String	-33	-35	-30	-3	-8

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
141	Junior High	Woodwind	-30	-26	8	31	-3
142	Junior High	Woodwind	-25	-10	3	-19	-38
143	Junior High	Woodwind	-29	-8	27	4	-28
144	Junior High	Woodwind	-4	15	38	24	-8
145	Junior High	Woodwind	-60	-40	9	-6	-49
146	Junior High	Woodwind	-14	10	32	22	-19
147	Junior High	Woodwind	-24	-3	35	12	-33
148	Junior High	Brass	-20	-20	52	7	-11
149	Junior High	Woodwind	-12	15	32	26	-8
150	Junior High	Woodwind	-39	25	40	-8	7
151	Junior High	Woodwind	-19	-13	12	4	-12
152	Junior High	Woodwind	-9	15	52	27	-9
153	Junior High	Woodwind	-19	5	32	11	-28
154	Junior High	Woodwind	58	94	23	7	-31
155	Junior High	Woodwind	-27	8	38	2	-24
156	Junior High	Woodwind	-17	-1	35	-9	-19
157	Junior High	Woodwind	-24	5	32	-9	-28
158	Junior High	Woodwind	-19	7	37	-1	-26
159	Junior High	Brass	-44	-18	22	-8	-39
160	Junior High	Woodwind	-4	4	11	6	9
161	Junior High	Brass	5	39	52	46	0
162	Junior High	Brass	-4	12	49	14	2
163	Junior High	Brass	-13	2	25	-5	-20
164	Junior High	Brass	-22	-11	23	-1	-19

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
165	Junior High	Brass	-2	10	48	16	-53
166	Junior High	Brass	-12	-5	-7	11	-31
167	Junior High	Brass	-12	57	42	-24	-13
168	Junior High	Brass	-22	27	-75	-83	59
169	Junior High	Woodwind	-20	0	5	7	-11
170	Junior High	Brass	-10	7	37	20	-23
171	Junior High	Brass	-14	17	32	14	-19
172	Junior High	Brass	-20	-15	30	27	-49
173	Junior High	Brass	-35	-20	15	4	-23
174	Junior High	Woodwind	-29	-20	12	11	-56
175	Junior High	Brass	-27	-25	2	1	-51
176	Junior High	Brass	-20	-10	30	11	-8
177	Junior High	Brass	-13	-1	28	8	-28
178	Junior High	Brass	-22	2	36	16	-23
179	Junior High	Brass	-12	7	5	11	-18
180	Junior High	Brass	-20	8	20	7	-26
181	Junior High	Brass	-14	5	42	1	-54
182	Junior High	Brass	-42	-1	5	9	-11
183	Junior High	Brass	0	14	-6	18	-6
184	Junior High	Brass	-22	5	32	7	-6
185	Junior High	Brass	-34	-13	13	-3	-33
186	Junior High	Woodwind	88	97	50	71	59
187	Junior High	Brass	-4	42	32	24	-21
188	Junior High	Brass	-37	-5	17	-6	-41

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
189	Junior High	Brass	-69	-48	-22	-23	-69
190	Junior High	String	-29	7	-13	6	-1
191	Junior High	String	-19	-23	8	-3	-9
192	Junior High	String	-17	-15	35	11	-43
193	Junior High	String	-17	5	38	41	-39
194	Junior High	String	-20	-18	-7	1	7
195	Junior High	String	-19	7	-15	16	19
196	Junior High	String	0	-6	33	31	-1
197	Junior High	String	0	5	8	-3	2
198	Junior High	String	16	29	37	11	-18

Appendix B

Directional Data: Flat/In-tune/Sharp

Appendix B

Directional Data: Flat/In-tune/Sharp
(In-tune is considered ± 6 cents)

