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THE EFFECT OF REAL-TIME PITCH TRACKING AND CORRECTION ON HIGH SCHOOL INSTRUMENTALISTS' TUNING ACCURACY

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The College of Music and Dramatic Arts

by
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Forever LSU.

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ABSTRACT

The main purpose of this study was to determine the effectiveness of pitch tracking and correction (auto-tuning) on the intonation performed by high school clarinet (n = 30) and trumpet (n = 30) players with at least three years of experience in the large ensemble setting. Participants (N = 60) were assigned to one of three treatment groups, each differentiated by means of intonation evaluation. An aural group (n = 20) used Real Time Pitch Tracking and Correction (RTPTC) software; a visual group (n = 20) used an electronic tuner; and a control group (n = 20) "played in-tune to the best of your ability." All three groups played target pitches documented as unstable from an intonation standpoint (clarinet A_4 and trumpet D_4) in single-pitch, melodic, and ensemble contexts. All performances were evaluated for cent deviation through the RTPTC software.

The 2-way interactions of instrument x lessons (p = .05), context x group (p < .05), and instrument x context (p < .05) were found to be significant. Clarinet participants with private lesson experience performed with more accurate but overall sharper intonation than their trumpet counterparts. Aural and visual groups were able to perform below the threshold of the just noticeable difference in the single pitch context and improved from out-of-tune to in-tune across treatments, while results for these groups in the melodic and ensemble contexts were mixed and may have been affected by the constraints of time. The control group showed improvement across the melodic treatment, but those improvements have questionable musical significance as they are not below the threshold of the just noticeable difference. Clarinets performed significantly more in-tune than trumpets in the single pitch context, while the opposite was true in the melodic and ensemble contexts. The main effects of group, instrument, context and lessons were not statistically significant (p > .05).

Responses to student questionnaires reflected knowledge of tuning strategies among a portion of participants including instrument tendencies, beat elimination techniques, and methods for correction. Time may have been a confounding factor related to comfort with included technology, based on student questionnaire responses. Director responses yielded themes related to fostering student independence with intonation, and daily use of methods for teaching intonation including the above mentioned tendencies, beat elimination, and correction strategies.

CHAPTER 1: INTRODUCTION

In rural south Louisiana in 2010, a popular local cover band, “Typikal Reasons,” is playing on a Saturday night. Among the band members is Joe, a saxophone player whose formal music education had been based in middle school and high school band. Despite his captivating showmanship, Joe struggles to play in-tune, a reality that goes mostly unnoticed by barroom audiences but not by his fellow band members. After several discussions and short lessons that are to no avail, a fellow band member and school band director, Victor, suggests that Joe purchase a stand-alone auto-tuner, a machine most often used in studio and live performances to correct the tuning of vocals or distort their timbre by means of manipulating the tuning and strength of overtones. After time spent mastering the machine, Joe plays along with the auto-tuner in live performance through a monitor speaker, and, for the first time, can hear what is “in-tune” and begins to correct his own performance to match what is produced by the machine. In essence, he is playing along with a perfectly tuned, unison duet partner. Over time Joe’s intonation improves. Even when he forgets the machine he surprisingly plays better in-tune than he once did.

The description of this experience as conveyed to me by Victor, along with hearing Joe before auto-tuning and after, was the impetus for the decision to examine how to recreate Joe’s auto-tuning experience and test its pedagogical effectiveness on a larger scale.

The Problem

Across all stages of music performance, intonation in instrumental music is an intricate web of perception, evaluation, and execution. Individual and mass tuning procedures are marred by a host of potential perpetrators, among them, deployment in a diverse setting of student musicians with varied degrees of awareness and ability, making the task of playing “in-tune” a complex process, especially in an ensemble setting and for those on the weaker end of the

spectrum. Equally numerous are the existing procedures for steering through this process, all attempting to navigate the complexities of evaluation source, training method, and correction procedure (Bennett, 1994; Cassidy, 1985; Latten, 2005; Miles, 1970, 1972; Pasqua, 2001; Schlacks, 1981; Smith, 1984). Despite the use of singing, drones, strobe tuner training, just tuning of chords, software training programs and tuning CDs to train the ear, embouchure, and hands—and the widely recognized important role of intonation in instrumental music—clear and effective approaches to teaching students how to perceive and manipulate intonation correctly continue to elude many music educators (Dalby, 1992; Garafalo, 1996; Powell, 2010; Schwartz, 2011; Wickes, 1990; Williamson, 1998).

The interchangeable use of the terms tuning and intonation contribute to the already muddy waters of the topic at hand. Intonation in *Grove Music Online* is described as an in-process and creative action: "the treatment of musical pitch in performance . . . it has an indispensable role in musical expression through the deliberate inflection of pitch to shade and colour melody" (Hayes & Leedy, 2012), while tuning is most often *a priori* and mechanical: "The adjustment, generally made before a musical performance, of the intervals or the overall pitch level of an instrument" (Lindley, 2012). Just, equal-tempered, and Pythagorean tuning systems dictate the "rules" by which intonation is executed. The present study is focused on the execution itself—specifically, the ability of amateur musicians to play in-tune.

Intonation research in instrumental music focuses on both perception and performance, with evidence showing a correlation between the two most often among more experienced students with a higher degree of musical proficiency (Duke, 1985; Fyk, 1985; Geringer & Witt, 1985; Morrison, 2000). The complicated nature of teaching intonation in the large ensemble setting, where variations of equipment, physiology, and context can burden pacing and restrict

authentic opportunities to practice manipulating pitch and receiving feedback, makes the case for training methods that include opportunities to perceive, perform, and evaluate correctly and efficiently. Beyond that, the proven disconnect between successful single-pitch tuning experiences (most often occurring with a repeated, familiar pitch) and successful tuning within a melodic context highlights the frequently embraced but somewhat ineffective nature of traditional tuning procedures (Morrison, 2004). Perception, performance, and feedback, all occurring simultaneously, make up the processes of authentic tuning, and the need for methodologies that duplicate this combination is clear from both empirical and pedagogical writing (Dalby, 1996; Garofalo, 1996; Karrick, 1997; Morrison, 2004; Williamson, 1998). Perhaps such experiences could bring about a higher degree of sensitivity to and success with intonation that have been correlated with proficiency and experience, but at a younger age.

CHAPTER 2: REVIEW OF LITERATURE

The following review of literature represents a summation of scholarly findings, theories, and methods related to the intonation of the instruments of the wind band and the relatively new technology known as auto-tuning. The wide body of literature related to this topic is first organized under the umbrella of those factors influencing the perception and performance of intonation, specifically: tempo and harmonic context, timbre, direction of mistuning and approach, performer experience, teaching methods, and characteristics of wind instruments. The final section summarizes the more limited body of knowledge related to pitch-tracking and correction, otherwise known as auto-tuning.

Pedagogues, researchers, and musicians alike have contemplated intonation for more than 150 years, yielding a vast array of assertions. Earliest documentation began with Delezenne's (1826) investigation of the perception of mistuned octaves, perfect fifths, major thirds, and major sixths as a means of confirming his hypothesis of a "natural scale" (Delezenne in Pikler, 1966, p.60) derived from a musical sense he believed to be a "natural and built-in property of the human species" and "matched to the specifications of the natural intervals" (p. 59). Meyer's (1903) investigation found a greater tolerance among trained musicians for expanded octaves and perfect fifths than contracted ones, while Seashore (1938) shared Delezenne's (1826) concept of a pitch discrimination as an inborn, natural ability, unable to be significantly improved through training. Increased intellectual and cultural awareness born from a large body of research and advances in technology have created a shift in this perspective reflected in more recent literature regarding the relationship of perception and performance (Byo, Schlegel, & Clark, 2011; Duke, 1985; Ely, 1992; Geringer & Worthy, 1999; Morrison, 2000; Yarbrough, Karrick, & Morrison, 1995; Yarbrough, Morrison, & Karrick, 1997); the success of various pedagogical methods

(Bennett, 1994; Dalby, 1992; Miles, 1972; Pasqua, 2001; Wickes, 1990); and the effect of instrument mechanics and environmental factors (Garofalo, 1996, Pottle, 1943; Stauffer, 1954).

Perception and Performance: An Overview

> The only way we can play in-tune together is by constantly listening and adjusting (Alfred Reed in Casey, 1993, p. 318).

While the perception and performance of intonation (and their relationship to one another) in instrumental music has been a major subject of empirical research particularly across the last forty years, the topic continues to be of great concern to performers and teachers alike. The complex relationship between the interpretation of aural information and execution of fine motor skills, daunted by the need to execute both almost instantaneously, has made these areas rich for investigation.

The ability to recognize "in-tune" and "out of tune" and to replicate that knowledge through action (performing "in-tune" and "out of tune") have been found to be discrete abilities. That is, the recognizing and doing appear to be two unrelated tasks (Ely, 1988, 1992; Geringer, 1976; Millsap, 1999; Morrison, 2000; Yarbrough et al., 1995; Yarbrough et al., 1997). Research examining the recognition of pitch discrepancies and the ability to correct them has been conducted in single pitch, interval, melodic and harmonic contexts; including variations of timbre, octave, pitch, direction of mistuning and interval, instructions, and training method; and with considerations including experience, private instruction, ensemble experience, and primary instrument.

While "one cannot control pitch any finer than he can hear it" (Seashore, 1938, p. 74), the ability to perceive pitch does not necessarily dictate the ability to manipulate it. Frisch, Lister, & Nikjeh (2008) investigated the relationship between pitch discrimination and the vocal production of pitch among female college non-musicians and trained instrumental and vocal

musicians. The first of two tasks in this experiment consisted of a test of participants' difference limens for frequency (DLFs), often referred to as the just noticeable difference or the threshold for aural recognition. To test DLF, participants listened to pairs of approximated piano tones presented simultaneously using a three-interval, three alternative forced-choice model where for each incorrect response the interval between tones increased, and three correct responses were required for the interval to decrease. Results for this portion of the experiment found a DLF of 23 cents for musicians, and 53 cents (greater than a quarter tone) for non-musicians, with instrumentalists and vocalists discriminating equally (Frisch et al., 2008).

The second task, a test of pitch production accuracy (PPA) that required participants listen to a single pitch for one second and sing the pitch for three seconds, yielded a musicians' mean score within 22 cents of in-tune and a non-musicians' mean score within 1.3 semitones of in-tune, a result that should be to some extent expected. While performance on the PPA test did not differ significantly between vocalists and instrumentalists, the standard deviation for vocalists was significantly smaller than for instrumentalists, suggesting greater consistency among vocalists. A significant positive correlation between DLF and PPA results was found for the instrumentalist group only, while for vocalists, performance was superior to perception. Frisch's comments that "PPA and DLF develop together in musicians [and] the relationship between PPA and DLF abilities is complex" (p. 336) speak to the intertwined but not interdependent nature of aural pitch perception and motor production, and the need for training that addresses both skills.

Threshold of the Just Noticeable Difference

Research has generated results that vary widely in regard to the difference limens for frequency (DLF) or just noticeable difference (JND). Frisch et al. (2008) found 23 cents as the

threshold for trained female, college age trained instrumental and vocal musicians in both a perception and performance task; Madsen, Edmonson, and Madsen (1969) revealed an average of 10 cents for wind players with a wide variety of years of experience in a single context; Parker (1983) found the most accurate recognition of mistuning at 20 cents among undergraduate music students listening to one-second long pairs of pitches; Rodman (1983) reported a minimum distinguishable level of 15 cents for sixth grade instrumental music students and approximately 6 cents for adult musicians when distinguishing between pairs present across multiple octaves and degrees of mistuning; and Clark (2012) found that college and high school wind players were best able to detect mistuning between 10 and 20 cents in a simultaneously presented setting.

Threshold standards vary across tuning research not seeking out the JND, but using it as a point of reference for declaring significance. Morrison (2000) used 0 cent deviation as the marker of "in-tune," dismissing the JND confusion altogether, while Byo, Schlegel, and Clark (2011) used a threshold of 5 cents for high school wind players listening to and playing along with authentic single pitches through headphones. Many do not report what standard was used.

Differences in methodology and context should be considered when considering differences in results and standards, as use of headphones or speakers, volume, years of experience, pitch context (simultaneous or sequential, single pitch or melodic) and the nature of the stimuli could all contribute to the disparity of results and raise questions of ecological validity. Smaller findings regarding DLF or JND may be unrealistic when considering an authentic rehearsal or performance setting, where variations in timbre, volume, tempo, pitch context (e.g. playing with or playing after), texture, and tone quality all come into play simultaneously, complicated by acoustics, seating, and instrumentation. Under these conditions, more liberal estimates may indeed be more realistic ones.

Tempo and Harmonic Context

Tempo and chord degree have been found to be significant contributors to accurate perception of intonation. Dunnigan (1999) conducted two experiments in which music majors, non-music majors enrolled in performing ensembles, and high school musicians listened to 28 recordings of short clarinet melodies performed with electronic accompaniment, and were asked to identify a single out-of-tune pitch. Twenty-four recordings contained a purposefully mistuned (sharp or flat by 25 cents) melody note, while four recordings were in-tune. Manipulated pitches represented either the root, third, or fifth of a major chord, with tempos of either 60 or 120 beats per minute. Participants identified errors significantly better when they were flat in pitch, the root of the chord, and performed at a slower tempo. Findings regarding a preference for flatness are corroborated by Geringer (1976), Madsen & Geringer (1981), and Morrison (2000), while results of tempo are logical—more time allowed perceiving differences should result in more accurate responses. These findings, along with previous research, lend credence to the need for methods that can provide instruction and authentic experience in deciphering and correcting intonation inaccuracies under multiple conditions, including variations of tone, tempo, melodic context, and direction of mistuning.

Timbre

Tone quality—a term interchangeable with timbre, and defined as “the characteristic quality of an instrument, which enables it to be identified” (Campbell & Greated, 1987, p. 141)—affects the ability to perceive pitch accurately (Geringer & Worthy, 1999; Wapnick & Freeman, 1980; Worthy, 1997). Worthy’s (1997) investigation of high school and college wind instrumentalists’ ability to perceive intonation accurately when listening to recordings of clarinet, saxophone, trumpet, and trombone performances manipulated to be either “bright” or “dark” in

tone revealed that participants identified bright performances with sharpness and dark performances with flatness. In addition, participants performed sharp when trying to match bright examples while participants attempting to match dark tones performed flat. Similarly-focused research by Geringer and Worthy (1999) yielded comparable results (bright/sharp and dark/flat) with university music and non-music majors participating in music along with high school students who were asked to evaluate pairs of bright, dark and standard tones presented in the mid-registers of clarinet, trumpet, and trombone.

The tendency of performers to confuse tone quality (bright/dark) with intonation is explained by Wuttke (2011) as a function of the harmonic series, which is made up of a fundamental pitch (the pitch perceived) and series of higher, weaker pitches referred to as overtones or harmonics, which combine to form what the ear perceives as characteristic instrumental timbres:

> When instrumentalists create sounds they are, in a sense, manipulating the amplitude of the fundamental and overtones in the harmonic series. For example, a bright tone reinforces the upper harmonics, diminishing the amplitude of the fundamental and lower harmonics. A dark tone reinforces the fundamental and lower harmonics, while a characteristic tone represents a balance between the fundamental and harmonics that define the distinctive timbre of the instrument or voice (Wuttke, 2011, p. 3).

In essence, the abundance of high overtones in a bright tone quality trick the ear to hearing sharpness and the player into performing the same, with the opposite being true for a tone quality perceived as dark.

Another factor found to affect perception of intonation is tone quality, where both bright and dark and good and bad can influence judgment. Madsen & Gerringer (1981) found that timbre and intonation discrepancies were misinterpreted when investigating college music majors' and non-music majors' ability to discriminate between tone quality and intonation in

unaccompanied flute and oboe duets. The unaccompanied duets were performed with either good or bad tone quality and close to equal temperament or fifty cents sharp. Thirty-eight percent of subjects labeled the duet performances as “sharp,” while 62% chose “flat,” despite the fact that no flat performances were presented. Subjects also perceived intonation errors more often than tone quality errors, although those perceptions were often incorrect. Results of this study align with others where preferences for intonation supersede preferences for tone (Geringer & Worthy, 1999; Madsen & Flowers, 1981), despite subjects’ indication of a preference for tone.

Geringer et al.’s (2001) investigation into the preference for trumpet tone quality versus intonation found a higher preference among listeners for tone quality. When listening to recordings of in-tune trumpet performance with either a poor or good tone quality accompanied by in-tune, sharp, or flat piano performance (and vice versa), both high school instrumental music students and college music majors gave higher ratings in both tone quality and intonation to performances where tone quality was “good,” despite poor intonation.

Timbre, when viewed in the context of different instruments and manipulated with vibrato, appears to have an effect on the perception and performance of intonation. Benson (1995) found an overall tendency for university, high school, and junior high school wind and string subjects to play flat in comparisons of stimuli that included oboe and electronic tuner timbres, vibrato and no vibrato, and three different frequencies (A430, A435, A440, and A445). Benson concluded that vibrato, timbre, and frequency had significant effects on participants’ ability to tune to the stimulus. Participants’ inaccuracy when tuning to the electronic stimuli may have been a manifestation of ecological validity, or familiarity with the oboe stimuli as a result of its role as a traditional tuning source in large ensemble settings.

This begs the question: in the large ensemble instrumental setting, what is the best tuning source? Oboe, clarinet, and tuba are common choices. The effect of stimulus octave and timbre on tuning accuracy investigated by Byo, Schlegel, and Clark (2011) included four tuning stimuli: B-flat$_4$ (the B-flat above middle C) sounded by flute, oboe, and clarinet, and B-flat$_2$ (the B-flat two octaves below middle C) sounded by tuba. High school music students were asked to tune to the recorded stimulus pitches sounded by all four instruments. Results revealed that responses to the tuba stimulus were significantly more out of tune than for flute, oboe, or clarinet, with responses to the latter three being very similar. Whether the octave or timbre of the tuba stimulus was responsible was not clear, but octave may be the most logical choice as responses to the different timbres of flute, oboe, and clarinet did not yield significant differences. Perhaps the most interesting finding was one of participant misconception regarding tuning. Eighty-two percent of participants tuned to the tuba as part of routine tuning procedures in their school ensembles. Forty-five percent reported the belief that they were able to best tune to the tuba, but in actuality only 17% tuned most accurately to it.

Cassidy's (1989) study of the influence of timbre and octave on tuning yielded somewhat different results. High school flutists and clarinetists tuned their instruments to multiple synthesized pitches under various timbre conditions (square wave, sine wave, and sawtooth wave) and three variations of octave placement (same, above, or below). Participants were best able to tune in lower octave sine wave (characteristic of flute) and square wave (characteristic of clarinet) situations along with same octave sawtooth wave (characteristic of oboe). Differing results between Byo et al. (2011) and Cassidy (1989) may be due to the use of authentic recordings of wind instruments versus synthesized tones, along with the inclusion of different instruments (Cassidy included flute and clarinet, while Byo et al. included flute, clarinet, bass

clarinet, alto, tenor and baritone saxophone, trumpet, horn, trombone, euphonium, and tuba). Cassidy also noted that the majority of subjects "made little attempt to alter their pitch. Seven students adjusted their instruments, but none used physical control (for example embouchure change, breath support) while tuning" (p. 19). It was unclear whether this was a result of the inability to detect a difference, or a lack of understanding of instrument tendencies and the methods for correction.

Context

The study and pedagogy of intonation is further complicated by melodic and tonal considerations. Individual pitches exist within the context of tonal structure often dictated by key, familiarity, and the context of a melodic line, where pitches are approached from above or below and either step, skip, or leap. These variables can affect intonation performance. Two studies conducted by Yarbrough, Karrick & Morrison (1995) and Yarbrough, Morrison, & Karrick (1997) attempted to evaluate the effect of prior knowledge of mistuning on perception and performance. In the first study (1995), participants included elementary and middle school wind instrumentalists ($N = 197$) with up to four years of experience. The performance task consisted of manipulating length of instrument to match a recorded F or B-flat, while the perception task consisted of manipulating a variable-pitch keyboard knob to match the same recorded tones. The second study (1997) used a similar method including high school wind instrumentalists ($N = 113$) with between five and seven years of experience. In both studies, participants were assigned to three treatment groups: informed that their instrument and the tuning knob were mistuned sharp; informed that their instrument and the tuning knob were mistuned flat; and given no information regarding mistuning. Both studies found no significance due to the treatment (groups of mistuning), and the first study found the mistuned sharp group

showed more sharp responses, the mistuned flat group showed more flat responses, and the control group showed an equal number of responses across sharp and flat. No statistical relationship was found between the perception and performance tasks.

Wind instrumentalists' performed tuning accuracy of four pitch intervals, major third, perfect fourth, perfect fifth, and major sixth, was investigated by Duke (1985). Four different pitches were selected as the lower note of interval pairs, E-flat, E, F, and F-sharp (G-flat), and were assigned each of the test intervals. The use of four different starting tones was based on several factors: previous research findings that suggested different stimulus tones result in significantly different performance accuracy, an apparent result of practice with a particular starting tone (typically A or B-flat, hence the omission of these pitches) (Vorce, 1964); the idiosyncrasies that result from the manufacturing of various wind instruments and how those issues affect intonation; and the unwanted learning effects that may have resulted from repeating a single tone within the trial (Duke, 1985). The effect of familiarity of tuning pitch on performed intonation has since been replicated by Morrison (2000). The selected pitches were in the comfortable middle registers of the majority of the instruments included. Middle school, high school, and college music students ($N = 48$) served as participants, and performed both ascending and descending intervals in a randomized order for both a pre- and post-test after a brief warm-up period and an opportunity to tune to A = 440 Hz. Each of the eight melodic intervals was performed by each subject, with performances recorded so as to be used as accompaniment for the harmonic treatment. The harmonic treatment consisted of the participant performing the interval in the opposite direction along with a recording of himself.

Results showed that while the direction of the performed interval affected intonation accuracy, the interval itself did not—participants who performed a major sixth out of tune

performed a major third the same, a finding validated by later research (Karrick, 1998; Morrison, 2000). Also found was instrumentalists' propensity to expand ascending intervals while contracting descending ones, a finding in contradiction to previous research on intonation in vocal (Forsythe, 1967) and string (Papich & Rainbow, 1974) performance. Surprisingly, there were no significant differences found regarding accuracy of intonation between the three levels of experience observed: middle school, high school, and college (Duke, 1985). A comparison between instruments was not included. While some results of this study were found to be statistically significant, their musical significance is minimal, as they reflected differences on average of three cents or less, smaller than most estimates of the just noticeable difference (Clark, 2012; Madsen, Edmonson, & Madsen, 1989; Rodman, 1999).

