

A COMPUTER APPLICATION FOR BEAT DETECTION TRAINING
AND INTONATION PERFORMANCE ASSESSMENT

by

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(Under the Direction of Brian Wesolowski)

ABSTRACT

This dissertation describes the development and testing of a software application known as *The Intonation Machine*. This application was designed as a *Method of Adjustment* style tool to be used by music educators and music education researchers as both a data gathering instrument used measure participants' ability to resolve two sinusoidal tones to a unison, and as a pedagogical tool to help participants improve their basic pitch sense through the aural detection and resolution of beat-interference. Literature regarding intonation perception and performance, intonation pedagogy, additional psychological factors, and ancestor technologies are reviewed. The research methodology known as *Software Development as Research* is used as a framework for the development of the key components of the application. These key components and their functions are described and used to develop a working piece of software. Qualitative data regarding the software was collected from three stakeholder groups (music educators, music education researchers, and music students) and was assessed regarding a number of factors such as ease of use and usefulness for education and research, with a majority of participants reporting the software to be useful for their stakeholder group and relatively easy to use. The implications and potential uses of this software are discussed. The application has been made available for free, and can be found at the URL <https://pastebin.com/PBSrtbij>.

INDEX WORDS: Software, Intonation, Method of Adjustment, Pedagogy, Music Education

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Dedication

To Amanda

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Chapter 1 - Introduction

The ability to perceive and adjust the tuning of an instrument is a fundamental skill for quality performance on any variable pitch instrument such as a violin (Platt & Racine, 1985). For many school music ensembles, intonation skill is considered a prerequisite to quality performances at any level (Dillon, 2002). In order for music educators to develop truly effective teaching strategies they must build those strategies on evidence-based theories which provide explanatory frameworks for how the human brain learns and processes information in various domains and environmental conditions (see Kretchmar, 2017). In order for music educators to design increasingly effective techniques for developing intonation perception and refining intonation skill, evidence-based theories of intonation learning must be developed and refined to provide the foundations for these techniques.

The process of developing a sound, evidence-based theory involves the collection and processing of data (see Dziak, 2018), which may often be long and cumbersome. In recent decades, however, the ability of computers to process data has been increasing at an exponential rate (see Lasky, 2017). Given the decreasing cost and increasing power of contemporary computing technology, it is increasingly possible to use ordinary personal computers for research purposes. In addition to being powerful tools for data processing in research, computers can also be powerful pedagogical tools (see Abramovich, 2012). The ability to gather and process data quickly enough to provide real-time feedback to students engaged in a learning task has great potential for increasing the speed and efficiency at which we learn many things (Wettstein, 2018). Additionally, the Tanglewood Symposium (Choate, 1968) called for the integration of

music technology for the improvement of music education at a time when contemporary music education technologies were limited to devices such as strobe tuners and metronomes that had developed the ability to be set to nonstandard tempos, accent beats, and subdivide (Franz Manufacturing Company, n.d.; Graves-Brown, 2015). In an effort to both answer the call for integration of contemporary music technology into pedagogy, and to support research into the improvement of intonation teaching techniques, the aim of the present investigation is to develop software that supports the furtherance of intonation learning as both a pedagogical tool and a research tool.

Need for the Study

There is both tremendous pedagogical and research potential in computer technology, as well as consistent calls to use contemporary technology in music education. There is also a need to increase and improve the body of literature on intonation teaching and learning. Therefore, the need for this study lies in its potential to improve the teaching and learning of intonation in music education. One of the basic job requirements of most music teachers is to help students develop and perform with accurate pitch. Currently, a large body of research exists pertaining to this topic, including studies that investigated human perception of pitch with guidance on improving intonational performance. These studies will be considered in detail in the literature review.

The present study is needed due to a gap in the literature regarding the collection of certain types of empirical information: namely information on reaction speed in intonation adjustment tasks. The present study is also needed in order to design software that can gather such data for use in future empirical studies on intonation perception and performance. In

addition, while a wealth of software exists for ear training generally, most of these software tools do not contain features that help to improve the basic pitch sense through beat-detection and elimination (see Brown, 2012 for an overview). The software under development in the present study seeks to address both of those needs.

Purpose of the Study

The purpose of the present study is to develop and test software that is both useful for conducting research on intonation perception and performance, and useful for teaching and developing intonation perception and intonation skill. However, as noted by Brown (2007), for researchers using the SoDaR methodology (described in more detail in the methodology section) it is important to:

maintain [...] a healthy skepticism about the degree of control the researcher has over outcomes. In this way control is understood as improvisation rather than direction and there should be a view to generating knowledge by capturing the opportunities that arise – this in the spirit of grounded theory (Strauss 1990). [...] Identifying the valuable opportunities from the distractions requires that a focus be maintained on the educational objectives of the activity.

Research Question

The research questions for this study are as follows:

1. Will this specific software design support a ‘method of adjustment’ type of apparatus to gather empirical data for researchers seeking to improve the teaching and learning of intonation skills?

2. Will this software design also function as an intonation teaching tool that will be useful for educators in the classroom?

Chapter 2 - Review of Related Literature

Intonation Perception and Performance

In order to develop software that can both improve intonation perception and performance, and serve as a research tool for developing more comprehensive theories of intonation learning, a fundamental understanding of the basis and inherent tendencies of intonation perception, discrimination, and performance must be reviewed. Literature regarding those basics and tendencies will be presented first.

Temperament

Because intonation learning is the primary focus in the present investigation, it is necessary to theoretically ground the work in current understandings of how intonation information is processed in the brain. This endeavor is obscured somewhat by the lack of a clear standard regarding what constitutes “in-tune-ness.” This confusion arises because there is little temperament (tuning system) standardization across musical contexts. Indeed, as recently as 2013 a study by McLachlan, Marco, Light, and Wilson (2013) in a publication of the American Psychological Association stated that “to date, no consensus exists in the literature as to theories of consonance and dissonance” (p. 1142). The most standard temperaments that do commonly occur are equal temperament, Pythagorean temperament, and just temperament (Mason, 1960). Just temperament is derived from pure interval ratios against a fundamental pitch, Pythagorean temperament is derived from “a series of [pure] perfect fifths,” and equal temperament is derived from an equal distribution of 12 notes across an octave (Gann, 1997a; 1997b). There has been

research that suggests a biological rationale for intonation perception within the context of a scale, generally (see Gill & Purves, 2009). There is also significant evidence, however, that for intervals larger than a semitone, perception of consonance and dissonance relative to temperament may largely be an artifact of enculturation, rather than a matter of innateness (McLachlan et al., 2013, pp. 1155-1157).

That finding is supported by Kopiez (2003), who suggested that staying within a familiar temperament is easier than attempting to play within an unfamiliar temperament. In a study testing whether professional musicians would adjust the temperament of their playing when a harmonization changed temperaments, researchers found that these professionals had fallen into a strong habit of playing in equal temperament after years of training, and would play equal tempered intervals even when the harmony changed to a just chord (Kopiez, 2003). There are other studies, however, that suggests some musicians are flexible with regard to temperament. One of these studies suggested that a musician's primary instrument on may affect their temperament preference (Mason, 1960). Another suggested that some musicians may alter temperaments, even on the same instruments, as performing situations change (Haack, 1974). Many instrumentalists tend to play with just or Pythagorean temperaments unless keyboard accompaniment necessitates adjustments to equal temperament (Haack, 1974; Mason, 1960). There is also evidence for a preference of equal temperament in melodies and a preference of just temperament in harmonies (Haack, 1974).

Like many topics in this investigation, debates about which of the temperaments are more pleasing or aesthetically "correct" are ongoing and remain unsettled. However, if the harmonic series is used as a biological rationale for scales (Gill & Purves, 2009) it seems to follow that just temperament would be the tuning system that produces the most cognitive ease with the least

amount of training. A study conducted by Edgar Miles gives tentative evidence for this position. In a study we will return to later in this review, Miles (1972) trained participants in beat interference detection and measured their ability to adjust intonation at various intervals. Participants' accuracy diminished as the tasks moved from perfect consonances to imperfect consonances. Regardless of temperament, this seems to give evidence that more foundational harmonies (i.e., harmonies lower in the harmonic series) should be easier to detect. This is supported with evidence that shows humans tend to perceive the fundamental note when they hear a set of overtones, even when the fundamental is removed (Clarkson & Clifton, 1985). Additional studies show that the singing and identifying of harmonies which are very low in the harmonic series (such as octave equivalences) appear to be innate in humans (Levitin & Tirovolas, 2009; Trainor, Tsang, & Cheung, 2002). These studies may give limited evidence for the assertion that just intonation is more primary, as it is a scale derived from pure ratios emanating from the harmonic series.

A clear finding from the information in this section is that intonation becomes more problematic to define as intervals move to more complex ratios. Therefore, to include complex-ratio intervals in the present study would likely present a number of layers of complexity that may complicate the validity of the software as a measurement instrument. Therefore, the present study will be restricted in scope to intonation performance accuracy on pitch matching (unison intervals) alone.

Enculturation

Caution must be taken, however, in discussions of the innateness of intonation tendencies such as the one above. Enculturation plays a large role in the amount of tolerance listeners have

toward mistunings in various directions and at different points in a given culture's musical scale (Larrouy-Maestri, 2018). As elaborated by Asaridou (2015): "experience, whether in the form of simple exposure to or explicit training with linguistic or musical sounds, is expected to explain a large proportion of the individual variation in sound processing." Some aspects of tonal perception may be innate, and some aspects of tonal perception may be influenced by culture. A study by Trainor, Tsang and Cheung (2002) showed that even infants as young as 2 to 4 months old are sensitive to differences in consonance and dissonance, and prefer the former: a finding that supports some of the tonal innateness claims of Gill and Purves (2009). Culture, however, also seems to play a role. One study of cultural influence on musical perception compared 6-month-old infants to adults in mistuning detection abilities for the Javanese gamelan scale and the Western diatonic scale respectively (Lynch & Eilers, 1992; Lynch, Eilers, Oller, & Urbano, 1990). The study found that while adults perceived native scales better than non-native ones, infants perceived native and non-native scales about the same. With regard to the software development process of the present investigation, the inclusion of only pitch-matching (unison) tasks should control for any potential enculturation effects.

Sharpness Preference

One of the most consistently replicated findings regarding these perceptual tendencies is that people perceive flatness with more speed and sensitivity than sharpness. This "sharpness preference" manifests in multiple ways. Research has shown that people detect errors of flatness more easily than sharpness (Geringer, 1978; Geringer & Witt, 1985; Geringer, Madsen, & Dunnigan, 2001; Wapnick & Freeman, 1980), that musicians tend to err on the side of sharpness in performance (Geringer, 1978; Kantorski, 1986; Madsen, Geringer, & Heller, 1994; Morrison,

2000; Papich & Rainbow, 1974; Salzberg, 1980), and that musicians tend to gradually sharpen their pitch, even within the duration of single notes (Geringer & Sogin, 1988; Sogin, 1989). A few anomalous studies contradicting these findings do exist, but they are rare. One such study by Byo, Schlegel, and Clark (2011) measured wind player intonation adjustments and did not find a sharpness preference. However, this discrepancy could be explained by the methodology (all students were flattened before being asked to tune), possibly introducing a bias by making them all tune up rather than down. With regard to the software development process of the present investigation, any differential effects of sharp and flat notes should be negated by the fact that the software selects randomly between either.

Effects of Timbral Differences

Timbral differences also have an effect on intonation perception. Several studies have shown that human perception conflates bright timbres with sharpness and dark timbres with flatness (Madsen & Geringer, 1999; Vurma, Raju, & Kuuda, 2011; Wapnick & Freeman, 1980; Worthy, 2000). Other studies have shown that poor tone quality can also be perceived as poor intonation (Ely, 1992; Geringer et al., 2001; Madsen & Geringer, 1981; Vurma et al., 2011). These findings suggest an interdependent relationship between perceptions of timbre and perceptions of intonation. This interdependence is further supported by studies involving vocal timbre which show that the intonation of a human voice is perceived differently than the intonation of a musical instrument, even if both are equally in tune (Geringer, 2015; Geringer et al., 2001). One striking finding about vocal timbres, in particular, is that people are more likely to think voices are in tune than instruments: a phenomenon that has been coined *the vocal generosity effect* (Geringer, 2015; Hutchins, Roquet, & Peretz, 2012). For the present study, the

differential effects of timbre perception vis-à-vis intonation will be controlled for by the exclusion of traditional musical instruments and the standardization of timbre via the use of a “pure tone” sinusoidal waveform synthesized via computer. Additional features that allow for the selection of a few other timbres (perhaps on a spectrum of dark to light timbres) may also be useful to researchers and educators.

Melodic Direction & Register

The register of a melody and the direction of a melodic line seems to impact how we hear intonation. A study by Russo and Thompson (2005) showed that in higher registers people perceive ascending intervals as wider than descending intervals, but if the intervals are presented in a lower register they perceive the opposite, hearing the descending intervals as wider (Besouw, Brereton, & Howard, 2008). Russo and Thompson's (2005) findings also suggested that intervals over an octave were perceived less accurately than pitches within an octave regardless of musical training, although musical training improved accuracy for intervals confined to an octave or less. There is also research suggesting that register, generally, may have an effect on ensemble tuning. A study by Byo, Schlegel, and Clark (2011) suggested that, despite a popular misconception of band directors, students tune more accurately to notes in the upper middle register than to notes in the lower register. With regard to the software development process of the present investigation, the differential effects of melodic direction can be controlled for by excluding tasks based on musical scales or intervals, in favor of a “pitch slider” that moves continuously up or down. A feature allowing users to select the pitch range used in a given session should also be useful to researchers in investigating these effects, and to educators in logically structuring a learning sequence using the software tool.

Methods for Improving Intonation

Practitioner Opinions

Part of the need for a study such as this is that there has been considerable writing on the subject of intonation teaching and learning from a non-researcher's perspective. Many music educators with considerable experience in the field have offered copious suggestions on this score. Some of these authors argue for their suggestions through logic and deduction, such as connecting intonation to body format (Hopkins, 2003). Other commentators refer to neither research findings, nor logic and deduction, but rely solely on the authors credentials as conductor, professor, or adjudicator for their authority. Two articles that stand out as examples of this kind of writing, include an article which appeared in the *Instrumentalist* magazine written by Jay-Martin Pinner (2000), a university string professor and local adjudicator, and a chapter of *Teaching Music Through Performance in Orchestra Volume 2* written by Jacquelyn Dillon (2002) also a university string professor in addition to being the author of a string methods book.

In these articles, many of the suggestions are hit or miss vis-à-vis the research literature. Despite lacking citations, many of these authors' suggestions are supported by research. For example, both authors suggest singing in rehearsals to improve intonation (Dillon, 2002, p. 43; Pinner, 2000, p. 82): a technique that has some studies directly supporting its efficacy (Davis, 1981; Gordon, 2007; Harris, 1977; Schlacks, 1981; Smith, 1995). Other suggestions such as Pinner's (Pinner, 2000, p. 81) suggestion to train in beat elimination, and Dillon's (Dillon, 2002 41) suggestion to maintain high expectations are also supported by research findings (Miles, 1972; Rosenthal & Jacobson, 1968; Smith, 1995). Other of their suggestions are research neutral. For example, Dillon's suggestion to insist on group correction of pitch by playing non-vibrato, marking half steps in music, playing slow and soft, and spending some time every day holding

out notes, or Pinner's suggestion to have only a few stands play at a time have little research literature to speak of regarding their efficacy. Some suggestions these authors make is actually contradicted by the research literature. For example, both authors suggest the use of finger markers for all beginning students to improve intonation (Dillon, 2002, p. 42; Pinner, 2000, p. 81). This suggestion is in direct contradiction to studies suggesting finger markers make no difference, and may actually be harmful to intonation in the long run (Smith, 1987; 1995). Both authors also suggest "listening down" to the lower instruments to tune more effectively (Dillon, 2002, p. 45), a suggestion which is refuted by Byo et. al (2011) whose work suggests that the upper and middle registers function better as for reference pitches than lower registers. The misalignment between research and practice seems a clear indication that more research on best practices is called for.

Instructional Texts

Among instructional texts on instrumental music pedagogy, there are many suggestions for how to play in tune. According to the American String Teachers Association, singing activities are an integral part of large ensemble string instruction (Benham, Wagner, Evans, Aten, & Odegaard, 2011, pp. 121-143). In *Teaching Band and Orchestra*, Lynn Cooper (2004) also insists that "a major development of in-tune playing is singing;" going on to note that "teaching an instrumental ensemble to sing well and in tune, will lead to an ensemble that plays with better intonation, blend, and phrasing" (Cooper, 2004, p. 121). However, in *Strategies for Teaching Strings*, Donald Hamann and Robert Gillespie (2013) do not mention singing activities at all when outlining best-practices for developing intonation and aural skills in string ensembles. In *Habits of a Successful Band Director*, Scott Rush (2006, p. 56) also leaves out any mention of

singing activities to improve ensemble intonation, instead favoring an emphasis on beat-detection and resolution training.

Research on Director Practices & Improvement Techniques

In a recent study by Ryan Scherber (2014), a number of contemporary pedagogical practices in current use among ensemble music directors ($n = 328$) was investigated. He found that directors seem to prefer live sound sources for tuning notes, and a preference for “bottom-up” tuning strategies where the lowest instruments sound their note first and the rest of the ensemble “listens down” to them (Scherber, 2014, p. 48). One of the most common techniques found to be in current use among directors was vocalizing, but other frequently used techniques included using an electronic tuner, playing against a drone pitch, training in beat elimination, training in musical temperaments, playing chorales, and holding chords (Scherber, 2014, p. 49). Less frequent techniques included the use of instrument tendency charts, discussion of balance/blend/tone, interval training, the use of methods books, and dictation (Scherber, 2014, p. 49). The Scherber study also discovered that the most frequent techniques for developing intonation skill at an individual level involved practice with a tuner and preparing tuning tendency charts, and the less frequent techniques involved the use of software, practicing with drones, and practice vocalizing (Scherber, 2014, p. 50).

Other studies have been conducted that investigated the usefulness of particular learning strategies for intonation. Dalby (1992), for example conducted a study that looked into how a computer based intonation training regimen could improve the intonation perception skills of a group of music education majors taking a conducting course. Dalby's (1992) study suggested a causal relationship between the drill-and-practice training regimen and improvement skills of

pitch discrimination. Liao (2008) also conducted a controlled study of techniques leading to pitch skills, and showed that gestures and hand symbols had a positive impact on vocal intonation in young children.

Instrument-Specific Research

There are some studies into instrument-specific intonation instruction techniques. Empirical investigations into string intonation teaching techniques, for example, are rare and most are over two decades old. In a review of the string intonation pedagogy literature of the time, Kantorski (1992) mostly cites intonation perception studies similar to those cited here. Some of Kantorski's citations, however, do provide additional insight into our inquiry and prompted further study. Among the citations Kantorski (1992) pointed to was a study by Cowden (1972) which revealed that starting violin students in third position is no better than starting them in first position, a study by English (1985) suggesting that piano use in string classes actually hurts intonation skills, and two studies by Smith (Smith, 1985; 1987) suggesting that the use of finger placement markers for beginning violinists makes almost no difference in how well they end up playing in tune, except that the students that had finger markers actually got worse when they were taken off. One of the most interesting aspects of one of Smith's finger marker studies had nothing to do with finger markers, but was a finding that one of the strongest statistical predictors of intonation skill on the violin was students' prior scores on intelligence tests (Smith, 1985), a finding similar to Cowden's (1972) finding that grade point average was a strong predictor of intonation skill.