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
1	University	Woodwind	Sharp	Sharp	Sharp	Sharp	Sharp
2	University	String	Flat	Sharp	Sharp	Sharp	In-tune
3	University	String	Flat	In-tune	Sharp	Sharp	In-tune
4	University	Woodwind	Flat	In-tune	Sharp	Flat	Sharp
5	University	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
6	University	Woodwind	Flat	In-tune	Sharp	In-tune	Flat
7	University	Woodwind	Flat	In-tune	Sharp	Sharp	Sharp
8	University	Brass	Flat	Flat	Flat	Sharp	Flat
9	University	Brass	Flat	In-tune	Sharp	In-tune	In-tune
10	University	Woodwind	Flat	In-tune	In-tune	Sharp	Sharp
11	University	Brass	Flat	Flat	Sharp	Flat	In-tune
12	University	Brass	Flat	In-tune	Sharp	Sharp	In-tune
13	University	Brass	Flat	Flat	Flat	In-tune	Flat
14	University	Woodwind	Flat	Flat	Sharp	In-tune	Flat
15	University	String	Flat	Flat	In-tune	Sharp	In-tune
16	University	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
17	University	Brass	Flat	Flat	Flat	Sharp	In-tune
18	University	String	Flat	Flat	In-tune	Flat	Sharp
19	University	Woodwind	Flat	In-tune	In-tune	Sharp	In-tune

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
20	University	Woodwind	Flat	In-tune	Sharp	Sharp	Sharp
21	University	String	Flat	In-tune	In-tune	Sharp	In-tune
22	University	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
23	University	Brass	Flat	Flat	In-tune	In-tune	Sharp
24	University	Woodwind	Flat	Flat	In-tune	Sharp	In-tune
25	University	Brass	Flat	In-tune	Flat	Sharp	Flat
26	University	Brass	Sharp	Sharp	Sharp	Sharp	Sharp
27	University	Brass	Flat	Flat	Flat	In-tune	Sharp
28	University	Brass	Flat	In-tune	Flat	Sharp	In-tune
29	University	String	In-tune	In-tune	In-tune	In-tune	In-tune
30	University	String	Flat	In-tune	In-tune	In-tune	In-tune
31	University	Woodwind	In-tune	Sharp	Sharp	Sharp	In-tune
32	University	Woodwind	Flat	In-tune	Sharp	In-tune	Flat
33	University	Woodwind	Flat	Sharp	Sharp	Sharp	In-tune
34	University	Brass	Flat	In-tune	In-tune	Sharp	In-tune
35	University	Brass	In-tune	In-tune	In-tune	Sharp	In-tune
36	University	String	Sharp	In-tune	Sharp	In-tune	Flat
37	University	Woodwind	Flat	In-tune	Sharp	Sharp	In-tune
38	University	Brass	Flat	In-tune	Flat	Sharp	Flat
39	University	Brass	Flat	Flat	Sharp	Sharp	In-tune
40	University	Woodwind	Flat	In-tune	Sharp	Sharp	Sharp
41	University	Woodwind	Flat	Sharp	Sharp	Sharp	In-tune
42	University	String	In-tune	In-tune	In-tune	Sharp	Sharp
43	University	Brass	Sharp	Sharp	Sharp	Sharp	Sharp

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
44	University	String	In-tune	Sharp	Sharp	Sharp	Sharp
45	University	String	Flat	In-tune	In-tune	In-tune	In-tune
46	University	String	Flat	In-tune	Flat	Sharp	In-tune
47	University	Woodwind	Flat	In-tune	Flat	Flat	In-tune
48	University	Brass	Flat	In-tune	In-tune	In-tune	In-tune
49	University	Brass	Flat	In-tune	Sharp	Sharp	Flat
50	University	Brass	Flat	Flat	In-tune	In-tune	In-tune
51	University	Brass	Flat	In-tune	Sharp	Flat	In-tune
52	University	Brass	Flat	sharp	Sharp	Sharp	Sharp
53	University	Woodwind	Flat	In-tune	In-tune	Sharp	In-tune
54	University	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
55	University	Brass	Flat	Sharp	Sharp	In-tune	In-tune
56	University	Brass	Flat	Flat	Flat	Flat	In-tune
57	University	String	Flat	Flat	Sharp	In-tune	In-tune
58	University	Brass	Flat	Flat	In-tune	Sharp	In-tune
59	University	String	Flat	In-tune	In-tune	In-tune	In-tune
60	University	Woodwind	Flat	Flat	Flat	In-tune	In-tune
61	University	String	Flat	Flat	In-tune	Sharp	In-tune
62	University	Woodwind	In-tune	In-tune	Flat	Sharp	In-tune
63	University	String	Flat	In-tune	In-tune	In-tune	In-tune
64	University	Woodwind	In-tune	Flat	In-tune	Sharp	In-tune
65	University	Woodwind	Sharp	Sharp	Sharp	Sharp	Sharp
66	University	String	Flat	Flat	Flat	Flat	Flat
67	University	Brass	Flat	Flat	Sharp	In-tune	Flat