The practice of mass tuning to an isolated pitch in large ensembles, while efficient, is often ineffective as a means for improving intonation in melodic, harmonic and other-note contexts (pitches other than the frequently rehearsed tuning note) (Morrison, 2000; Powell, 2010; Yarbrough, Karrick & Morrison, 1995; Yarbrough, Morrison, & Karrick, 1997). Morrison's (2000) study of elementary, middle and high school instrumentalists' performance of a target pitch (G) in multiple melodic contexts and an isolated pitch (B-flat) found that participants were able to tune to the individual pitch with significantly greater accuracy than target pitches embedded within a melodic context. These results indicate that the ability to tune to an isolated pitch may be the result of practicing just that: tuning to *that* pitch, and may not be representative of the ability to perceive and play in-tune in the broad sense, in the context of a melodic or harmonic line, or selections in keys not closely related to the chosen pitch. This consistent disconnect in wind-band pedagogy was brought into perspective by veteran conductor Frank Wickes:

> I remember a guy who had the B flat tuned perfectly with the strobes in the warm up room. He continued tuning individuals to B flat, even after the curtain had opened. Then, they played the *Fantasia in G Major* of Bach! The band was terribly out of tune, though he had worked that B-flat extensively (Casey, 1993, p. 20).

While a great deal of research investigating the perception and performance of intonation in the instrumental performance of individuals has been conducted using either an isolated pitch or two-note intervals (Benson, 1995; Byo et al., 2011; Duke, 1985; Frisch et al., 2008; Greer, 1970; Pottle, 1943; Worthy, 1997; Yarbrough, Karrick, & Morrison, 1995; Yarbrough, Morrison, & Karrick, 1997), considerably less has been conducted investigating the tuning of multiple subsequent pitches, or a melodic line (Kantorski, 1986; Morrison, 2000; Sogin, 1989; Yarbrough & Ballard, 1990). This is despite the finding that "the context in which instrumentalists perform pitches has been identified as a significant factor in the accuracy of response and direction of error" (Morrison, 2000, p. 40) and scant evidence that supports a relationship between accurate perception of intonation discrepancies and matching a single target pitch (Ely, 1992; Geringer, 1983; Geringer & Madsen, 1987; Morrison, 2000). This disconnect is due in part to the complexity of the instruction/performance/assessment process, one that complicates rehearsal pacing and differs across the instruments of the wind band, muddled by the realities of hearing, air, fingering, embouchure, tone quality/timbre, seating, volume, context, and equipment manufacture—each of which differs from player to player, instrument to instrument. Both the body of empirical research and continued criticism from expert teachers and conductors in the instrumental music field regarding intonation further the cause for more efficient and effective approaches to informing students' understanding of intonation across the multiple contexts of perception and performance.

Performer Experience Versus Instruction

As might be expected, accuracy in pitch discrimination and performance has been found to be greater among more experienced students (Duke, 1985; Elliot, 1974; Geringer, 1983; Morrison, 2000; Yarbrough, Green, Benson, & Bowers, 1991) and a correlation between perception of intonation discrepancies and pitch-matching ability has been observed among students with a higher degree of musical proficiency (Fyk, 1985; Geringer & Witt, 1985). But is experience the only factor at play in the increased ability to perceive and match pitch among veteran musicians? Morrison's (2000) study questioned this assumption, based on his finding that across elementary, junior high, and high school students, scores representing accurate intonation performance were higher for second, forth, and sixth year players, years that represent transitional junctures in education (elementary to middle and middle to high school). Morrison's question (it remains a question) is this: does the ability to accurately perform "in-tune" increase over time as a result of experience alone, or do students who do not progress in this area (and likely in other areas of music performance) leave the instrumental music classroom? One answer to this question may lie in the influence of experience not measured in years in school, but in time spent focused on the challenge of in-tune playing in ensembles—an area of research in need of further probing.

Yarbrough et al. (1995) revealed significance in tuning tasks related to years of instruction, showing significant improvement in both the performance and perception tasks from the first year to fourth year participants, while Yarbrough et al. (1997) showed no significance due to years of instruction among high school participants. When considering the large amount of progress made across the beginning stages of wind instrument study that affect intonation—including ear, air, and embouchure—the discrepancy between the first and second study

regarding years of experience is not surprising. The second study also found more accurate responses on the perception task and that those participating in private lessons performed both tasks significantly better, a factor not considered by the first study.

Other questions regarding experience abound: if the ability to tune to an isolated pitch can be developed over time across multiple age levels as a result of experience, can the same be done for melodic selections? How can this be accomplished in an efficient and effective way in the instrumental ensemble setting, where mass tuning procedures prevail? Current single-pitch mass-tuning practices, while efficient, are an inauthentic method for both assessing student ability to play and perceive in-tune as well as an ineffective method for teaching such skills (Morrison, 2000; Powell, 2010; Yarbrough, Karrick & Morrison, 1995; Yarbrough, Morrison, & Karrick, 1997). A parallel could be made here to teaching a particular rhythmic pattern (say, four sixteenth notes) independent of musical context (in a warm-up), but that pattern never being addressed in the context of repertoire, where those same four sixteenth notes will be preceded and followed by other rhythms, morphed by various articulation and pitch patterns, varied by tempo and interpretation. Transfer through an opportunity to apply procedural knowledge in an authentic context is one of the greatest signs of understanding, as "The goal is no longer the acquisition of knowledge and skills but the application of knowledge and skills in situations that have not been taught explicitly" (Duke, 2005). And yet the bridge between massed, single-pitch tuning procedures (the application of procedural knowledge) and tuning in authentic, musical, melodic and harmonic contexts (complex application) is often not effectively built or crossed in instrumental music classrooms.

Teaching Methods

Instruction, both in the private lesson and ensemble setting, has been found to be the most influential factor affecting accurate perception and performance of intonation, with studies investigating the effectiveness of intonation training methods yielding positive results related to both perception and performance (Bennett, 1994; Dalby, 1992; Latten, 2005; Miles, 1972; Pasqua, 2011; Wuttke, 2011). Among the methods tested are beat recognition and elimination, vocalization, and technology-assisted training tasks.

Instruction was found to be a determinant factor in Wuttke's (2011) study of wind band intonation, where "instrument quality, experience in band and private lessons, and aural acuity combine to affect intonation scores, but these student attributes are less influential than instruction" (p. ii). Band directors ($N = 5$) and their students ($N = 200$) were given tests to measure knowledge of tuning tendencies and aural skills, and those results were combined with data regarding experience, private lesson participation, and equipment quality. Results of these tests were compared to each band's warm-up, tuning, and rehearsal procedures, along with the performance of a chorale in B-flat using spectrum analysis to measure ensemble intonation at certain unison and chordal points. Results indicated that instruction and student attributes accounted for 99.3% of the variance in wind-band intonation, with private lesson participation and ensemble activities incorporating aural-based tuning strategies, tuning intervals, and the tuning of chords resulting in higher intonation scores. These results place a greater influence on the effectiveness of instruction than years of instruction—with the latter having been found to be a significant factor in previous research.

The importance of teaching students to both perceive and correct intonation problems, validated empirically by Wuttke (2011), is a theme found frequently in research and trade

journals, method books, and instrument pedagogy texts (Byo, 1990; Casey, 1993; Cassidy, 1989; Garofalo, 1996; Latten, 2005; McGarry, 1984; Pasqua, 2001; Williamson, 1998). Yet intonation—recognition and correction—still remains a major problem among wind instrumentalists, a reality that may be due to the complex nature of the task, lack of familiarity with appropriate teaching methods and the mechanics that underpin them, and unwillingness to commit rehearsal time to executing them. Mullins (2001) lamented that “too many teachers decide that young players are simply incapable of playing in-tune, and they basically . . . learn how to tune out bad intonation” (p. 48).

Teaching student musicians to recognize “beats” (the oscillations heard when two frequencies are unmatched above the threshold of the just noticeable difference) as a means of recognizing tuning discrepancies is a now prevalent teaching method among wind instrumentalists (Powell, 2010). Miles’s (1972) investigation of beat elimination as a means of teaching intonation recognition involved beginning wind players matching two pitches produced by an electronic device; matching a pitch played by an electronic device with their own wind instrument; matching a single pitch with another wind instrument; matching perfect fourths and fifths with Miles himself; and eliminating beats when performing triads with two other student musicians. Subjects were inexperienced, having completed only one semester of training on their instruments. After becoming familiar with beat elimination both with the electronic device and their own instrument, and following multiple opportunities (up to 20) to execute each task, all subjects were able to perceive the beats between mistuned pitches. On each task, at least 79% of subjects were able to play in-tune both with the electronic device and their own instrument.

Pasqua’s experiment testing a “method for developing intonation awareness” (2001, p. 4) among high school instrumentalists yielded similar positive results. Using a treatment/control

structure, the treatment group (n = 28) participated in ten sequenced small tuning activities focused on the recognition and resolution of beats over a six-month period, while the control group (n = 19) continued participation in normal classroom activities. Training activities all utilized students' own instruments, and included adjusting when sharp and when flat to a given pitch, correctly adjusting fourths and fifths, and adjusting to sharp and flat pitches. Results showed significance regarding the treatment group's ability to tune with greater accuracy, shortened tuning time, and increased confidence related to tuning tasks. The inclusion of instruction for both recognizing and executing by both Miles (1972) and Pasqua (2001), combined with the apparent success of the treatments, make a strong argument for students' potential to play in-tune when given instruction in methods for recognizing *and* executing regardless of level of expertise. These findings are supported by empirical and pedagogical publications alike (Byo, 1990; Williamson, 1998; Wuttke, 2011). Neither study, however, proposed methods for practicing these concepts independent of a teacher. Both required researcher participation throughout the training process.

Latten's (2001) investigation into experienced private and ensemble instrumental music educators' methods for teaching intonation yielded three common conditions participants considered to be requirements for developing intonation control: quality instruments tuned to equal temperament, characteristic tone quality, and the ability to audiate. Audiation, what Joukamo-Ampuja and Wekre (1999) describe as "the foundation of all good intonation . . . a clear plan or desire for the exact coming pitch" (p. 47), is best demonstrated by vocalization, a method widely advocated by pedagogues for improving intonation with limited foundations in empirical research (Casey, 1993; Colwell & Goolsby, 1994; Williamson, 1998). Garofalo referred to singing as "without question the single most powerful way to develop good

intonation" (1996, p. 75), also saying "singing has magical powers that rarely fail to produce better intonation" (1996, p. 76).

Bennett (1994), Schlacks (1981), and Smith (1984), investigated the effectiveness of vocalization as a means for improving pitch accuracy among middle school, high school, and collegiate musicians using a variety vocalization exercises. Results showed that significant improvement in intonation was achieved among high school students when intervals were both sung and played daily for approximately six minutes per day across twenty days in an ensemble setting, but not when singing was practiced alone, without playing (Schlacks, 1981). Training that included collegiate musicians singing arpeggiated exercises for a short period before playing them (Smith, 1984) and middle and high school musicians humming isolated pitches across a four-week period after which they attempted to play those same pitches (Bennett, 1994) showed no significance. In the case of Smith (1984), this may be due to the short amount of time allotted for singing (only 30 seconds). When comparing the results of Bennett (1994) with Schlacks (1981), the lack of significance found in Bennett's instructional method may be due to the absence of a playing task during the training itself (playing was only required during the post-test). The combination of singing *and* playing isolated pitches, intervals, or melodic lines gives performers the advantage of removing the mechanical obstructions created by the instrument from the execution of tuning during the singing task, allowing a greater focus on the accuracy of perceived pitch before it is performed, then combining the two so that they can apply what the ear has discovered to the instrument itself.

But one question is left unanswered by this research: while singing may be an asset to tuning, what if the students are unable to vocally match pitch? Lyons (2013) investigated the influence of singing on performed tuning accuracy of ascending and descending step-wise three-

note combinations among middle school instrumentalists following a six-week vocal instruction period. Results showed that the most out of tune playing occurred directly following the singing stimulus, a result most likely influenced by participants' poor singing overall. Lack of confidence, discomfort with the vocal task, and negative effects of the male voice change were common qualitative themes that emerged from participants regarding their comfort with singing, and may have affected results.

A variety of technology inclusive methods for improving musicians' ability to recognize and perform intonation have been developed by researchers and practitioners alike (Dalby, 1992; McQuerry, 1957; Tromblee, 1972; Wickes, 1990). To help musicians better understand the intonation tendencies of their instruments, several practitioners—including collegiate wind band Frank Battisti, Donald Hunsberger, Craig Kirchhoff, and Frank Wickes and a panel of high school wind conductors, studio faculty, and intonation researchers—recommend a strobe-tuner centered buddy system where the tuning tendencies (exactly how many cents flat or sharp) of each pitch on the instrument are documented, one pitch at a time (Latten, 2005; Wickes, 1990; Williamson, 1998). While an understanding of the tendencies of the instrument has been proven to be a vital part of the over-arching ability to manipulate an instrument to best play in-tune (Wuttke, 2011), this process serves to inform the player of the problem but not of the means for addressing it, and not in the context of a melodic or harmonic setting. Perhaps the most meaningful aspect of this strobe-centered task is its inclusion of pitches that are not the focus of daily tuning tasks in the large ensemble setting. Morrison's (2000) finding that participants' ability to play in-tune across the range of the instrument was not represented accurately by their ability to tune standard large ensemble tuning notes could be addressed by this method, one that is not constrained by the limits of large ensemble pacing and varied instrumentation.

The existence of oscillations, or beats, can be the result of either mistuning (as addressed above) or the nature of equal-tempered harmony, where only perfect unisons and octaves truly produce no beats (Campbell & Greated, 1987; McGarry, 1984). A more recent movement in wind band pedagogy has attempted to address this by instructing players to lower or raise chord tones in the ensemble setting in order to create beat-less, or just, harmony. *The Tuning CD* (Schwartz, 2011), *Musical Instrument Tuning Helper* (Ball, n.d.), and Yamaha Corporation's *Harmony Director* (Yamaha, 2012) are all examples of drone-based methods for teaching wind instrumentalists "an acute awareness of intonation . . . using your ear's natural tendencies" (Schwartz, 2011, p. 4), with "natural tendency" being just intonation.

All three methods provide instrumentalists and vocalists with opportunities to both hear and play intervals and chords according to just intonation, in order to "learn how to tune individual notes within chords, so that entire chords may be tuned" (Yamaha, 2012, p. 1). While the acute awareness encouraged by these methods is an asset, the conflict between just intonation instruction and the more familiar equal tempered world muddies the waters. Long-used tuners are calibrated to equal temperament, piano accompaniment (a standard of solo wind literature and advanced wind ensemble literature) requires it, and our ears learned long ago to accept it, as we are surrounded by both live and recorded performances in the Western tradition settled within this system by means of necessity (Kopiez, 1996; McGarry, 1984). The idea of training wind musicians to perform with just intonation "in sustained chordal passages and at other times when harmonic concerns take precedence over melody" (Dalby, 1992, p. 141) is not a new concept, and has been recommended in a number of pedagogical articles and texts despite equal temperament's long standing acceptance as the standard for Western harmony (Kohut, 1973; Lloyd, 1937; Stegeman, 1967). Research findings, however, show performers' tendencies to

deviate least from equal temperament and most from just intonation in a harmonic setting suggest that these methods may not be widely accepted, or are not effective (Dalby, 1992; Karrick, 1998; Mason, 1960).

The effectiveness of a computer-based intonation training program including both just and equal tempered intonation with college music majors (*N* = 20) was the purpose of Dalby's 1992 study. After passing an investigator-developed discrimination test and fulfilling academic requirements based on ACT scores and class standing, participants in the experimental group (*n* = 10) engaged in digital synthesizer-derived drill and practice exercises using triads, intervals, and short harmonic passages including three- and four- voices in both equal temperament and just intonation. Results showed a significant difference in favor of the experimental group following the nine-week training period, and participants indicated mostly positive attitudes toward the program. Despite previous findings to the contrary, Dalby's results showed no difference between performances on sharp and flat tasks. Participants identified the location of errors more accurately than the direction (sharp or flat). The significant gains made by the experimental group may be attributed in large part to their performance on just intonation tasks, where much larger gains were made than on equal-tempered tasks. Dalby explained this as a result of a "newly acquired background in just intonation," (p. 147), suggesting that students were not familiar with the concept of just intonation previously. Kopiez's (2003) study of professional trumpet players' intonation within both the equal temperament and just system yielded similar results, which he attributed to Ericsson's (1996) "expertise theory" (2003, p. 408) where expertise is found to be domain-specific (in this case, equal-temperament specific) and requires significant time for skill acquisition (e.g., adjustment to the just system).

Technology centered instructional tools that can provide feedback in an individual practice setting may serve to duplicate the advantages of private instruction on performed and perceived intonation found by Wuttke (2011) and others (e.g., Yarbrough, Morrison, & Karrick, 1997). Both time spent alone with instructional tools and in a private instruction setting with a qualified teacher may serve to rectify the inherent faults of ensemble tuning procedures by allowing time for a greater understanding of the tendencies of one's own instrument, the methods and amount of manipulation necessary to correct them, the sound of mistuning (and tuned), and time to practice perceiving and executing within these confines without slowing the pace of an entire classroom.

Despite the positive results of studies investigating intonation training methods and assets available to educators, a clear understanding among music educators of appropriate and effective methods for training students to perceive and adjust intonation at various stages of training does not seem to exist. When considering the reality that clear approaches to other musical concepts do exist—for example, the teaching of rhythm—the lack of clear thinking about how to approach intonation concepts with students is most likely due to the complexity of the concept of intonation itself, how it varies across equipment, environment, musical context and player; as Colwell and Goolsby say, "A little knowledge is a dangerous thing, and pitch is an area about which many have only a little knowledge" (2002, p. 412). Music teachers must first start a solid foundation of their own musical ability and a clear understanding of these concepts before effective teaching methods can take place. Examples of experienced students who are able to recognize in-tune and out-of-tune but who are not familiar with methods of adjustment and/or the tendencies of their own instruments, as referenced in writings (Byo, 1990; Cassidy, 1989; Williamson, 1998; Wickes, 1990; Wuttke, 2011) and observed in pilot studies for this study,

clearly make the case for the need to better prepare educators with concrete, practical methods for approaching intonation in their classrooms.

Characteristics of Wind Instruments Influencing Intonation

> No matter how good the instrument is that is in your hands, it is impossible to manufacture any wind instrument, brass or wood or plastic, that is perfectly in-tune with the tempered scale. If we were to produce such an instrument, the holes and the keys would be in such places that no human fingers could reach them. (Alfred Reed in Casey, 1993, p. 318).

Perhaps the most tangible reason for difficulty with teaching and understanding intonation in instrumental music is the instruments themselves; their physical characteristics (of wind instruments especially) and how these characteristics contribute to intonation discrepancies by means of acoustical and environmental properties. Pottle's (1943) investigation into the effect of external temperature on wind instruments found that an increase in external temperature resulted in a rise in pitch, while a decrease caused a lowering in pitch, with large instruments affected to a higher degree than smaller instruments, a position supported by Young (1967). Pottle concluded that wind instruments require frequent adjustment during performances, as a result of potential changes to external temperature across the course of a performance.

Both Stauffer (1954) and Elliott (1971) measured the effect of acoustical characteristics inherent in both instrument and mouthpiece manufacturing on intonation, finding that the intonation of wind instruments is strongly influenced by both factors on flute, clarinet, oboe, bassoon, baritone saxophone, trumpet, cornet, horn, baritone, and tuba. Close lay mouthpieces (where the distance between the facing of the mouthpiece and the reed is smaller) were found by Stauffer (1987) to play consistently sharper than open lay mouthpieces. The speed of the air stream produced by the performer also directly affects intonation, with slower air resulting in a flatter pitch and faster air resulting in a sharper pitch (Garofalo, 1996). Kopiez's "informal

measurements" (2003, p. 408) showed a range of intonation as wide as a half-step controlled by embouchure alone among professional trumpet players. He concluded that intonation of wind instruments is influenced by at least four factors: instrument-specific causes, partial position, musical context, and pitch class independent of musical context. The effects of musical context, of which there are a wide variety, and pitch class independent of musical context (e.g., Kopiez's finding that the same ascending interval is performed differently in one key than in another) on intonation further the case for the need for authentic tuning "practice" methods, where musicians can better replicate the realities of the rehearsal hall.

Clarinet and trumpet were chosen for this study for several reasons: their inclusion in the standard wind band setting in relatively large numbers; status as beginning band instruments; a similar tessitura; and problematic pitches residing within the characteristic range for high school musicians that are also commonly found in wind band literature.

Clarinet

> Clarinets, like all other wood-wind instruments, are considerably out of tune, perhaps played out of tune, but most certainly made out of tune.
> (McGinnis & Pepper, 1944, p. 188).

There are inherent faults in the manufacture of all woodwind instruments, a result of compromises of tube length, tone hole placement, and the manufacture of tone holes (e.g., pad construction and key height) (McGinnis & Pepper, 1944). Perhaps the greatest single source of intonation inconsistency on the clarinet results from what Stauffer (1987) refers to as the "one speaker-hole malady," or the existence of a single register key allowing the instrument to over-blow at the interval of a twelfth. If practicality were of no concern and acoustical considerations were paramount, more consistent intonation could be achieved across the instrument if each register contained tone holes of various sizes and if a separate register key existed for every

chromatic note to accommodate differing acoustical properties (Garofalo, 2000). When considering practical spacing and location of tone holes and only the part-time use of the thumb at a clarinetist's disposal, the impracticality of these options is clear.

Clarinet A_4, along with the other pitches in the range of the throat tones, is widely characterized as possessing intonation flaws most commonly labeled as sharp in pedagogical texts depending on one or more of several things, namely instrument manufacture and upkeep, reed, and reed/mouthpiece combination (Colwell & Goolsby, 2002; Fabrizio, 1994; Garofalo, 1996). The problematic nature of the throat tones, including a less characteristic tone when compared to the rest of the instrument, is the result of its engagement of the short tube of the clarinet, closest to the mouthpiece. If acoustical adjustments were to be made to improve the nature of the throat tones, those tones in other registers in which the longer tube is utilized would be directly compromised; thus the task of correcting throat tone intonation is left in the hands of the skilled performer. Strategies for addressing the tuning of clarinet A_4 in performance include opening (in the case of sharpness) or closing (in the case of flatness) the oral cavity and alternative fingerings (in the case of sharpness) to increase the length of tubing, bringing down the pitch (Colwell & Goolsby, 2002; McGinnis & Pepper, 1944; Stauffer, 1987).

Trumpet

The three-valve system was adopted more than 100 years ago as a means of extending the pitches available on the valve-less bugle. By depressing each valve individually, the overtone series (and therefore available pitches) of three separate bugles were combined into one; and by incorporating all available combinations of multiple valves depressed at once (1-2; 2-3; 1-3; 1-2-3) the complete chromatic range was made available to the modern trumpet player. While the expanded number of pitches made available by this system makes it essential for modern

repertory, compromises in tuning arise as a result of the mechanics of tube length, and must be corrected by the player by various means.