Beat Detection and Elimination

As mentioned previously, beat detection and elimination has been mentioned explicitly in widely available best-practices texts for in-service music educators such as *Habits of a Successful Band Director* (Rush, 2006, p. 56). This method of measuring intonation perception and performance (through the ability to tune a variable tone to a static tone using some kind of slider or dial) has a history in psychoacoustic research, and is known as the *method of adjustment* (MOA) system (Burns & Ward, 1978). The earliest experiments using the MOA system were conducted by Moran and Pratt (1926), and utilized a machine called a *Stern Tone Variator* that utilized a mechanically engineered pump that would produce a consistent pitch which would go up or down with the press of a lever. This early study revealed that among three musical experts attempting to tune a harmonic perfect fifth, the mean error was 14.8 cents (Moran & Pratt, 1926). With improved electronic technology in the mid-twentieth century, the MOA apparatus was updated by Ward (1954) which used electronic oscillators (which generated sinusoidal waves), amplifiers, earphones, and other electronic equipment instead of air. An experiment done by Ward (1954) with this apparatus revealed similar results to earlier studies, showing that a group of professional musicians tuned octaves with a mean error of 10 cents.

A study by Miles (1972) began to apply the MOA system to music education. Miles (1972) created an MOA device similar to one used in the Ward (1954) study (which he labeled the “Intonation Trainer”) that produced two different sine waves between 20Hz and 500Hz which could be adjusted using two dials (Miles, 1972, p. 3). With the Intonation Trainer, Miles would establish a reference pitch by turning one dial and the participant would then manipulate the second dial to match the first (Miles, 1972, p. 3). Participants were also trained in beat-detection and elimination with the intervals of a perfect fifth and a major third (Miles, 1972, p. 3). In order

to transfer learning, subjects were then asked to execute the same process on their wind instruments (Miles, 1972, p. 3). It is not entirely clear from the research report how accuracy data was collected, but it appears that success or failure to correctly resolve beats or play in tune was rated by the single researcher alone (Miles, 1972). This fact, combined with the lack of a control group, introduces the potential for a number of confounding variables and decreases the internal validity of the study considerably (Miles, 1972). However, the results of the study appear to suggest that the beat-elimination process was beneficial, resulting in improved intonation among subjects, and further experimental research is called for (Miles, 1972).

Additional studies have been conducted using the MOA system approach, however, most of these studies collect data related to mean error of pitch in pitch resolution exercises and do not address intonation learning, or speed of intonation adjustment. One such study is that of Elliot, Platt, and Racine (1987) which examined the difference between musically experienced and musically inexperienced participants vis-à-vis their ability to tune a perfect fifth in an MOA task. The result of that study was that musically experienced participants had a mean error of 11.6 cents, while the musically inexperienced participants had a mean error of 20.2 cents. A study by Demorest lends evidence for the ecological validity of the MOA task as a proxy for intonational aural skill by showing that consistently in-tune singers perform significantly better on MOA tasks than inconsistently in-tune singers (Demorest, 2001). MOA measurement tasks have begun to be implemented using computer software as well. A study by Demorest and Clements (2007) used a software program called the *Pitch Matching Perception Test* (PMPT) which administered MOA tasks via computer to adolescent boys in the 6th through 9th grade, and resulting in a successful replication of the earlier Demorest (2001) study. Another example of MOA task software was developed by Hopkins (2014) which included features that could measure pitch

matching tasks for a unison or perfect fifth. The software (named the *Tuning Perception Test*) was written in the Processing language; a common programming language for computer music (Hopkins, 2014). Again, however, this software was designed to measure accuracy in an MOA task, not assess speed or effectiveness of MOA tasks as teaching tools. The Hopkins (2014) study did show that string players tend to do better at MOA tasks with more years of training; a finding that fits with those of previous studies showing similar differences among singers (Demorest, 2001; Demorest & Clements, 2007).

The connection between pitch perception (as measure by MOA tasks) and pitch skill on a voice or instrument is not so clear, however. The problem is outlined clearly by Powell (2010) who noted that:

Although it may seem counter-intuitive, the research has shown no consistent relationship between the ability to hear and identify intonation problems (perception) and the ability to perform in-tune on a wind instrument. Students who excel at aurally identifying intonation problems may not necessarily transfer that skill to intonation performance on instruments. [...] Intonation performance problems on wind instruments may often result from the difficulty in manipulating pitch with the embouchure or a lack of air support rather than problems perceiving pitch issues. Additionally, differing timbres and tone qualities seem to play a factor. This suggests that intonation perception and intonation performance may be discreet abilities (e.g., Ely, 1988, 1992; Geringer, 1976; Milsap, 1999; Yarbrough, Karrick, & Morrison, 1995; Yarbrough, Morrison & Karrick, 1997) (Powell, 2010, p. 91).

This may explain, for example, why much advice on intonation improvement in large ensemble instruction places a primary focus on technical issues such as posture and tone production over

perception enhancement techniques such as beat detection and elimination. However, it stands to reason that without intonation perception as a foundation (i.e., being able to hear when something is out of tune), one would not be able to make the proper adjustments to perform in tune: even with the proper physical technique. This difference between pitch perception and performance is also contrasted, somewhat, by the findings of MOA studies which showed a significant correlation in the ability of subjects to accurately perceive pitch errors and to perform with accurate intonation on a string instrument or voice (Demorest, 2001; Demorest & Clements, 2007; Hopkins, 2014). Although it is beyond the scope of the present investigation, future research should investigate the nature and potential ways to improve transfer between intonation perception and intonation performance and to further clarify this relationship. Indeed, the software tool created in this study may be of help in investigating that very question.

Binaural Diplacusis

While the software being developed in this study can be used with either mono speakers, stereo speakers, or stereo headphones, there is a potential threat to the measurement validity of the software in the form of a psychological phenomenon known as binaural diplacusis. There is some evidence to suggest that some individuals may perceive pitch differently depending on whether the pitch is presented to the right ear or the left (Colin, Micheyl, Girod, Truy, & Gallégo, 2016), especially among those with low-tone hearing loss (I. Ichimiya & Ichimiya, 2019). To correct for any potential confounds due to binaural diplacusis, the two test tones will not be routed to separate stereo channels, but all digital signal output in the application will be routed to one mono channel, with the same sounds (including the tones of both pitches) coming out of any speakers or headphones attached to the computer.

Response Time as a Useful Measure of Cognitive Skill

The first research question of this study asks how we can design a software architecture that provides useful data to researchers investigating ways to improve intonation performance. It is therefore important to determine what types of data would be useful in that way. One potentially useful type of data for this purpose may be a measurement of the time taken to achieve correct pitch in a MOA task (reaction time). As has been indicated previously, most MOA studies that have been conducted have collected accuracy data as the main form of data. Few, to date, have measured reaction speed as a useful variable. As will be described below, one potential reason for this may have been the lack of available computer equipment with which to measure speed data. However, before hypothesizing as to the reasons for the dearth of studies using this form of data, a commonsense outline of why speed data may be important will be presented.

A common technique used by music educators to improve intonation performance on instruments of variable pitch is to have students attempt to match a pitch (or a specific interval in relation to a pitch) and, if their muscle memory is not sufficiently developed to achieve the correct pitch immediately, to use their ear to adjust to the correct pitch as quickly as possible (Dillon, 2002). Even among professional musicians who play instruments of variable pitch in ensemble settings, minor relative adjustments to pitch must be done quickly and accurately to reach a consensus pitch (Papich & Rainbow). Speed of adjustment, therefore should be considered a useful variable when examining methods used to teach intonation performance, and developing psychological constructs of intonation performance upon which those methods will be based.

Outside of a purely musical context, speed is frequently considered a first-order latent factor in theories of cognitive ability (Bouchard & McGue, 2003; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Roberts & Stankov, 1999; J. J. Thompson, Yang, & Chauvin, 2009). Deary (1989) notes that:

There are three main indices of processing speed (Mackintosh, 1989) which are found to correlate with ability test scores; namely, various measures of reaction time (e.g., Jensen & Vernon 1986), components of brain average evoked potentials (Blinkhorn & Hendrickson, 1982), and inspection time (Nettlebeck, 1987; Vickers, Nettlebeck, & Willson, 1972). (Deary, 1989).

The fact that speed is considered such a latent factor of cognitive ability which presents in multiple domains, that it is considered an index of cognitive processing speed, and the face validity of gradual increases in student intonation adjustment speed as an educational goal all seem to suggest that software capable of gathering data on the speed of intonation adjustment would be useful. The fact that few older studies using MOA systems used speed as a variable is not surprising, however, as most psychological testing paradigms did not track reaction time as it was not practical to do so prior to the advanced capabilities and wider availability of computer technology (see Wang & Hanson, 2005).

Software for Education and Music Pedagogy

In recent decades, there have been a number of software programs that have sought to either improve or assess skill at musical tasks. These programs have typically fallen into three categories: (a) aural skills suites, (b) tuners & metronomes with enhanced features and feedback,

and (c) music assessment software. The most prominent software programs in each category will be explored in the following paragraphs.

Aural Skills Applications

There are a variety of aural skills software currently on the market. For the sake of concision, discussion of these suites will be limited to their use as tools for improving tonal aural skills, omitting any rhythmic aural skills features that may also be included. The majority of aural skills software products focus on tasks that one would encounter in a freshmen-level college aural skills class. These include features that train users in things such as the identification and performance of various intervals, scales, chord qualities, and chord progressions. A popular software suite called EarMaster (“EarMaster - Music Theory & Ear Training on PC, Mac and iPad,” n.d.) presents a number of lessons, followed by activities and drills which are sequenced by level of difficulty and require the user to not only identify and select the correct answer, but to input sound (vocal or otherwise) into the microphone for pitch analysis and assessment of accuracy. EarMaster thus serves as both a pedagogical tool, and an assessment tool. EarMaster, however, does not address instruction or assessment in basic pitch sense via any MOA approach. It is also oriented toward more advanced and serious music students and is not recommended for the younger or less experienced (Ajero, 2017). The Auralia (“Auralia,” n.d.) software suite offers essentially the same features and also omits any features for training the basic pitch sense. Similar features (and omissions) can also be found on software suites for mobile phones such as Perfect Ear (Osmanov, n.d.).

Despite the focus of most ear training software on traditional ear training curriculum, there is extant software that focuses on training other aspects of aural perceptual skills. One such

application is Sound Gym (“Sound Gym,” n.d.). This application is geared primarily toward audio engineers seeking to improve their timbral perception in order to better mix and master audio recordings. This application, however, is also void of features designed to train the basic pitch sense.

Tuning Applications

Electronic tuners have been available to aid in the teaching, learning, and assessment of intonation since at least the 1960s (Graves-Brown, 2015). The main feature of such devices is a display where users receive visual feedback about whether or not the pitch they are currently playing corresponds to a predetermined reference pitch. This feature is of obvious pedagogical use (providing feedback to the user about the accuracy of their performance and which direction to alter the pitch in order to correct it) and assessment use (accuracy information on the display used to provide an assessment of intonation performance skill). These tuners have become more feature-rich and compact over time (Brown, 1995), and in the present day, mobile phone applications are able to provide all the same functionalities as early tuners with a number of additional features.

Of the more feature-rich tuning applications available is Tonal Energy (McKeever, n.d.). There are four main interfaces in the Tonal Energy application. In each interface throughout the application, the user can either view the feedback while performing or chose to record themselves and view the feedback after they finish. The first interface (labeled “Tuner”) is a both a traditional tuner which gives color-coded visual feedback, and also a far more advanced tuning interface which contains numerous options regarding sensitivity of in-tune range, temperaments (including rare and historical temperaments), transpositions, timbral inputs (wind, string, voice),

and damping (sensitivity to variations in post-attack pitch vis-à-vis the difference between an A played on a guitar and an A played on a violin). Users are also able to access a built-in metronome start/stop button from this interface. The second interface (labeled “Sound”) is a sound generation device which plays (with or without sustain) any chromatic pitch. Users can select the timbre of the pitch from a number of options including pure waveform, string, brass, wind, and organ timbres. In the center of the pitch wheel (where users select the note they wish to play) the visual tuning display from the first interface is still visible. The third interface (labeled “Analysis”) contains a split-screen. On the top of the screen is a miniaturized version of the “Tuner” interface. On the bottom of the screen is a display that shows an analysis of the sound (which could either be the real-time sound of the musician or an audio file recently recorded within the application). This analysis displays the sound as either a waveform/pitch, a spectral analysis, or an analysis of the relative energy of various harmonic overtones. The fourth interface contains an advanced metronome which is able to most conceivable meters and subdivisions, contains an option panel where users can make decisions regarding accent, light, metronome timbre (with a wide range of sound options) volume, whether or not to count out a measure before beginning, and whether or not to get gradually faster each measure. This is clearly an advanced application with wide-ranging pedagogical and assessment uses. However, there are no pitch comparison or beat-detection training features such as those present in MOA studies, and there is no way to export analysis data in order to subject it to any statistical analysis for research purposes.

A mobile phone tuning application that does come closer to beat detection training is the Intunator (“Intunator,” n.d.) application. This is a rather straightforward and simple app purports to develop pitch sense in users through real-time audio feedback. The user is instructed to plug in

headphones to the phone, select the instrument they are using, and begin playing. The application automatically detects the note the user is attempting to play, and (rather than giving visual feedback) gives audio feedback by playing that note (using the appropriate instrumental timbre) back to the user in their headphones with the correct intonation (similarly to auto-tune). The user is then confronted with the presence of beat-interference if the note is not in tune. The application is marketed as a practice aid for intonation training. This seems to be the closest commercial application on the market to a MOA-type interface for beat-detection intonation training.

Intonation Assessment Applications

Regarding intonation assessment technology, much has already been covered in this review in the section on beat detection and method of adjustment literature. The Pitch Matching Perception Test developed by Demorest and Clements (2007) and the Tuning Perception Test application developed by Hopkins (2014) were both explicitly designed to assess intonation skill and have already been discussed. The widely-used SmartMusic software ostensibly assesses pitch accuracy within the performance assessment feature (Buck, 2008), one of the most useful features of this program is the ability for users to replay their performances at various tempi while they observe visual feedback in the form of musical notation (with correct and incorrect notes marked) as well as a traditional tuner that displays pitch accuracy in cents. SmartMusic, however, does not have any features for aurally comparing incorrect pitches to correct reference pitches and therefore does not address instruction or assessment in the basic pitch sense and beat detection.

Max/MSP

In order to develop software, it is necessary to work with a programming language. According to the publication materials, Max/MSP is a “visual programming language for the specialized needs of artists, educators, and researchers working with audio, visual media, and physical computing” (“Cycling '74: Tools for sound, graphics, and interactivity,” n.d.). It was developed primarily by Miller Puckette in the mid 1980s at the Institute for Research and Coordination in Acoustics and Music in Paris (Puckette, n.d.). Since its initial development it has come into wide adoption for the composition of electronic music, and to develop individualized interactive music systems for performance, education, and research (Manzo, 2016).

It is distinguished from most other programming languages by the fact that programmers do not construct applications using text-based code, but rather assemble visual programming objects. The user interface is, in many ways, quite similar to the way early modular synthesizers were assembled by connecting the various modules via patch cables; indeed, the earliest version of the Max/MSP environment was known as “The Patcher” (Puckette, n.d.). While this may be an apt analogy, it is incomplete. While analog signal data is transferred between modules (just as in early modular synthesizers), Max/MSP allows users to transfer data such as numbers and text between modules as well, and can also (in some cases) convert analog signal information into digital information. This flexibility, extensive development over several decades, orientation toward audio, and extensive documentation on the function of each module within the language suggest that Max/MSP is uniquely suited for the present research. Additionally, its widespread use and long history make it more likely that an application made to run in the Max/MSP environment will be used by other educators and researchers in the future, and perhaps developed further.

Chapter 3 - Methodology

Methodological Framework

The concept of software development as a research methodology in music education is not a new one. Andrew Brown (2007) proposed a new approach to arts education research which he called Software Development as Research (SoDaR). Software development, he argued, “can externalize ideas, stimulate action and reflection, and provide evidence to support the educative value of new software-based experiences” (Brown, 2007). Brown’s model of SoDaR will be used as the basis of the present investigation. This framework has three stages, and according to Brown “at each stage, the researcher is encouraged to describe the objectives for that stage, collect data resulting from work undertaken at that stage, and to reflect on the outcomes, problems, and progress of the research to that point” (Brown, 2007).

The first stage is to define the activity. This stage would include descriptions of the educational or research potential of the software in question and its initial specifications. This also involves making explicit any educational theories and assumptions and explaining how these theories and assumptions would be integrated into an initial prototype (Brown, 2007). The second stage of Brown’s SoDaR model is software design and production (Brown, 2007). This stage involves taking the specifications outlined in the first stage and engineering computer software that fits those specifications. The third stage of Brown’s SoDaR model is usage and refinement. During this stage, there are several iterations of others using the software and researchers using the data gathered from those sessions to further refine the software (Brown,

2007). The present investigation will operate under the methodological assumptions of this framework.

Stage 1: Defining the Activity

Stage one of the SoDaR model asks that the researcher describe the educational or research potential of the software in question and its initial specifications. The primary educational potential of this software is that it may serve as a pedagogical tool to teach students intonation skills by allowing them opportunities to practice detecting beat-interference in two sinusoidal tones and resolving the two tones to match one another. There is some evidence that practice such as this can lead to improvement in intonation learning outcomes (Miles, 1972), however gathering additional evidence for the efficacy of such methods for intonation instruction is also a potential way music education researchers could use this software, as it can be used as a data-collection tool; providing researchers interested in intonation perception and performance with data on the speed (in milliseconds) taken to resolve two sinusoidal tones into a unison pitch. Further tests and data gathering with a tool such as this may provide additional insight into the efficacy of MOA-type devices for pedagogical use. Software is the best medium for this type of experience due to its ability to give real-time feedback to users about their intonation performance and due to its ability to easily gather precision speed data.

The initial specifications for this software involved:

- a means of generating an initial tone which would remain fixed throughout a single iteration within a session,
- a means of generating a secondary tone which the user is easily able to adjust until it is in unison with the fixed tone,

- a timer that is triggered when the user generates the secondary tone,
- a subroutine that stops the timer when it detects that the user has adjusted the movable tone to match the fixed tone,
- a subroutine that collects the speed data in numeric form,
- a subroutine that resets the software to its initial settings when the user is ready for the next iteration,
- a subroutine that exports numerical data to a common file-type,
- subroutines that inform the user on what to do via messages or other displays, and
- a graphical user interface.

Stage 2: Software Design, Production, and Measurement Reliability

General Overview

The overall purpose of the software designed for this study (referred to hereafter as the *Intonation Machine*) is to train people in beat interference detection and elimination, and to investigate relevant questions in music psychology and pedagogy (vis-à-vis intonation) through the creation of a digital MOA-type apparatus modeled on the one used in Miles' (1972) study. In addition to the ability to carry out the same operations through software that earlier apparatuses carried out through hardware, this apparatus will contain the additional features of randomizing the fixed tone of each example within a user-selected range and gathering user data regarding the speed of intonation adjustment for assessment and research purposes.