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
68	University	Brass	Flat	Flat	In-tune	In-tune	Flat
69	University	Brass	Flat	Flat	Sharp	Sharp	Flat
70	University	Brass	Flat	Flat	Flat	In-tune	Flat
71	University	Brass	Flat	Flat	Flat	Flat	Flat
72	University	Woodwind	Flat	Flat	Sharp	Sharp	Flat
73	University	String	Flat	In-tune	In-tune	In-tune	In-tune
74	University	String	Flat	Flat	Flat	In-tune	Sharp
75	University	String	Flat	Flat	Sharp	Sharp	In-tune
76	University	String	Flat	Flat	Sharp	Sharp	Sharp
77	University	String	Flat	Flat	In-tune	Flat	Flat
78	University	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
79	University	String	Flat	Flat	Sharp	In-tune	In-tune
80	University	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
81	University	String	Flat	In-tune	In-tune	Sharp	In-tune
82	University	Woodwind	Flat	In-tune	Sharp	Sharp	In-tune
83	University	String	Flat	Flat	Sharp	In-tune	In-tune
84	University	Brass	Flat	Flat	Sharp	In-tune	Sharp
85	University	String	Flat	In-tune	In-tune	In-tune	In-tune
86	High School	Woodwind	Flat	Flat	Sharp	In-tune	In-tune
87	High School	Woodwind	Flat	In-tune	Sharp	In-tune	Flat
88	High School	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
89	High School	Woodwind	Flat	Flat	Sharp	In-tune	Flat
90	High School	Woodwind	In-tune	Flat	Sharp	Sharp	Sharp
91	High School	Woodwind	In-tune	Sharp	Sharp	Sharp	In-tune

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
92	High School	Woodwind	In-tune	Sharp	Sharp	Sharp	In-tune
93	High School	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
94	High School	Woodwind	Flat	Flat	Sharp	In-tune	Flat
95	High School	Woodwind	Flat	In-tune	Sharp	In-tune	Flat
96	High School	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
97	High School	Brass	Flat	Sharp	Sharp	Sharp	Flat
98	High School	Brass	Flat	Sharp	Sharp	Flat	Flat
99	High School	Brass	In-tune	Flat	Sharp	Sharp	Sharp
100	High School	Brass	Flat	Flat	Sharp	Sharp	Flat
101	High School	Brass	Flat	Flat	In-tune	In-tune	Flat
102	High School	Brass	Flat	Flat	Sharp	Sharp	Flat
103	High School	Brass	Flat	Flat	Sharp	Sharp	Sharp
104	High School	Brass	Flat	Flat	Flat	Flat	Flat
105	High School	Brass	Flat	Flat	Flat	Sharp	In-tune
106	High School	Brass	Flat	Sharp	Flat	Flat	Sharp
107	High School	Brass	Flat	Sharp	Sharp	Sharp	Flat
108	High School	Brass	Flat	In-tune	Sharp	In-tune	Sharp
109	High School	Brass	Flat	Flat	Flat	In-tune	Flat
110	High School	Brass	Flat	Flat	Sharp	Flat	Flat
111	High School	Brass	Flat	In-tune	Sharp	Sharp	Flat
112	High School	Brass	Flat	Sharp	Sharp	Sharp	Flat
113	High School	String	Flat	Flat	Flat	In-tune	Flat
114	High School	String	Flat	Flat	In-tune	In-tune	Flat
115	High School	String	Flat	Flat	Flat	In-tune	Flat