For the most part, the trumpet and all other valved instruments are constructed such that each individual valve, when depressed, lowers the fundamental (valve-less) pitch of the instrument by one half-step. Problems occur when combinations of valves are used, as every half-step is not created equal: the length of the wave increases as the player descends chromatically from any starting note, which is why the length of a wave doubles itself every octave below the original wave (Campbell & Greated, 1987).

The clearest explanation compares the lengths of tubing used on a B-flat valved tenor trombone to the more flexible (and therefore more accurate) lengths of the slide trombone. Descending chromatically, depressing the second valve lowers the open (fundamental) pitch by one half-step, extending the tubing by 176mm; depressing the first lowers the pitch another half step, extending the tubing by 363mm; and depressing the third valve does the same, extending the tubing by 560mm. Depressing the valves in order (2-1-3) is comparable to moving through the first four positions on the slide trombone, lowering the fundamental pitch one half-step at a time. To keep descending down the chromatic scale valve combinations must be used, with the first combination being the 2nd and 3rd valves, which extend the length of tubing by 176+560, or 736mm. Because the length of tubing necessary to continue descending down the chromatic scale grows across each half-step, the 2-3 valve combination comes up short—a tuned fifth position on the slide trombone adds 770mm to the fundamental pitch, while the 2-3 valve combination adds only 736, making the tubing 34mm too short. These discrepancies, when translated into cents, make for approximate pitch discrepancies of 16 cents sharp for the second and third valves combined, 30 cents sharp for the first and third, and 54 cents sharp (more than a

quarter tone) for all three valves depressed at the same time (Campbell & Greated, 1987, p. 356). The severity of these compromises to intonation are often lessened across higher quality trumpets by incorporating a variety of changes in the proportion of cylindrical tubing and adding a small section of the third valve that can slide in and out, lengthening or shortening the valve and making these inherent mis-tunings approximate (Hall, 2002, p. 273).

Trumpet D_4, achieved by a first and third valve combination, falls distinctly into the category of pitches exhibiting inherent intonation flaws as a result of shortened tubing. Elongation of the third- and first-valve slides along with changes to the oral cavity (open=lower pitch) are recommended to negotiate the sharpness that results from instrument manufacture necessities (Baily et al., 1992; Garofalo, 1996; Stauffer, 1987).

Pitch Tracking and Correction

"…in skilled hands, Auto-Tune is the rare gimmick that can lead to innovation." (Tyrangiel, 2009, p. 2)

Until recently, technology available to the classroom teacher designed to aid in the performance and perception of intonation has been limited to tuners and single pitch or chord drone sounds. Tuners and drone sources, while beneficial, are centered around the adjustment of a single pitch, and are of limited use in a melodic setting. Additionally, feedback from tuners is visual, not aural, and requires that the player move slow enough to *see* what the tuner has to communicate—a process University of Colorado Director of Bands Alan McMurray calls "a big mistake . . . they need to listen to hear when they are in-tune. They can't look at the machine all the time" (Williamson, 1998, p. 59).

Buckmaster's (2006) qualitative study of successful college trombone professors' teaching strategies revealed intonation as the second most frequent theme (with tone quality being the first). While the use of a tuner was encouraged to inform these trombonists of the

intonation tendencies of their instrument, it was regarded as “a tool mostly for use on one’s own” (p.83) and was described as ineffective in a group setting. Several of Buckmaster’s participants required that students use tuners in individual practice, but must “tune to me [the professor] in lessons” (p. 83). While the benefits of tuners are not disputed, their one-dimensional, visual feedback removes tuning from an actual musical context, a problem that hampers much of the single-pitch tuning research as well (Karrick, 1998). This reality, along with time spent in the large ensemble setting tuning to individual pitches, may play a part in instrumentalists’ documented ability to play isolated pitches distinctly better in-tune than those in a melodic or harmonic context (Karrick, 1998; Morrison, 2000).

Auto-Tune, a mass-marketed pitch correction software that corrects out-of-tune vocal performances, has rocketed through the popular music scene since 1998, and is often regarded as a paradoxical technology: while software maker Antares’s Auto-Tune plug-in (a software component that adds specific pitch correction abilities to a larger software application) was the best-selling audio plug-in ever as of 2011 (Crews, 2011), Auto-Tuning has been labeled in the media as “making purists cringe” (Crews, 2011, p. 58), the “sonic equivalent of plastic surgery” (Tyrangiel, 2009, p. 2), and was included in TIME Magazine’s 2010 list of “The 50 Worst Inventions,” where it was “a technology that can make bad singers sound good” (Fletcher, 2010). Auto-tuning follows slightly

Despite its wide use in popular music, the use of pitch-correction applications has been a source of discontent among some popular musicians, who protested its use during the 51st Grammy Awards, artist/rapper Jay-Z produced a recording titled “D.O.A (Death of Auto-Tune),” and singer-songwriter Allison Moorer released her album with a sticker stating that “Absolutely no vocal tuning or pitch correction was used in the making of this record” (Ryan, 2003, p. 2).

Auto-tune in particular, and pitch correction in general, is relatively unused in musical academic pursuits, and no documentation of its use in instrumental music could be found.

Even though music educators and performers have long been highly motivated to overcome the challenge of flawed intonation, "so much discussion and diversity continues to exist in a quest to provide *the solution* when teaching the fundamentals of instrument tuning" (Lisk as quoted in Garofalo, 1996, p. 16). Surrounded by a surfeit of texts, research, journal articles, clinics, and instructional technology focused on improving wind band intonation, a lack of consistent, empirically based pedagogy still persists concerning how to structure meaningful instruction and experiences (Byo et al., 2011; Casey, 1993; Criswell, 2008; Wuttke, 2011).

Supplemented with an understanding of the methods used to manipulate pitch, use of real-time pitch correction software may provide students with an opportunity to *practice* both perceiving and performing in-tune and out-of-tune alone in single-pitch, melodic, and ensemble contexts. Using this technology, student musicians may be able to focus on intonation with immediate aural feedback, allowing them to move at their own pace and possibly discover the intonation problems inherent to their own equipment, approach, and physiology, along with the best methods for correction.

In an effort to assess the effectiveness of pitch-correction software as a means of improving intonation, one overarching question motivates this research: to what extent is the use of real-time pitch correction software a viable tool for teaching intonation to instrumentalists?

These sub-questions will fuel the data-collection process:

1. Are there significant differences in performed intonation among aural (auto-tuned), visual (tuner), and control group treatments?

2. Does performed intonation of a targeted pitch (clarinet A_4 or trumpet D_4) in single pitch, melodic, and ensemble contexts improve from pre-test to post-test?
3. Are there significant differences in performed intonation among single pitch, melodic, and ensemble contexts?
4. Are there significant differences in performed intonation among individual pitches within and across each performance?
5. Does instrument (clarinet or trumpet) significantly affect participants' performed intonation?
6. What is the nature of participants' knowledge about tuning and intonation? What are their perceptions of the training and testing experienced in this study?

CHAPTER 3: METHOD

This investigation examined the effect of real-time pitch-correction software on high school clarinet and trumpet players' ability to correct tuning inaccuracies within their own performances. Specifically, the study tested the effect of the Real Time Pitch Tracker and Corrector (RTPTC) software on participants' performed intonation accuracy of an isolated pitch that has been identified as having inherent intonation flaws—clarinet A_4 or trumpet D_4 (Colwell & Goolsby, 2002; Garofalo, 1996; Stauffer, 1987)—and a short melody containing that same targeted pitch played with no accompaniment and again in an ensemble context.

Sixty high school clarinet and trumpet players participated in the study, along with four directors from the two participating schools. Single pitch, melodic, and ensemble contexts along with melodic direction and pitch comparison were included as within-group independent variables, and instrument and treatment group were included as between-group independent variables. Real-Time Pitch Tracker and Corrector (RTPTC) software was developed to provide pitch corrected feedback, ensemble sounds, and data for analysis. Pilot testing of middle school, high school, and college music students led to multiple adjustments in a procedure that finalized in a quasi-experimental repeated measures design with an embedded qualitative component in the form of questionnaires. Cent deviation data was analyzed for both statistical and musical significance, while student- and director-participant questionnaire responses were categorized and analyzed for emergent themes.

Participants

Students ($N = 60$) from two successful south Louisiana public school band programs of comparable configuration served as participants for this study. Success was defined by means of consistent superior ratings at state-sanctioned adjudicated large ensemble festivals where

intonation is included in the adjudication process (Louisiana, n.d.). The purposive sample was one of convenience, and was comprised of volunteers who had completed between three and seven years of uninterrupted study on either clarinet or trumpet. The goal of this study was to investigate the *doing* of tuning—whether participants were better able to perform in-tune as a result of feedback from the software as compared to feedback from the electronic tuner or none at all. It is for this reason that high school freshmen, sophomores, juniors, and seniors were chosen to participate in this study: they represent a group that has had the time to develop the necessary musculature to produce and manipulate a characteristic pitch (Garofalo, 1996; Stauffer, 1987), and have participated in experiences in school band—including aural-based, interval based and chordal exercises, vocalization, and beat recognition— that have been found to positively influence intonation perception and performance (Bennett, 1994; Casey, 1993; Millsap, 1999; Wuttke, 2011). Students from each school were assigned to one of three treatment groups after parental consent was received and before participation in the project was scheduled. Every attempt was made to balance the groups according to years of experience on the instrument, private lessons, and school affiliation, the latter to control for possible teacher effect.

A purposive sample of participants was placed into each of the following populations: clarinet, aural group (n =10); clarinet, visual group (n =10); clarinet, control group (n =10); trumpet, aural group (n =10); trumpet, visual group (n =10); trumpet, control group (n =10). Participants on clarinet and trumpet were evenly balanced across years of experience, with n = 6 in each of the 3 year, 4 year, 5 year, 6 year, and 7 year categories. Sixteen clarinet and fourteen trumpet participants participated in less than two months of consistent private instruction, so were coded as not having studied privately. Fourteen clarinet and sixteen trumpet participants studied privately for two months or more. Of the total participants (N = 60), n = 19 were

members of the band at School A and *n* = 41 were members of the band at School B. The participants in the study were evenly split between male (*n* = 30) and female (*n* = 30).

All students who participated in the study had an instrument in good working condition. Prior to conducting the study, exemption from institutional oversight was granted from the Louisiana State University Institutional Review Board. Parental consent and student assent forms were collected from all participants under the age of 18, and three participants who were already 18 did not require parent signature. IRB exemption and sample consent forms can be found in Appendix A.

The four director participants in the study taught for 5, 16, 23, and 33 years. All earned Bachelor's degrees in Music Education, with two having earned Master's degrees—one in clarinet performance and the other in Music Education. The group was evenly split also in regards to where they earned their degrees, with two having graduated from the same public university in north Louisiana and two from a south Louisiana public university; one graduate from each university was teaching at each of the participating schools.

Within Group Independent Variables

Context: Single Pitch, Melodic, and Ensemble

While a great deal of previous research has addressed the performed intonation accuracy of single pitches and isolated intervals in a variety of conditions with those pitches most often being standard tuning notes (Benson, 1995; Byo et al., 2011; Church, 1989; Duke, 1985; Frisch, 2008; Geringer & Worthy, 1999; Greer, 1969; Worthy, 2000), considerably fewer have addressed the tuning of those pitches found to have inherent intonation flaws and the tuning of pitches (flawed or not) within a melodic or ensemble context (Ely, 1992; Kopiez, 2003; Morrison, 2000). Previous research has emphasized the need for more ecologically valid tuning

research conditions, specifically selecting pitches not routinely addressed in the large ensemble tuning process (Morrison, 2000) and tuning within a melodic and harmonic context (Duke, 1985; Karrick, 1998; Morrison, 2000), skills necessary for musicians to consistently play in-tune in both the solo and ensemble settings. Therefore, in this study single pitch, melodic, and ensemble contexts were included.

For the single pitch setting, pitches were selected that are not normally considered tuning notes (Morrison, 2000). Clarinet A_4 and trumpet D_4 served as the target pitches in all contexts, because of their well-documented inherent intonation flaws that cannot be corrected when determining proper instrument length at joints and main tuning slides, but rather by means of adjusting embouchure, fingering, valve slide length, and/or the aural cavity in performance (Byo, 2008; Colwell & Goolsby, 2002; Ely & Van Deuren, 2009; Garofalo, 1996; Pottle, 1960; Stein, 1958). Clarinet A_4 is most often sharp, but may be flat, depending on equipment, embouchure, and voicing (Colwell & Goolsby, 2002; Garofalo, 1996; Stauffer, 1987; Woolery, 2011), and trumpet D_4 requires the use of the inherently sharp first and third valve combination, a result of mechanical necessity (Bailey et al., 1992; Stauffer, 1987). Pilot testing using these isolated pitches along with Real-Time Pitch Tracker and Corrector software resulted in verbal comments affirming students' ability to hear the out-of-tuneness of both clarinet A_4 and trumpet D_4 when compared to the tuned stimulus, including "my A's are a problem," "I fixed the A quicker this time," and "D is not right." Clarinet A_4 and trumpet D_4 are both located in a comfortable range of the instrument for intermediate players and are commonly found in wind-band literature (Bailey et al., 1992; Westphal, 1990), and as a result were familiar to high school participants.

Much of the research in tuning has been focused on the accuracy of performed single pitches, however the contexts in which instrumentalists perform multiple pitches have been

found to significantly influence tuning accuracy (Byo et al. 2011; Cassidy, 1989; Duke, 1985; Karrick, 1988; Morrison, 2000). To provide both melodic and ensemble context, an arrangement of the melody in the first eight measures of *December Sky* (Morales, 2005), a grade two piece for concert band, was used as the excerpt in this study (see Appendix B). The comfortable and limited range (clarinet G_4 to E_5, trumpet C_4 to A_4), short duration, absence of unfamiliar accidentals, and multiple occurrences of sustained target pitches (clarinet A_4 and trumpet D_4) were all factors considered when selecting this melody, as suggested by previous research (Cassidy, 1989; Frewen, 2010; Morrison, 2011). The rhythmic content of the original excerpt was altered to include dotted half note target pitches in measures two and four, in order to provide participants with more time to focus their attention on listening and adjusting the target pitches. The clarinet melody was maintained in the original key of concert B-flat. So that trumpet target pitches would occur during long notes, the trumpet arrangement was transposed into the key of concert E-flat. While a more recognizable melodic excerpt could have been chosen, the comfortably set but less common *December Sky* arrangement mitigated the confounding variable of familiarity.

The complexity of evaluating one's own intonation in an ensemble context makes Karrick's statement that, "A major drawback to tuning research is that most investigations have been . . . removed from any actual musical context" a valid one (1998, p. 125). In an effort to enhance the ecological validity of this research and continue the logical progression of tasks beyond single pitch and melodic contexts, an ensemble context was included. Participants performed the same melodic line played for the melodic treatment along with a digitally synthesized accompaniment, *December Sky Arrangement*, by professional wind band composer

and arranger Alan Clark (2012). The arrangement was composed with Finale 2012 software utilizing Garritan Instrument Sounds (Finale, 2012).

Pitch Comparisons and Melodic Direction

The focus of this study was one inherently out of tune target pitch on each instrument. The pitch, when put into the melodic context used in this study, appears twice as a dotted half note. One time it is approached from a whole step above, the second time from a whole step below, a characteristic that has been shown to affect intonation (Duke, 1985). The effect of direction of approach on the target pitches was explored. Analysis of all twenty-three pitches contained in the melodic line was conducted in an effort to evaluate their intonation relationship to the target pitches and the consistency of intonation within and across each performance.

Between Group Independent Variables

Instrument

Several factors contributed to the decision to include clarinet and trumpet in this study. They were:

1. Overlapping tessitura within a comfortable range of the instrument to facilitate using the same melodic excerpt for both instruments while avoiding extreme registers.
2. Familiar keys, resulting in familiar fingerings and notated pitches.
3. Pitches with inherent intonation flaws that are within the comfortable playing range for the intermediate player, are commonly found in intermediate and advanced wind band literature, and do not require the use of unfamiliar fingerings.

Treatment Groups

Three treatment groups were used for comparison: aural, visual, and control. Participants in the aural group used the RTPTC while playing in the single pitch, melodic, and ensemble

contexts as a means of aurally assessing the tuning accuracy of their own performance. As the participants played, the RTPTC collected pitch information via the external microphone, edited the pitch to conform to in-tune as defined by equi-tempered tuning, and then provided an in-tune aural model that was mixed with the student's own pitch and played back for aural comparison. Functionally, it was as if they were playing a unison duet with a perfectly tuned partner, allowing participants the opportunity to try to match an aural example. Participants heard the mixed sounds through headphones.

Participants in the visual group performed the same tasks, but with a KORG TM-40 electric tuner as a means of assessing the tuning of their own performance. This tuner provided information in the form of a dial that indicated visually whether each pitch was in-tune or out of tune. The pointer displayed distance from in-tune in flat (left) or sharp (right) directions, and a green light illuminated when pitches were in-tune. The tuner was placed by each participant on the music stand such that it was in the same visual field as the music from which the student was reading.

Participants in the control group were only instructed to "play in-tune to the best of your ability." They completed the same number of repetitions as the aural and visual groups so as to control for time and number of repetitions in the various contexts.

Dependent Variable

The dependent variable in this study was performed pitch accuracy in the single pitch, melodic, and ensemble contexts. Since wind-band instrumentalists are surrounded by equal temperament in the form of wind instrument manufacturing standards, electronic tuners, and the Western classical harmonic system and previous research has found equal temperament to be the tuning system most familiar to these musicians, the conditions included in this study were

centered around equal temperament (Karrick, 1998; Kopiez, 2003; Stauffer, 1987). Cent deviation from the equi-tempered standard was calculated for all pitches and formed the data set for statistical analysis.

Software Development

During the planning stages for this study, several pre-existing software and hardware options were considered for the aural treatment condition based on previous research and expert recommendations. These included Melodyne Vocal/Pitch Editing Software, Antares Auto-Tune Pitch Correction Software, the Peterson Autostrobe 590 with automatic note tracking, and the TASCAM TA-1VP Vocal Processor with Antares Auto-Tune. The final decision to design and develop the RTPTC in-house was based on the recommendations of electronic music and digital media experts and the need for a two-fold program: one that could track and correct pitch but also produce data reporting intended pitch, performed pitch, and cent deviations for data analysis. RTPTC software was developed and modified through four versions by Dr. Jeff Albert (Real Time, 2013).

Development of the RTPTC and Related Components

Musical pitch is directly related to frequency, or the number of waves passing through a medium per unit of time. As sound waves reach the ear, the air pressure at the ear changes in accordance with the form of the wave. That change of air pressure, or oscillation, is heard by the ear and can also be recorded by a microphone as an analog signal, which can in turn be converted into a digital signal. In this study, analog to digital conversion was accomplished by means of the ART XConnect, a USB microphone interface with a built in analog to digital (A/D) 16-bit converter. Since a computer is only able to store and recognize separate values, the continuous nature of an analog sound wave must be digitized by the A/D converter into a series

of frequency readings, or bits, which can in turn be manipulated by the computer. Each of these samples is recorded and stored as a particular value. The number of values read during the A/D conversion is dependent on the converter itself; a 16-bit A/D converter can store a great deal more than an 8-bit A/D, resulting in higher quality resolution that more accurately represents the original, analog sound. Once conversion is complete a long list of values corresponding to a series of currents, sampled thousands of times a second, is available for editing or storage. To listen to the audio the process is reversed: values are decoded by a Digital-to-Analog converter (DAC), and output as a signal which can be amplified through a speaker (Peimani, 2009).

The values assigned to the recorded sounds are displayed by RTPTC as MIDI note numbers, as seen in Figure 3.1, a screen shot of the RTPTC. MIDI note numbers are values

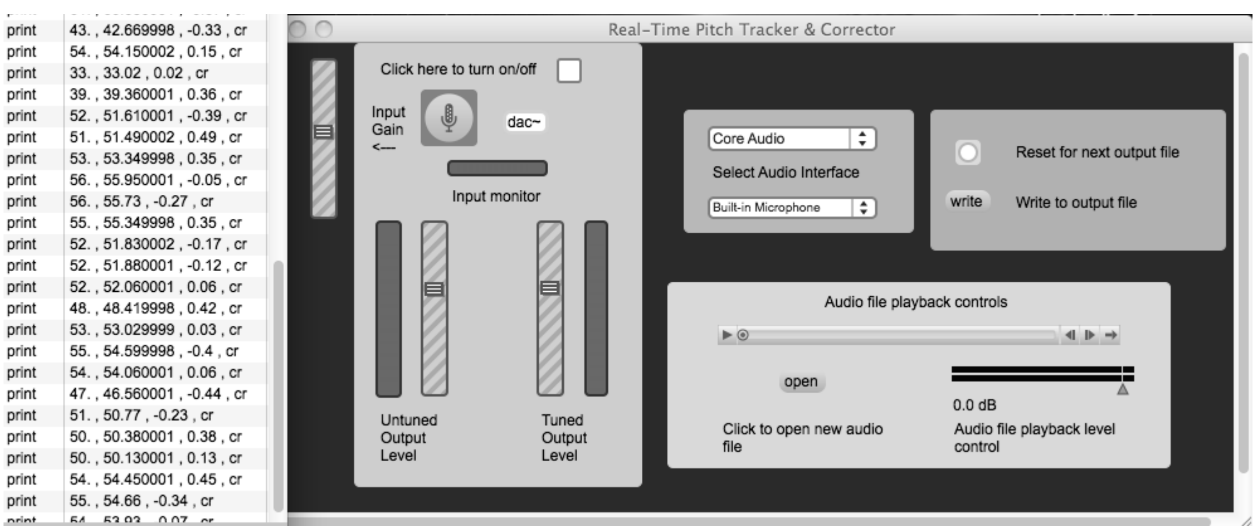


Figure 3.1. Screenshot of RTPTC, including output data and audio controls. Output data includes intended pitch and performed pitch displayed as MIDI note numbers, and difference data displayed in cents sharp or flat.

assigned to pitches where 60 is the equivalent of middle C, and every half step above adds one value, and half step below subtracts one (e.g., 61 is C sharp, and 59 is B natural). To assign a MIDI note number to the performer’s pitch, the RTPTC reads the performed pitch—for example,

59.678—and assigns it to the nearest MIDI value—in this case, 60, or middle C. Conversely, 59.023 would be assigned to 59, or B below middle C. This process is completed by the software eleven times per second.