Design Considerations

The software design described above required several interlocking components to function. The first group of components to be considered were those that involve the

management of audio which will be heard and manipulated by the user (*audio management components*). These components fell into two classes: (a) *range selection* and (b) *tone generation*. The range selection component needed to give the user the ability to choose the range of frequencies to be selected from for each session. This component served the dual roles of defining the maximum and minimum frequencies possible for the randomized fixed tone, and the minimum and maximum frequencies possible for the variable pitch user interface component. The tone generation components were divided into two separate components: a *fixed tone generator* and a *variable tone generator*. The fixed tone generator needed to receive and store the initial user-selected range, and then to send a command to a sinusoidal oscillator object to generate a random tone within that range when directed by the user. Similarly, the variable tone generator needed to do everything the fixed tone generator would do, but in addition, the user-selected range also needed to limit the degree to which the user could adjust the variable frequency via the user interface (allowing some additional space at the extremes of the range to help control for user guessing). These tone generation components will also need to be programmed to turn off after (a) the user has matched both pitches and (b) the program has recorded the data.

The second group of components to consider were the *data management components* which handled the calculation and processing of important data throughout the program. These components fell into two classes: (a) *speed measurement*, (b) *data storage*. The speed measurement component needed to (a) begin a stopwatch when the user triggers the variable tone, (b) continuously monitor both tones to detect if they match, (c) stop the stopwatch after the two pitches match, and (d) send the timing data to the data storage component. One design consideration for the data management components was how to account for user guessing

behavior. If the stopwatch were simply designed to stop as soon as the two frequencies matched, the user could easily turn the dial randomly until it stopped (given the processing speed of modern computers). If measurement validity is to be ensured, the speed measurement component should be designed such that the user must make a firm decision that the two pitches are identical before they are considered successful. An engineering solution to this validity problem involved requiring the user to settle on their solution for three seconds before the timer is stopped. An accounting for that delay in the data is described in the Data Design section below. After the stopwatch had stopped, the speed measurement component would send a user message indicating success and prompting the user to continue. The continue press would trigger the data storage component which, having received data from the speed measurement component, would take that data and store it in a buffer until prompted by the user to export it.

Lastly, the software needed *user interface components* that are intuitive enough to be used with relative ease by students, music educators, and music education researchers. These components included instructions for users, interactive objects that allowed users to adjust the basics of the sound such as volume, interface components that allowed users to select frequency range, buttons to trigger the fixed and variable pitches, user messages about the status of the program, buttons that export data, and buttons to reset the program. Additionally, for the *Intonation Machine* to be a true digital analog of the MOA device described in Miles (1972), a physical/hardware dial was used to control the variable pitch component. This was done by mapping the user interface dial object to move up and down with up and down keystrokes such that an external dial capable of being mapped to keystrokes (such as the XP-Pen AC 19 Remote) could be used to control the program.

Data Design

The first step in the dataflow will be the input of frequency ranges by the user. Users must select the frequency ranges they wish to use, and must turn on the audio and adjust the volume before continuing. This was made clear in the user instructions visible in the main user interface. The user would then push a button to trigger a random frequency within the selected range to be used as the fixed frequency. The user would then push a second button to trigger the variable frequency and the internal stopwatch. The speed measurement component would monitor the two frequencies to see if they remain matched for three seconds, at which point it would stop. The user would be informed of success and prompted to continue. Upon the continue press, the stopwatch object would send the speed datum of that iteration to the data storage component, which would create an ordered pair with the iteration number followed by the speed datum, the two separated by a comma and finalized by a semicolon to conform to csv format for later research use. That datum and all data of subsequent iterations (up to a hundred) were to be stored in a buffer object. The user would then receive a message that the data from that iteration has been recorded. The tone generators would stop, and the user will be free to either complete another session or click on the save button to export the extant data to a text file. A reset button will be located on the user interface which, if selected, clears the data buffer and resets the iteration number to one.

Component Design

The range selection component received input from the user interface, and output to functions within the tone generators. Due to its origin in music technology (and therefore MIDI),

one limitation in Max/MSP was the restriction of many user objects (including sliders and dials) to a scale of zero to one hundred and twenty-seven (as this is the standard data range of much standardized MIDI data types). In order to allow the user to select any frequency range (in Hz) and also to allow the manipulation of those tones with a dial object, it was necessary to convert any user selected range into an array of one hundred and twenty-seven evenly spaced steps within the selected frequency range while allowing for an additional step at the top and bottom to prevent user success due to guessing behavior. To program these tone generators, an algorithm is first needed which is able to convert integers within the 127 range into evenly spaced steps within the desired frequency range and place a randomly generated step between 1 and 126 on the appropriate relative step in the user selected frequency range. This will be referred to hereafter as the *frequency generation algorithm*. For the frequency generation algorithm, let R be a random integer between 0 and 125, let a be the user-selected minimum frequency, and let b be the user-selected maximum frequency, and let xHz be the frequency of the sine tone output. The frequency generation algorithm can be expressed as Equation 1. The fixed tone generator only needed one instance of the frequency generation algorithm controlling a sine-tone object to function properly. Figure 1 displays the implementation of the frequency generation algorithm for the fixed tone generator component in Max/MSP.

$$(R + 1) \left(\frac{a - b}{127} \right) + a = xHz \quad (1)$$

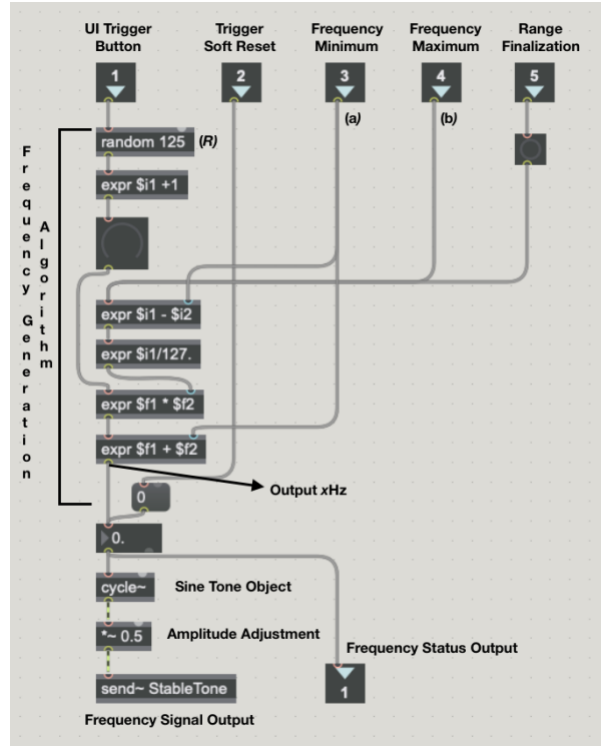


Figure 1. Fixed tone generator component implementation in Max/MSP.

The variable tone generator, however, also needed algorithms to account for the user's ability to manipulate the frequency with a dial, and to make sure the frequency adjustments steps up or down begin at the initial randomly generated frequency. To program the variable pitch generator an algorithm was needed that could convert dial movements to steps up and down within the parameters and at the origin determined by the frequency generation algorithm. The algorithm controlling that process will be referred to hereafter as the *frequency adjustment algorithm*. For the frequency adjustment algorithm, let U be discrete user dial movements up and down, with each step up constituting an integer of 1 and each step down constituting an integer of -1, let yHz be the new frequency after being adjusted by the user, and let xHz be defined as the result of the frequency generation algorithm. For each discrete dial movement, the frequency adjustment algorithm can be expressed as Equation 2. In addition, a keystroke mapping of *up* keystrokes to $U = 1$, and *down* keystrokes to $U = -1$, along with a mapping of discrete clockwise dial

movements to up keystrokes and counterclockwise dial movements down keystrokes should allow the user to manipulate the frequency with an external hardware dial. For the purposes of the present investigation, the hardware dial being used is an XP-Pen AC 19 Remote. Figure 2 displays the implementation of the frequency adjustment algorithm for the fixed tone generator component in Max/MSP.

$$xHz + U = yHz. \tag{2}$$

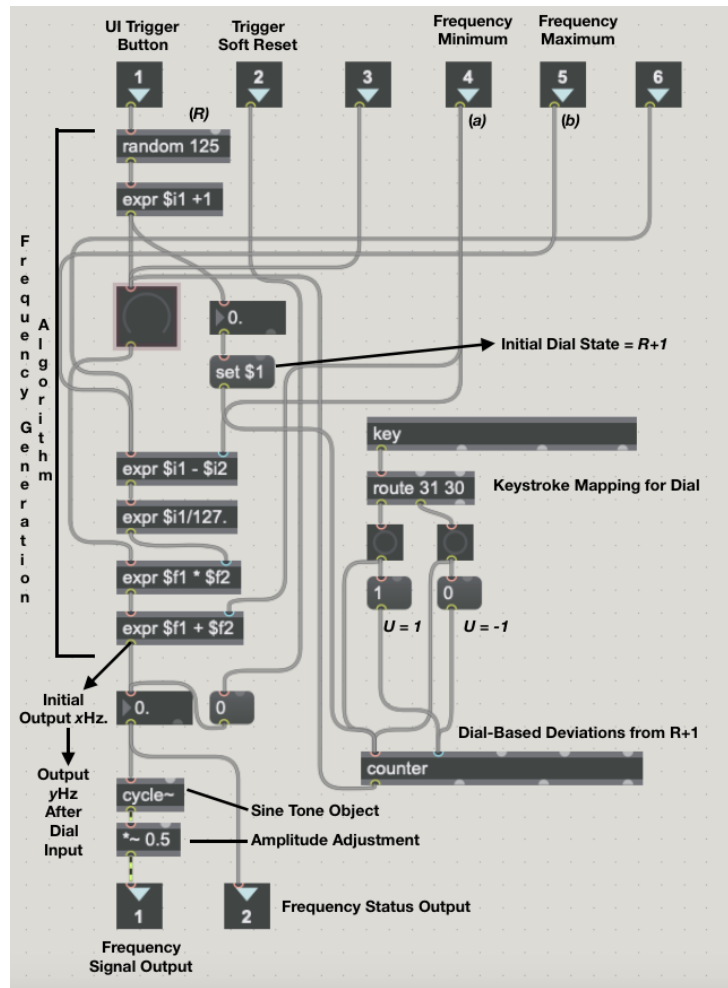


Figure 2. Variable tone generator component implementation in Max/MSP.

To summarize the algorithmic specifications for the audio management components, the range selection components supplied data to both audio management components. Within the audio management components, the fixed tone generator only needed to utilize the frequency generation algorithm, while the variable tone generator needed to utilize both the frequency generation algorithm and the frequency adjustment algorithm. All tones reverted to a frequency of 0 Hz upon the user's press of a continue button upon completion of an iteration, hereafter referred to as the *soft reset*.

The data management components will now be discussed, beginning with the speed measurement component. The same user interface button that triggered the variable pitch generator to begin also triggered a stopwatch within the speed component measuring time in milliseconds. The speed measurement component was designed to continuously compare the output frequencies of the fixed pitch generators and the variable pitch generators to see if they match. Once the two frequencies match a command to stop the stopwatch was to be triggered on a three second delay. If the two frequencies ceased to match, that command would be canceled. Once the delayed command successfully reaches the stopwatch, the stopwatch would stop, reset, and display a user message to continue. Stopwatch data from the particular iteration was to be sent to the data storage component when the user presses continue. The speed processing algorithm can be expressed as Equation 3, where S is the speed datum to be read by the data management component and x is the raw speed data from the stopwatch in milliseconds. Figure 3 displays the implementation of the speed measurement component in Max/MSP.

$$S = \frac{x}{1000} - 3 \quad (3)$$

The data storage component needed to join the particular iteration number with the speed datum of that iteration and store it in a text file as a comma-separated ordered pair. Iteration numbers were appended from a list of one to one hundred (using the Max/MSP *qlist* object) for each session until the user presses the reset button, hereafter referred to as a *hard reset*. Once the numbers were joined into an ordered pair they were to be stored in a text buffer using the Max/MSP *coll* object. The user could retrieve this data from the text buffer by clicking on the *save* button in the user interface. In the unlikely event that both pitch generators return the same frequency on first press, the data storage object will return an error message indicating that the data can no longer be used and the program must receive a hard reset. Figure 4 displays the implementation of the data storage component in Max/MSP.

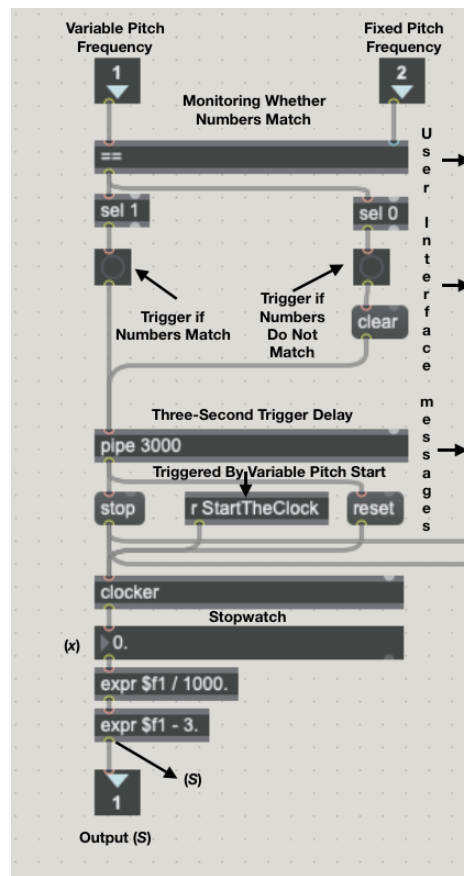


Figure 3. Speed measurement component implementation in Max/MSP.

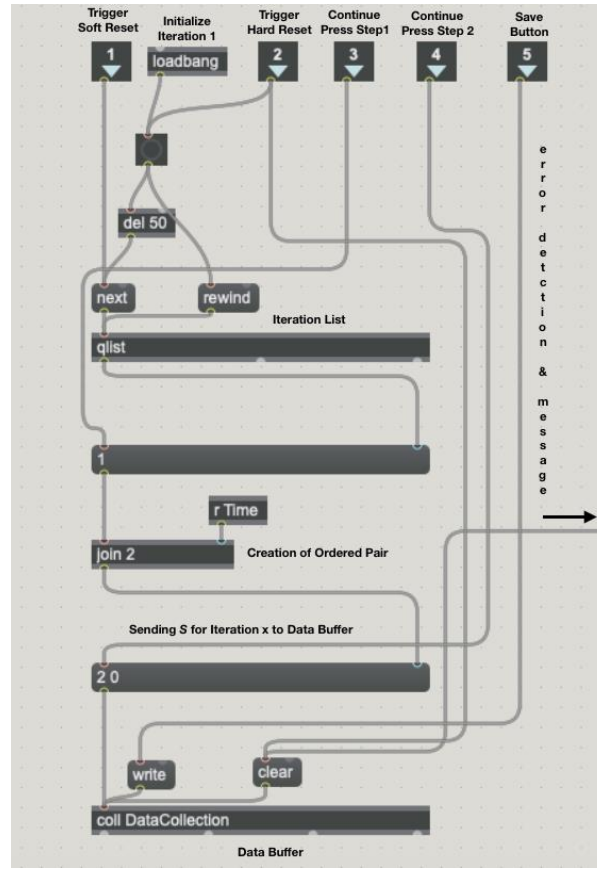


Figure 4. Data storage component implementation in Max/MSP.

User Interface Design

The user interface consisted of (a) the main interface, (b) instructions, (c) settings, and (d) options. The main interface consisted of (a) audio on/off and volume control, (b) buttons to trigger the fixed tone and the variable tone, (c) a visual display of the dial state, and (d) messages for the user. User messages were to include whether the two tones match (resolved or not resolved), and prompt for continue presses, status of the session, and error messages.

Instructions for how to use the program were to appear as static text in the user interface. The settings interface contained number boxes that could be adjusted with integer numbers to define the minimum and maximum frequencies desired for the session, as well as a button to

finalize those settings. The options interface contained a button to save results (export as a text file) and to reset (a hard reset of the program). Figure 5 displays the implementation of the user interface component in Max/MSP.

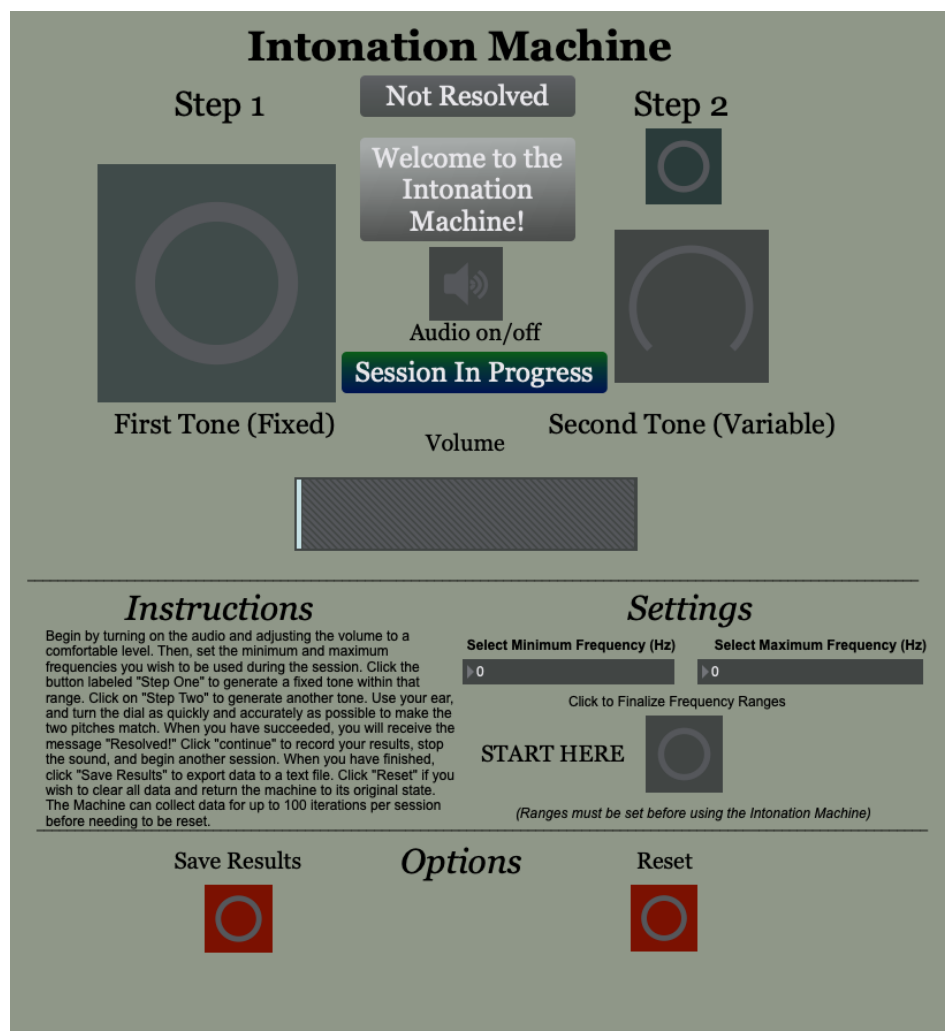


Figure 5. User interface component implementation in Max/MSP.

Stage 3: Software Usage and Refinement

According to Brown (2007), the third stage of the SoDaR methodology involves “several iterations of student engagement in the activity and software revision,” as well as a “description of the experience as a ‘lesson plan’ [...] and notes [...] for each activity session detailing actions

and behaviors of students, comments made by participants, and observable successes and failures.” This implies that this stage of the research process is where most data is to be collected, analyzed, and used to refine the final software product.