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
116	High School	String	Flat	In-tune	Sharp	Sharp	Flat
117	High School	String	Flat	Flat	Flat	Flat	In-tune
118	High School	String	Flat	In-tune	Flat	In-tune	Sharp
119	High School	String	Flat	In-tune	Sharp	In-tune	In-tune
120	High School	String	Flat	Flat	In-tune	In-tune	Sharp
121	High School	String	Flat	Flat	Flat	Sharp	In-tune
122	High School	String	Flat	Flat	In-tune	Sharp	In-tune
123	High School	String	Flat	Flat	In-tune	In-tune	Flat
124	High School	String	Flat	Flat	Sharp	Flat	In-tune
125	High School	String	Flat	Flat	In-tune	Sharp	In-tune
126	High School	String	Flat	Flat	Sharp	In-tune	Flat
127	High School	String	Flat	In-tune	Flat	In-tune	In-tune
128	High School	String	Flat	In-tune	In-tune	Sharp	In-tune
129	High School	String	Flat	Flat	In-tune	In-tune	In-tune
130	High School	String	Flat	In-tune	Sharp	In-tune	Sharp
131	High School	String	Flat	In-tune	In-tune	Sharp	In-tune
132	High School	String	Flat	In-tune	Sharp	In-tune	Sharp
133	High School	String	In-tune	Sharp	Sharp	In-tune	Sharp
134	High School	String	Flat	In-tune	Sharp	Sharp	Sharp
135	High School	String	Flat	Flat	Sharp	Sharp	Flat
136	High School	String	Flat	In-tune	Flat	In-tune	Sharp
137	High School	String	Flat	Sharp	Flat	Sharp	Flat
138	High School	String	Flat	Flat	Sharp	Sharp	Sharp
139	High School	String	Flat	In-tune	In-tune	In-tune	Sharp

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
140	High School	String	Flat	Flat	Flat	In-tune	Flat
141	Junior High	Woodwind	Flat	Flat	Sharp	Sharp	In-tune
142	Junior High	Woodwind	Flat	Flat	In-tune	Flat	Flat
143	Junior High	Woodwind	Flat	Flat	Sharp	In-tune	Flat
144	Junior High	Woodwind	In-tune	Sharp	Sharp	Sharp	Flat
145	Junior High	Woodwind	Flat	Flat	Sharp	In-tune	Flat
146	Junior High	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
147	Junior High	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
148	Junior High	Brass	Flat	Flat	Sharp	Sharp	Flat
149	Junior High	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
150	Junior High	Woodwind	Flat	Sharp	Sharp	Flat	Sharp
151	Junior High	Woodwind	Flat	Flat	Sharp	In-tune	Flat
152	Junior High	Woodwind	Flat	Sharp	Sharp	Sharp	Flat
153	Junior High	Woodwind	Flat	In-tune	Sharp	Sharp	Flat
154	Junior High	Woodwind	Sharp	Sharp	Sharp	Sharp	Flat
155	Junior High	Woodwind	Flat	Sharp	Sharp	In-tune	Flat
156	Junior High	Woodwind	Flat	In-tune	Sharp	Flat	Flat
157	Junior High	Woodwind	Flat	In-tune	Sharp	Flat	Flat
158	Junior High	Woodwind	Flat	Sharp	Sharp	In-tune	Flat
159	Junior High	Brass	Flat	Flat	Sharp	Flat	Flat
160	Junior High	Woodwind	In-tune	In-tune	Sharp	In-tune	Sharp
161	Junior High	Brass	In-tune	Sharp	Sharp	Sharp	In-tune
162	Junior High	Brass	In-tune	Sharp	Sharp	Sharp	In-tune
163	Junior High	Brass	Flat	In-tune	Sharp	In-tune	Flat