Once the analog microphone signal is converted into corresponding digital data, a Fast Fourier Transform, or FFT, evaluates the sound data to identify overtones and their particular magnitudes, all of which play a part in the unique timbre of the recorded sound. Once these frequency points (called bins) are labeled by the FFT for their corresponding strength or weakness, a pitch shifter evaluates FFT information, assesses how much adjustment is necessary to correct pitch across the various bins, and makes the adjustment. The signal's pitch-corrected fundamentals and overtones are then reassembled by means of an Inverse Fast Fourier Transform, or IFFT, so that the pitch corrected sound may be played. The timbre of the original signal is not affected because the original structure of the fundamental pitch and overtones is preserved, and corrections are made a maximum distance of a quarter step in the direction of the closest "tuned" pitch. The frequency with which the signal is sampled for pitch correction is dependent on the computer used for processing; tests of the MacBook Pro used for this study revealed a typical speed of 40 samples/second, or one sampling every 25 milliseconds (J. Albert, personal communication, June 28, 2012; Peimani, 2009).

Pitch tracking (or auto-tuning) can be performed either in real time or delayed, with the delayed function used most often for studio pitch editing. The RTPTC tracks and corrects pitch in real time, providing users with instant feedback, as if they were playing a unison duet with a perfectly tuned partner. The timbre of the original sound is maintained. Audio quality is dependent on microphone and headphone quality, and was found in pilot testing to be adequate with the Shure SM-57 Microphone and Auvio 33-279 Concert Class Stereo headphones. In order

to best replicate an authentic ensemble rehearsal setting, both the participant's performed pitch and the auto-tuned pitched were mixed through RTPTC; feedback was muted for visual and control group participants. The Finale generated ensemble arrangement was linked through the RTPTC software so that participants could play into the microphone and hear their own performance mixed with the sounds of the ensemble through the headphones.

The reliability of RTPTC was established through both expert opinion and a review of wind instrument intonation literature (J. Albert, personal communication, April 3, 2012; J. Allison, personal communication, February 15, 2012; Dalby, 1992; Kantorski, 1986; Peimani, 2009).

Pilot Testing

Three middle school students, twelve high school students, one undergraduate and three graduate students played both single pitches and various melodies with RTPTC. Both data analysis and conversations with participants led to several changes in the software, hardware, procedures, and participants.

Modifications to software included altering the format of cent deviation difference data to include the hundredth and the addition of an input gain control so as to better manipulate audio quality. Three microphone options were tested, including the computer's internal microphone, a digital Sony ECM 719, and a Shure SM 57. The Shure SM 57 with an XLR to USB audio interface was chosen based on participant responses regarding audio quality and expert advice. The decision to use headphones was a result of pilot testers' preference, the problem of feedback when using speakers, and Duke's (1985) finding that there was no significant difference between the use of headphones and speakers in a listening task.

The procedure was evaluated by asking participants (whose primary instruments included flute, clarinet, saxophone, trumpet, French horn and trombone) to play a variety of single pitches, documented as problematic for their instruments (Garafolo, 1996). Problems of range—pitches that were difficult for young players to produce, much less tune—were exposed during this process for both middle and high school students, as was undergraduate and graduate music students' ability to tune single pitches independent of the software. Based on student verbal responses and comparison of cent deviation mean differences across test, training phase, and re-test (before software, while using software, and after use of software), high school students were found to be the most appropriate choice of participants. Middle school students displayed a lack of knowledge in regard to tuning procedures, or how to tune "in action." It was decided that instruction in the methods of physical manipulation of the instrument for means of tuning, while needed, was beyond the scope of this study when considering time restraints.

The appropriateness of various melodic excerpts was evaluated in a similar way, using examples from previous research, including an adaptation of the J.S. Bach chorale *O Sacred Head Now Wounded* (Karrick, 1998) which exposed the need for shorter, more familiar excerpts with smaller intervals between pitches (perfect fifths and major sixths were particularly difficult for brass players) to allow participants the opportunity to focus on intonation rather than be concerned about correct pitches. Several short melodies from an array of band methods, including *Alouette* (Bierschenk et al., 2000), *Au Claire de Lune* (Rhodes et al., 1991), *Jingle Bells* (Bullock & Maiello, 1996), *Pierrot* (Duke & Byo, 2010) and *Rolling Along* (Rhodes et al., 1991) were considered across several instruments as well, with preference for those that contained documented "problem pitches" (Garafolo, 1996). The constraints of range, key, inclusion of problem pitches, note length, interval distance, and existence in the concert band

repertoire—all aspects included in Morrison's use of *French Folk Song* (2001) with the exception of the inclusion of problem pitches and repertoire—resulted in the decision to arrange the melody from the first eight measures of *December Sky* (Morales, 2005) to include longer and more frequent target pitches, while maintaining the integrity of the piece.

Some pilot testing participants did not maintain an appropriately slow tempo such that the target pitches could best be heard and manipulated (Dunnigan, 1999), and as a result later pilot testing included one measure of 60 beats per minute sounded on a DB 1000 Dr. Beat metronome before participants were instructed to play. A short amount of time was added during later pilot tests for participants to become familiar with the elements contained in the task, including experiencing the sound of the auto-tuned pitch through the headphones (on a note other than the target pitch), practicing the melodic excerpt until comfortable, and adjusting headphone volume.

While most participants in pilot testing played the target pitches considerably out of tune even after setting the length of the instrument appropriately (so that familiar tuning pitches were in-tune), some did not. All of these cases were students who were more advanced players of their instruments. For this reason, the decision was made to assess each participant's performed intonation of the target pitch after tuning the instrument, and those who were within 10 cents of in-tune (Clark, 2012) were eliminated from the study, as it has been shown that high school age students are more successful at assessing in-tune and out-of-tune beyond the ten cent mark, a manifestation of the just noticeable difference (Clark, 2012; Madsen et al, 1969).

Procedures

Participants ($N = 60$) included high school clarinet and trumpet players with at least three years of uninterrupted participation in band on their current instrument. Purposive sampling was used, with an attempt to control for years of study and participation in private instruction. Data

collection took place between January and April of 2013, during regularly scheduled band classes and after school rehearsals, in an acoustically appropriate room separate from the large ensemble rehearsal space.

Before entering the testing site all participants completed a data form listing name, gender, primary instrument, years of experience on primary instrument, and years of private lesson participation. Signed parental consent forms were confirmed, and student assent forms were signed. Participants entered the testing site individually, where they sat down in front of a music stand and microphone (Shure SM 57). Following a two-minute optional warm-up period, participants tuned to a Korg TM-40 digital chromatic tuner set at A=440 Hz, using whatever pitch or pitches they were accustomed to. I assisted participants in this process, as pilot testing revealed some students were not accustomed to using a tuner without assistance. After completing this task, students were asked to play the target pitches (clarinet A_4 or trumpet D_4) to assess the relationship of the tuning of these pitches to the equi-tempered standard. Those students who played the target pitch within ten cents of "in-tune" were eliminated from the study.

Participants were asked to complete the data form found in Appendix C, and were then read instructions that can be found in Appendix D. The three treatment groups each utilized different strategies in an effort to assess their effect on performed intonation accuracy in the single pitch, melodic, and ensemble contexts. In the case of the aural group, participants completed each task along with the RTPTC software, which mixed their performance and a tuned version of that same performance in real time, presented through headphones. In the visual group, participants completed the same tasks while looking at a digital tuner placed on the music stand. The tuner produced a visual measurement of pitch, where a needle pointing right of center

indicated sharpness, left of center indicated flatness, and centered (at which time a green light was activated) indicated in-tune. The control group completed the same tasks as the aural and visual groups with no visual or aural feedback. As the participants completed each portion of the treatment, cent deviation data, in the form of comma separated values (a format where each reading is separated by a comma), was collected for each pitch played.

To determine the potential benefit from using pitch correction software to better play an isolated pitch or target pitch in a melodic context, a quasi-experimental repeated measures design was used. Procedural steps, in order, for each of the three treatment groups were as follows:

1. Assess the tuning of the target pitches. Those students who were not beyond five cents out of tune were eliminated from the study.
2. Using Auvio 33-279 Concert Class Stereo headphones, participants played concert B-flat while receiving auto-tuned feedback from RTPTC (aural group), visual feedback from the tuner (visual group), or no feedback (control group) in order to become accustomed to the technology. Volume adjustments were made at this time.
3. Pre-test 1: Sustain the target pitch (clarinet A_4 or trumpet D_4) for eight beats at 60 beats per minute. Tempo was sounded as four clicks by a Korg TM-40 digital metronome prior to the performance. This tempo was chosen to facilitate better focus on the tuning of the target pitches, especially under the melodic conditions (Dunnigan, 1999). The target pitch was notated and read from the music stand (see Appendix E) and the performance was played through RTPTC, without pitch correction (participants only heard their own performance).
4. Treatment 1: Participants played the target pitch for eight beats at 60 beats per minute three times while receiving treatment-specific feedback. A metronome sounded the

tempo prior to performance, as in step one. Each performance was recorded separately. Participants were instructed to try to adjust to match the stimulus using whatever techniques were familiar. Control participants were instructed to play the pitch as in-tune as possible.

5. Post-test 1: Played the target pitch for eight beats at 60 beats per minute without feedback, recorded.
6. Practiced the *December Sky* excerpt, found notated on the music stand (see Appendix E), until familiar.
7. Pre-test 2: Played *December Sky* once at 60 beats per minute (recorded).
8. Treatment 2: Played *December Sky* three times at 60 beats per minute with treatment-specific feedback. As in step three, each performance was recorded separately and a metronome sounded the tempo prior to performance, and participants were instructed to try to play as in-tune as possible.
9. Post-test 2: Played *December Sky* once without feedback at 60 beats per minute (recorded).
10. Post-test 3 and 4: Played *December Sky* excerpt along with pre-recorded wind band accompaniment twice. No differential feedback was included in this step.

Participant data forms can be found in Appendix C and scripts used in the treatment of all three groups can be found in Appendix D.

After finishing Re-test 3, participants completed a questionnaire consisting of both dichotomous and open-ended questions, created to determine:

• participants' feelings regarding the effectiveness of the software

• whether they perceived their own performance as having improved

- their chosen methods of manipulating pitch used during the experiment (if any)
- what they believed could have allowed them to be more successful

Questions were grouped by topic on the questionnaire to aid the organization of analysis (Patton, 1990), and are shown in Table 3.1 while the complete questionnaire form as given to participants can be found in Appendix F.

Table 3.1
Questions from Participant Questionnaire

Do you think you were able to improve your tuning during this project?
If you answered YES to the above question, describe how you attempted to change the pitch of your performance.
If you answered NO to the first question, why do you think you were not able to improve your tuning?

While the need for methods for teaching intonation perception and performance is clear in programs considered to be “unsuccessful,” it is not clear what teaching strategies were utilized by the programs chosen to participate in this study (e.g., alternate fingerings, embouchure adjustment, ensemble chordal exercises, documented time spent with a tuner). In an effort to clarify the connection between classroom instruction regarding intonation and performance on assigned tasks among the participants in this study, directors of participating programs completed a questionnaire, found in Appendix G, designed to discover what instructional strategies are used in the teaching of intonation skills in their classrooms and how often these strategies are employed. Questions are displayed in Table 3.2.

Table 3.2
Questions from Director Questionnaire

How many years have you been teaching instrumental music?
How often do you incorporate instruction related to tuning in your classroom? *Daily* *Weekly* *Monthly* *Never*
Describe your daily tuning process (e.g., how you tune your band).
In rehearsal, when you detect intonation flaws in a tutti section of the music, what do you do?
Is there anything you do in score preparation that readies you for intonation challenges in rehearsal?
How do you motivate students to address tuning independently?

Data Analysis

Cent deviation data representing both the directional (sharp/flat) and absolute difference between the performed pitch and equi-tempered standard for all performed pitches comprised the raw data for statistical analysis. Analysis of pilot testing data showed no significant difference in means or standard deviations between the entire target pitch and the middle portion (eliminating the attack and release), so data from the entire pitch was used. While previous research has often cropped the attack and release of performed pitches so as to avoid the pitch fluctuation that exists at the beginning and end of an articulated note (Byo et al., 2011) , results from means and standard deviation analysis, the large amount of raw data (RTPTC software evaluated cent deviation 11 times per second), and the inconsistent articulation of pitches (the melody was slurred, and participants were allowed make breathing decisions independently) negated the influence of attack and release on the accuracy of data in this study.

In the melodic and ensemble contexts, mean cent deviation data from the target pitch (clarinet A_4 and trumpet D_4) was isolated for analysis. Mean cent deviations of all pitches in the melody were observed for consistency and other statistical trends.

Thematic qualitative analysis of questionnaire responses by student and director participants was used to identify themes related to their perception of the tasks. Qualitative analysis of director questionnaire responses was focused on isolating those strategies used to teach concepts related to intonation perception and performance in the classroom setting while also gathering demographic information. Triangulation was used as a validating process, and involved the responses to both the student and director questionnaires, along with researcher field notes.

CHAPTER 4: RESULTS

The purpose of this investigation was to examine the effect of real-time pitch-correction software on high school clarinet and trumpet players' ability to correct tuning inaccuracies within their own performances. Clarinet A_4 and trumpet D_4 were chosen for their well-documented intonation flaws (Colwell & Goolsby, 2002; Fabrizio, 1994; Garofalo, 1996), and were incorporated into single-pitch, melodic, and ensemble contexts. Participants from three groups played in each of these contexts. Each group was lead through a quasi-experimental repeated measures design, where the treatment consisted of three repetitions of the single-pitch and melodic contexts, and two iterations of the ensemble context during which participants played the same melody from the melodic context along with a digitized wind band accompaniment. An embedded qualitative component consisted of a participant questionnaire that was completed following the performance treatment, from which responses were triangulated with director questionnaire responses and researcher field-notes (Creswell & Plano-Clark, 2007). As quantitative data constituted the majority of information gathered, statistical analysis and results are presented first, followed by themes related to these results that emerged from student and director questionnaires.

Groups were balanced for years of experience and participation in private lessons, and consisted of students from two south Louisiana high schools with similarly structured and successful band programs. Participant performances were evaluated for cent deviation through the RTPTC software, with feedback muted for visual and control group participants. Pilot data were compared to observe the effect of attack and release on cent deviation data (mean and standard deviation of un-edited pitches versus pitches with attack and release removed). Differences in means in standard deviations were insignificant, so pitches were analyzed intact.

Target pitches (A_4 on clarinet and D_4 on trumpet) were compared in order to look at the effect of treatment on intonation. Participants played the target pitches 19 times; five in single pitch context (pretest, treatment, treatment, treatment, posttest), ten in melodic context (two times in the melody; pretest, treatment, treatment, treatment, posttest), and four in ensemble context (two times in the melody; posttest 1, posttest 2). Mean absolute cent deviations of the target pitch on the final posttest in each context were used in the analysis. In the melodic and ensemble contexts, target pitches occurred twice, approached once from above and once from below. The mean absolute cent deviation of combined iterations of the target pitches was used in this analysis.

A Four-Way ANOVA with repeated measures (3 contexts x 3 groups x 2 lessons x 2 instruments) was calculated using post-test data. Results of this test are shown in Table 4.1. Means reported below, when multiplied by 100, represent cent deviation from A_4 = 440 Hz for clarinet and D_4= 294 Hz for trumpet.

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated $\chi^2(2) = 4.42$, $p = .11$ suggesting homogeneity among the variances. No significant difference due to the main effect of context was found, [$F(2, 48) = .27$, $p > .05$], with single pitch ($M = .13$, $SD = .01$), melodic ($M = .14$, $SD = .01$), and ensemble ($M = .13$, $SD = .01$) cent deviations falling within one cent of each other. The main effect of group [$F(2, 48) = .08$, , $p > .05$] revealed no significant differences among aural ($M = .14$, $SD = .01$), visual ($M = .13$, $SD = .01$), and control ($M = .14$, $SD = .01$) treatments with means, again, within one cent of each other. There were no significant differences between the main effects of instrument (clarinet $M = .13$, $SD = .01$; trumpet $M = .14$, $SD = .01$) and lessons (lessons $M = .13$, $SD = .01$; no lessons $M = .14$, $SD = .01$).

Table 4.1
Four-Way ANOVA with Repeated Measures for Context, Group, Instrument, and Lessons

Source	Sum of Squares	df	Mean Square	F-Value	P-Value
Context (C)	.002	2	.001	.27	.76
Error	.206	48	.004		
Treatment Group (TG)	.002	2	.001	.08	.93
Instrument (Inst)	.002	1	.002	.18	.67
Lessons (Y/N) (L)	.013	1	.013	1.28	.26
Group x Instrument (TG x Inst)	.011	2	.006	.56	.58
Group x Lessons (TG x L)	.000	2	.000	.01	.99
Instrument x Lessons (Inst x L)	.040	1	.040	3.93	.05
Group x Instrument x Lessons (TG x Inst x L)	.002	2	.001	.08	.93
Error	.488	48	.010		
Context x Group (C x TG)	.045	4	.011	2.48	.03
Context x Instrument (C x Inst)	.051	2	.026	5.66	.01
Context x Lessons (C x L)	.002	2	.001	.22	.78
Context x Group x Instrument (C x TG x Inst)	.013	4	.003	.71	.58
Context x Group x Lessons (C x TG x L)	.002	4	.000	.11	.99
Context x Instrument x Lessons (C x Inst x L)	.008	2	.004	.91	.41
Context x Group x Instrument x Lessons (C x TG x Inst x L)	.013	4	.003	.73	.57
Error	.435	96	.005		

Two-Way Interactions

There were three significant two-way interactions. The interaction between Instrument and Lessons [$F(1, 48) = 3.93$, $p < .05$] is displayed in Figure 4.1, where it can be seen that trumpet players who participated in private lesson instruction performed with an appreciably lower cent deviation ($M = .11$, $SD = .01$) than those who did not ($M = .16$, $SD = .02$), while there was very little difference between the cent deviation of clarinet players who studied privately ($M = .14$, $SD = .02$) and did not study privately ($M = .13$, $SD = .02$); in the clarinet group, private lesson participants actually played slightly more out of tune than their counterparts.

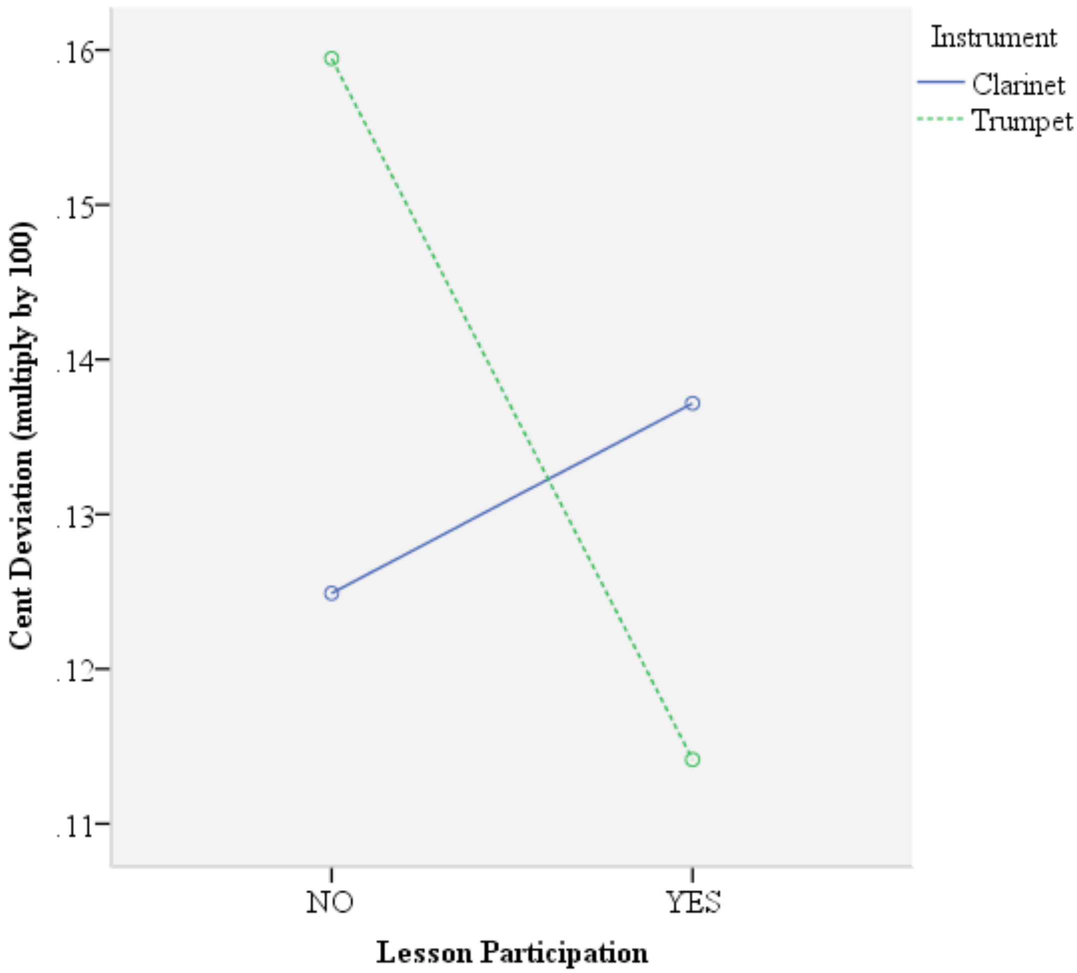


Figure 4.1. Interaction Between Instrument and Private Lesson Participation

In the Context by Group interaction [$F(4, 96) = 2.48$, $p < .05$] shown in Figure 4.2, the control group performed with a higher cent deviation on the single pitch task than both the aural and visual groups, while the inverse was true in the melodic and ensemble tasks, where the control group performed with lower cent deviation than the aural and visual groups. Means and standard deviations for the melodic and ensemble contexts across all three groups are shown in Table 4.2.