The research questions presented involved at least three significant stakeholders who would be involved in the use of this software: (a) researchers interested in using the software for intonation research, (b) music educators interested in using the software as an intonation teaching tool, and (c) the students who would be using the software in either a research or educational setting. According to Brown, SoDaR should be conducted in “the spirit of grounded theory” and that “reporting structures for SoDaR projects naturally lend themselves to a narrative focus that follows the progress through each stage” (Brown, 2007). In describing the sampling process for grounded theory, Morse (2007) makes the observation that “an excellent participant for grounded theory is one who has been through, or observed, the experience under investigation.” (p. 231). She goes on to note that qualitative sampling “often begins by recruiting participants solely based on whether they have experienced the research topic in question.” (Morse, 2007, p. 232). The sampling method for the present study will be theoretical sampling which is described by Morse (2007) as a sampling methodology wherein “participants are selected according to the descriptive needs of the emerging concepts and theory, [and] these needs dictate the sampling strategies and goals” (p. 235). Morse (2007) describes the theoretical sampling methodology as follows:

Researchers deliberately seek participants who have had particular responses to experiences, or in whom particular concepts appear significant. These participants are then asked to tell their story, adding to the existing data set about a particular concept or category; the participants may also be asked targeted questions, and the resulting data

may be used to verify the theory in its entirety. The participants may also be asked to supplement information about linkages between two categories, hence contributing to the emerging theory. *Negative cases*, or participants who have not responded in the anticipated way, or who have opposite reactions to the majority to a particular phenomenon, are called negative cases. In grounded theory, negative cases are not discarded, but rather integrated into the emerging theory. Negative cases are therefore a part of the sampling process, and cannot simply be ignored or discarded. [...] The trick in grounded theory is therefore to determine the differences between a negative case and what quantitative researchers refer to as an outlier. (Morse, 2007, pp. 240-241).

The sampling and data collection methodologies, therefore, hewed closely to this description, while also intentionally diversifying the sources and methods of data collection through triangulation.

The sources of data were triangulated using three different types of interview subjects for whom the software under development appeared significant, per Morse (2007). Participants ($n = 15$) included music education researchers actively employed in music departments at institutions of higher education ($n = 5$), in-service or retired music educators ($n = 5$), and adult students currently studying music through a community choir ($n = 5$). The methods of data collection were also triangulated by using three different types of data for analysis: (a) video recordings of participants using the software, (b) field notes taken by the researcher of software testing sessions, and (c) structured interviews with participants after the software testing session.

For the initial data collection, participants sat down in front of a laptop computer running the software under investigation. Standard consent forms from the University of Georgia Office of Research were signed by all participants. A video camera was set up behind each participant

and recorded participant interactions with the software and with the researcher. The researcher explained how the program works and answered any questions about the program that participants might have had. The researcher then explained the potential relative usefulness of the software for intonation pedagogy and data collection and asked each participant to reflect on those uses as they test the software. As participants used the software the researcher took field notes, describing any participant reactions that either conformed to or defied expectations. After they were instructed in its use, participants were encouraged to test the software for as long as needed to familiarize themselves with how it worked. However, participants were also informed that they may test it for a longer period if they wish. After the software testing session, participants completed a structured interview with the researcher (see appendix A) which was recorded with digital audio. All audio recordings were then converted to written transcripts for data analysis (see Appendix B). All data was stripped of personally identifying information and replaced with a code (Music Student 1, Researcher 3, etc). A spreadsheet indicating the identity of participants, as well as all audio and video footage was kept on a password protected USB storage device which was erased at the conclusion of the study.

After the data was collected, each data stream was analyzed through an inductive coding methodology. Initial coding involved exploring all streams of data for common themes. The common themes that emerged from this exploratory process constituted the initial set of codes (see Appendix C). After the initial set of codes was established, each stream of data was coded with the initial codes: field notes and interview transcripts received line-by-line codes and video data received a timestamp code. After the coding process was complete, similar codes were organized into categories and the broader implications of the coded data in each category was

synthesized into a narrative about the strengths and weaknesses of the software for its intended purposes.

After the data was analyzed, a member-checking procedure was conducted to bolster the internal validity of the results. Following the member checking methodology of software development research proposed by Santos, Magalhães, and Silva (2017), overall results were presented to participants in the form of the following assertions derived from those results.

- Clear and concise instructions need to be included to help new users familiarize themselves with both how the program works and how it should be used.
- The interface could be re-arranged in such a way that the steps for using the app are clearer to the user.
- Once the user has learned the initial steps for using the app it is relatively easy to use.
- This app could be useful to music students for training their ability to match pitch (students only).
- This app could be useful to music educators for training their students to match pitch (educators only).
- This app could be useful to music education researchers for answering questions about things such as pitch perception and intonation performance skills (researchers only)
- The frequency-range selector should be made more user friendly by allowing users the option to pick pitches on a keyboard rather than only allowing users to input a frequency in Hz.
- Users should be given the option to temporarily mute one of the sounds in order to only hear one or another of the two tones in case they forget or are no longer able to hear the original pitch.

- In future versions of this app, the option to match various intervals (harmonies) in addition to matching a single note would be useful.

Participants will rate each of those assertions on a 4-point, forced choice, Lykert-type scale. Internal validity was said to be supported if the average rating of each item pointed toward participant agreement with the assertions presented. Explanations, context, or reworking of methodology may have been needed if member checks contradicted analysis findings.

All results were to be used to highlight improvements that could be made to the software. Any improvements or fixes to the software that were practical would be implemented, and explanations would be given for any known issues that were not able to be resolved.

Chapter 4 – Results

Data analysis yielded several categories and subcategories. The first type of data to be discussed will be related to the user interface which will include data relating to (1) ease of use and layout, (2) the frequency range interface, (3) the tone generators interface, (4) the dial hardware, (5) the volume control interface, and (6) additional recommended features or modifications. The other type of data to be discussed will be participant perceptions of the usefulness of the software.

User Interface

Ease of Use and Layout

While most participants had mild to moderate difficulty during the initial process of learning how to use the program, most found it easy to use once they understood the interface and the task. This was true of all three categories of participants. Educator 1 noted that using the software “really easy,” and Educator 4 remarked that using the software was “just a little bit of a learning curve to learn what to do, but once I got the procedure it was smooth.” Researcher 4 noted that

The interface was intuitive, simple, and clean. The combination of buttons and text were not obtrusive or overly busy. I found it to be very natural and easy to use.

The student participants responded in much the same way. Student 1 noted:

I think once you’ve done it, you know, you first have to go through it, but once you’ve gotten it I don’t think it’s particularly difficult.

Field notes and video data indicated more of an initial difficulty in learning how to use the program than participants reported themselves in interviews. This was potentially due to the necessity for more detailed instructions on both the interface and the task itself. At least one participant per category showed an initial lack of understanding of some element of the user interface when using it after instruction. Field notes and video data also highlighted problematic aspects of the interface that may malfunction if not used correctly. The importance of this was raised by Student 5 who mentioned that while the program was “very straightforward and very logical in its layout, [you have to] learn the steps though, [...] the steps are critical.” This raises a potential concern that the steps necessary to complete the task is not entirely obvious from the layout of the application. This issue was raised by Researcher 1, who noted that

the layout [...] could be more intuitive. But, [...] it all makes sense on the page. Like, it says ‘step one, clearly do this first.’ But, maybe, have the frequency selector up top instead so [...] you have to do that before you do this.

However, these initial difficulties should not be taken as overly problematic, as all new software takes time for users to learn. As noted by Researcher 1, who said “I just had to sit there and play with it for a little bit... but, I think that’s *most* new software,” and Educator 4 who noted that the program was “pretty simple once [the researcher] explained, especially if you’re used to using technology: you know, start, stop, continue.” This assertion was confirmed through the member checking survey. When asked to rate their agreement on a scale of -2 to 2 (strongly disagree to strongly agree) for the statement “Once the user has learned the initial steps for using the app it is relatively easy to use,” the average rating was 1.27, indicating an overall agreement from users on that statement (see Table 1). There was one aspect of the user interface that presented as particularly problematic in all three streams of data: the frequency range selector.

Table 1

Results of Member Checking Survey

Statements	Mean Agreement Rating
Clear and concise instructions need to be included to help new users familiarize themselves with both how the program works and how it should be used.	1.57
The interface could be re-arranged in such a way that the steps for using the app are clearer to the user.	0.80
Once the user has learned the initial steps for using the app it is relatively easy to use.	1.27
This app could be useful to students for training their ability to match pitch (asked to student participants only).	1.40
This app could be useful to music educators for training their students to match pitch (asked to music educators only).	2.00
This app could be useful to music education researchers for answering questions about things such as pitch perception and intonation performance skills (asked to music education researchers only).	1.60
The frequency-range selector should be made more user friendly by allowing users the option to pick pitches on a keyboard rather than only allowing users to input a frequency in Hz.	0.60
Users should be given the option to temporarily mute one of the sounds in order to only hear one or another of the two tones in case they forget or are no longer able to hear the original pitch.	0.53
In future versions of this app, the option to match various intervals (harmonies) in addition to matching a single note would be useful.	1.33

Note. Participants rated each statement on a 4-point Likert-type scale, with 2 representing strong agreement, and -2 representing strong disagreement.

Frequency Range Interface

There were a number of problems with the frequency range selection interface from both a user interface and a task understanding perspective. As documented in the video data, every

student, a majority of educators, and one researcher seemed to lack a clear understanding of Hz as a measurement of pitch such that they had a difficult time understanding what to select. The fact that the program did not have a default selection and required users to select the frequency further problematized that task. At least five participants encountered issues with the interface despite the task having been explained and a default number having been given. At least two participants set the maximum frequency below the minimum frequency causing a program crash. Still others continued to press the “start here” button attached to that part of the interface despite it only needing to be pressed after the number is changed. There was also a bug in the interface that, if the number box containing the frequency information is not explicitly deselected, will cause that number to move instead of the tone generator when the wheel is turned.

These problems occur throughout the field notes and video timestamps. Educator 1 noted that, for her, the frequency range selection interface “was confusing; if the kids had to figure out the frequency without [explicit instruction] that would be an absolute [problem].” This turned out to be true for the student participants who all needed the researcher to tell them what frequencies to select. Several participants made recommendations for modifications to this interface.

Regarding the frequency range selector, Educator 5 noted issues both in the placement of the frequency selector in the overall user interface, and the way frequencies were selected; observing that

when selecting the Hertz, I feel like it should go in step order. So, right now you’ve got to go down here, and then in the middle for the volume, and then here, so maybe the Hertz first? [...] when you are assigning the Hertz, maybe show where that note is on the grand staff? So, like, as you scroll or as you enter or as you are selecting it could show you where you were in relation to middle C. [...] Because some people, you might say, ‘well

what's 440 Hertz?' and they might go 'well, I know that's A, but I can't tell you what A it is.'

This sentiment was echoed by Researcher 1 who suggested that

[...] the layout [...] could be more intuitive. But, I mean, it all makes sense on the page. Like, it says 'step one, clearly do this first.' But, maybe have the frequency selector up top instead so it's just 'you have to do that before you do this.'

These aspects of the qualitative data, however, should be taken with some caution in light of the results of the member checking survey. Despite the problems that seemed to arise during the course of the study with this aspect of the program, when asked to rate the statement that this aspect of the interface should be changed to something more user friendly (such as a keyboard) the mean agreement among participants was only .60, representing a rather mild agreement at most. Similarly, when asked to rate agreement on a statement that the interface should be changed such that the steps were clearer, mean participant agreement was .80, also indicating mild agreement (see Table 1).

Tone Generator Interface

Field notes and video data indicated that many participants were initially confused regarding the on-screen display of the dial state with the button they were supposed to press for the second tone generator, a problem that could be easily solved with a resizing and re-orienting of the interface objects. Additionally, many of the participants (including all but one student) had a difficult time differentiating the two notes from the tone generator after they had both begun to play. This may be expected of students in the earlier stages of instruction in beat detection, but it also happened to Educator 4, who suggested that

it would be nice to, kind of, reset [...] the first pitch again, then get to do the second one; because I got kind of turned around on [the] fourth example. I couldn't find where I was going. So, [it might be beneficial] to hear the first one and not have them combatting.

This could also be easily implemented with a feature that can temporarily mute one of the two tone generators without stopping the stopwatch. When asked to rate a statement indicating that the software should be changed to include this feature, participants responded with a mean agreement of .53, indicating mild agreement.

Dial Hardware

The ability to manipulate a physical dial was felt by the researcher to be an important aspect of the replication of an MOA device. Participants seemed to enjoy and appreciate this tactile aspect of the experience as well, as noted by Researcher 4 who remarked:

I really liked how we're using the dial; that's really nice. [...] I think that's more [...] reflective of how you would think about tuning in any case.

There were, however, some issues with the functioning of the dial during the study. The XP-Pen AC 19 has several settings which allow the dial to serve other functions in addition to mapping up and down keystrokes. The device changes between these functions with the middle button, which several participants clicked mistakenly. There were also several instances of the dial not being set to the correct setting prior to a testing session. Additionally, if participants turned the dial prior to setting the frequency range or clicking the "Step 2" button they sometimes inadvertently triggered the second tone generator which occasionally caused a program crash.

Every crash documented with video was seemingly caused by this kind of dial movement at the wrong time.

Volume Control

Field notes and video timecodes indicated occasional misuse of the volume control (gain) object in the software interface, with at least two participants raising the gain to a level that distorted the pitch and several participants leaving the gain at a level too quiet to properly hear and execute the task. Field notes propose the creation of a default volume setting upon program that can be adjusted by the user if needed.

Additional Recommended Features or Modifications

There were a number of recommended feature additions and modifications that emerged from the interview data. Researcher 1 recommended that the software add features that, in addition to measuring time, had the option of measuring accuracy:

So, like, you could set up the actual program so the dial itself didn't change, but the program... you could re-do it. So, it could record sharp or flat in cents, or it could record time, or it could record whatever it needed to [...]. I'd just be interested to know, maybe, what else we could do with it to make it more practical (again, not saying that time is not practical) [...], I just think accuracy or a way to export the pitch accuracy could be added. [...] [For example], each new session ended when it was resolved for three seconds; I wonder if we could (or if you could) make it so that you said 'okay, here's tone A and here's tone B, match this pitch as close as you think you can, and then when you're done, press this button.

Researcher 2 suggested that there be an additional feature that recorded the frequency of the initial pitches generated by the random number generator in order to determine whether a subject was adjusting up or down and in order to determine the distance that was required for the subject to adjust a pitch in order to reach a resolution:

So, in the readout I would want to know what the pitch (1) that was presented was, and what pitch (2) ... the starting pitch that the participant is manipulating... what that would be, or what that was in each trial so that I could ask questions such as “the further away the pitch is... how does that effect the time of adjusting the pitch to the given pitch?” and, you know, other questions as, you know, “is a particular participant better at adjusting up than down?”

Researcher 2 also recommended a feature that could measure where the participant moved the dial throughout a session:

It would be interesting if there was a way to actually write out the curve... In other words, let's say the pitch is here (I'm holding out my hand) and I have a pitch that's too high, and then I go down below the curve... but how many times do I miss it? Right? [...] So, here it would be interesting to see those curves as they end up at the right pitch. I think most of the time I went down below it and back up again, and I think a couple of times I went down and landed on it. But, just giving me the time wouldn't tell me how many times I went below and back up again.

Researcher 5 recommended a similar type of measurement, allowing a user to see how they adjusted up or down throughout a session:

I think recording the students attempt so they can listen back to what their tendency was Did they go too far? Did they overshoot? Did they undershoot? Based on the interval

they're coming from to try and find the unison, do they do better when its farther away? Do they do better when its closer? But if the student can actually go back and watch their own performance, in the same way that in any flight simulator or in other quick reflex athletic or aeronautical training simulators you can go back and watch yourself perform to see how you did.

A number of participants indicated a desire for a feature that could perform the same types of operations and measurements on various intervals rather than a unison alone. Researcher 4, for example, noted that "intervals [could be added as a feature] if you're doing something like just intonation, getting a third or a fifth exactly right." This desire was expressed by Student 1 as well, who, when asked if there were any features she would like to see added to the program responded, "I can't see anything adding to it, unless you wanted to take it further and do the pitches that would harmonize." Educator 1 also expressed a desire for intervallic options in the program, asking:

do you remember the game Simon? Where it had, you know, a number of different pitches? Some intervals that they also had to match? I don't know, like a repeat-after-me type of thing.

There were other feature recommendations as well, such as when Researcher 4, commenting on potential features for intonation training in students, mentioned that

It would be cool if there was some way to put this in the future on something that they can use at home. Usually they use phones nowadays, you know, some sort of app that they can use on their own time.

Participant Perceptions

Perceived Usefulness

There is strong evidence that all categories of participants perceived this software to be useful for their particular milieu, beginning with the fact that field note and video data document unsolicited expressions of joy and thoughts of potential uses of the software as participants were engaging in the software testing process. Member checking surveys also verified this fact. Music students, when asked to rate their agreement with a statement indicating the software would be useful for training in matching pitch, the mean score was 1.40, indicating strong agreement. Music education researchers, when asked to rate their agreement with a statement indicating that this software would be useful in answering research questions about pitch perception and intonation performance skills, the mean score was 1.60, indicating strong agreement. Finally, when music educators were asked to rate their agreement with a statement indicating this software would be useful in training their students to match pitch, they responded with a mean score of 2.0, indicating that every music educator that participated rated this statement as “strongly agree.”

Interview data confirms this data and adds context to the situations in which this software may be useful (see appendix B). Music educators saw the software as being primarily useful for ear training at a middle school to adult level, as Educator 3 noted,

I think it would be great, of course, for singers and for string players, you know, that rely on needing to have accurate pitch. I think it would be great for, just, that type of thing. Maybe, I don't know about elementary students, but maybe middle and high schoolers especially. I don't know if I could see *young* young children, like kindergarten, first,

second grade, but maybe on up... maybe it would be more useful to them and they would understand what to do.

Educator 2 indicated a similar attitude toward the software, commenting that

you could even use it in a middle school level if you wanted to [...] when it [...] comes to training ears; and even the older aspect... I could see this being used in, like, an aural skills class or something... even on the collegiate level.

Researchers, when asked how this software might be of use to music education researchers, indicated that it would be useful in conducting studies on questions of intonation perception and performance. For example, Researcher 2 indicated a wider ranging application for this software:

I can think of lots of research questions that I could investigate with this software. [...] I would study how good kids are at manipulating pitch and maybe do correlations between how well they use this software and how well they play in tune on their instruments. [...] You know, one of the questions that's always bothered me is with young string players that play out of tune. Are they playing out of tune because they can't hear it, or because of the physical question that has to do with they don't know how to use their fingers? [...] this would be a way of disentangling that issue.

Researcher 5 also noted a variety of research applications regarding intonation perception and performance, noting that

You could study the various effects that different stimuli have on students when they are trying to tune in an ensemble setting. For example, if you're having students try to tune from above or below a drone, you could see comparatively by grade, by instrument, by register, what propensities students have to finding or matching the pitch.

The student participants also expressed the perception that the software was useful in helping them learn how to effectively match pitch, as Student 1 commented,

I think if you use it regularly you certainly would be able to hear pitches better... or to match pitches better I guess I should say.

Or, as student 4 responded when asked if she felt the software had helped her improve:

“Yes. Oh yea, [I feel like I improved from using the software]. I kept going down in seconds [it took to resolve the pitch], so [...] I think it will be very useful.