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
164	Junior High	Brass	Flat	Flat	Sharp	In-tune	Flat
165	Junior High	Brass	In-tune	Sharp	Sharp	Sharp	Flat
166	Junior High	Brass	Flat	In-tune	Flat	Sharp	Flat
167	Junior High	Brass	Flat	Sharp	Sharp	Flat	Flat
168	Junior High	Brass	Flat	Sharp	Flat	Flat	Sharp
169	Junior High	Woodwind	Flat	In-tune	In-tune	Sharp	Flat
170	Junior High	Brass	Flat	Sharp	Sharp	Sharp	Flat
171	Junior High	Brass	Flat	Sharp	Sharp	Sharp	Flat
172	Junior High	Brass	Flat	Flat	Sharp	Sharp	Flat
173	Junior High	Brass	Flat	Flat	Sharp	In-tune	Flat
174	Junior High	Woodwind	Flat	Flat	Sharp	Sharp	Flat
175	Junior High	Brass	Flat	Flat	In-tune	In-tune	Flat
176	Junior High	Brass	Flat	Flat	Sharp	Sharp	Flat
177	Junior High	Brass	Flat	In-tune	Sharp	Sharp	Flat
178	Junior High	Brass	Flat	In-tune	Sharp	Sharp	Flat
179	Junior High	Brass	Flat	Sharp	In-tune	Sharp	Flat
180	Junior High	Brass	Flat	Sharp	Sharp	Sharp	Flat
181	Junior High	Brass	Flat	In-tune	Sharp	In-tune	Flat
182	Junior High	Brass	Flat	In-tune	In-tune	Sharp	Flat
183	Junior High	Brass	In-tune	Sharp	In-tune	Sharp	In-tune
184	Junior High	Brass	Flat	In-tune	Sharp	Sharp	Flat
185	Junior High	Brass	Flat	Flat	Sharp	In-tune	Flat
186	Junior High	Woodwind	Sharp	Sharp	Sharp	Sharp	Sharp
187	Junior High	Brass	In-tune	Sharp	Sharp	Sharp	Flat

Subject	Educational Level	Instrumental Group	Non-vibrato	Vibrato	A = 430 Hz	A = 435 Hz	A = 445 Hz
188	Junior High	Brass	Flat	In-tune	Sharp	In-tune	Flat
189	Junior High	Brass	Flat	Flat	Flat	Flat	Flat
190	Junior High	String	Flat	Sharp	Flat	In-tune	In-tune
191	Junior High	String	Flat	Flat	Sharp	In-tune	Flat
192	Junior High	String	Flat	Flat	Sharp	Sharp	Flat
193	Junior High	String	Flat	In-tune	Sharp	Sharp	Flat
194	Junior High	String	Flat	Flat	Flat	In-tune	Sharp
195	Junior High	String	Flat	Sharp	Flat	Sharp	Sharp
196	Junior High	String	In-tune	In-tune	Sharp	Sharp	In-tune
197	Junior High	String	In-tune	In-tune	Sharp	In-tune	In-tune
198	Junior High	String	Sharp	Sharp	Sharp	Sharp	Flat

VITA

Wilma Louise Benson was born May 8, 1958 in Hazard, Kentucky. She attended public school in Floyd County, Indiana graduating from New Albany High School in 1976. Completing her Bachelor of Music Education at Western Kentucky University in 1981, Ms. Benson went on to receive her Masters in Education from the University of Louisville in 1985 where she served as a graduate teaching assistant. Doctoral work at Louisiana State University began in 1985 where she also served as a graduate teaching assistant.

Ms. Benson began teaching in the private studio at the age of fifteen and has continued private lesson instruction throughout her career. Her first public school position came in 1981 for the Floyd County School Corporation, Indiana where she served as orchestra director. In 1983 she moved to Jasper, Indiana to assume the position of director/administrator of the privately supported Jasper String Program.

Ms. Benson assumed a position as orchestra director in the Jefferson County Public Schools, Louisville, Kentucky in 1989. She still serves in that capacity. Wilma continues as an active performing violist, adjudicator, guest conductor, and guest lecturer throughout the Mid-West. She has served in state and local offices for the Kentucky Music Educators Association and Kentucky String Teachers Association. Ms. Benson will complete her doctorate in May of 1995.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Wilma L. Benson

Major Field: Music Education

Title of Dissertation: The Effect of Tuning Stimulus Vibrato, Timbre, and Frequency on Tuning Accuracy of University, High School, and Junior High School Instrumentalists

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

November 4, 1994