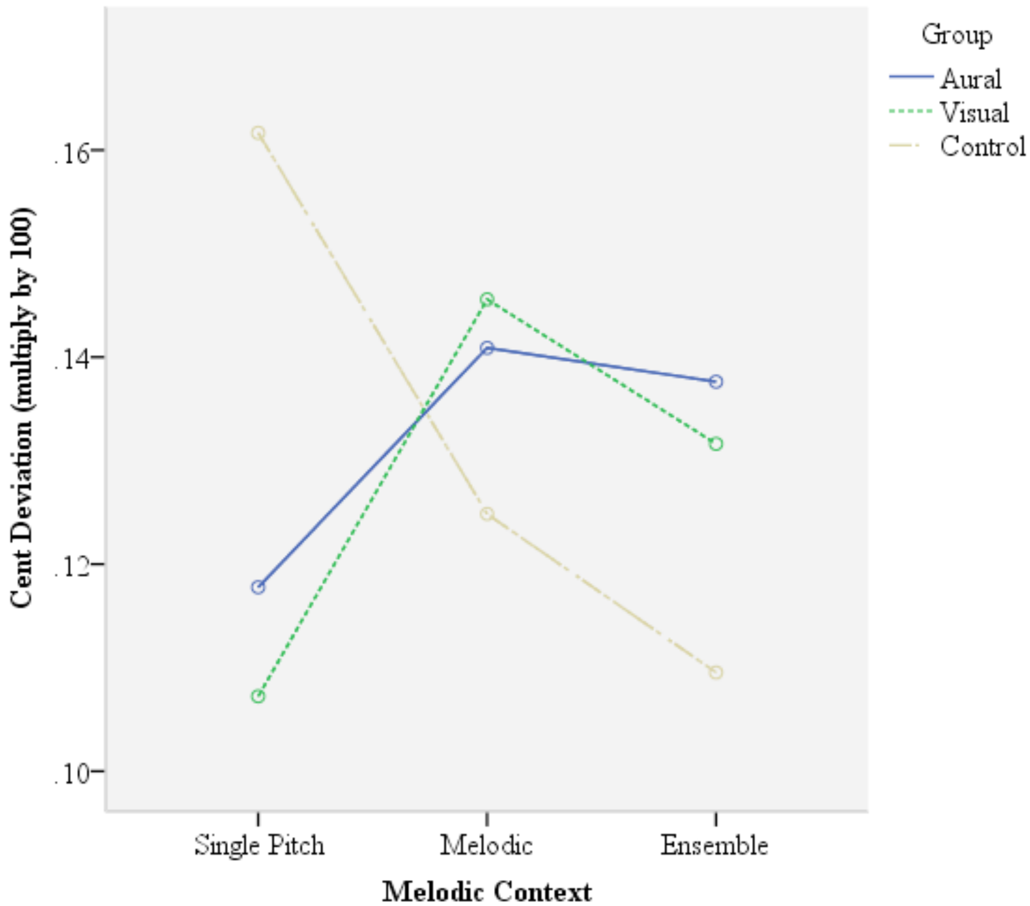


Figure 4.2. Interaction Between Context and Group

Table 4.2
Means and Standard Deviations for the Interaction of Group and Context

Group	Context	Mean	S.D.
Aural	Single Pitch	.12	.02
	Melodic	.15	.02
	Ensemble	.14	.02
Visual	Single Pitch	.12	.02
	Melodic	.15	.02
	Ensemble	.13	.02
Control	Single Pitch	.17	.02
	Melodic	.12	.02
	Ensemble	.11	.02

Shown in Figure 4.3, the two-way interaction between Context and Instrument [*F*(2, 96) = 5.66 , *p* < .01] demonstrates that clarinet participants performed the single-pitch context (*M* = .10, *SD* = .01) with greater accuracy than the melodic (*M* = .15, *SD* = .02) and ensemble (*M* = .14, *SD* = .02) contexts, while trumpet participants were the opposite, performing the single pitch context (*M* = .16, *SD* = .01) with less accuracy than both the melodic (*M* = .13, *SD* = .02) and ensemble (*M* = .13, *SD* = .02) tasks. There were no other significant 2-, 3-, or 4-way interactions (*p* > .05).

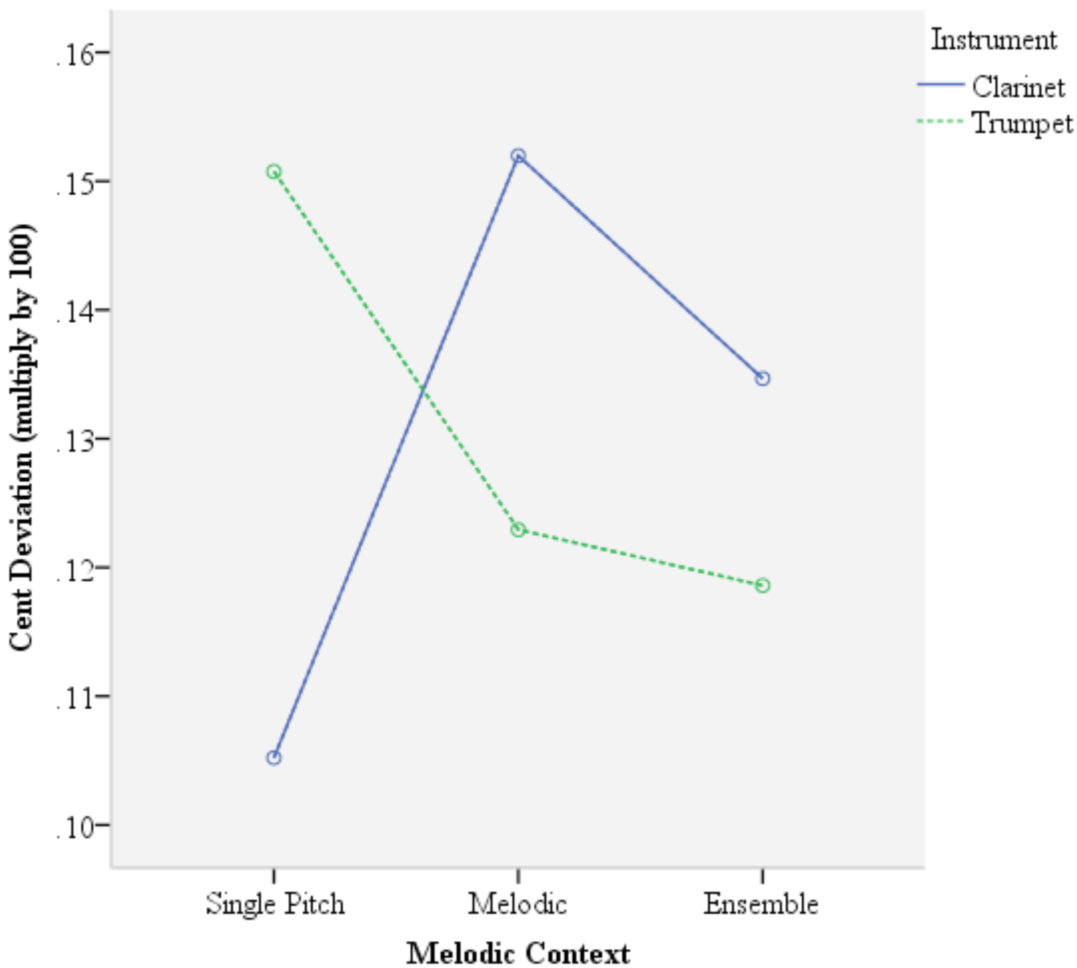


Figure 4.3. Interaction Between Context and Instrument

Differences Across Treatments

Closer inspection of the details of treatments within each group (aural, visual, and control) and between instruments (clarinet and trumpet) confirmed that changes in or differences between cent deviation scores, while statistically significant, were not musically significant. According to the results of the Clark (2012) study, the auditory threshold appears to reside around ten cents. The results of the current study were within that ten cent auditory threshold. However, in some cases there was change across time that resulted in means closer to "in-tune," implying participant recognition of a need to adjust. Also, most means were "out of tune" by more than ten cents, therefore potentially providing participants with the perceptual information necessary to make judgments based on intonation.

In the single pitch context, the control group exhibited the widest range of responses across treatments while both the aural and visual groups performed more (but not completely) consistently across time (see Figure 4.4). The visual group benefitted most noticeably by the second treatment, reducing cent deviations from what could be considered to be beyond the just noticeable difference for most (M = .14) to close to the threshold (M = .10), and maintaining that level to the posttest, implying a learned adjustment and judgment of 10 cents as being "in-tune." The aural group performed the single pitch most in-tune by the third treatment, but, perhaps more importantly, manipulated what likely was perceived as "out of tune" on the pretest (M = .14, SD = .02) to close to the threshold (M = .10, SD = .02) during the first treatment. While the second treatment and post test in the aural group had a higher absolute cent deviation than the first and third treatments, differences are musically negligible, as there are less than five cents difference between them. Means and standard deviations across treatments for each group are shown in Table 4.3.

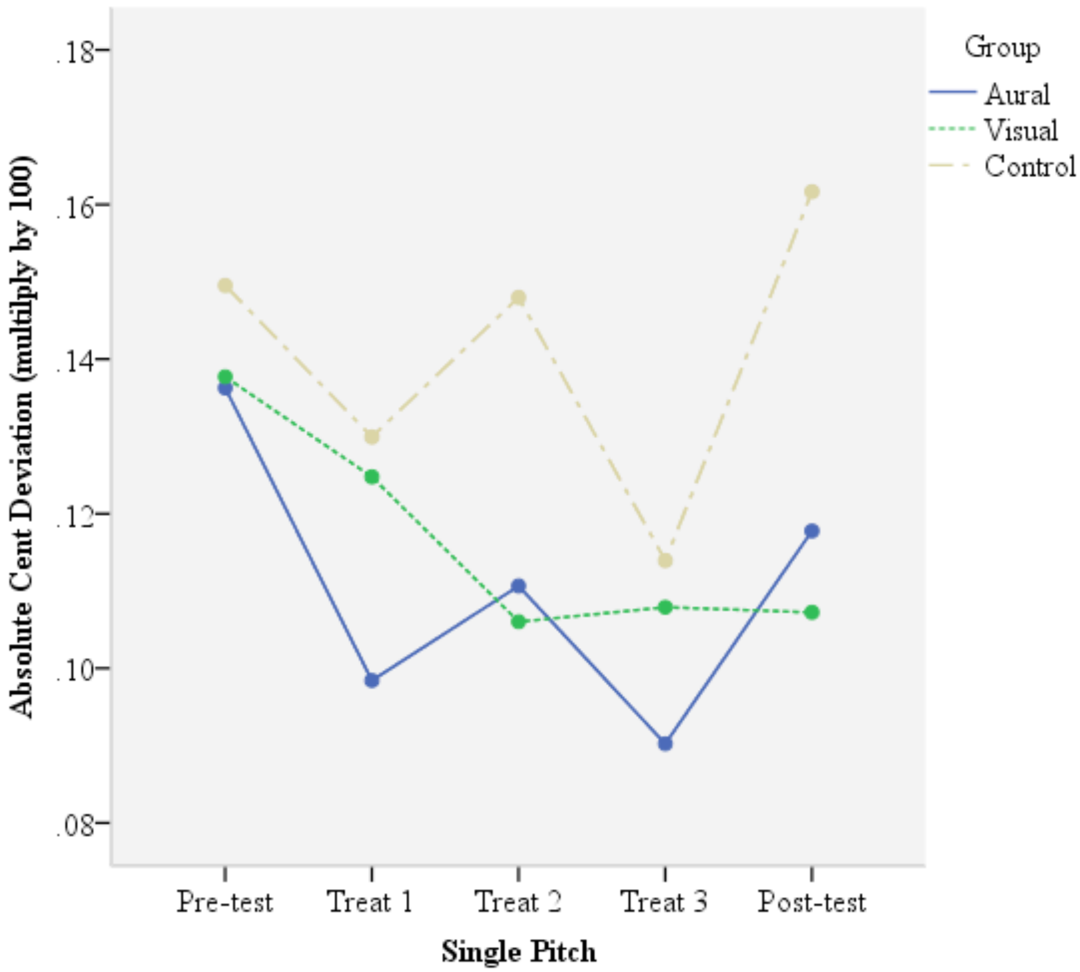


Figure 4.4. Group Responses across the Single Pitch Treatment

Table 4.3
Means and Standard Deviations of Groups in the Single Pitch Treatment

Group	SP Pretest	SP Treatment 1	SP Treatment 2	SP Treatment 3	SP Posttest
Aural	*M* = .14	*M* = .10	*M* = .11	*M* = .09	*M* = .12
	SD = .02	*SD* = .02	*SD* = .02	*SD* = .02	*SD* = .02
Visual	*M* = .14	*M* = .13	*M* = .11	*M* = .11	*M* = .11
	SD = .02	*SD* = .02	*SD* = .02	*SD* = .02	*SD* = .02
Control	*M* = .15	*M* = .13	*M* = .15	*M* = .11	*M* = .16
	SD = .02	*SD* = .02	*SD* = .02	*SD* = .02	*SD* = .02

When comparing the single pitch treatment across instruments, two interesting results are shown clearly in Figure 4.5: the more stable performance of clarinet participants (mean range of one cent) as compared to trumpet participants (mean range of six cents); and the location of

clarinet responses, residing closer to the JND (with mean absolute cent deviations between .10 and .11) than the trumpets (with mean absolute cent deviations between .11 and .17). It appears that no treatment had any effect on clarinet intonation on the single target pitch. Trumpet participants' cent deviation did decrease during treatment with the best intonation performed in the "Treatment 3" trial, but gains were not maintained to the posttest. It appears, though, that the treatments may have had some effect on participants by moving them closer to being in-tune. Means and standard deviations of absolute cent deviation across instruments are shown in Table 4.4. When comparing performances across clarinet and trumpet, it should be noted that two-thirds of participants (those in the aural and visual groups) participated in active treatment using RTPTC software or an electric tuner during the second, third, and fourth treatment, while the control group simply performed the same task five times after being asked to "play in-tune to the best of your ability."

Figure 4.6 shows the relationship between clarinet and trumpet across the melodic context treatments. In this context, target pitches were observed while participants performed a melody that included those pitches. While the lack of musical significance still holds true, the differences in trends are interesting: trumpet participants progressed (lowered performed cent deviation) from treatment two to posttest while in a melodic context, while clarinet participants steadily regressed. In all cases, means are above the ten cent threshold (Clark, 2012) which indicates the "out of tuneness" may have been perceptible. Means and standard deviations for both instruments are shown in Table 4.6.

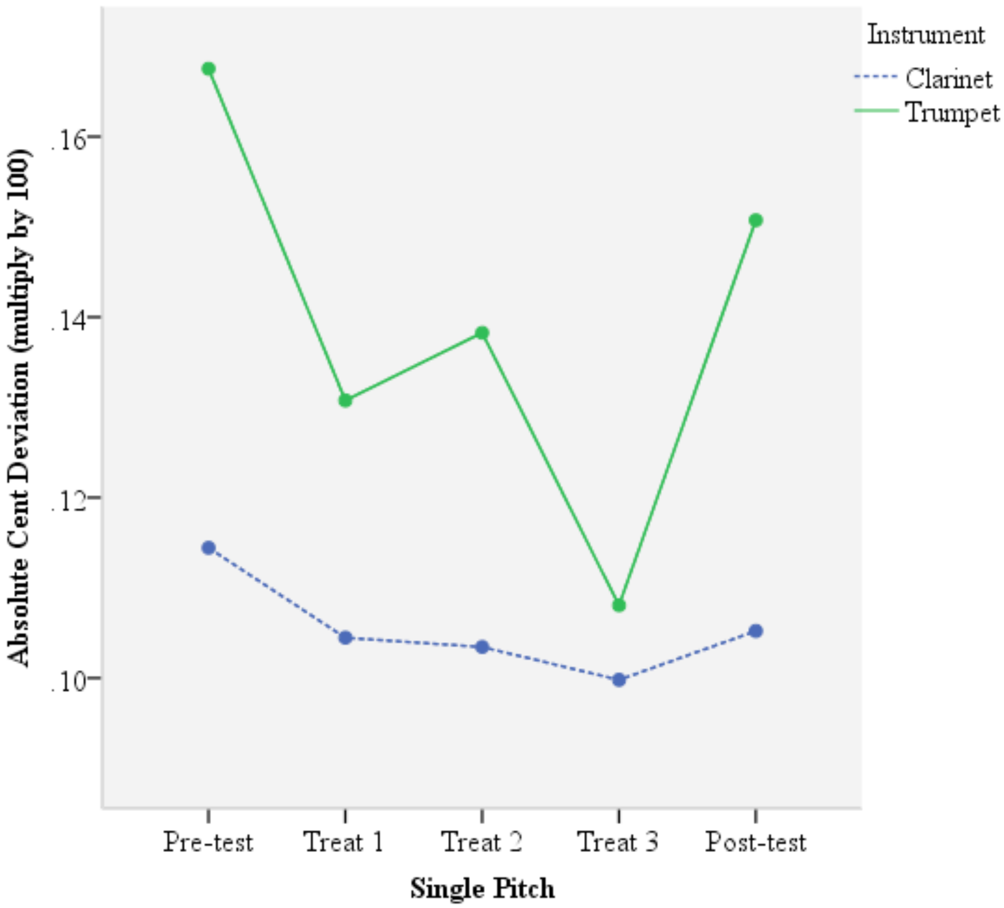


Figure 4.5. Instrument Responses across the Single Pitch Treatment

Table 4.4
Means and Standard Deviations of Instruments in the Single Pitch Treatment

Instrument	SP Pretest	SP Treatment 1	SP Treatment 2	SP Treatment 3	SP Posttest
Clarinet	*M* = .11	*M* = .10	*M* = .10	*M* = .10	*M* = .11
	SD = .07	*SD* = .06	*SD* = .08	*SD* = .07	*SD* = .06
Trumpet	*M* = .17	*M* = .13	*M* = .14	*M* = .11	*M* = .15
	SD = .11	*SD* = .11	*SD* = .10	*SD* = .08	*SD* = .09

Performance results by group in the Melodic treatment are shown in Figure 4.7, where negligible musical significance holds true, but interesting trends are apparent. The control group regressed from pretest to treatment, without a consistent trend across performances (absolute cent deviation means ranged from .10 to .14). The visual group was more consistent and made

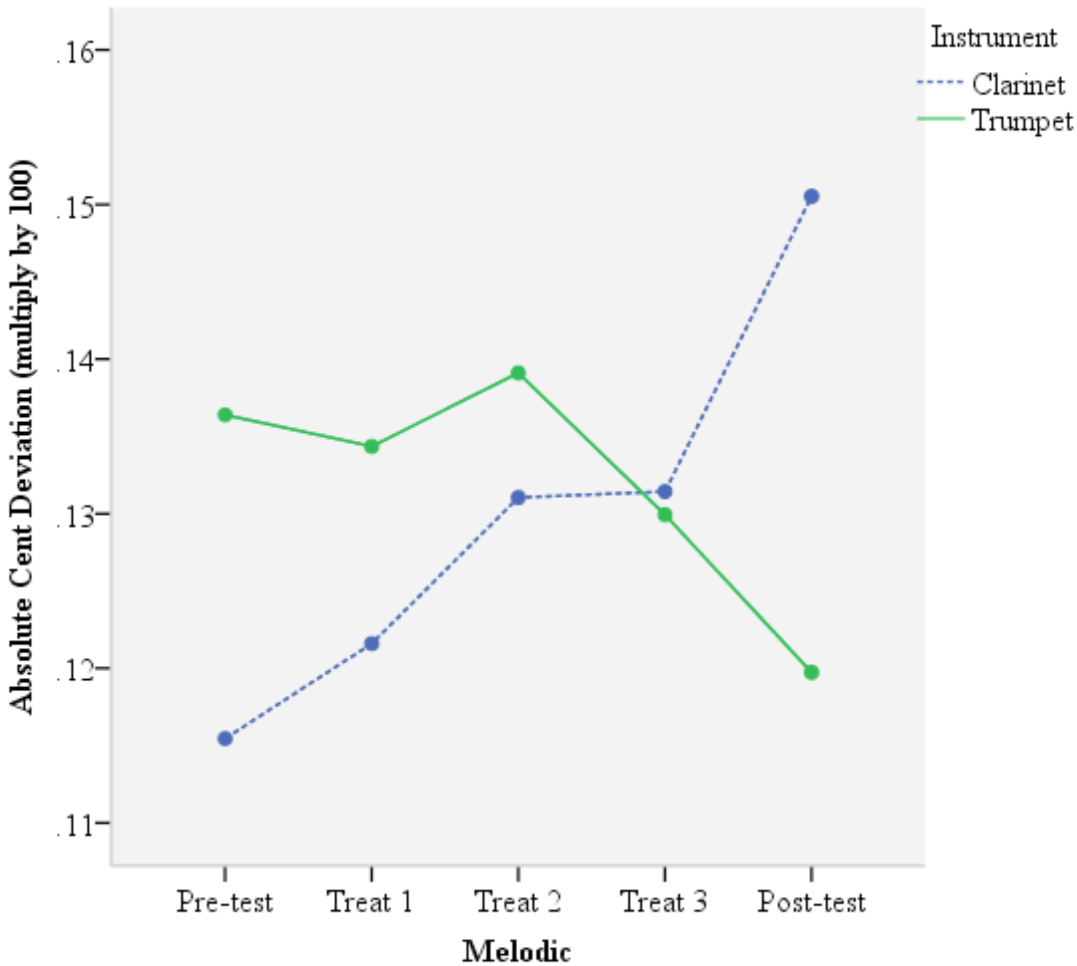


Figure 4.6. Instrument Responses across the Melodic Treatment

Table 4.5
Means and Standard Deviations of Instruments in the Melodic Treatment

Instrument	Melodic Pretest	Melodic Treatment 1	Melodic Treatment 2	Melodic Treatment 3	Melodic Posttest
Clarinet	*M* = .11 *SD* = .06	*M* = .12 *SD* = .07	*M* = .13 *SD* = .07	*M* = .14 *SD* = .07	*M* = .15 *SD* = .07
Trumpet	*M* = .14 *SD* = .08	*M* = .14 *SD* = .08	*M* = .14 *SD* = .07	*M* = .13 *SD* = .09	*M* = .12 *SD* = .09

little change across treatment, performing all iterations within 1 cent of each other, an unnoticeable difference. The aural group made quick progress from the pretest to treatment one, bringing absolute cent deviation scores from 14 cents to 11 cents. This group regressed from

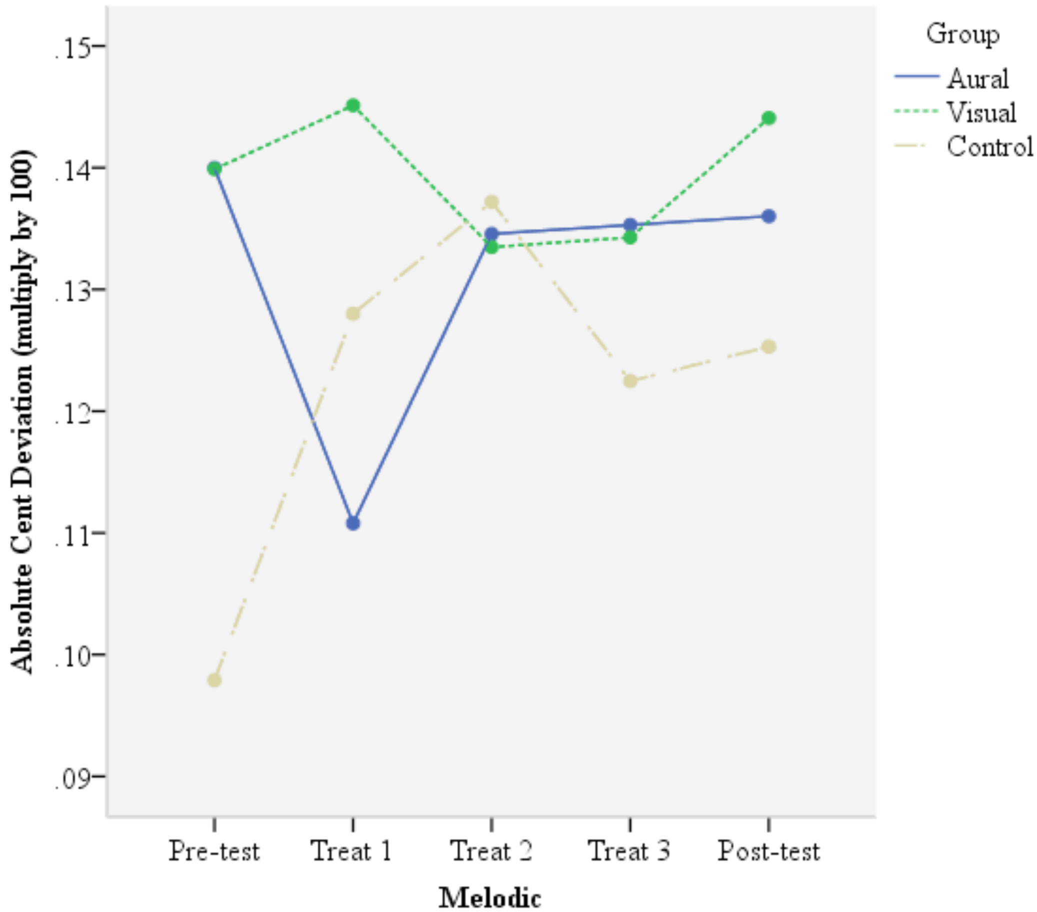


Figure 4.7. Group Responses across the Melodic Treatment

Table 4.6
Means and Standard Deviations of Groups in the Melodic Treatment

Group	Melodic Pretest	Melodic Treatment 1	Melodic Treatment 2	Melodic Treatment 3	Melodic Posttest
Aural	*M* = .14	*M* = .11	*M* = .13	*M* = .13	*M* = .14
	SD = .08	*SD* = .07	*SD* = .05	*SD* = .07	*SD* = .07
Visual	*M* = .14	*M* = .15	*M* = .14	*M* = .14	*M* = .15
	SD = .08	*SD* = .08	*SD* = .07	*SD* = .08	*SD* = .08
Control	*M* = .10	*M* = .13	*M* = .14	*M* = .12	*M* = .12
	SD = .05	*SD* = .07	*SD* = .07	*SD* = .08	*SD* = .09

treatment 1 to the following treatments and posttest, returning to nearly the same deviation as the pretest. Means and standard deviations for all groups are shown in Table 4.7.