Chapter 5 – Discussion

This investigation began with the expression of a concern about a lack of evidence-based techniques for intonation teaching and learning and the desire to create a tool capable of investigating such questions empirically. The expressed purpose of the study was to develop and test a piece of software that would be useful both for conducting research on intonation perception and performance, and for teaching and developing intonation perception and intonation skill. This led to two research questions.

Return to Research Questions

The first question was related to whether or not the software designed through this investigation could support a ‘method of adjustment’ type of apparatus to gather empirical data for researchers seeking to improve the teaching and learning of intonation skills. The qualitative data seem to support an affirmative conclusion as demonstrated by multiple qualitative data streams and by unanimous agreement among music education researchers (some with stronger agreement than others) that this software would be useful for music education research projects studying intonation. Researchers pointed to a number of potential research questions about intonation and intonation learning that could be answered. And, while most researchers had numerous suggestions regarding how the tool could be refined and what features could be added, they all indicated that the tool would be useful for investigating questions about intonation perception, performance, and learning.

The second question asked whether or not this software design could also function as an intonation teaching tool that will be useful for educators in the classroom. The data here also seem to support an affirmative conclusion as demonstrated by multiple streams of qualitative data, and by the unanimous strong agreement among music educators on that question in the member-checking survey (see Table 1). The fact that, during the investigation, several music educators gave unsolicited exclamations about how much they liked the software and about how they could implement it with their current students lends additional qualitative weight to this conclusion. With the evidence suggesting that both proposed research questions be answered in the affirmative, the tool that has emerged from this research process may now be used to help future researchers develop and refine further evidence based theories of intonation teaching and learning.

Implications for Future Intonation Research

Although the present study was primarily qualitative in nature, it can also serve as the basis for a large number of future qualitative studies. This is due to the fact that sessions with the software result in quantitative data (speed taken to resolve the two tones) that can be used in statistical analyses. In fact, prior to the present investigation, it was the goal of the author to conduct a quantitative study on the efficacy of various teaching techniques on the intonation perception of students. The problem, however, was a lack of available tools to conduct such research; thus, the present study was born. Future research may use the software to test, empirically, the efficacy of different teaching techniques on intonation perception or the relationship between intonation perception and performance, or a number of other research questions suggested by the music education researchers that participated in this study. However,

another reason it was difficult to conduct quantitative research on these questions was the lack of wide availability of any such investigatory tools to the public. One particular virtue of the present study is that, not only is the software design and architecture being made widely available to the public, but both the app itself and the source code are being released for free for anyone to use. This means that, not only will the software be immediately available for any music educator or researcher who wishes to use it, but also that anyone who knows Max/MSP can modify, update, add features, or otherwise change the software to suit their purposes.

Implications for Researchers

The applications for this software for music education researchers are vast. Returning, momentarily, to the review of literature, there are a number of questions that this software would be helpful in clarifying. For example, by using the frequency range feature, researchers can continue to investigate the effect that register has on intonation perception; expanding on the work of Russo and Thompson (2005) and Byo, Schlagel, and Clark (2011). Researchers conducting studies on intonation performance can isolate whether intonation errors are due to perceptual problems or in problems physically manipulating their instrument or voice, helping to resolve the differences between, for example, the finding of Demorest (2001) that intonation perception and intonation performance on an instrument are highly related, and the finding of Powell (2010) that they may, instead, be discreet tasks. The software could help to ground the assertions of Dillon (2002) and Pinner (2000) (that singing is an effective method of intonation instruction) in quantitative research.

Many additional research questions that could be investigated with this software were raised by the music education researchers that participated in this study. Researcher 2 suggested

a study looking at the correlation between how well students used the software and how well they played in tune on their instruments, perhaps helping to disentangle the relationship between intonation perception and performance (see Appendix B). Researcher 4 suggested a study investigating the differences in how well music students who played various instruments performed on the software; perhaps to determine if performers on various instruments have differences in intonation perception skills, or perhaps differences in intonation perception skill in various ranges given the range of their primary instrument (see Appendix B). Researcher 5 suggested comparing performance on the software by grade, instrument, and/or register to determine if there were differences among those groups in intonation perception ability.

Music educators currently serving in music classrooms can also use this software, free of charge, with their own students to help them train their ability to hear whether they are matching pitch correctly. The Miles (1972) study has demonstrated that training of this kind is effective, and the educators interviewed for this study all agreed on the pedagogical potential of the application. Educator 1 expressed, for example, that it would be useful for ear training in the choral classroom, and Researcher 3 (who is also an in-service music educator), expressed that it could be useful in the string classroom as a consequence-free tool to help teach students how to tune their open strings with fine-tuners (see Appendix B). In addition, however, to the pedagogical uses in the music classroom, this software gives in-service music educators access to a free tool that they can use to assess their students' intonation skill and thus get a clearer and more objectively valid measure of intonation perception than a subjective rating would give. In addition, this would also give in-service music educators a free, open-access research instrument with which to conduct action research on intonation learning in their classrooms.

Implications for Future Versions of the Software

Data from this investigation also indicate that there are a number of changes that may be desirable in future updates or possible modifications of the software that could be made by future developers. For example, detailed instructions for the use of the software should be included with the software when it is downloaded. However, although ultimately reporting, on average, that the software was mostly easy to use, many participants had some difficulty with initial acclimation to the user interface and with understanding the steps involved to use the software. Therefore, more detailed instructions in future versions would ease the difficulty in the initial task of learning how to use the interface.

One particularly problematic aspect of the user interface that emerged from the data seemed to be the frequency range selector. Many users had difficulties with this aspect of the interface, and throughout the study interventions needed to be made by the researcher to ensure that this aspect of the user interface was being used correctly. Interestingly, however, despite these difficulties the majority of participants expressed relatively mild views on whether this aspect of the user interface should be changed to allow users to select the range on a digital keyboard rather than entering the frequency in Hertz (see Table 1). This aspect of the graphical user interface could, perhaps, be re-arranged to be more intuitive and user-friendly in future updates or modifications by future developers.

Both Student 5 and Researcher 1, for example, indicated in interviews that understanding the steps to complete the task were of utmost importance in being able to effectively use the program (see Appendix B). This may be one reason why the frequency selector was particularly problematic. Selecting the frequency range was the first step users were required to complete before being able to use the program. The location of this object, however, was at the bottom of

the app. Perhaps a helpful modification to the program would simply be to rearrange the user interface such that each interface object was organized from bottom to top in the order the user was expected to need to engage with it. Another aspect of the user interface that appeared to be potentially problematic was a certain aspect of the tone generators.

The tone generators in the current version only allow the user to first select the fixed pitch (which begins playing) then the variable pitch (which begins playing at the same time. The problem this creates is that, often, a user may lose track of the harmony and begin to perceive the two pitches as a single complex tone. This occurred several times during the study with the students, but even occurred with one of the educators (see Appendix C). This led to Educator 4 suggesting an additional feature which would allow one or the other of the tone generators to be temporarily muted so that the user could hear only one of the tone generators in isolation while the timer continues to count down. This is a potentially useful feature that could be included in future updates of the software. However, when asked whether they agreed or disagreed with a statement indicating that this feature should be included in future versions of the software, member checking surveys indicated only very mild agreement among participants (see Table 1).

There were several instances of the program crashing during the course of the study (see Appendix C). However, all instances of the program crashing occurred when users moved the physical dial prior to clicking on the appropriate buttons triggering the fixed and variable tones. Future versions of this software would benefit from a software engineering solution that prevented dial movement from having any effect on data movement within the program prior to the completion of the two prerequisite tasks of triggering the fixed tone and triggering the variable tone. This would likely prevent any future crashing of the program due to user actions that are not in the correct order. A similar solution that prevented any user action that was out of

the correct order would likely be beneficial to the user experience and should be included in future updates or modifications of the application.

Many participants requested features that would allow them to complete similar intonation perception tasks with various intervals rather than with unison pitches alone (see Appendix C). The statement to this effect on the member checking survey was also met with strong agreement (see Table 1). It may benefit users if future versions of this software include options allowing users to resolve the two tones to intervals other than a unison. However, due to the engineering expertise and time required to design a software architecture that would support such features, and due to the concerns regarding temperament that were raised in the review of literature, this feature was determined to be outside of the scope of the present investigation.

There were several other features that were recommended by participants which should receive consideration for integration in future updates or modifications of the software. Researcher 4 suggested that future versions may include mobile versions that could be used by students at home on mobile devices (see Appendix B). Researcher 5 suggested a feature that could measure how users move the variable pitch through time and a feature that includes a recording of the user movements that can be played back at a later time (see Appendix B).

The current version of the program, however, as indicated by multiple data streams, was considered by most participants to be both easy to use once learned and useful for research and pedagogy in intonation.

Finding and Using the Application

The current version of this program can be found at <https://pastebin.com/PBSrtbij> and can be run by copying the text, downloading the latest version of Max/MSP from

<https://cycling74.com>, and selecting *File* → *New From Clipboard*. Max/MSP, while costing money to purchase for the creation of new programs, remains free if the user is simply running a pre-existing program. This software will remain available at this link for the foreseeable future for any interested music students, music educators, or music education researchers that are interested in utilizing it. Any future updates or additions will be found at the same location.

Conclusions

The present investigation set out to design a tool that would be useful in both investigation questions relevant to music education researchers studying intonation pedagogy and useful in the teaching of basic skills in intonation. Based on the review of literature conducted on extant related research, the construction of the software architecture described herein based on that literature, and the qualitative data described herein which was gathered from participants belonging to the groups most likely to use such software, it seems safe to say that the aims of the present investigation were achieved. The data gathered regarding user experience on the software will also be useful in any future refinements of this application. Helping students improve their intonation is something that many music educators do every day. This application should serve to help those educators improve student intonation; whether through direct use of this application, or as a result of future research conducted with it which can help to inform future evidence-based best practices for intonation pedagogy.

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Appendix A – Structured Interview Questions

Music Education Researchers

- Please describe your user experience on this software, including any positive or negative aspects of your user experience that come to mind.
- From a music education research perspective, do you perceive this software to be useful to music education researchers? If so, in what contexts?
- Did you encounter any problems while using the software? If so please describe them.
- As a music education researcher, what features could be added to this software to increase its utility?

Music Educators

- Please describe your user experience on this software, including any positive or negative aspects of your user experience that come to mind.
- From a music education perspective, do you perceive this software to be useful to music educators? If so, in what contexts?
- Did you encounter any problems while using the software? If so please describe them.
- As a music educator, what features could be added to this software to increase its utility?

Music Students

- Please describe your user experience on this software, including any positive or negative aspects of your user experience that come to mind.
- Do you feel that you got better at resolving the two tones the more you practiced on the software?
- Did you encounter any problems while using the software? If so please describe them.
- As a music education researcher, what features could be added to this software to increase its utility?

Appendix B – Interview Transcriptions

Educator 1

Researcher: Please describe your experience on this software, including any positive or negative aspects of your experience that come to mind.

Educator 1: Um, as far as positive I could see it being a big help, in the choral classroom anyway, when it comes to matching pitch and sight reading for sure. I think... I didn't really find any negative things...

Researcher: In using the software?

Educator 1: Mm mm [no].

Researcher: You didn't find it difficult to use?

Educator 1: Oh, no. It was really easy.

Researcher: Was the frequency thing confusing?

Educator 1: Well, for me, yea.

Researcher: If I wasn't here to explain it to you do you think it would be difficult for you to get started?

Educator 1: Yea.

Researcher: Okay.

Educator 1: If the kids had to figure out the frequency without...

Researcher: ... that would be an absolute...

Educator 1: Yea

Researcher: Okay.

- Educator 1: But, no, that's about it. I didn't know how to do the frequency.
- Researcher: Okay. [...] From music education perspective, do you believe this software to be useful to music educators? And, if so, in what contexts?
- Educator 1: With chorus, for sure, like I was saying, for sight reading it would be a good help. Even when it comes to... like right now with learning voice parts and being able to stick to your voice part, and blocking out the other ones, and making sure that you're actually in tune with each other. As well as the whole choir, that, it would be a big help because I think sometimes they don't realize they're singing the wrong note; especially if they hear voices next to them that may possibly be singing the wrong note too. So, yea, this would be good practice to do, you know, maybe during some warm-up time, in an assignment, some group work...
- Researcher: Okay. Did you encounter any problems while using the software? If so, please describe them... I know, I kind of recorded some of the problems that we had... The wheel didn't work for a second, and then it didn't scroll down right...
- Educator 1: Right...
- Researcher: I'm putting words in your mouth, I'm sorry...
- Educator 1: No, but that was the only thing, it just messed up when I was trying to do the little scrolling... the pad thing... but, I don't see... I like it. I liked that a lot.
- Researcher: Okay. As a music educator, what features could be added to this software to increase its utility?

Educator 1: Um... maybe if it had a... do you remember the game Simon? Where it had, you know, a number of different pitches? Some intervals that they also had to match? I don't know, like a repeat-after-me type of thing.

Researcher: So, you mean besides just unisons, you mean expanding it into different kinds of intervals?

Educator 1: Mmhmm, that would be cool.

Researcher: Okay.

Educator 2

Researcher: Please describe your experience on this software including any positive or negative aspects of your experience that come to mind.

Educator 2: Say that again...

Researcher: Please describe your experience on this software including any positive or negative aspects of the user experience that come to mind.

Educator 2: [...] I believe it's real friendly... age-appropriate friendly, like, you could even use it in a middle school level if you wanted to. Just... when it really just comes to training ear... and even the older aspect, I could see this being used in, like, an aural skills class or something; even on the collegiate level. Of course, a few things have to be understood as far as, like, the Hertz, and I guess that would have to be included in, like, a lesson plan... just so the kids and the adults can understand what Hertz are and how frequency waves effect intonation. I could see that being tied into a nice little lesson plan.

Researcher: Okay. Anything else that was good or bad that you can think of that need to be changed in terms of the user experience?

- Educator 2: Um...
- Researcher: I noticed you didn't try to save any of the data.
- Educator 2: Yea, I didn't... Um, the only thing I would say is, just... I say the only thing... is just letting them know that the Hz has to be an even number. I'd say that.
- Researcher: Okay. That brings me to the second point: did you encounter any problems using the software? So describe them.
- Educator 2: Yea, so that when, it was like the Hz, when it was an odd number, you were not able to get it in tune no matter how much you tried, because it was an odd number. So, when we moved it to the even number then we were able to get to resolution.
- Researcher: But when it was functioning with the even numbers everything seemed to be functioning like you would want it to?
- Educator 2: Everything was fine.
- Researcher: Okay. As a music educator, what features could be added to this software to increase its utility?
- Educator 2: There's nothing I could really think of off the top of my head. If I had to make one suggestion I would say just make it a little more appealing; more colors and, just, a little more exciting for kids to look at it. Show results, as far as percentage; seeing the percentage and everything. Showing them something so they could see the immediate results. Kind of like when I look at musictheory.net, when I do the stuff it shows the time frame it takes for them to do the sequence and, of course, you know, the accuracy.

Researcher: Okay. Great!

Educator 3

Researcher: Please describe your user experience on this software, including any positive or negative aspects of your user experience that came to mind.

Educator 3: Well, I just used it right now, and it took me a second to catch on to it, but I loved it. It was fun. I think children would enjoy, just, you know, the actual working with it, because it was a fun thing to do.

Researcher: Alright. Any negative aspects of the user experience?

Educator 3: I don't think so, it's just a little bit of a learning curve to learn what to do, but once I got the procedure it was smooth.

Researcher: Alright, great! From a music education perspective, do you believe this software to be useful to music educators, and if so, in what contexts?

Educator 3: I think it would be great, of course, for singers and for string players, you know, that rely on needing to have accurate pitch. I think it would be great for, just, that type of thing. Maybe, I don't know about elementary students, but maybe middle and high schoolers especially. I don't know if I could see young young children, like kindergarten, first, second grade, but maybe on up... maybe it would be more useful to them and they would understand what to do.

Researcher: Okay. Did you encounter any problems while using the software? If so, describe them.

Educator 3: [laughter] Just a couple of user errors! [laughter] It was my fault. Just... remembering the procedure. But, you know, if I were to do this several days in a row or for an extended period of time, that wouldn't be a problem.

Researcher: Okay. As a music educator, what features could be added to this software to increase its utility?

Educator 3: I really can't think of anything. Sorry.

Researcher: Okay.

Educator 4

Researcher: Please describe your experience on this software, including any positive or negative aspects of your user experience that come to mind.

Educator 4: I really enjoyed it, because I liked, I think, the ear training is important especially as you get older. As an educator, you want to keep your ears, I guess, working with those of things, you know. But, it would be nice to kind of reset, here, the first pitch again, then get to do the second one. Because I got kind of turned around on that, I think it was, fourth example... I couldn't find where I was going. So, to hear the first one and not have them combatting... like, maybe get, you know, still take the time and say "let's hear that first one again." Like, it's still recording the length that it takes you, obviously, so it...

Researcher: But maybe have something where you can silence the first or silence the second pitch to just re-orient your ears? To isolate them so you can hear whether one's higher or lower?

- Educator 4: MmHm. So you can still see that it took a student x amount of time... and even.. you could record... I don't know how difficult it is to say they did have to listen to that first note to begin with...
- Researcher: Sure, okay. Good. Any other positive or negative aspects of the program?
- Educator 4: I mean, it's pretty simple... once you explained... especially if you're used to using technology, you know, start, stop, continue...
- Researcher: Okay. From a music education perspective do you perceive this software to be useful to music educators? If so, in what contexts?
- Educator 4: Yes. Yes, absolutely... because I'm working with my students now on recognizing intervals, half step vs. whole step, making sure they're singing the half-step correctly. Sometimes I can hear that they're not singing it correctly. They can't because their ears aren't used to that. So, this would be a really good exercise to get their ears used to hearing those finer details and what it means to be sharp or flat.
- Researcher: Okay, great! Did you encounter any problems while using the software? If so, please describe them.
- Educator 4: Nope. Aside from losing myself on that fourth example... that would be the only problem to me. But, everything else was pretty clear.
- Researcher: Great! As a music educator, what features could be added to this software to increase its utility? You already gave one...
- Educator 4: I think that would be it... especially with the children trying to learn... and I've worked with high school in the past and now I'm working with middle school and younger in elementary school, so, like, really for the middle

school – high school range when you're trying to develop that ear I think it's really useful.

Researcher: Okay. Anything else you want to say?

Educator 4: Nope, thank you for letting me have a part in this.

Educator 5

Researcher: Please describe your user experience on this software including any positive or negative aspects of the user experience that come to mind.

Educator 5: Can I give constructive criticism?

Researcher: Please, as much as you can.

Educator 5: When selecting the Hertz, I feel like it should go in step order. So, right now you've got to go down here, and then in the middle for the volume, and then here, so maybe the Hertz first?

Researcher: Almost every music educator I've interviewed said the same thing.

Educator 5: Okay. The next thing that I would notice is using the tab or, at least, larger areas to input the Hertz... Um... this seems kind of cool [referring to the dial].

Researcher: Okay...

Educator 5: Yea, I like the click. Each click represented a cent, I noticed, so there were seven in each...

Researcher: That's actually evenly divided in whatever the range is you give.

Educator 5: Okay. So if it's 200 to 400 you get 200 clicks in there each click is... one click?

Researcher: It's actually divided by 127 because it's MIDI protocol. So, it's whatever the frequency is divided by 127 is what a click is.