A graph group of responses to the ensemble context is shown in Figure 4.8. Target pitches were observed within the same melody as practiced under the “melodic context” treatment, but this time while playing amidst an ensemble with no visual or aural treatment. In this context, the control group performed consistently and with both the lowest cent deviation maintaining a mean absolute cent deviation of .11, close to the 10 cent JND. The aural group regressed by a musically insignificant amount of 2 cents while the visual group exhibited a larger absolute cent deviation than the control, but showed little change across the two treatments. Both aural and visual groups were likely beyond the range of the JND, insinuating that tuning discrepancies should have been perceptible. Means and standard deviations for groups in the ensemble treatment are shown in Table 4.7.

Clarinet and trumpet responses in the ensemble context, shown in Figure 4.9, are interesting because of the difference when compared to single pitch responses. While clarinets performed with lower absolute cent deviation as compared to trumpets in the single pitch context, the opposite is true in the ensemble context, where trumpets performed with a lower absolute cent deviation ($M = .11$, $SD = .01$) than clarinets ($M = .13$, $SD = .01$). Trumpet participants made more of a regression on the second posttest than did clarinet participants. Means and standard deviations for both group and instrument in the ensemble treatment are shown in Table 4.8.

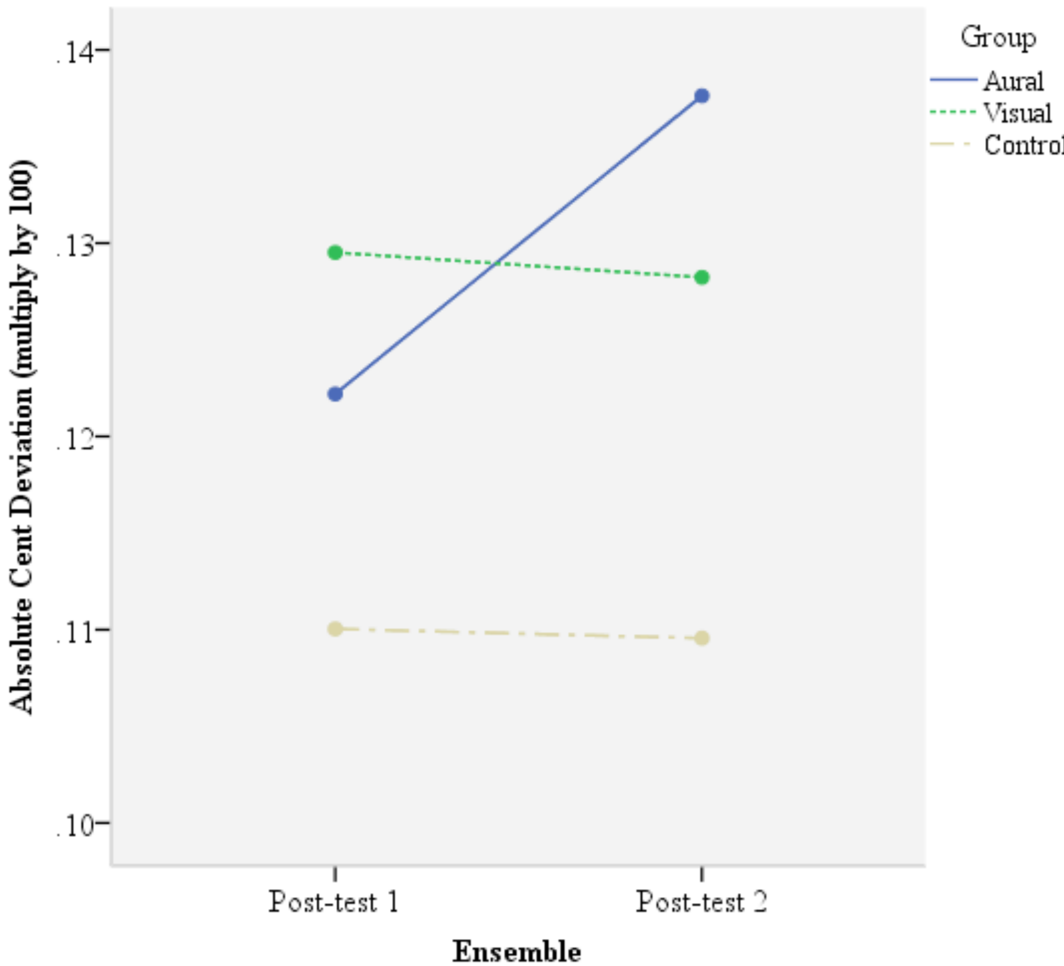


Figure 4.8. Group Responses across the Ensemble Treatment

Table 4.7
Means and Standard Deviations of Groups in the Ensemble Treatment

Group	Ensemble Posttest 1	Ensemble Posttest 2
Aural	*M* = .12	*M* = .14
	SD = .07	*SD* = .08
Visual	*M* = .13	*M* = .13
	SD = .07	*SD* = .08
Control	*M* = .11	*M* = .11
	SD = .09	*SD* = .07

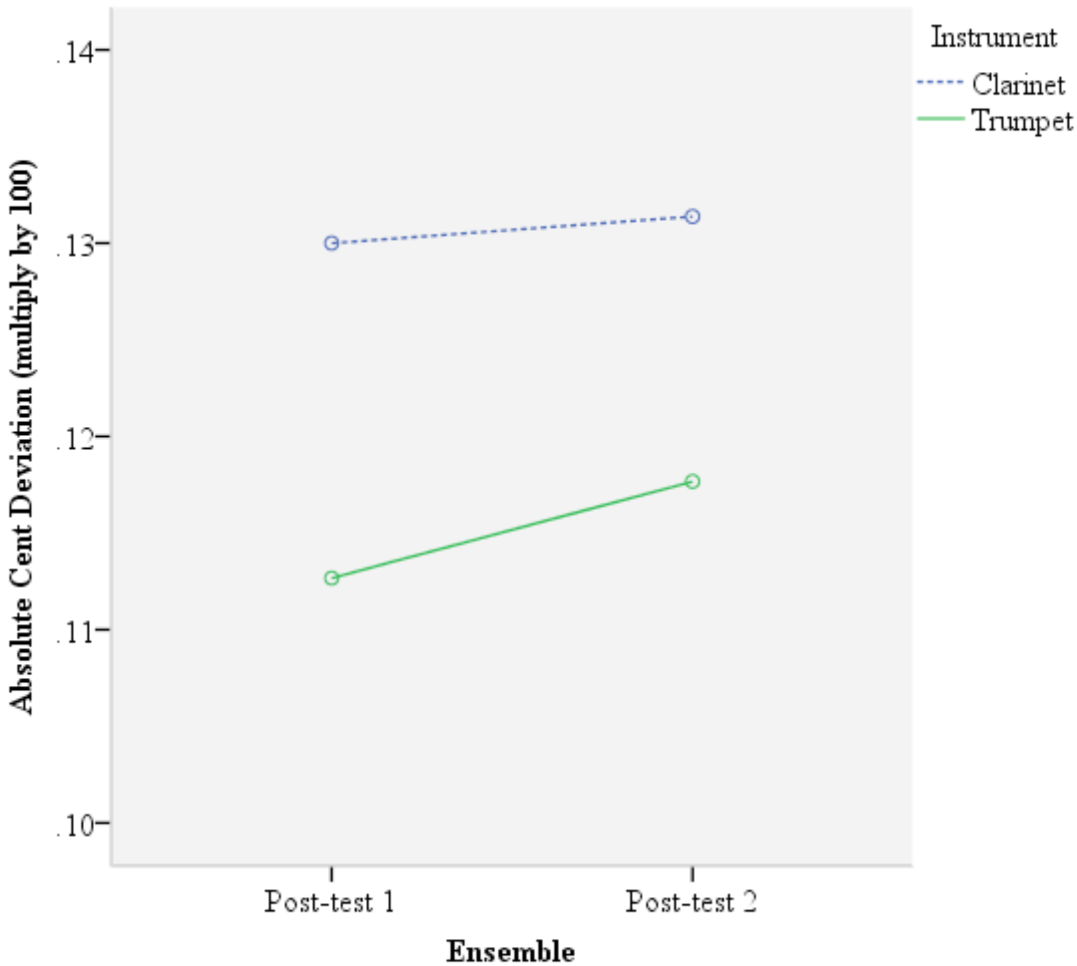


Figure 4.9. Instrument Responses across the Ensemble Treatment

Table 4.8
Means and Standard Deviations of Instruments in the Ensemble Treatment

Instrument	Ensemble Posttest 1	Ensemble Posttest 2
Clarinet	*M* = .13	*M* = .13
	SD = .07	*SD* = .07
Trumpet	*M* = .11	*M* = .12
	SD = .08	*SD* = .09

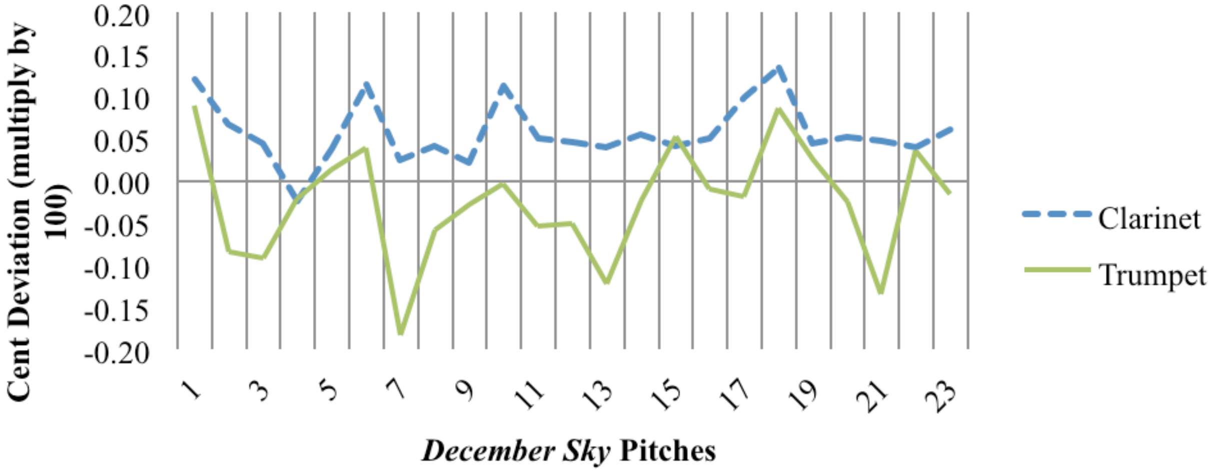
Pitch-By-Pitch Cent Deviation Analyses

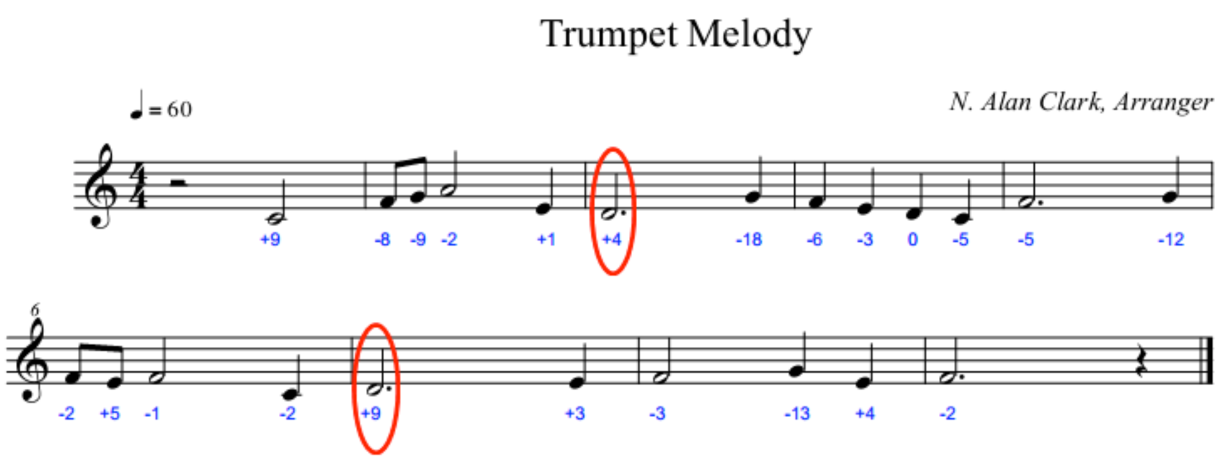
A more inclusive observation of all pitches in the performed melody is presented below. Directional (sharp and flat) mean cent deviation for all trials of the melody (five times in melodic

context, two times in ensemble context) by pitch and instrument are presented in both graphically and in conjunction with pitch notation in Figure 4.10. A graph of cent deviation means across all pitches in *December Sky*, shown at the top of Figure 4.10, illustrates the consistently flatter (lower cent deviation) trumpet intonation as compared to mean clarinet intonation.

Mean cent deviation score for the first target pitch (Note 6, approached from above) is lower in both clarinet and trumpet than the second target pitch, which was approached from below; in other words, participants tended to overestimate the whole step interval when approaching it from below. Target pitches were confirmed as being more out of tune than the majority of the other pitches in the melody. Interestingly, despite being referred to in the literature as a stable note in terms of intonation (Colwell & Goolsby, 2002; Garofalo, 1996), the tuning inaccuracy of all four instances of the open-valve trumpet G_4 (refer to notation) were consistently more out of tune than the target pitch of D_4. Always approached from below and consistently flat, the mean deviation for trumpet G_4 was 13 cents, with a range as high as 18 cents flat for the G_4 approached by an interval of a fourth from below (from the target pitch D_4)—the most out-of-tune note for trumpet in the melodic line. Both iterations of the D_4 target pitch in the melodic and ensemble contexts, while sharp by a mean of 4 cents and 9 cents respectively, were below the threshold of the just noticeable difference (Clark, 2012).

Cent-deviation analysis of each pitch in the clarinet melody yielded more predictable outcomes, shown in the same Figure for comparison. Those pitches located in the characteristically unstable and sharp throat-tone register were the most out of tune, with the greatest of those being clarinet G_4 (M = 9 cents sharp) and the target pitch A_4 (M = 12 cents





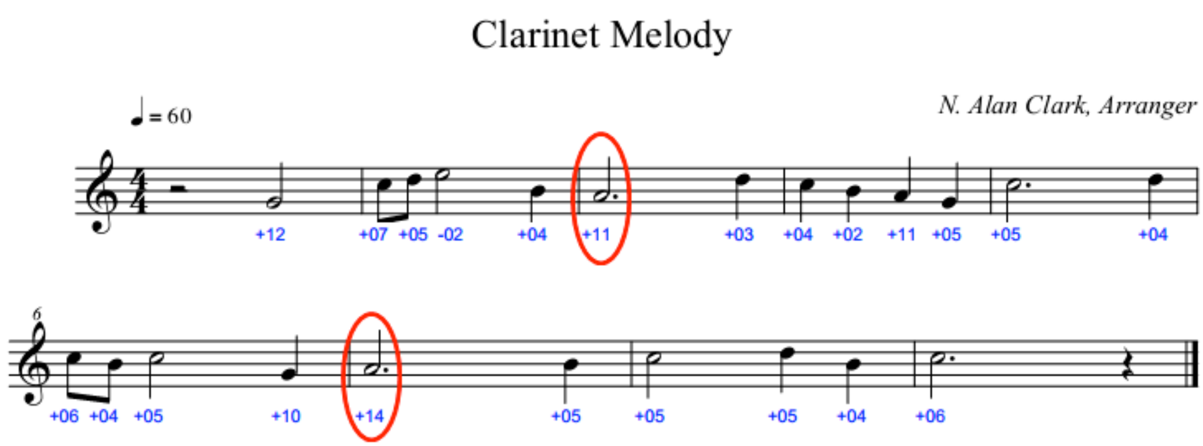


Figure 4.10. Cent Deviation of Each Pitch in the Melodic and Ensemble Contexts by Instrument. Note: Target pitches are circled.

sharp). Average cent deviation across all clarinet performances was sharp throughout, with the exception of E_5.

Questionnaire Responses

Analysis of student and director responses to written questionnaires regarding performance and teaching strategies related to intonation and participant perceptions of improvement constituted the qualitative data gathered in this study. Reponses were categorized and a thematic analysis was conducted.

Student Responses

Participant perceptions related to improvement, specifically answers to the dichotomous yes/no question “Do you think you were able to improve your tuning during this project?” did not yield meaningful responses; only one participant responded “no” to this question, with all others responding “yes.” While time spent addressing/thinking about/“working on” intonation (whether fruitfully or not, according to cent deviation data) may be perceived as improvement, the lack of statistically significant results regarding tuning improvement across treatments makes this response unreliable.

On the other hand, participant responses to the second question, “Describe how you attempted to change the pitch of your performance” yielded several meaningful comments that can be analyzed both descriptively and thematically. Of the 37 responses referring to strategies used by clarinet players to adjust intonation, 37% described adjusting the jaw, using terms including “open up more,” “open or close my teeth,” and “dropped my jaw”; 37% said they adjusted their embouchure, referred to in a multitude of ways including “changed the amount of muscles in my mouth,” “loosened my mouth’s grip on the mouthpiece,” and “relaxed my embushure [sic]”; 23% responded that they added or removed fingers in the right hand; and 7%

described changing the speed of air or playing volume. Two participants indicated they changed the amount of mouthpiece in their mouths and raised or lowered their head.

Trumpet responses to the tuning strategies question were fewer than clarinet responses, numbering only 15—the majority of trumpet respondents did complete the questionnaire, but centered their responses around the thoughts regarding the technology and/or perceptions of improvement (how they heard or "knew" they were in or out of tune). Regarding adjustment strategies, 20% of participants referred to moving the third valve slide in or out; 13% said they adjusted the firmness of their embouchure, using terms including "lipped down," "loosened or firmed up," "adjusting my lip," or "firmed my corners"; 16% indicated they adjusted the jaw with responses like, "lowered my jaw," "dropped my chin," and "brought the pitch down with my mouth"; and two respondents (6%) made reference to adjusting their air stream.

Several participants answered the "describe how you attempted to change the pitch of your performance" question with descriptions of strategies for perception. Of those responses the most frequent reference was to the presence or absence of "waves," to which 30% of responses were similar to, "It was easy to tell when I adjusted the wrong way because I could hear the waves," "I heard the waves when I was not in-tune," "I put my right hand on the keys while playing an 'A' and I also dropped my jaw eliminating sound waves," and "I could hear the 'waves' in the sound and in the recording and adjusted those two things until it sounded more in-tune." The method of recognizing intonation discrepancies through the perception of "waves" or "beats" (as referred to by Powell, 2010) was listed by all four directors, summarized by the statement that, "students are told to listen for waves, then given strategies (firm up, loosen up, listen for what works)" and "I try to make tuning an 'easy' concept. Just get rid of the 'waves.'" Responses regarding the recognition of beats or waves were isolated to those in the aural group

with two exceptions—both in the visual group. These two respondents may have been referring to playing along with the ensemble context, or may have only been repeating what they thought was an appropriate answer. Other less frequent references were to out-of-tune playing with the auto-tuner not "blending" while in-tune playing with the auto-tuner "sounded like one sound."

Of notable interest was a response related to the relationship between air speed/amount of air and intonation, saying,

> I am a very quiet player, and sometime that affects the quality of my notes (how sharp or flat it is). So by cranking up the volume just a tad it made me feel as if I had to play louder to hear myself. So I walked out feeling that I could play louder than had prior to. In moderation of course.

Two respondents referred to their own uncertainty in the pitch-correction process, saying, "I heard the dissonance but didn't know where to bend my pitch," and "making the changes to my own pitch was a challenge."

Two others in the aural group made reference to unique aspects they perceived while playing along with the software, saying, "For me as a trumpet player, I always try to imagine the note I'm about to play in my mind before I actually do it. This software helped tremendously in that aspect" and,

> Since trumpets bell is pointed away it is hard to find out if I'm in-tune. Since I was able to hear what I was playing I could adjust my embouchure to make it more in-tune. It seems that instead of you playing and the tuner telling you what the pitch is, but with this it is like playing with another trumpet [sic].

These responses can be triangulated with Director questionnaire responses and researcher field notes. All four directors at the two participating schools referred to the strategies listed by participants in their questionnaire responses, with one director calling problems related to trumpet D_4 and clarinet A_4 "the usual suspects," for which students are instructed to "add right hand fingerings," "kick-out on 1 and 3, re-evaluate, and then adjust the jaw if necessary," and/or

"lip down." Another director referred to these strategies generally, and their function within the process of evaluating and adjusting intonation: "I always try to find the underlying cause whenever possible and give students tools to fix it now and deal with it in the future." Adjustments of the jaw, lips, fingerings, and 3rd valve slide were all observed by the researcher during the treatment process, and recorded in field notes.

Director Responses

Descriptive questionnaire results from Directors revealed that the Directors from School A had taught for 5 and 33 years, and Directors from School B for 16 and 23 years. All four Directors responded to the question, "How often do you incorporate instruction related to tuning in your classroom?" with "Daily."

When describing their daily tuning processes, Directors referred to several strategies, mostly related to the warm-up period. These included work with unison passages and excerpts, with the "explicit intention of improving intonation"; Remington exercises, where students play descending unison expanding intervals, beginning with a minor second and finishing with a perfect fifth (Rush, 2006); and chorales. Directors from School A both referred to a process using a student as a tuning source, where the ensemble first tunes to a concert F from the tuba, humming or singing the pitch then "playing/tuning on their own." This is followed by a concert Bb from the clarinet utilizing the same process. One director from School A referred to a process where students first tune in a tutti setting, then "match each other in smaller groups or by twos. I don't tell them if they are sharp or flat. I want them to get rid of the 'waves' by opening up or firming up and using faster air and then they know what to do with the instrument (pull out/push in)." A Director from School B described a similar student-centered process, saying:

> We will only use the tuner to fix major problems. There are very few times when we go through this process without making the experience interactive; that is, rarely do I just go down the line and say "push in" or "pull out," without students knowing why and taking some of the responsibility.

When asked, "In rehearsal, when you detect intonation flaws in a tutti section of the music, what do you do?" processes described were similar to those used in the warm-up setting. These included drawing students' attention to the problem, singing, and small group pitch matching.

Director responses to the question regarding score preparation overlapped each other frequently. All four directors mentioned browsing their scores to varying degrees for what one referred to as "the usual suspects," including clarinet throat tones, trumpet 5^{th} partial, C_3 on alto sax, trumpet D_4 and C-sharp$_4$. Also mentioned was score preparation that included awareness of dissonant chords where students will often not interpret the distance between small intervals appropriately, specifically half and whole steps. One more concept-related response related to score or lesson preparation was, "the most important thing I do is to spend time planning opportunities for students to face challenging intonation issues and solve them in the music."

Much like the previous quotation, a theme that emerged from director questionnaires regarding perception and performance was the concept that intonation must be the responsibility of the student, exemplified by the quotes included in Table 4.9.

Table 4.9
Director Responses Related to Intonation and Student Independence

"Motivation to tune independently comes from the director consistently questioning the students about their thoughts on the intonation of a section. At least once during every rehearsal, I will stop somewhere in the music and ask specific students, 'What did you think about our intonation from A-B?'".
"The most important thing I do is to spend time planning opportunities for students to face challenging intonation issues and solve them in the music."

“Generally students are very good at hearing flaws with pitch if they are simply given the task and the opportunity to work through the problem on their own.”

“I try to make them HATE playing out of tune.”

“I teach students that their sound is the number one priority. Their sound has to be what they take pride in. If they buy into this, every aspect of teaching music becomes something they have ownership in. They don't want to accept…bad intonation.”

“First, students sing and then play/tune on their own. Then I have students match each other in smaller groups or by twos. I don’t tell them if they are sharp or flat—I want them to get rid of the ‘waves’ by opening up or firming up and using faster air, and then they know what to do with the instrument (pull out or push in).”

“I am patient with [the tuning] process with the idea in mind that if they learn to tune on their own, it will happen in the music we perform.”

One director wrote a list on the back of the questionnaire in response to the question, “How do you motivate students to address tuning independently?” The entries from that list referred to concepts related to both intonation and general student motivation. Intonation-centered comments included “Make playing in-tune a priority—talk about and do it daily,” “Talk about the tendencies of the instruments often, including solutions,” and “The better they get at tuning the more their ‘ears’ get used to hearing a good pitch center.” Motivational references included, “stay positive, as long as the students are trying and improving, we are reaching our goal,” and “refer to tuning as an ‘easy’ concept.” All four participating directors referred to incorporating instruction related to intonation on a daily basis in their classrooms.

Technology

Nine responses (15%) referred to problems related to using the RTPTC software and related peripherals or the electronic tuner. Two participants perceived a delay between their own performance and the sound generated by the auto-tuner, saying it was “bothersome” and “makes it difficult to stay in time” while two others referred to problems related to the quality of sound

through the headphones. Six participants described difficulty playing along with the ensemble treatment, saying, “The only weakness of this is that when playing a tune or piece…you also have to focus on two things at one time,” and “I personally found it a little distracting playing with the band playing,” “the band music didn’t sound the same through the headphones as it was written to me [sic],” while one participant described problems with adjusting to the auto-tuned melodic treatment, saying, “During the performance where I was consistently changing notes…I could hear when I wasn't in-tune but found it hard to correct myself in small time frames.”

Three participants in the visual group (15%) alluded to problems watching the tuner while playing, with all three comments similar to “it was hard if I played with the tuner because I had to find where I stopped in the music again.”

CHAPTER 5: DISCUSSION

Remember the story of Joe and Victor: the barroom saxophone player and his fellow bandsman, a high school band director. Joe, a former middle and high school band member, was an enthusiastic showman who frequently played out-of-tune, a problem Victor tried to address with several traditional methods that were unsuccessful. But when Victor suggested that Joe play along with a stand-alone auto-tuner that would provide him with tuned feedback in real-time, something seemed to change: with the feedback from the machine, Joe began to play better in-tune. The apparent positive effect of the auto-tuner on Joe's intonation was the motivation for this research: an attempt to investigate the effectiveness of Real-Time Pitch Tracker and Corrector (RTPTC) software on the performed intonation of characteristically unstable pitches on clarinet (A_4) and trumpet (D_4). How does cent deviation data from participants using RTPTC compare to those using a more traditional electronic tuner or only their own ears? Does context (single pitch, melodic, or ensemble), instrument, and/or participation in private lessons influence results? What are the implications for teaching and learning in music?

This study was designed with these questions in mind, rooted in experiences intended to investigate participants' ability to perform in-tune—a skill that cannot be consistently divorced from perception, but participants' ability to perceive was not investigated. And just as the relationship between the perception and performance of intonation in music has been found to be complex (Ely, 1992; Geringer, 1983; Geringer & Madsen, 1987; Morrison, 2000), the results of this study show the answers to the aforementioned questions to be effected by lessons, instrument, melodic and intervallic context, and experience.

So, did RTPTC work? Yes, in the single pitch context, where aural group participants made immediate improvement from the pre-test to Treatment 1 and even greater improvement in

Treatment 3 (where the average cent deviation was 8 cents, lower than both the visual and control groups). The success of RTPTC in the melodic and ensemble settings is not as apparent, as results show average cent deviation above the 10-cent marker. More time for participants to become accustomed the software, the *December Sky* melody and *December Sky Arrangement* may have led to more sustainable results, a conclusion validated by participant questionnaire responses.

Defense of the use of a 10-cent marker of “in-tune” in this study can be made in conjunction with the above mentioned single-pitch results. During the single pitch task, aural group participants reduced average pre-test cent deviation from approximately 14 cents to 10 cents. This was followed by Treatment 2 with an average cent deviation of 11 cents and Treatment 3 with an average deviation of 8 cents. This dancing back and forth across the 10-cent line lends credence to the idea that students were able to perceive 14 and 11 cents as out-of-tune, with 10 and 8 cents as in-tune. While these differences are small and labeling a single number as *the* threshold would involve ignoring a multitude of factors, these results lend some credence to the use of a 10-cent threshold for declaring musical significance in this study.

The conundrum of multiple factors influencing how intonation is perceived and performed makes the case against teacher-centeredness as the sole approach (e.g., “you’re flat, push in”), and instead advocates for a more student-centered, independent approach because the variety of settings in which intonation decisions have to be made is endless. To be successful manipulators of intonation in this study—and more importantly in the authentic instrumental rehearsal and performance setting— young musicians must be able to do three things: hear the problem; deploy thoughtful strategies to fix; and reassess. These three events do not exist in a vacuum. For a multitude of students who enter the band room with a variety of experiences,

abilities, and ways of knowing both between and within them, these mini-situations must be presented in a variety of ways, because:

> Memories stored in organic brains are ever changing. Everything that we encounter, we perceive and remember somewhat differently than the person next to us, because each of us brings a different set of memories to the moment of shared experience…and our memory of a given *now* is susceptible to modification by what we experience in the future (Duke, 2012, p. 38).

Herein lies the advantage of using real-time pitch tracking and correction software as a method for improving intonation: while it is not the "cure-all" many music teachers would hope for, it is another effective method that can be combined with strobe experiences, Remington exercises, vocalization, thoughtful questioning, drones, the tuning CD, chorales, beat recognition, melodic context, single pitch context, just tuning of chords, and other intonation-centered experiences to make a range of students better able to adjust across the breadth of their experiences with music.

As with most applications of technology in the classroom, there is a time and place for using pitch-correction software. While many approaches can be introduced in the large ensemble setting, often the most meaningful work is done when the student is set up with strategies to solidify knowledge independently. This may be the most meaningful application of RTPTC software: providing students opportunities to move at their own pace *with feedback*, a solution to the problem that exists in the classroom setting where teacher-time spent working with an individual, if too long, can be at the expense of others. That is not to say that pitch-correction software does not have applications in the classroom setting. Much like a strobe tuner can be used alone at the student's pace or in the large ensemble in short teaching scenarios, so can pitch-correction software, providing students with aural opportunities to correct pitch as opposed to

visual ones, perhaps even from their own smart phone or other independent device placed on the music stand, much like tuners are used today.

Participants

Student participants in this study were drawn from a well-defined pool of subjects: two high school bands with compatible socio-economic status in rural south Louisiana, both successful at district- and state-wide ensemble festivals where intonation is assessed, both with 90-minute daily ensemble rehearsals and student participation in private lessons. But, as is often acknowledged in educational research, participant descriptions on paper cannot completely accurately represent participant experiences or ability. Once confronted with the required tasks, differences among the participants from School A and School B became apparent. School B was large enough to field three large concert bands, while School A had two of average size. This may have been the greatest contributing factor to what came to be a difference between the performance of students from the two schools that was clear when working with participants. The freshman musicians at School B (larger band program) represented the majority of the members of their 80-member "3rd Band." The freshman musicians at School A (smaller band program) were interspersed among older students in the 50-piece "2nd Band." This could have positively affected the intonation-centered experiences of the younger musicians at School A—providing an experience that included the more tacit, "music-mediated communication" (Hager & Johnsson, 2007, p. 112) that has been found to occur among developing musicians, in turn providing them the skills and knowledge to perform the tuning tasks with greater accuracy than those at School B. A greater number of students from School A also participated in private music study, a factor that has been found in previous research to significantly affect success with tuning tasks (Yarbrough, Morrison, & Karrick, 1997). While instrumentation, ability, and other factors

play into the decision making process of assigning students to performing ensembles, in situations where scheduling allows for less experienced players to benefit from simply playing next to their more experienced peers, it should be taken advantage of. Where it is not possible during the school day, efforts to combine students in chamber ensembles, sectional rehearsals, or large ensemble rehearsals after school can provide opportunities for the more tacit, experienced-centered learning of intonation to take place at the same time as directed instruction from the teacher, surrounding the young player with multiple influences and experiences.

Technology

While all participants indicated on the questionnaire that their intonation improved while using the software, the statistical results tell a different story—a result that may be due in part to technology. Some participants in the visual group did not have extensive experience watching a tuner while playing, and the task itself is difficult to execute from a visual standpoint (looking back and forth at music and tuner), as mentioned by some participants. Also, those in the aural group had little time to acquaint themselves with the software as each context (single pitch, melodic, and ensemble) included three, three, and two repetitions respectively with the software. Considering that the task at hand required that participants acquaint themselves with the sound generated by the software, evaluate intonation, execute, and reassess, three repetitions utilizing a moving melodic line may not have been enough time for some to reach their fullest potential or possibly even begin to progress. This assertion is reflected in the literature, where "time to personally explore, digest, and experiment with technology as well as time to maintain skills" (Leggette & Persichitte, 1998, p. 33) has been found to be the greatest barrier to the implementation of new technology among people of all ages.

The same necessity for time to adjust may have affected participant responses to the use of headphones and volume levels. While Duke (1985) found no significant difference between the use of headphones versus speakers, some participants expressed discomfort with the headphones both mentioning their discomfort and exhibiting it non-verbally. This may be due to the unfamiliarity of the task and the need for time to adjust, much like the situation described above. When considering ecological validity, the use of RTPTC software and synthesized ensemble tracks is more valid than playing only with a tuner or alone, but it is not familiar territory for student musicians who are accustomed to playing along with authentic sounds in large rehearsal rooms.

Despite unfamiliarity, RTPTC's overall design was a successful one—it performed as intended both in the areas of pitch production and data gathering, and was easy to use. Future applications might be better served if participants were able to adjust volume independently, as comfort level varied widely across participants. This also may have been a factor impeded by time needed to adjust to new technology (Leggette & Persichitte, 1998), as some students requested volume levels that were very low, an adjustment that has been found to have implications on the ability to accurately assess intonation discrepancies (Dunnigan & Gerringer, 2002).

Instrument Comparisons

Acoustical and mechanical differences make the clarinet and trumpet two distinctly different instruments: the clarinet, unless overblown, produces only one pitch per fingering combination while the trumpet can practically produce up to thirteen different pitches (each aligning with a different "partial") on one valve combination, depending on adjustments of the player's lips. Additionally, previous research has found that trumpet players can adjust a single

pitch as wide as a half-step with embouchure adjustment alone (Kopeiz, 2003). And while clarinet participants may have greater ease getting in the "ballpark" by using kinesthetic adjustments (e.g., right hand down, jaw down or up) simply because their ballpark is smaller, trumpet participants have a larger aural space to navigate, requiring a more discerning ear—in essence, a greater emphasis on auditory perception combined with proprioception as opposed to proprioception alone.

This concept can be connected to the opposite results from clarinet and trumpet performance in the melodic and ensemble contexts, where trumpet participants played more in-tune than their clarinet counterparts. The inclusion of musical intervals in these contexts—settings within which all pitches had to be placed and evaluated against each other—may have provided an environment that was more advantageous to the evaluation of pitch accuracy for trumpet participants than for clarinet, simply because of their daily experiences resulting from the mechanics of the instrument and embouchure. Performing with accurate intonation in a single pitch setting is less complicated than in a melodic or ensemble setting, where not only the accuracy of pitches themselves but the relationship between pitches has to be assessed. This is where trumpet experiences may provide an advantage: trumpet players are constantly practicing the execution and assessment of not just fingering combinations, but also partial placement (e.g., "Am I pushing the right valves AND playing high or low enough?"). The same concept is exemplified by Vurma's description of vocalists, who "not only remember the sound of different intervals, but also the procedure of how to sing them, although this knowledge is hard to verbalize" (2010, p. 31). Focus on those pitches found in previous literature and validated in this study to be problematic on the clarinet from an intonation standpoint stand to benefit from consistent experiences centered on listening, adjusting, and reassessing. Every clarinet player,

from a young age, should be taught, provided opportunities to experience, and re-taught about the instability of the throat tone register and the effects of embouchure adjustment and alternate fingerings on the instability as if this process is simply a part of the fingering and playing process itself.

The complex relationship between performance and evaluation is at the heart of teaching young musicians about intonation, because "as [students] gain physical skill, there must be commensurate gains in auditory and physical discrimination" (Duke, 2012, p. 39). Wuttke's dissertation revealed the importance of opportunities to recognize intervallic relationships on intonation accuracy in the classroom setting, where he found that bands with more accurate intonation in the large ensemble setting regularly performed long tones descending chromatically and intervallically along with experiences specifically tuning perfect intervals (2012, p. 89). A connection to the importance of varied experiences in the educational setting can be made here: in order to excel with a task to the greatest potential in the shortest time period, students must be surrounded by multiple opportunities to experience the same concept, including opportunities to audiate, or create "a clear plan or desire for the exact coming pitch" (Joukamo-Ampuja & Wekre, 1999, p. 47), execute, perceive the discrepancy between the planned pitch and the outcome, and change behavior to eliminate that discrepancy across multiple repetitions (Duke, 2012). This set of experiences creates a setting for learning intonation from a single pitch, intervallic (melodic), and ensemble (melodic and harmonic) context where knowledge can be formed, executed, and reformed, a cycle that stabilizes and enhances musical knowledge (Allen, 2012).

While trumpet participants in this study exhibited better overall performed intonation in the melodic and ensemble settings than clarinet participants, a noticeable inaccuracy resided in

the repeated pitch G_4, an open-valve pitch that is characteristically stable and often used as a tuning note from which to base the overall tuning of the trumpet (Garafalo, 1996). The four iterations of G_4 in *December Sky* ranged from 9 to 18 cents flat, with three of the four occurrences more than 12 cents flat. Their location outside the range of the JND (Clark, 2012) coupled with findings from previous research that indicate we hear flatness more accurately than sharpness (Wapnick & Freeman, 1980), along with the mechanical stability of the open valve combination make this result surprising. The largest discrepancy in intonation occurs on the second iteration of G_4 where it was approached from a fourth below by the target pitch of D_4. The direction of approach may or may not play a part in the explanation of the discrepancy, as Duke (1985) found that ascending intervals tend to be contracted (played flat in relation to the initial pitch), but Forsythe (1967), Papich & Rainbow (1974), and Geringer (1978) found that both vocalists and tended to perform ascending intervals sharp.

The surrounding iterations are more difficult to explain, as they are all approached from a smaller, more manageable major 2nd below, an interval played frequently in scalar exercises. While the explanation is unclear, the frequency of trumpet G_4 either as a tuning note or note within a tuning sequence on the trumpet strengthens the case against the effectiveness of repeated single pitch tuning experiences in the large ensemble setting, an experience that Morrison (2002) found to be ineffective as well.

Maybe the answer to these results—and to the overall high cent deviation of several performances in this study—lies in the language of playing in-tune. While students accurately described and sometimes used strategies for addressing intonation problems with alternate fingerings and embouchure adjustments, perhaps a solid foundation in the *sound* of an in-tune 2nd, 4th, or octave did not exist pervasively among the participants. While students playing along

with a unison partner (as they did in the aural group in the single and melodic pitch settings only) were able to recognize “waves” or “beats” between their performance and that of the computer, two-thirds of participants were left to perceive the tuned relationship between pitches with the help of a slow moving tuner or simply on by understanding the relationship between pitches. Without an understanding of the sound of these intervals when played in-tune, students are left without the ability to audiate before playing, removing them from the more advantageous “I see-I hear-I play” process of performing and placing them into the less active “I see-I play-I hear,” where they have to move on to the next pitch before much listening and assessing can take place (Bujes, 2013).

Lessons

The better average cent deviation of trumpets with versus without private lessons helps to reinforce the necessity for specific, guided instruction regarding intonation among these students. While private lessons have been found to be beneficial across all instruments (Yarbrough et al, 1995) and the difference in this study between clarinets studying privately and those who did not was musically insignificant, the nature of pitch production on brass instruments (as discussed above), including lip buzzing and the confounding effect of the overtone series makes the significant effect of private lesson participation on trumpet students all the more understandable. The variable nature of pitch production on brass instruments may require either longer or more specific instruction in regards to intonation than on reed instruments, where once the proper embouchure is established and the mechanics of air and fingerings are in place, a single, in-tune pitch is more easily produced.

Conclusions

Conclusions are organized according to research questions.

1. Did training with real-time pitch correction software lead to better performed intonation than without it?

Yes, for some. This question is answered more specifically through the following sub-questions.

2. Were there significant differences in performed intonation among aural (auto-tuned), visual (tuner), and control group treatments?

Yes. While there was no significant main effect due to group, a significant interaction was found between context and group, where the aural (pitch-corrected) group performed with significantly better intonation than the control group in the single pitch context, and differences between these two groups in the melodic and ensemble contexts were musically negligible, according to the just noticeable difference. Differences between the aural and visual groups across all three contexts were musically negligible.

3. Did performed intonation of a targeted pitch (clarinet A_4 or trumpet D_4) in single pitch, melodic, and ensemble contexts improve from pre-test to post-test?

In the single pitch context, target pitches were analyzed for each occurrence. In the melodic and ensemble contexts each target pitch occurred twice during the melody, and cent deviation scores were averaged to create a single unit of data for analysis.

In the single pitch context, improvement from pretest to posttest was made, but it was not in the control group. Intonation was most accurate for the aural group in the single pitch context on treatment three, and immediate gains were made by this group from pretest to treatment 1, where intonation was adjusted from what could be heard as out of tune to what would be

considered in-tune. When considered by instrument, trumpet participants in the single pitch context made a musically significant difference from pretest to treatment three, but those gains were not maintained to the posttest. Clarinet participants improved in the single pitch context but those gains were not musically significant—their performance from pretest to posttest was within the range of the JND, and would have been perceived as in-tune throughout.

In the melodic context, trumpet participants improved while clarinet participants regressed. The aural group made the most gains from pretest to treatment 1, while the visual group made improvements from treatment 1 to treatment 3, but did not maintain those improvements to the posttest. The control group performed sporadically and worse from pre- to posttest.

The ensemble context contained only two posttests, where the aural group regressed from the first to second by a musically insignificant amount of 1 cent from 12 cents to 13 cents. Although it was a musically insignificant difference, both iterations may have been able to be perceived as out of tune due to their relationship to the JND. The visual group did not change, maintaining a 13 cent difference from in-tune. The control group was the most in-tune, maintaining an 11 cent absolute cent deviation from in-tune from post test 1 to post test 2.

4. Were there significant differences in performed intonation among single pitch, melodic, and ensemble contexts?

Yes and no. There was no significant main effect due to context, but there were two significant 2-way interactions between context x group and context x instrument, indicating that context did effect intonation within certain situations.

The interaction between context and group was discussed in the answer to question two. The aural (pitch-corrected) group performed with significantly better intonation than the control

group in the single pitch context, and differences between these two groups in the melodic and ensemble contexts were musically negligible, as were differences across all contexts in the aural and visual groups.

Clarinet participants performed better in-tune in the single pitch context, where they played with a perceptively in-tune mean absolute cent deviation of 10 cents, while trumpet participants played with a mean deviation of 15 cents, which should have been heard as out of tune. This situation reversed in the melodic and ensemble contexts, where clarinets performed worse (but not significantly musically different) than trumpets, and at a level that should have been perceived as out of tune. From these results the reality of differences in acoustics and/or experiences relative to instrument must be considered.