Educator 5: Copy that. Ah, that makes sense to me. I'm a nerd like that. That makes perfect sense to me. So that's kind of cool. Um, and you said it will be an app later, so it won't be on a screen where you have to use a keyboard. And I think that would take some of the bulkiness...

Researcher: Well, I'm going to compile it for Windows and Mac, but if we were going to go further for something like an iPhone or anything like that where you would do a touch screen or something, I would need to involve people that were specialists in software development. I'm kind of doing this as a proof-of-concept, as a music educator, for what a good tool for developing the psychology of intonation would be... is sort of the idea.

Educator 5: Copy that. And the other thing is that on the first test and third test I heard three notes at a time. And, I don't know if you do or not, that might be me, but I hear three pitches playing. When it's asking you to take that second pitch and move it to where it's supposed to be on the first one and the third one I heard three pitches.

Researcher: Oh, that's interesting. There's only two sine-tone generators...

Educator 5: I know, I hear three though... I'm just saying.

Researcher: That could be the overtones...

Educator 5: Yes... I think... I don't know if there's a way you can isolate it out, but it drove me a little crazy for a second, because, it's like, obviously this note's

lower than this one, right? But I still hear a higher note in there at the same time... But that might be me, I don't know.

Researcher: Okay...

Educator 5: That's a fourth above, by the way.

Researcher: [laughter] So it might be the overtone... From a music education perspective do you perceive this software to be useful to music educators, and if so in what contexts?

Educator 5: Yes, I do for ear-training contexts majoritively. Um, I think it could be extended intervallically as well. So, if you were starting to train intervals, or sight-singing, those things... I think it has an opportunity for that as well.

Researcher: Just curious, if we were going to do intervals, would you be in favor of... the problem I thought of when I was trying to develop it... in thinking about that question, because that's a question I thought about, was thinking about temperament. If you're training a choir, I'm not sure you would want to use equal-tempered thirds. You know what I mean? That's... disincentivizing just intonation. Or even if we're using just intonation, what flavor of just intonation? Mathematically it's a little more difficult to do intervals that are not lower-ratio intervals... I mean, maybe fifths and fourths... You know?

Educator 5: I think you could pick between the two safely, I mean, you know, of just and plain. I think you could pick between the two and just have seven equal cents between each pitch as equal temperament, then adjusted... or as what we would call here adjusted (even though it's musically incorrect).

- Researcher: Sure. Anything else? Oh, actually this brings me to the other thing. As a music educator, what features could be added to the software to increase its utility (besides the one you just mentioned, which was adding different intervals)?
- Educator 5: Hmm... This one's going to be a little bit crazy, but maybe it's possible, when you are assigning the Hertz, maybe show where that note is on the grand staff?
- Researcher: Okay...
- Educator 5: So, like, as you scroll or as you enter or as you are selecting it could show you where you were in relation to middle C.
- Researcher: That would be relatively easy to implement, yea.
- Educator 5: Yea?
- Researcher: Yea, we could do that... Nice idea.
- Educator 5: Because some people, you might say, "well what's 440 Hertz?" and they might go "well, I know that's A, but I can't tell you what A it is..."
- Researcher: Or maybe even let them click a digital keyboard?
- Educator 5: Yea yea yea, sure, that kind of thing.
- Researcher: Okay, cool. And did you encounter any problems when using the software?
- Educator 5: Just me hearing the error that happened... and hearing the third note... but... that's probably going to be a one-percenter, so I don't want to get you all jacked up on that.
- Researcher: Alright that's it.
- Educator 5: Cool!

Researcher: Thank you [name].

Educator 5: Your welcome.

Researcher 1

Researcher: Please describe your user experience on this software, including any positive or negative aspects of your user experience that come to mind.

Researcher 1: I think, once I figured out how to use it, it made a lot of sense. I just had to sit there and play with it for a little bit... but, I think that's most new software.

Researcher: Anything else positive or negative that comes to mind initially?

Researcher 1: I think you're right with the wheel as far as the matching goes. Maybe if you're going to disseminate this... there's a lot of things that [...] all make sense, but [...] the layout of it could be more intuitive. But, I mean, it all makes sense on the page. Like, it says "step one clearly do this first." But, maybe have the frequency selector up top instead so it's just "you have to do that before you do this."

Researcher: If it's any consolation, that problem's come up in every test.

Researcher 1: Okay! [laughter]... But like, once you sit down and look at it, it all makes a lot of sense.

Researcher: Okay, fantastic! From a music education research perspective, do you perceive this software to be useful to music education researchers? If so, in what contexts?

Researcher 1: I do, especially for people doing intonation studies... I wonder if the data you export could, maybe... I know it's exporting time it took to match (which is a useful thing because you need to know if students, or anybody, can match pitch and how quickly they can do that), but one of the things that was so good about the CRDI is that you could change what it was measuring... sorry, Continuous Response Digital Interface that Gerringer did... So, like, you could set up the actual program. So the dial itself didn't change, but the program... you could re-do it. So, it could record sharp or flat in cents, or it could record time, or it could record whatever it needed to. So, I think it's certainly got a purpose. It's certainly very useful. I'd just be interested to know, maybe, what else we could do with it to make it more practical... again, not saying that time is not practical. But, like, with regard to closeness of intonation...

Researcher: Like, adding the degree to which errors were flat or sharp, or how wide the responses were... like standard deviations and things like that?

Researcher 1: Right... Because it seemed like every time the second tone played it always started from the low end, and then we went up to the pitch...

Researcher: Well, it's a random number generator.

Researcher 1: Okay... But the second tone always starts below?

Researcher: No, that just happened to be...

Researcher 1: Those three? Okay. Well, that makes sense too... Well, that could be interesting too... to see if you're hearing what you think you're hearing.

- Researcher: But maybe it would be useful to be able to set it to start from below, or start from above?
- Researcher 1: Well, I like that it's random, because it's easier to tune if you're coming from below. And, so, if you're working with children it would be nice to hear if you... "oh, can you actually hear that that pitch is higher or if that pitch is lower?" And, so, I'm just thinking about application of the tool... I'd have to sit with that for a little bit longer, but... I like it.
- Researcher: Okay. Great! Did you encounter any problems while using the software? If so please describe them.
- Researcher 1: Yes, but that was user error! [laughter]
- Researcher: Okay. As a music education researcher, what features could be added to this software to increase its utility?
- Researcher 1: Yea, I just think accuracy or a way to export the pitch accuracy could be added.
- Researcher: As opposed to requiring them to be one-hundred percent accurate?
- Researcher 1: Correct. Right, so, like, each new session ended when it was resolved for three seconds... I wonder if we could (or if you could) make it so that you said "okay, here's tone A and here's tone B, match this pitch as close as you think you can, and then when you're done, press this button." Just to see, like, were you really as close as you thought you were? And you also used straight tones for this... so, I wonder if you could use, like, I don't know... it would be harder... some kind of, like... anything with vibrato?
- Researcher: That could be engineered...

Researcher 1: Just to see, like, can you match this pitch when there's vibrato added? Or, can you match this pitch when it's a different timbre?

Researcher: Right... For sure, and that might actually help research that shows that brighter timbres tend to be sharp, or darker timbres tend to be flat... you could add to that body of literature too.

Researcher 1: Yea, so maybe, just, importing different kinds of sounds to match? I don't know how feasible that would be...

Researcher: Well, any time you talk about features its always, you know, hard to add. You know, but that's part of what I want to put it.. what all is possible... Any other comments?

Researcher 1: Maybe label the dial? Because I kept pressing that button to click okay... So maybe, just be, "don't push that!" or, I'm sure it said it somewhere, I just overlooked it... But, no... well done!

Researcher 2

Researcher: Please describe your experience on this software, including any positive or negative aspects of the experience itself that came to mind; as a researcher.

Researcher 2: It was very positive. It was very easy to use. I mean, I don't think I pressed... there wasn't a lot of buttons that I pressed that did something unexpected. And, it would seem... I can think of lots of research questions that I could investigate with this software.

Researcher: Okay. Great! Secondly, from a music education research perspective, do you perceive this software to be useful to music education researchers? If so, in what contexts?

- Researcher 2: Yea, so, you know, I would study how good kids are at manipulating pitch and maybe do correlations between how well they use this software and how well they play in tune on their instruments... something like that... [...].
- Researcher: Did you encounter any problems when using the software?
- Researcher 2: Only the fact that you said that I had to press outside of the box.
- Researcher: Okay, that one bug? Okay.
- Researcher 2: And then the fact that it seemed like the lower range, because of the computer speakers, were much softer than the higher range. So, ideally, you would want a speaker that's more even in the range.
- Researcher: Okay. So, finally, as a music education researcher, what features could be added to this software to increase its utility?
- Researcher 2: Right: So, in the readout I would want to know what the pitch (1) that was presented was, and what pitch (2) ... the starting pitch that the participant is manipulating... what that would be, or what that was in each trial so that I could ask questions such as "the further away the pitch is... how does that effect the time of adjusting the pitch to the given pitch?" and, you know, other questions as, you know, "is a particular participant better at adjusting up than down?" [...] So that would be easy, right? You should be able to write out the pitches; the two pitches presented... And then, you have seconds... I mean, it would be interesting if there was a way to actually write out the curve... In other words, let's say the pitch is here (I'm holding out my hand) and I have a pitch that's too high, and then I go down below the curve... but how many times do I miss it? Right? So, the way I teach my

string players to tune is I say, you know, they always ask me, you know, kids, is it up or down? And I say “don’t worry about it, just turn it and see if it gets better or worse. And they can usually hear if it gets better or worse, but then at some point it gets better, but then at some point it gets worse if they go past the pitch... Right, so here it would be interesting to see those curves as they end up at the right pitch. I think most of the time I went down below it and back up again, and I think a couple of times I went down and landed on it. But, just giving me the time wouldn’t tell me how many times I went below and back up again.

Researcher: That’s true. That’s a great idea. Any other comments before we finish?

Researcher 2: No. Look forward to seeing it finished... Actually, I do have one more comment... You know, one of the questions that’s always bothered me is with young string players that play out of tune... are they playing out of tune because they can’t hear it, or because of the physical question that has to do with they don’t know how to use their fingers, and this would be a way of disentangling that issue.

Researcher: For sure. Thank you.

Researcher 3

Researcher: Please describe your user experience on this software, including any positive or negative aspects of the user experience that come to mind.

Researcher 3: Once the researcher went through the instructions it was very clear, it was very straightforward... there just was one little discrepancy about the clicks

and how it related to the two tones... how they resolved, basically. But other than that, it was very user friendly.

Researcher: Okay. So, from a music education perspective do you perceive this software to be useful to music educators, and if so in what contexts?

Researcher 3: I could definitely see this helping with tuning, especially as an orchestra director in that initial teaching students how to tune open strings... that could be like a pre-lesson before we actually let students have at tuning their open strings. To figure out whether the static tone is sharp or flat compared to another tone... that would help with tuning their open strings, which is really important.

Researcher: Okay. Do you think it would be useful to music education researchers?

Researcher 3: Yes.

Researcher: In what ways? In what contexts? And, just to say, this app was designed to study questions about intonation perception...

Researcher 3: Okay... Um... At the collegiate level, helping with aural skills teachers... examining their students... that's still an educator, not necessarily a researcher standpoint... Um... I don't know. I would have to think about that.

Researcher: Okay. That's fine. Did you encounter any problems while using the software?

Researcher 3: No.

Researcher: Okay. And what features could be added to this software to increase its utility?

Researcher 3: Hmm... Nothing off the top of my head... I would... because I get what it's going for... maybe a visual aspect to what the student... but, no, that kind of defeats the purpose of them learning how to tune aurally, so no visual aspect, no...

Researcher: So, you think it's kind of good as it is?

Researcher 3: Yes.

Researcher: Okay, that's fine.

Researcher 4

Researcher: Describe your user experience on this software, including any positive or negative aspects.

Researcher 4: I really liked it. It was very user-friendly. It's just, if you were trying to teach it with kids you would probably have to sit there and go through with where you click and everything, but it looks like it's very well coded. And, I really liked how we're using the dial; that's really nice.

Researcher: The tactile aspect? Instead of having to do it on the mouse?

Researcher 4: Right, right. And, I think that's more... I feel like it would be more reflective of how you would think about tuning in any case... it's more of a...

Researcher: Tighten it up verses loosen?

Researcher 4: Yea!

Researcher: That's interesting, because it is kind of the same as a fine tuner on a violin... you tighten it or you loosen it...

Researcher 4: Yea...

Researcher: Interesting... Okay. Anything negative?

Researcher 4: Not really.

Researcher: Okay. That's fine. So, [...] from a music education perspective, do you perceive this software to be useful to music educators? If so in what contexts?

Researcher 4: I think so. I personally use a lot of ear training with my kids to get them better on intonation. We go through thi there's a game that's similar to this that I found... but it's not as easy to use as this, or in terms of accuracy... I really like that you have to wait three seconds for it to actually register. Because, for my other game kids will play around with it and it will go in tune and out of tune, in tune and out of tune, and they'll just keep guessing you know? So... Um... Let's see... It would be cool if there was some way to put this in the future on something that they can use at home. Usually they use phones nowadays... you know, some sort of app that they can use on their own time. I think in terms of feedback... the seconds are a good way to measure it, but... I don't know how you would... So, in the game that I was telling you about it gives you feedback based on how many cents you're off on... but see, those are... that's really finicky because (1) you have to explain cents to kids, and I teach middle school and I make it a point thing. I don't really go over what a cent... I go over it briefly, but not in depth like that. But it does tell them, like, you're two cents off (or something like that) when they submit the answer. But this one, I think it takes away that because it just tells you whether or not you get it right....

Researcher: Because you have to resolve it...

Researcher 4: Which I think is a better statement for the students anyway, in a sense of, like, “no, it’s not right.” Which is something in instrument they don’t normally hear that they’re out of tune and you have to kind of show them slowly that, you know, you’re not matching this person next to you. And sometimes you have to isolate it, and all that. So, I think it speaks volumes in terms of feeding back... or giving back feedback that... it should be really good for kids.

Researcher: Okay. Great! What about from a music education research perspective? Do you think it would be useful to researchers in terms of, you know, doing studies and things like that on intonation perception or anything else?

Researcher 4: I think it would work really well. It would be cool to see if different things affect how long it would take for you to reach it, or resolve the notes, because... I just like the timing of it. Sometimes, you know, intonation could be like that [snaps fingers], or sometimes, you know, especially if you’re doing different ranges, you know, it would be cool to see different primary instruments and how quickly things go. Because, I’ve observed that me, as a bass player, I can pinpoint out-of-tune low notes a lot quicker than I can higher notes.

Researcher: So, you’re saying that it would be interesting to see if they’re quicker in one range verses another range to see if intonation’s perceived more clearly in an upper register verses a lower register? Something like that?

Researcher 4: Yea.

Researcher: Okay.

- Researcher 4: So, I think there's some really cool research things in there.
- Researcher: Okay. Fantastic. So, are there any features that you think could be added to the software to increase its utility?
- Researcher 4: Possibly intervals. If you're doing something like just intonation, getting a third or a fifth exactly right. I think that would be really cool, especially at a more advanced level where you're talking about this with kids. A lot of us will try to play on the piano and get them to tune to that, but those are equal temperament notes. And, so, you know... otherwise I know a lot of people use harmony directors and I think that through this it could save a lot of money. Harmony directors are very expensive, and...
- Researcher: I don't know what a harmony director is.
- Researcher 4: They're little keyboards that allow you to change the tuning to just and equal. And it's... they're usually like \$3,000 or something crazy like that, but they're a full keyboard. Lots of band teachers use them. From my experience, they're only just now making their way to orchestra directors. But, yea, so there's controls to move the pitch up and down a couple cents to make it exactly in tune and you can play it through a speaker so kids can hear the difference between the two. But, like I said, it's very expensive. I personally don't have it at my school so I use other tuners that go between just and equal temperament just to show them, but it would be a more cost-effective way (and a more interactive way) because then the kids could come up and actually try it out.
- Researcher: Okay. Great!

Researcher 5

Researcher: Please describe your user experience, including any positive or negative aspects of your user experience that come to mind.

Researcher 5: The interface was intuitive, simple, and clean. The combination of buttons and text were not obtrusive or overly busy. I found it to be very natural and easy to use.

Researcher: Thank you. Okay, great. From a music education research perspective, do you perceive this software to be useful to music education researchers? If so, in what contexts?

Researcher 5: Absolutely. You could study the various effects that different stimuli have on students when they are trying to tune in an ensemble setting. For example, if you're having students try to tune from above or below a drone, you could see comparatively by grade, by instrument, by register, what propensities students have to finding or matching the pitch. You could also, based on the pieces you're preparing, you could combine disparate sections of instrument low brass and violin, or viola and trumpet; something where you could see if the timbre of the instruments is a factor in helping students or preventing students from quickly matching pitch. You could also do intervallic training with this. Trying to find out if perfect intervals are easier or harder for a certain group.

Researcher: I have to say, at the moment it's only set up to where it's only unison the way the app's constructed at the moment. So that would have to be an additional feature.

- Researcher 5: Right, but I can imagine that if you started to do 5ths, adding other intervals in, it would be just as useful.
- Researcher: Great. Okay. Did you encounter any problems while using the software? If so please describe them.
- Researcher 5: I was confused where it said, "Start Here." I realize "Start Here" is for the first time. So, that's the only issue I had, and it was quickly resolved.
- Researcher: As a music education researcher, what features do you think could be added to this software to increase its utility?
- Researcher 5: I think recording the students attempt so they can listen back to what their tendency was Did they go too far? Did they overshoot? Did they undershoot? Based on the interval they're coming from to try and find the unison, do they do better when its farther away? Do they do better when its closer? But if the student can actually go back and watch their own performance, in the same way that in any flight simulator or in other quick reflex athletic or aeronautical training simulators you can go back and watch yourself perform to see how you did.
- Researcher: Okay. But, like you said too, also in the data measurement: measuring also the starting point of the one vs the other so that we know if it started from above or below. All that kind of stuff too.
- Researcher 5: Right, so students know if they have a more natural ability to do one or the other. I think it's great. I'm very excited.

Student 1

Researcher: Please describe your user experience of this software including any positive or negative aspects of your user experience that came to mind.

Student 1: Well, I think if you use it regularly you certainly would be able to hear pitches better... or to match pitches better I guess I should say.

Researcher: Okay. Anything about the program itself that seemed positive or negative? Easier to use or harder to use?

Student 1: I think once you've done it, you know, you first have to go through it, but once you've gotten it I don't think it's particularly difficult.

Researcher: Great. Do you feel like you got better at resolving the two tones the more you practiced on this software?

Student 1: Well, I think so. I don't know, that middle one sort of threw it all off I guess!
[laughter]

Researcher: Okay. Did you encounter any problems? If so please describe them.

Student 1: Well, once I understood what you were looking for, I guess, for me sometimes the lower sounds are... I guess that always depends on the person, but for me the lower sounds are harder to... it seemed like...

Researcher: Okay. As a music student, what features do you think could be added to the software to increase its utility? Do you think anything should be added to it?

Student 1: Well... at this point the goal is to match the pitch, right? So, you know, I think that's fine. I can't see anything adding to it, unless you wanted to take it further and do the pitches that would harmonize, you know.

Student 2

Researcher: Please describe your user experience on this software, including any positive or negative aspects of your user experience that come to mind.