5. Are there significant differences in performed intonation among individual pitches within and across each performance?

Yes. Target pitches (clarinet A_4 and trumpet D_4) were indeed out of tune, with the clarinet target pitches 11 and 14 cents sharp, and trumpet target pitches 4 and 9 cents sharp. Intonation across the trumpet performances varied widely across sharp and flat, ranging all the way to 18 cents flat on open-valve G_4 (a characteristically stable pitch) to 9 cents sharp on the second iteration of the target pitch. Overall clarinet intonation was consistently sharp, with the exception of only one pitch registering flat by 5 cents. Clarinet trends followed the indications provided in instrumental texts and previous research with throat tones (including G_4) sharp to a musically significant extent (Garofalo, 1996; Stauffer, 1987).

The inconsistency of trumpet performances makes the case for a lack of understanding of the language of tuning when nested among other pitches, and the potentially negative (or at least

more complicated) effect of lip-buzzed pitches as opposed to reed generated pitches on intonation.

6. Does instrument (clarinet or trumpet) significantly affect participants' performed intonation?

Yes. While there was no main effect due to instrument, a significant interaction existed between instrument x lessons and instrument x context, indicating that instrument (clarinet or trumpet) did affect results. Trumpets participating in private lesson instruction for two months or longer scored significantly better from both a musical and statistical standpoint than those without lessons, with a difference of 11 and 16 cents. The difference between clarinets who participated in lessons and those who did not was not significant.

Clarinets performed more in-tune in the single pitch context while trumpets had greater success in the melodic and ensemble contexts. Clarinet intonation was consistently sharp, while trumpet intonation was inconsistent, both sharp and flat.

7. What is the nature of participants' knowledge about tuning and intonation? What are their perceptions of the training and testing experienced in this study?

Perceptions varied, as would be expected. Themes that emerged related to knowledge about tuning and intonation included experiences perceiving "waves" or "beats" (resulting from perceptible differences in intonation), knowledge of physical tuning strategies including embouchure adjustment, aural cavity adjustment, alternate fingerings, and adjustments of air speed or direction. Themes were not consistent across all participants or within either instrument, but were mentioned by enough participants to be considered meaningful. Strategies and understandings were triangulated through director questionnaire responses and researcher field notes, when applicable. Director responses in regards to approaches to teaching intonation often

centered around the necessity of independence. The success of a number of students with the tuning tasks in this study reflected that independence, but it was not universal.

Perceptions related to the experiences related to this study varied. All but one participant indicated on a dichotomous yes/no question that their tuning improved across the course of the study, making those responses unreliable from a statistical standpoint. Other themes related to the tasks centered around technology, including familiarity, volume, and sound quality.

Future Research and Applications

Future study utilizing pitch –tracking and correction software should include a longer period of time for participants to become familiar with the technology, which in turn can help to maximize the potential of the software. The extension of this software into a wider variety of musical scenarios, including ascending and descending intervals, harmonic intervals, and chordal contexts should be considered. Additionally, pitch-tracking experiences that incorporate just-intonation in a chordal setting could replicate experiences where different chord members are adjusted to achieve beatless tuning, a topic of interest in the instrumental music setting.

Finally, the development of software similar to RTPTC that also includes the features of the other two groups used in this study (visual tuning and independent tuning), combined with easily interpreted feedback that tracks student performance across time could provide music students with tuning experiences in a variety of settings and approaches, helping to diversify their learning experiences.

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APPENDIX A: IRB FORMS

Application for Exemption from Institutional Oversight

Institutional Review Board
Dr. Robert Mathews, Chair
131 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu
lsu.edu/irb

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples, or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

-- Applicant,Please fill out the application in its entirety and include the completed application as well as parts A-F, listed below, when submitting to the IRB. Once the application is completed, please submit two copies of the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://research.lsu.edu/CompliancePoliciesProcedures/InstitutionalReviewBoard%28IRB%29/item24737.html

-- A Complete Application Includes All of the Following:
(A) Two copies of this completed form and two copies of parts B thru F.
(B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1&2)
(C) Copies of all instruments to be used.
*If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
(D) The consent form that you will use in the study (see part 3 for more information.)
(E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: (http://phrp.nihtraining.com/users/login.php)
(F) IRB Security of Data Agreement: (http://research.lsu.edu/files/item26774.pdf)

1) Principal Investigator: Kathryn E. Strickland **Rank:** Doctoral Student

Dept: Music **Ph:** 225-936-6747 **E-mail:** kstric6@lsu.edu

2) Co Investigator(s): please include department, rank, phone and e-mail for each
*If student, please identify and name supervising professor in this space

Jane W. Cassidy; Alumni Professor and Vice Provost; (225)-578-7662

IRB# E8075 LSU Proposal #______
Complete Application
Human Subjects Training

3) Project Title: The Effect of Real-Time Pitch Tracking and Correction Software on High School Instrumentalists' Tuning Accuracy

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 12/4/2015

4) Proposal? (yes or no) no **If Yes, LSU Proposal Number**

Also, if YES, either
This application completely matches the scope of work in the grant
OR
More IRB Applications will be filed later

5) Subject pool (e.g. Psychology students) High school musicians
*Circle any **"vulnerable populations" to be used:** (children <18; the mentally impaired, pregnant women, the ages, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature Kathryn E. Strickland **Date** 12/6/12 (no per signatures)

** **I certify my responses are accurate and complete.** If the project scope or design is later changes, I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

Screening Committee Action: Exempted X Not Exempted ____ Category/Paragraph ____
Signed Consent Waived?: Yes / No
Reviewer S. Kim MacGregor **Signature** S. Kim MacGregor **Date** 12/5/2012

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 12/4/2015

Parent Consent Form

Study Title: The Effect of Real-Time Pitch Tracking and Correction Software on High School Instrumentalists' Tuning Accuracy

Performance Sites: Catholic High School (Baton Rouge), Denham Springs High School, Dutchtown High School, East Ascension High School, St. Amant High School

Investigators:	Principal Investigator	Faculty Supervisor
	Kathryn Strickland	Jane W. Cassidy
	(225)-936-6747	(225)-578-7662
	kstric6@lsu.edu	jcassid@lsu.edu

Purpose of the Study: The purpose of this research project is to examine the effectiveness of pitch correction (otherwise known as auto-tuning) software as a tool for enhancing performed tuning accuracy among high school clarinet and trumpet players.

Subject Inclusion: Student participants ($N = 60$) must be current participants in large ensemble instrumental music who have participated in the large ensemble instrumental classroom for at least three years with trumpet or clarinet as their major instrument.

Study Procedures: In an effort to assess the effectiveness of different methods for improving the ability to play "in tune," participants will be separated into three groups. One third of the students will be in an aural group, in which participants will listen to accurately tuned feedback from pitch correction (auto tuning) software mixed with their own performance; a visual group, where participants will watch feedback provided by a digital tuner regarding their tuning accuracy; and a control group, where participants will be asked to tune to the best of their ability using their own aural skills. In each of the groups, students will be asked to play in tune to the best of their ability when playing a single pitch, a melody, and a melody along with a recorded accompaniment, all of which will be recorded using a microphone and software that will provide numerical data to be used in statistical analysis. Students will complete these tasks individually, and will be asked to complete a survey evaluating their experience and describing their tuning techniques. The entire process will take approximately 15 minutes, and will be completed during students' band classes or after school band rehearsals. The identity of all participants will be kept confidential.

Benefits and Risks: The study may yield valuable information regarding instructional strategies for teaching performed intonation accuracy to wind instrumentalists. There are no risks to participants in this study.

Right to Refuse: Participants may choose not to participate or to withdraw from the study at any time.

Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subject identity will remain confidential unless disclosure is required by law.

Financial Information: There is no cost for participation in this study, nor any financial compensation.

Thank you for your time and consideration of this investigation into the effect of pitch correction software on young instrumentalists' tuning accuracy. Please return this form to your child's teacher whether or not you wish for your child to participate.

Signatures:
The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225)-578-8692, irb@lsu.edu, www.lsu.edu/irb. I acknowledge the investigator's obligation to provide me with a signed copy of this consent form upon request.

Yes, I give my permission for my child to participate.

Parent Signature ______________________________ Name (print)__________________

Child's Name (print) ____ Date________________

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 I www.lsu.edu/irb
Exemption Expires: 12/4/2015

Student Assent Form

I, ______________________________, agree to participate in a study that investigates the effectiveness of pitch correction software on high school instrumentalists' performed intonation accuracy. I agree to use the pitch correction software or digital tuner as needed in this study. I will complete the questionnaire regarding my opinion toward the tuning methods used when it is presented. I understand that I may choose not to use the software or tuner or complete the questionnaire at any time.

Student signature: ______________________________ Age ________

Student name (print): ______________________________ Date ________

Witness: ______________________________ Date ________
(Witness was present for the assent process)

APPENDIX B: ARRANGEMENTS OF *DECEMBER SKY*

December Sky Arrangement

For Clarinet

Score

Erik Morales
Arr. N. Alan Clark


6
Fl.
Ob.
Bsn.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
A. Sx.
T. Sx.
B. Sx.
6
B♭ Tpt. 1
B♭ Tpt. 2
Hn.
Tbn.
Euph.
Tuba

December Sky Arrangement

For Trumpet

Erik Morales

Arr. N. Alan Clark

Score


6
Fl.
Ob.
Bsn.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
A. Sx.
T. Sx.
B. Sx.
6
B♭ Tpt. 1
B♭ Tpt. 2
Hn.
Tbn.
Euph.
Tuba

APPENDIX C: PARTICIPANT DATA FORM

Louisiana State University
College of Music and Dramatic Arts
The Effect of Real-Time Pitch Correction Software on
High School Wind Instrumentalists' Tuning Accuracy

Participant Data Form

PARTICIPANT NUMBER:

1. Please print your name:	
2. Circle your gender:	Male Female
3. Circle the grade you are currently in:	Freshman (9) Sophomore (10) Junior (11) Senior (12)
4. Circle your primary instrument:	Clarinet Trumpet
5. List your school name:	
6. List the total number of years you have played your primary instrument (either clarinet or trumpet).	
7. List the total number of years you have participated in private lessons (write 0 if you have never taken private lessons).	
8. List the name of your assigned band class (for example, "4th block Concert Band").	

APPENDIX D: SCRIPTS OF INSTRUCTIONS FOR TREATMENT SESSIONS

Louisiana State University
College of Music and Dramatic Arts
The Effect of Real-Time Pitch Correction Software on
High School Wind Instrumentalists' Tuning Accuracy

Script for Tuning Task: Aural Group

Thank you for agreeing to participate in this project. During this process you will play both a single pitch and short melody. You will play alone and with accompaniment, which you will hear through headphones. When playing, you should use whatever strategies you are familiar with to play in-tune to the best of your ability, with the exception of stopping to lengthen or shorten your instrument. Do you have any questions so far?

First, we are going to set the tuning notes you are most familiar with by using this tuner. I will help you through this process.

[Tune familiar tuning notes]

Please sustain the pitch shown in line number one.

[At this time, those participants not beyond the five-cents out of tune will be eliminated from the study]

Please play line number one again [Clarinet: A/ Trumpet: D], shown on the music in front of you, at this tempo [sound metronome at 60 beats per minute, record].

[Play line one, once.]

Please play line number two [Concert Bb] along with the auto-tuning software. You will hear your performance through the headphones along with one that is perfectly in-tune, played by the software. Please let me know if the volume needs to be adjusted, you should be able to

hear it clearly. Do your best to play in-tune with the sound you are hearing through the headphones.

[Play line two.]

Please play line number one again, this time along with the auto-tuning software. Use the tempo sounded by the metronome. You will play this line three times. Each time, do your best to tune to the sound you hear through the headphones.

[Play line one, three times. Each performance prompted by researcher.]

Please play number one again, without the headphones. Try to repeat whatever tuning adjustments you made while using the headphones.

[Play line one, once.]

Take a moment to play through line three at this tempo [sound metronome at 60 beats per minute], until you are familiar with it.

Please play line three at this tempo [sound metronome], while I record your performance.

[Play line three, once.]

Now you are going to play line three at the same tempo along with the auto-tuning software. Use the tempo sounded by the metronome. You will play this line three times. Each time, do your best to tune to the sound you hear through the headphones.

[Play line three, three times. Each performance prompted by researcher.]

Please play line three again, without the headphones. Try to replicate whatever tuning adjustments you made while using the software.

[Play line three, once.]

Now you are going to play line three along with recorded band accompaniment, which you will hear through headphones. You will hear four clicks before you begin playing, and you

will play twice with the accompaniment. Try to replicate whatever tuning adjustments you made when using the auto-tuning software while playing along with the recording.

[Play line three, two times, along with recorded accompaniment.]

Please complete this short questionnaire. Thank you for your participation in this project!

Script for Tuning Task: Visual Group

Thank you for agreeing to participate in this project. During this process you will play both a single pitch and short melody. You will play alone, with a tuner, and with accompaniment, which you will hear through headphones. When playing, you should use whatever strategies you are familiar with to play in-tune to the best of your ability, with the exception of stopping to lengthen or shorten your instrument. Do you have any questions so far?

First, we are going to set the tuning notes you are most familiar with by using this tuner. I will help you through this process.

[Tune familiar tuning notes]

Please sustain the pitch shown in line number one.

[At this time, those participants not beyond five cents out of tune will be eliminated from the study]

Please play line number one again [Clarinet: A/ Trumpet: D], shown on the music in front of you, at this tempo [sound metronome at 60 beats per minute].

[Play line one, once.]

Please play line number two [Concert Bb] while watching this tuner. When you read the tuner, if the needle is to the right you are sharp, to the left you are flat, and centered (which will make the green light appear) you are in-tune. Do your best to play in-tune according to the information from the tuner. Do you have any questions about how to read the tuner?

[Play line two.]

Please play line number one again, this time along with the tuner. Use the tempo sounded by the metronome. You will play this line three times. Each time, do your best to tune according to the tuner.

[Play line one, three times. Each performance prompted by researcher.]

Please play number one again, without the tuner. Try to replicate whatever tuning adjustments you made while using the tuner.

[Play line one, once.]

Take a moment to play through line three at this tempo [sound metronome at 60 beats per minute], until you are familiar with it.

Please play line three at this tempo [sound metronome], while I record your performance.

[Play line three, once.]

Now you are going to play line three at the same tempo along with the tuner. Use the tempo sounded by the metronome. You will play this line three times. Each time, do your best to tune according to the tuner.

[Play line three, three times. Each performance prompted by researcher.]

Please play line three again, without the tuner. Try to replicate whatever tuning adjustments you made while using the tuner.

[Play line three, once.]

Now you are going to play line three along with recorded band accompaniment, which you will hear through headphones. You will hear four clicks before you begin playing, and you will play twice with the accompaniment. Try to replicate whatever tuning adjustments you made when using the tuner while playing along with the recording.

[Play line three, two times, along with recorded accompaniment.]

Please complete this short questionnaire. Thank you for your participation in this project!

Script for Tuning Task: Control Group

Thank you for agreeing to participate in this project. During this process you will play both a single pitch and short melody. You will play alone and with accompaniment, which you will hear through headphones. When playing, you should use whatever strategies you are familiar with to play in-tune to the best of your ability, with the exception of stopping to lengthen or shorten your instrument. Do you have any questions so far?

First, we are going to set the tuning notes you are most familiar with by using this tuner. I will help you through this process.

[Tune familiar tuning notes]

Please sustain the pitch shown in line number one.

[At this time, those participants not beyond five cents out of tune will be eliminated from the study.]

Please play line number one again [Clarinet: A/ Trumpet: D], shown on the music in front of you, at this tempo [sound metronome at 60 beats per minute].

[Play line one, once.]

Please play line number two [Concert Bb] *[Play line two.]*

Please play line number one again. Use the tempo sounded by the metronome. You will play this line three times. Each time, do your best to play in-tune.

[Play line one, three times. Each performance prompted by researcher.]

Take a moment to play through line three at this tempo [sound metronome at 60 beats per minute], until you are familiar with it.

Please play line three at this tempo [sound metronome], while I record your performance.

[Play line three, once.]

Now you are going to play line three at the same tempo while focusing on playing in-tune. Use the tempo sounded by the metronome. You will play this line three times. Each time, do your best to play in-tune.

[Play line three, three times. Each performance prompted by researcher.]

Now you are going to play line three along with recorded band accompaniment, which you will hear through headphones. You will hear four clicks before you begin playing, and you will play twice with the accompaniment. Try to replicate play in-tune while playing along with the recording.

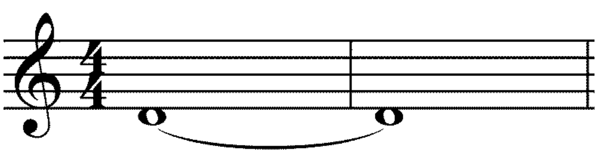
[Play line three, two times, along with recorded accompaniment.]

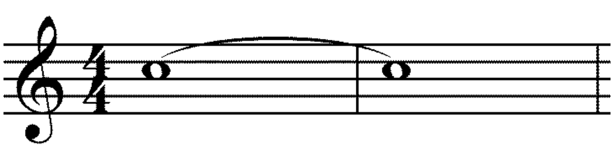
Please complete this short questionnaire. Thank you for your participation in this project!

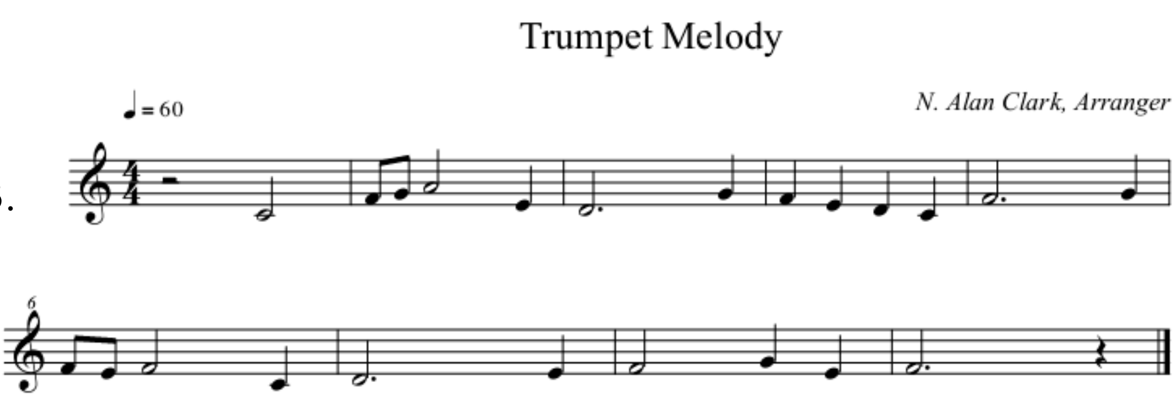
Louisiana State University
College of Music and Dramatic Arts
The Influence of Real-Time Pitch Correction Software on
High School Wind Instrumentalists' Tuning Accuracy

Single Pitch and Melodic Excerpts

Trumpet

1. 

2. 

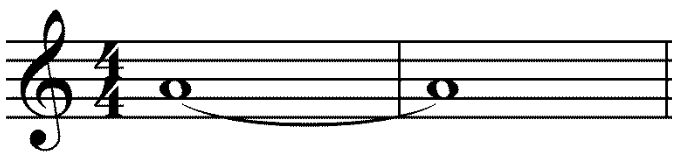
3. 

Louisiana State University
College of Music and Dramatic Arts
The Influence of Real-Time Pitch Correction Software on
High School Wind Instrumentalists' Tuning Accuracy

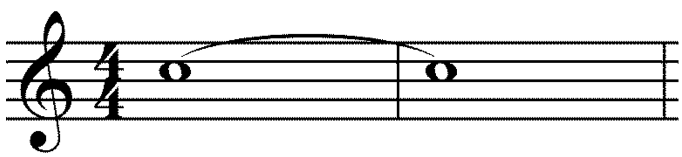
Single Pitch and Melodic Excerpts

Clarinet

1.



2.



Clarinet Melody

N. Alan Clark, Arranger

3.

APPENDIX F: STUDENT QUESTIONNAIRE

Louisiana State University
College of Music and Dramatic Arts
The Influence of Real-Time Pitch Correction Software on
High School Wind Instrumentalists' Tuning Accuracy

Participant Questionnaire

PARTICIPANT NUMBER:

1. Circle your primary instrument:	Clarinet Trumpet
2. Do you think you were able to improve your tuning during this project?	Yes No
3. If you answered YES to question 2, describe how you attempted to change the pitch of your performance (use the back of this page if necessary):	
4. If you answered NO to question 2, why do you think you were not able to improve your tuning? (use the back of this page of necessary)	

APPENDIX G: DIRECTOR QUESTIONNAIRE

Louisiana State University
College of Music and Dramatic Arts
The Effect of Real-Time Pitch Correction Software on
High School Wind Instrumentalists' Tuning Accuracy

Director Questionnaire

SCHOOL CODE:

1. How many years have you been teaching instrumental music?	
2. How often do you incorporate instruction related to tuning in your classroom?	Daily Weekly Monthly Never

Answer the following questions on a separate sheet of paper.

3. Describe your daily tuning process (e.g., how you tune your band).

4. In rehearsal, when you detect intonation flaws in a tutti section of the music, what do you do?

5. Is there anything you do in score preparation that readies you for intonation challenges in rehearsal?

6. How do you motivate students to address tuning independently?

VITA

Originally from Gainesville, Florida, Kathryn Strickland is a candidate for the degree of Doctor of Philosophy in Music Education from Louisiana State University, where she obtained a Bachelor of Music Education degree in 2000 and a Master of Music Education in 2010. From 2000-2008 she taught secondary instrumental music at East Ascension High School in Gonzales, Louisiana, team-taught at both Central and Gonzales Middle Schools, and served as percussion instructor from 2000-2013. Her bands at East Ascension consistently received excellent and superior ratings at the district and state levels. From 2005-2007 Ms. Strickland served as public relations chair on the executive board of the Louisiana Music Educators Association, and from 2003-2006 as secretary of the District IV Band Directors Association. In the Fall of 2008 she was awarded a graduate assistantship with the Louisiana State University Band Department, where she assisted with all aspects of the university band program, and in the fall of 2009 was inducted into Phi Beta Mu International Bandmaster's Fraternity. In 2010 Ms. Strickland began working toward the Doctorate in Music Education at LSU, at which time she was also awarded an Assistantship with the Music Education department where she served as teacher of record for multiple undergraduate courses.

Ms. Strickland has served as a clinician and adjudicator of bands and percussion groups across south Louisiana, and has presented her research at both state and national conferences. She recently accepted the position of Director of Athletic Bands and Assistant Professor of Percussion at Northwest Missouri State University starting in the Fall of 2013.