Student 2: I improved with each... with the help of the instructor (the creator here) training me, I got better each time. And I think the more I used it the better I would get at this. But, I think it's real helpful, because I was finally catching on to how to listen and say "oh, that note's a little higher, that's a little lower, where do I want to go with that," so... especially when the two notes are quite close, that's really kind of challenging.

Researcher: Mmhmm. Okay, great. Do you feel you got better at resolving the two tones the more you practiced?

Student 2: Absolutely. Yea.

Researcher: Okay. Great! Did you encounter any problems while using the software? If so, please describe them.

Student 2: No. I just needed... I'm a grandmother... an older... I just needed you to walk with me for a few times. But then, once it became clear what I needed to do, I think I could practice alone on it and I could use it, probably, better, so...

Researcher: Okay, great! As a music student, what features do you think could be added to this software to increase its utility?

Student 2: Hmm... Well, I guess just personally for me, you know, if I had a note I'd like to be able to sing a note... my note... and see if I'm really matching the note, you know? Like [makes various vocal tones on "aah"] am I really

doing “aah” or am I doing “aah” ... and then, you know, so I could see that I was off a little bit. Does that make any sense? You know, so I could tune to the correct... so then I wouldn't sing flat... or sharp... probably flat... is what I would say. Maybe that would help to train myself a little bit to hit right on the note and hear it more.

Researcher: Okay. Great!

Student 3

Researcher: Please describe your experience of using this, including any positive or negative things that came to mind.

Student 3: Well... I was nervous, and it took me a while to get the hang of it... I have the feeling that if I kept doing it, it would have probably improved quite a bit... fast... but... [...] it was an unfamiliar task to me, to get it to... you know, stop making noise.

Researcher: Okay. Do you feel you got better at resolving the two tones the more you practiced on the software?

Student 3: Yes. I felt like I got, maybe, a teeny bit better.

Researcher: A teeny bit better?

Student 3: But, I think if I did it more, I would have gotten into it more... but that's a guess.

Researcher: Okay. Did you encounter any problems while using the software? If so, please describe them.

Student 3: I had a little trouble understanding the assignment.

Researcher: Okay. Alright. As a music student, what features do you think could be added to this software to increase its utility? Do you think anything should be added to it?

Student 3: Maybe a... well... you demonstrated it, but maybe if there were... well, I was going to say a demonstration beforehand, but you did demonstrate it beforehand... so...

Researcher: Did it seem unclear how it should be used? Should it be more clear on how the user uses it? Was it too complicated?

Student 3: Uh... It wasn't that it was complicated... it was that... first I was looking for, you know, two tones... and they were pretty... and then after that I was just looking to get it down to the... circle down to zero. So, I changed what I was looking for.

Researcher: Okay, alright. I think that's it. Thanks!

Student 4

Researcher: Please describe your experience on this software including any positive or negative aspects of the user experience that came to mind.

Student 4: Uh, at first I didn't get it. But, once I did... you explained it to me and showed me... I learn that way... I learn by actually doing it, and somebody helping me with that, so... I thought it was great. Once I got it, it was easy.

Researcher: Okay, great! Did you feel like you got better at resolving the two tones the more you practiced on the software?

Student 4: Yes. Oh yea. I kept going down in seconds [it took to resolve the pitch], so...

- Researcher: Okay, good! Did you encounter any problems when using the software? If so, please describe them.
- Student 4: Not really, no. The software was easy once I learned...
- Researcher: Okay. As a music student, what features could be added to this software to increase its utility? Do you think anything should be changed or added?
- Student 4: Well, I imagine you would have more range if you wanted to... like 200 and 400 [Hertz] could be different. So, does it have the capability to...
- Researcher: Yea, you can put in whatever number you want... to make it go as high or as low...
- Student 4: Hmm... I could see where that would be useful. I mean, I was going to be using it in a practical application would I have... I would have a laptop and I would be doing this with music I'm working on?
- Researcher: No. So, this isn't for specific music. This is just for developing your ability to hear what's in tune and what's not in tune.
- Student 4: Oh. Okay.
- Researcher: Because, you know, a lot of people have a hard time being in tune in the first place. So, it's not for specific music, it's just to help practice your ability to be in tune.
- Student 4: To hear...
- Researcher: Yea, it's an ear training tool.
- Student 4: Okay, well, that's great! I think it will be very useful.

Student 5

Researcher: Please describe your user experience on this software including any positive or negative aspects of your experience that came to mind.

Student 5: Pretty easy to learn... but I'm probably a computer geek anyway. But, very straightforward and very logical in its layout. Gotta learn the steps though. You know, the steps are critical... and one of the most typical things people will have is setting their volume based on whatever kind of equipment they're using. I mean, I saw where your volume went... on my laptop that would have put you up against that back wall because its got powerful speakers. But I like it. I like the software.

Researcher: Okay. Good! Were there any negative... any other aspects of the user experience you want to talk about?

Student 5: No. Like I said, I thought it was straightforward once I realized what you were trying to do. I will say thi the wobble is kind of a giveaway that you're getting close.

Researcher: Well, good! That's part of what it's trying to teach!

Student 5: Oh, okay! Good!

Researcher: That's how you hear what's in tune or not, so you've learned!

Student 5: Okay, good!

Researcher: So, there you go. So, when you're singing with others and you hear a wobble you know you're out of tune.

Student 5: Okay!

Researcher: Okay, so, did you feel like you got better at resolving the two tones the more you practiced?

Student 5: Yes. And I would have gotten more so, I think, with more experience on it.

Researcher: Okay. Did you encounter any problems while using the software? If so, please describe them.

Student 5: Other than I've got fat fingers. I'm not very good on a mouse, but...

Researcher: Okay. As a music student, what features could be added to this software to increase its utility?

Student 5: What I would really like to see is a visual representation of the tone.

Researcher: More than just a wheel?

Student 5: Right, right. Or even on the image itself, like, when it gives the tone "Bb4" is an example, or, you know, "C5" or something like that. Just... living in music and singing, I like knowing where that tone fits. That's the only thing I would add to it. But that's me.

Appendix C – Qualitative Data Organized into Codes

Ease of Use & Layout

Educators

Field Notes

- Educator 1
 - Participant seemed confused about how the hertz selector worked; not only the GUI, but the way the frequency works in general. Researcher provided the pitch range after participant demonstrated confusion.
 - Participant not initially understanding the task, despite being a teacher. The process of beat detection and resolution with a sign tone still not entirely clear at first.
 - After training on the task by researcher, and despite initial problems, the participant operated the program with relative ease.
 - Participant expressed pleasure with the app and seemed to be engaged once she familiarized herself with both the task and the GUI.
 - The fact that she had to scroll down to get to the save button made the task more difficult.
- Educator 2
 - The steps of the tasks necessary in the GUI were not clear to the participant and needed to be clarified by the researcher.

- After initial training, the participant used the program with relative ease.
- Educator 3
 - Despite the more detailed explanation, the participant still needed significant help after the initial explanation in order to use the app, and still made several errors, including not initially understanding the continue dialog.
 - After several minutes of trial and error (and explanations by the researcher), the participant was able to use the program with relative ease.
- Educator 4
 - After initial training participant used the app with relative ease.
- Educator 5
 - Seemed miffed that he couldn't use the tab key to change from box to box on the Hz selector.
 - After initial training, the participant used it with relative ease.
 - Continue button seems problematic and confused this participant initially.
This dialog might not be necessary.

Video Timecodes

Lack of Initial Understanding of GUI Communication Elements (such as “Continue” or “Step 2”)

- Educator 1 | 3:48 – 4:15
- Educator 3 | 6:05 – 6:39, 7:10 – 7:30
- Educator 4 | 2:43 – 2:50

Interviews

“It was really easy.” (Educator 1)

“[...] I believe it’s real friendly... age-appropriate friendly, like, you could even use it in a middle school level if you wanted to. Just... when it really just comes to training ear... and even the older aspect, I could see this being used in, like, an aural skills class or something; even on the collegiate level.” (Educator 2)

“[...] it took me a second to catch on to it, but I loved it. It was fun. I think children would enjoy, just, you know, the actual working with it, because it was a fun thing to do.”

(Educator 3)

“[...] it’s just a little bit of a learning curve to learn what to do, but once I got the procedure it was smooth. [...] [The program is] pretty simple... once you explained... especially if you’re used to using technology, you know, start, stop, continue [...] Aside from losing myself on that fourth example [...] everything else was pretty clear.” (Educator 4)

Researchers

Field Notes

- Researcher 1
 - Participant seemed confused by the GUI and the steps necessary to execute the task, despite being a researcher. This seems like clear evidence that the GUI needs to be a bit clearer and more user friendly. (However, less of an

explanation was given to this participant than to subsequent participants, possible contributing to the issues.)

- After initial problems (which seemed like they were due to lack of GUI clarity), the participant used the app with relative ease.
- Researcher 2
 - The *Resolved* and *Continue* buttons in the GUI not immediately clear to participant (had to be pointed out).
 - After initial training, participant seemed to use the software with relative ease.
- Researcher 3
 - Same GUI problems with Hz selector keep happening. This definitely needs to be changed.
 - Seemed a bit confused that the dial worked in notches (digital) and that it wasn't an analog device.
 - After initial training, participant seemed to use the app with relative ease.
- Researcher 4
 - Had to indicate to researcher that the first step was to set frequency ranges.
 - Not clear on the fact that he had press the continue button. Again, an unclear GUI issue.
 - After initial training, participant seemed to use the app with relative ease.
- Researcher 5
 - Problem with Hz box staying selected (as in other trials), needs an auto-deselect.

- Seemed to demonstrate ease of use and understanding of app quite quickly.

Video Timecodes

Lack of Initial Understanding of GUI Communication Elements

- Researcher 1 | 2:28 – 2:50
- Researcher 2 | 3:55 – 4:10

Interviews

“I think, once I figured out how to use it, it made a lot of sense. I just had to sit there and play with it for a little bit... but, I think that’s *most* new software. [...] once you sit down and look at it, it all makes a lot of sense. [...] the layout of it could be more intuitive. But, I mean, it all makes sense on the page. Like, it says ‘step one, clearly do this first.’ But, maybe have the frequency selector up top instead so it’s just ‘you have to do that before you do this.’” (Researcher 1)

“It was very easy to use. I mean, I don’t think I pressed... there wasn’t a lot of buttons that I pressed that did something unexpected.” (Researcher 2)

“Once the researcher went through the instructions it was very clear, it was very straightforward...” (Researcher 3)

“It was very user-friendly. It’s just, if you were trying to teach it with kids you would probably have to sit there and go through with where you click and everything, but it looks like it’s very well coded.” (Researcher 4)

“The interface was intuitive, simple, and clean. The combination of buttons and text were not obtrusive or overly busy. I found it to be very natural and easy to use. [...] I was

confused where it said, “Start Here.” I realize “Start Here” is for the first time. So, that’s the only issue I had, and it was quickly resolved.” (Researcher 5)

Students

Field Notes

- Student 1
 - The dialog box not obvious to participant.
 - The frequency selector seems to be the most obviously problematic part of the GUI, especially for non-professional musicians (although it has also been a problem for the professionals).
 - Despite aural difficulties in completing the task (which would be expected of a student that’s still learning) the participant seemed to be able to use and interact with the app with relative ease after it was explained.
- Student 2
 - Oblivious to Hz problem, had to be given the frequency and each way of manipulating the GUI in that area by the researcher.
 - Mistaken button presses on the app resulted in problems of initial use. GUI may need more clarity. The three-second rule was also not obvious and needed to be explained (may need to be made more explicit in the GUI or a readme).
 - Despite aural difficulties in completing the task (which would be expected of a student that’s still learning) the participant seemed to be able to use and interact with the app with relative ease after it was explained.

- Student 3
 - Hz problems, etc. (she needed me to tell her what to put in the box and where to click.)
 - Continue button not obvious (showed participant by clicking on it myself), and even after that, on the next session the dial itself was pushed, causing a crash. Maybe look into how to lock various aspects of the GUI until certain conditions are met.
- Student 4
 - Button click problems, GUI not intuitive at first, etc.
 - Despite aural difficulties in completing the task (which would be expected of a student that's still learning) the participant seemed to be able to use and interact with the app with relative ease after it was explained.
- Student 5
 - Wheel click needed to be adjusted (not set correctly initially).
 - Continue behavior not obvious.
 - After initial training, participant seemed to use the app with relative ease.

Video Timecodes

Lack of Initial Understanding of GUI Communication Elements (such as “Continue” or “Step 2”)

- Student 3 | 4:48 – 5:04

Interviews

“I think once you’ve done it, you know, you first have to go through it, but once you’ve gotten it I don’t think it’s particularly difficult.” (Student 1)

“I just needed you to walk with me for a few times. But then, once it became clear what I needed to do, I think I could practice alone on it and I could use it, probably, better [...]” (Student 2)

“Well... I was nervous, and it took me a while to get the hang of it... I have the feeling that if I kept doing it, it would have probably improved quite a bit... fast... but... [...] it was an unfamiliar task to me, to get it to... you know, stop making noise. [...] I had a little trouble understanding the assignment. [...] It wasn’t that it was complicated... it was that... first I was looking for, you know, two tones [...] and then after that I was just looking to get it [...] down to zero. So, I changed what I was looking for.” (Student 3)

“[...] at first I didn’t get it. But, once I did... you explained it to me and showed me... I learn that way... I learn by actually doing it, and somebody helping me with that, so... I thought it was great. Once I got it, it was easy.” (Student 4)

“Pretty easy to learn... but I’m probably a computer geek anyway. But, very straightforward and very logical in its layout. Gotta learn the steps though. You know, the steps are critical.” (Student 5)

Ease of Use – Beat Resolution Task

Field Notes

- Educator 1
 - Participant not initially understanding the task, despite being a teacher. The process of beat detection and resolution with a sign tone still not entirely clear at first.
- Educator 3
 - It seems like educators (such as this participant) need training as well on what “beats” are in pitch and how those contribute to intonation perception. Even though music educators are the ones teaching intonation, they may not be familiar with the way these concepts are thought of scientifically and may require their own kind of education.
 - After several trials, the participant was gradually able to understand the task and to perceive the aural phenomenon required for the app.
- Researcher 3
 - Researcher did not seem to know, initially, that beat interference resulted in a wobble that needed to be resolved. This speaks to a potential lack of understanding in the nature of intonation perception vis-à-vis pure tones.
- Student 1
 - Had a hard time differentiating the two pitches, and needed considerable instruction and teacher help to finally resolve the note.
- Student 2
 - Participant identifying consonant harmonies as resolved tones.

- Participant unable to remember or differentiate between the two tones at one point.
- Student 3
 - Trouble differentiating between two notes. One issue is the inability to stop the sounds once they begin unless they are resolved.
- Student 4
 - Lost track of the original note and needed education on how to hear both. Would have been easier if the app had the ability to turn off the tone generators temporarily.
 - Participant identifying consonant harmonies as resolved unisons (inability to differentiate).

Video Timecodes

Lack of Clarity on Nature of Task (How to Listen, What to Move, Etc.)

- Educator 3 | 6:05 – 6:39
- Researcher 3 | 3:38 – 3:56
- All Students Received Extensive Instruction on Task

No Longer Hearing First Note [Stable Pitch] (Aurally Blending the Sound)

- Educator 3 | 5:41 – 6:28
- Student 1 | 8:15 – 9:20
- Student 2 | 6:37 – 6:50
- Student 3 | 5:58 – 6:20
- Student 4 | 3:55 – 4:35

Interviews

“[...] it would be nice to kind of reset [...] the first pitch again, then get to do the second one. Because I got kind of turned around on [the] fourth example. I couldn’t find where I was going. So [it might be beneficial] to hear the first one and not have them combatting. [...] So you can still see that it took a student x amount of time.” (Educator 4)

Perceived Usefulness

Field Notes

- Educator 1
 - Unsolicited expression while using the app that there were current students in her classes that could benefit from the use of the app.
- Educator 4
 - Participant, unsolicited, expressed pleasure with the app and indicated current classroom situation where she would find it useful.

Video Timecodes

Unsolicited Expressions of Usefulness

- Educator 1 | 6:10 – 6:33
- Educator 4 | 3:55 – 4:05

Interviews

Educators

“With chorus, for sure, [it would be useful]. [...] for sight reading it would be a good help. Even when it comes to... like right now with learning voice parts and being able to stick to your voice part, and blocking out the other ones, and making sure that you’re actually *in* tune with each other. As well as the whole choir, that, it would be a big help because I think sometimes they don’t realize they’re singing the wrong note; especially if they hear voices next to them that may possibly be singing the wrong note too. So, yea, this would be good practice to do, you know, maybe during some warm-up time, in an assignment, some group work...” (Educator 1)

“[...] you could even use it in a middle school level if you wanted to [...] when it [...] comes to training ears; and even the older aspect... I could see this being used in, like, an aural skills class or something... even on the collegiate level. Of course, a few things have to be understood as far as, like, the Hertz, and I guess that would have to be included in, like, a lesson plan; just so the kids and the adults can understand what Hertz are and how frequency waves effect intonation. I could see that being tied into a nice little lesson plan.” (Educator 2)

“I think it would be great, of course, for singers and for string players, you know, that rely on needing to have accurate pitch. I think it would be great for, just, that type of thing. Maybe, I don’t know about elementary students, but maybe middle and high schoolers especially. I don’t know if I could see *young* young children, like kindergarten, first, second grade, but maybe on up... maybe it would be more useful to them and they would understand what to do.” (Educator 3)

“I’m working with my students now on recognizing intervals, half step vs. whole step, making sure they’re singing the half-step correctly. Sometimes *I* can hear that they’re *not* singing it correctly. They can’t because their ears aren’t used to that. So, this would be a really good exercise to get their ears used to hearing those finer details and what it means to be sharp or flat. [...] Especially [...] for the middle school – high school range when you’re trying to develop that ear I think it’s really useful.” (Educator 4)

“Yes, I do [think the software would be useful] for ear-training contexts majoritively. Um, I think it could be extended intervallically as well. So, if you were starting to train intervals, or sight-singing, those things... I think it has an opportunity for that as well.” (Educator 5)

Researchers

“I do [think the software would be useful], especially for people doing intonation studies. [...] I think it’s certainly got a purpose. It’s certainly very useful.” (Researcher 1)

“I can think of lots of research questions that I could investigate with this software. [...] I would study how good kids are at manipulating pitch and maybe do correlations between how well they use this software and how well they play in tune on their instruments. [...] You know, one of the questions that’s always bothered me is with young string players that play out of tune. Are they playing out of tune because they can’t hear it, or because of the physical question that has to do with they don’t know how to use their fingers? [...] this would be a way of disentangling that issue.” (Researcher 2)

“I could definitely see this helping with tuning, especially as an orchestra director in that initial teaching students how to tune open strings... that could be like a pre-lesson before we actually let students have at tuning their open strings. To figure out whether the static tone

is sharp or flat compared to another tone... that would help with tuning their open strings, which is really important. [...] Yes [I think it would also be useful to music education researchers].” (Researcher 3)

“I think [the software would be useful to music educators]. I personally use a lot of ear training with my kids to get them better on intonation. We go through [...] a game that’s similar to this that I found, but it’s not as easy to use as this, or [as accurate]. [...] I think it would [also] work really well [for music education researchers]. It would be cool to see if different things affect how long it would take for you to reach it, or resolve the notes. I [...] like the timing [measurement]. Sometimes, [...] intonation could be [quick], or sometimes, especially if you’re doing different ranges, it would be cool to see different primary instruments and how quickly things go. Because I’ve observed that, as a bass player, I can pinpoint out-of-tune low notes a lot quicker than I can higher notes.” (Researcher 4)

“You could study the various effects that different stimuli have on students when they are trying to tune in an ensemble setting. For example, if you’re having students try to tune from above or below a drone, you could see comparatively by grade, by instrument, by register, what propensities students have to finding or matching the pitch. You could also, based on the pieces you’re preparing, you could combine disparate sections of instruments: low brass and violin, or viola and trumpet; something where you could see if the timbre of the instruments is a factor in helping students or preventing students from quickly matching pitch.” (Researcher 5)

Students

“I think if you use it regularly you certainly would be able to hear pitches better... or to *match* pitches better I guess I should say. [...] I think [I improved], I don’t know. That middle [session] sort of threw it all off I guess!” (Student 1)

“I think it’s real helpful, because I was finally catching on to how to listen [...]” (Student 2)

“I felt like I got, maybe, a teeny bit better. [...] But, I think if I did it more, I would have gotten [...] it more.” (Student 3)

“Yes. Oh yea, [I feel like I improved from using the software]. I kept going down in seconds [it took to resolve the pitch], so [...] I think it will be very useful.” (Student 4)

“Yes, [I feel like I improved from using the software], and I would have gotten more so, I think, with more experience on it.” (Student 5)

Potential Usefulness to Researchers

Interviews

“[...] one of the things that was so good about the CRDI is that you could change what it was measuring... sorry, *Continuous Response Digital Interface* that Gerringer did... So, like, you could set up the actual program so the dial itself didn’t change, but the program... you could re-do it. So, it could record sharp or flat in cents, or it could record time, or it could record whatever it needed to. So, I think it’s certainly got a purpose. It’s certainly very useful. I’d just be interested to know, maybe, what else we could do with it to make it more practical... again, not saying that time is not practical. [...] “I do [think the software would be useful], especially for people doing intonation studies. [...] I think it’s certainly got a purpose.” (Researcher 1)

“I can think of lots of research questions that I could investigate with this software. [...] I would study how good kids are at manipulating pitch and maybe do correlations between how well they use this software and how well they play in tune on their instruments. [...] You know, one of the questions that’s always bothered me is with young string players that play out of tune. Are they playing out of tune because they can’t hear it, or because of the physical question that has to do with they don’t know how to use their fingers? [...] this would be a way of disentangling that issue.” (Researcher 2)

“I think it would [also] work really well [for music education researchers]. It would be cool to see if different things affect how long it would take for you to reach it, or resolve the notes. I [...] like the timing [measurement]. Sometimes, [...] intonation could be [quick], or sometimes, especially if you’re doing different ranges, it would be cool to see different primary instruments and how quickly things go. Because I’ve observed that, as a bass player, I can pinpoint out-of-tune low notes a lot quicker than I can higher notes.”

(Researcher 4)

“You could study the various effects that different stimuli have on students when they are trying to tune in an ensemble setting. For example, if you’re having students try to tune from above or below a drone, you could see comparatively by grade, by instrument, by register, what propensities students have to finding or matching the pitch. You could also, based on the pieces you’re preparing, you could combine disparate sections of instruments: low brass and violin, or viola and trumpet; something where you could see if the timbre of the instruments is a factor in helping students or preventing students from quickly matching pitch. You could also do intervallic training with this. Trying to find out if perfect intervals

are easier or harder for a certain group. [...] I can imagine that if you started to do 5ths, adding other intervals in, it would be just as useful.” (Researcher 5)

Potential Usefulness to Music Educators

Interviews

“With chorus, [...] for sight reading it would be a good help. Even when it comes to... like right now with learning voice parts and being able to stick to your voice part, and blocking out the other ones, and making sure that you’re actually *in* tune with each other, as well as the whole choir. It would be a big help because I think sometimes they don’t realize they’re singing the wrong note; especially if they hear voices next to them that may possibly be singing the wrong note too. So, yea, this would be good practice to do, you know, maybe during some warm-up time, in an assignment, some group work...” (Educator 1)

“[...] you could [...] use it in a middle school level if you wanted to. [...] when it [...] comes to training ear. And even the older aspect, I could see this being used in, like, an aural skills class or something; even on the collegiate level.” (Educator 2)

“I think children would enjoy, just, you know, the actual working with it, because it was a fun thing to do. [...] I think it would be great, of course, for singers and for string players, you know, that rely on needing to have accurate pitch. I think it would be great for, just, that type of thing. Maybe, I don’t know about elementary students, but maybe middle and high schoolers especially. I don’t know if I could see *young* young children, like kindergarten, first, second grade, but maybe on up... maybe it would be more useful to them and they would understand what to do.” (Educator 3)

“I’m working with my students now on recognizing intervals, half step vs. whole step, making sure they’re singing the half-step correctly. Sometimes *I* can hear that they’re *not* singing it correctly. They can’t because their ears aren’t used to that. So, this would be a really good exercise to get their ears used to hearing those finer details and what it means to be sharp or flat. [...] Especially [...] for the middle school – high school range when you’re trying to develop that ear I think it’s really useful.” (Educator 4)

“Yes, I do [think the software would be useful] for ear-training contexts majoritively.”
(Educator 5)

“I could definitely see this helping with tuning, especially as an orchestra director in that initial teaching students how to tune open strings... that could be like a pre-lesson before we actually let students have at tuning their open strings. To figure out whether the static tone is sharp or flat compared to another tone... that would help with tuning their open strings, which is really important.” (Researcher 3)

“I think [the software would be useful to music educators]. I personally use a lot of ear training with my kids to get them better on intonation. We go through [...] a game that’s similar to this that I found, but it’s not as easy to use as this, or [as accurate]” (Researcher 4)

User Interface – Frequency Range Interface

Field Notes

- Educator 1
 - Participant seemed confused about how the hertz selector worked; not only the GUI, but the way the frequency works in general. Researcher provided the pitch range after participant demonstrated confusion.
- Educator 2
 - Pitch ranges set by researcher because it was not clear to the participant what to set them to. This was likely the reason for the program crash.
 - When the frequency ranges were changed, the dial began moving the number box and participant had to be instructed to click off the box.
- Educator 3
 - Continued explaining the process of the task and the GUI in more detail to each new participant. It seems safe to assume at this point that music educators are not necessarily versed in describing pitch in terms of Hz, and are not necessarily versed in the use of non-commercial (lower budget) software. Therefore, explanations became more detailed.
- Educator 4
 - Participant didn't seem confused by the concept of Hz, but did ask what would be a recommended range for the frequency. This seems like it might imply a lack of familiarity with thinking about pitch as measured in Hz.

- Educator 5
 - Even though he expressed familiarity with Hz, he still wanted to know what I recommended as a range.
 - Seemed miffed that he couldn't use the tab key to change from box to box on the Hz selector.
- Researcher 1
 - Caused the program to crash due to setting minimum frequency to above maximum frequency.
- Researcher 2
 - Still issue with clicking outside of the Hz box (need to research auto-deselect solutions).
- Researcher 3
 - Same GUI problems with Hz selector keep happening. This definitely needs to be changed.
- Researcher 4
 - Had to indicate to researcher that the first step was to set frequency ranges.
- Researcher 5
 - Problem with Hz box staying selected (as in other trials), needs an auto-deselect.
- Student 1
 - The frequency selector seems to be the most obviously problematic part of the GUI, especially for non-professional musicians (although it has also been a problem for the professionals).

- Student 2
 - Oblivious to Hz problem, had to be given the frequency and each way of manipulating the GUI in that area by the researcher.
- Student 3
 - Hz problems, etc. (she needed me to tell her what to put in the box and where to click.)
- Student 4
 - Hz problems, etc. Didn't know what they should pick (gave the frequencies)
- Student 5
 - Need to click outside of Hz still an issue.

Video Timecodes

Set Minimum Frequency Above Maximum Frequency

- Educator 2 | 2:45 – 3:00
- Researcher 1 | 0:00 – 2:50

Lack of Prior Understanding of Frequency as Measured in HZ

- Educator 1 | 0:20 – 1:55
- Educator 2 | 2:45 – 3:00
- Educator 4 | 1:57 – 2:31
- Researcher 4 | 2:20 – 2:43
- Student 1 | 4:26 – 4:56
- Student 2 | 3:09 – 4:07
- Student 3 | 4:06 – 4:31

- Student 4 | 2:33 – 3:07
- Student 5 | 3:15 – 3:39

GUI Issue with Hertz Selector (Click Behavior)

- Educator 3 | 2:38 – 3:09
- Educator 5 | 2:13 – 2:56
- Researcher 2 | 2:30 – 3:03
- Researcher 3 | 2:23 – 2:50
- Researcher 5 | 1:41 – 2:00

Hitting “Start Here” Multiple Times Unnecessarily

- Researcher 4 | 3:29 – 3:37
- Researcher 5 | 2:27 – 2:33

Interviews

“For me, yea, [the frequency selector] was confusing. If the kids had to figure out the frequency without [explicit instruction] that would be an absolute [problem].” (Educator 1)

“Of course, a few things have to be understood as far as, like, the Hertz, and I guess that would have to be included in, like, a lesson plan... just so the kids and the adults can understand what Hertz are and how frequency waves effect intonation. I could see that being tied into a nice little lesson plan.” (Educator 2)

“When selecting the Hertz, I feel like it should go in step order. So, right now you’ve got to go down here, and then in the middle for the volume, and then here, so maybe the Hertz first? [...] when you are assigning the Hertz, maybe show where that note is on the grand staff? So, like, as you scroll or as you enter or as you are selecting it could show you where

you were in relation to middle C. [...] Because some people, you might say, ‘well what’s 440 Hertz?’ and they might go ‘well, I know that’s A, but I can’t tell you what A it is.’

(Educator 5)

“[...] the layout of it could be more intuitive. But, I mean, it all makes sense on the page.

Like, it says ‘step one, clearly do this first.’ But, maybe have the frequency selector up top instead so it’s just ‘you have to do that before you do this.’” (Researcher 1)

“The next thing that I would notice is using the tab or, at least, larger areas to input the Hertz.” (Educator 5)

User Interface – Tone Generators

Field Notes

- It seems like many participants are mistakenly clicking on the on-screen dial display rather than the second tone generator trigger.

Video Timecodes

Mistakenly clicking on the on-screen dial display rather than the second tone generator trigger.

- Educator 1 | 3:41 – 3:53
- Educator 4 | 2:45 – 2:48
- Researcher 3 | 3:04 – 3:09
- Researcher 4 | 2:54 – 2:59
- Student 1 | 5:20 – 5:28
- Student 3 | 4:53 – 5:01

Interviews

“[...] it would be nice to kind of reset [...] the first pitch again, then get to do the second one. Because I got kind of turned around on [the] fourth example. I couldn't find where I was going. So [it might be beneficial] to hear the first one and not have them combatting. [...] So you can still see that it took a student x amount of time.” (Educator 4)

“I like that it's random, because it's easier to tune if you're coming from below. And, so, if you're working with children it would be nice to hear if you [they can] actually hear that that pitch is higher or if that pitch is lower. [...] you also used straight tones for this... so, I wonder if you could use [...] anything with vibrato, just to see [if a subject can] match this pitch when there's vibrato added? Or, can [they] match this pitch when it's a different timbre? [...] so maybe, just, importing different kinds of sounds to match?” (Researcher 1)

User Interface – Dial

Field Notes

- Participants seemed to enjoy using the dial.
- Educator 1
 - Crash issue caused by dial turn when first pitch had not yet been triggered precipitating reset of program, as well as false button press.
- Student 3
 - Continue button not obvious (showed participant by clicking on it myself), and even after that, on the next session the dial itself was pushed, causing a crash. Maybe look into how to lock various aspects of the GUI until certain conditions are met.

Video Timecodes

Mistaken Click on Inner Button Wheel

- Educator 1 | 1:56 – 3:27
- Researcher 1 | 0:40 – 1:14, 2:28 – 2:50

Dial Not Set at Up/Down Initially

- Educator 2 | 3:05 – 3:20
- Researcher 2 | 3:41 – 3:55
- Student 4 | 3:38 – 3:50
- Student 5 | 4:06 – 4:28

Interviews

“I really liked how we’re using the dial; that’s really nice. [...] I think that’s more [...] reflective of how you would think about tuning in any case.” (Researcher 4)

User Interface – Volume Control

Field Notes

- Educator 3
 - The participant did not seem to understand that the distortion of the sine waves could make the task impossible.
- Researcher 1
 - Mistakenly set volume to excessively high (distorted).
- Researcher 2
 - Raised volume to distortion levels accidentally, but quickly brought it back.

- Student 5
 - Raised volume to distortion levels and had to be directed to reduce it.

Video Timecodes

Researcher Manipulation of Volume Due to Being Too Quiet

- Researcher 4 | 2:44 – 2:51
- Student 1 | 4:56 – 5:13
- Student 2 | 3:33 – 3:42
- Student 5 | 3:05 – 3:13

Misuse of Volume Control (Causing Distortion)

- Educator 3 | 3:01 – 5:03
- Researcher 1 | 0:00 – 1:14

Feature Recommendations – Measurement and Data

Interviews

“I know it’s exporting time it took to match (which is a useful thing because you need to know if students, or anybody, can match pitch and how quickly they can do that), but one of the things that was so good about the CRDI is that you could change what it was measuring... sorry, *Continuous Response Digital Interface* that Gerringer did... So, like, you could set up the actual program. So the dial itself didn’t change, but the program... you could re-do it. So, it could record sharp or flat in cents, or it could record time, or it could record whatever it needed to. So, I think it’s certainly got a purpose. It’s certainly very useful. I’d just be interested to know, maybe, what else we could do with it to make it more

practical, again, not saying that time is not practical [...], I just think accuracy or a way to export the pitch accuracy could be added. [...] [For example], each new session ended when it was resolved for three seconds; I wonder if we could (or if you could) make it so that you said 'okay, here's tone A and here's tone B, match this pitch as close as you think you can, and then when you're done, press this button.'" (Researcher 1)

"So, in the readout I would want to know what the pitch (1) that was presented was, and what pitch (2) ... the starting pitch that the participant is manipulating... what that would be, or what that was in each trial so that I could ask questions such as "the further away the pitch is... how does that effect the time of adjusting the pitch to the given pitch?" and, you know, other questions as, you know, "is a particular participant better at adjusting up than down?" [...] So that would be easy, right? You should be able to write out the pitches; the two pitches presented... And then, you have seconds... I mean, it would be interesting if there was a way to actually write out the curve... In other words, let's say the pitch is here (I'm holding out my hand) and I have a pitch that's too high, and then I go down below the curve... but how many times do I miss it? Right? So, the way I teach my string players to tune is I say, you know, they always ask me, you know, kids, is it up or down? And I say "don't worry about it, just turn it and see if it gets better or worse. And they can usually hear if it gets better or worse, but then at some point it gets better, but then at some point it gets worse if they go past the pitch... Right, so here it would be interesting to see those curves as they end up at the right pitch. I think most of the time I went down below it and back up again, and I think a couple of times I went down and landed on it. But, just giving me the time wouldn't tell me how many times I went below and back up again." (Researcher 2)

“It would be cool to see if different things affect how long it would take for you to reach it, or resolve the notes. I [...] like the timing [measurement]. Sometimes, [...] intonation could be [quick], or sometimes, especially if you’re doing different ranges, it would be cool to see different primary instruments and how quickly things go. Because I’ve observed that, as a bass player, I can pinpoint out-of-tune low notes a lot quicker than I can higher notes.”

(Researcher 4)

“I think recording the students attempt so they can listen back to what their tendency was Did they go too far? Did they overshoot? Did they undershoot? Based on the interval they’re coming from to try and find the unison, do they do better when its farther away? Do they do better when its closer? But if the student can actually go back and watch their own performance, in the same way that in any flight simulator or in other quick reflex athletic or aeronautical training simulators you can go back and watch yourself perform to see how you did.” (Researcher 5)

Feature Recommendations – General

Interviews

“do you remember the game Simon? Where it had, you know, a number of different pitches? Some intervals that they also had to match? I don’t know, like a repeat-after-me type of thing.” (Educator 1)

“If I had to make one suggestion I would say just make it a little more appealing; more colors and, just, a little more exciting for kids to look at it. Show results, as far as percentage; seeing the percentage and everything. Showing them something [so] they could see the immediate results. Kind of like when I look at musictheory.net, when I do the stuff it

shows the time frame it takes for them to do the sequence and, of course, you know, the accuracy.” (Educator 2)

“I think it could be extended intervallically as well. So, if you were starting to train intervals, or sight-singing, those things... I think it has an opportunity for that as well.” (Educator 5)

“It would be cool if there was some way to put this in the future on something that they can use at home. Usually they use phones nowadays, you know, some sort of app that they can use on their own time.” (Researcher 4)

“Possibly intervals [could be added as a feature]. If you’re doing something like just intonation, getting a third or a fifth exactly right. I think that would be really cool, especially at a more advanced level where you’re talking about this with kids. A lot of us will try to play on the piano and get them to tune to that, but those are equal temperament notes. And, so, you know... otherwise I know a lot of people use harmony directors and I think that through this it could save a lot of money.” (Researcher 4)

“I really like that you have to wait three seconds for it to actually register. Because, for my other game kids will play around with it and it will go in tune and out of tune, in tune and out of tune, and they’ll just keep guessing you know? I think is a better statement for the students anyway, in a sense of, like, ‘no, it’s not right,’ Which is something in instruments [that shows up frequently]. they don’t normally hear that they’re out of tune and you have to kind of show them slowly that, you know, you’re not matching this person next to you. And sometimes you have to isolate it, and all that. So, I think it speaks volumes in terms of feeding back.” (Researcher 4)

“I can’t see anything adding to it, unless you wanted to take it further and do the pitches that would harmonize, you know.” (Student 1)

“Well, I guess just personally for me [...], I’d like to be able to sing a note [...] and see if I’m really matching the note. [...] so, I could tune to the correct [note so that] I wouldn’t sing flat or sharp.” (Student 2)

“What I would really like to see is a visual representation of the tone.” (Student 5)

Bugs & Crashes

Field Notes

- Educator 1
 - Crash issue caused by dial turn when first pitch had not yet been triggered precipitating reset of program, as well as false button press.
- Educator 2
 - Program crash due to reasons that need to be analyzed in video footage.
 - Pitch ranges set by researcher because it was not clear to the participant what to set them to. This was likely the reason for the program crash.
 - The participant identified what he believed to be a problem with not being able to get a solution to a set of two tones. We hypothesized that this was because the ranges were set to an odd number, but subsequent tests were unable to replicate the problem.
- Researcher 1
 - Caused the program to crash due to dial movement at the wrong time
- Student 3

- Continue button not obvious (showed participant by clicking on it myself), and even after that, on the next session the dial itself was pushed, causing a crash. Maybe look into how to lock various aspects of the GUI until certain conditions are met.

Video Timecodes

Dial Movement at Wrong Time Causing Crash (Every Case)

- Educator 1 | 2:30 – 3:27
- Educator 2 | 2:18 – 2:44
- Researcher 1 | 0:00 – 1:14
- Student 3 | 7:37 – 7:50

Interviews

“[...] the Hz, when it was an odd number, you were not able to get it in tune no matter how much you tried, because it was an odd number. So, when we moved it to the even number then we were able to get to resolution.” (Educator 2)