Three Studies of Emotional Cues in Instrumental Music Inspired by Acoustical Cues in Vocal Affect

Thesis

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By

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Abstract

Musicians commonly regard the human voice as a model for emotional expressiveness. Similarly, modern psychological research suggests that the human voice offers a useful model for understanding how sounds represent or convey emotions (e.g. Juslin & Sloboda, 2011). This thesis reports on three studies, each of which is inspired by different features of vocal emotion. That is, the three studies investigate whether instrumental music exhibits or emulates these features.

Study 1 was motivated by the observation that a darker timbre is an acoustical characteristic of sad voice (Scherer, Johnstone & Klasmeyer, 2003). Given that open strings generate a brighter timbre than stopped strings (Schelleng, 1973), composers writing nominally sad music might choose keys and notes that prohibit the use of open strings. Specifically, the proportion of potentially-open-to-stopped strings was compared between a sample of slow minor-mode movements and matched major-mode movements.

Study 2 was inspired by certain acoustical characteristics of laughter. First, to verify the possibility of hearing laughter from an instrument other than voice, participants adjusted the speed and duty cycle of looped tones to produce the most laughter-like sound. Next, the study examined whether the acoustical characteristics of laughter appear in real music by comparing amounts of staccato and rhythmically isochronous passages found in musical compositions of a comedic genre.
(humoresques, badineries, and Scherzos) and in similar-tempo works by the same composers.

Study 3 was motivated by the observation that high emotionality (e.g. fear, rage, excitement) often results in speaking within the upper pitch register (Scherer et al., 2003). To be able to identify pitch register, one must know the range of the speaking voice, something that research indicates humans can accurately perceive (Honorof & Whalen, 2005). The study first tested whether range information is similarly perceptible for instruments, specifically for cello. Participants were asked to identify which tones, of pairs, were played in high playing positions. Next, the study tested whether melodies played in high playing positions portray greater emotionality. In a 2AFC paradigm, listeners chose which of a pair of recordings of a melody - one each played in a high or low pitch register - they perceived as more emotionally expressive.

Contrary to the hypothesis of study 1, examination of a sample of quartet movements by Haydn, Mozart and Beethoven failed to exhibit the conjectured relationship between darker timbre and the use of stopped versus open strings. Study 2 results were mixed. The adjusted tempos and articulations were consistent but slower and longer than those of actual human laughter. Additionally, the nominally humorous works were found to contain more staccato passages. However, these were not more likely to be isochronous. Study 3 also produced mixed results. Participants were reasonably able to identify which note was played in a high playing position. However, participants selected melodies played in a high register as more expressive only for recordings by Cellist A. The opposite results occurred for recordings by Cellist B.
Dedication

This document is dedicated to my parents, Colleen and Henry Trevor, and to my undergraduate music theory professor who encouraged me to pursue this field,

Joseph Plazak.
Acknowledgments

I would like to thank my family for supporting me in my research endeavors. I would also like to thank my advisor, David Huron, for his invaluable guidance and inspiration. Moreover, I would like to thank the other members of my committee, Marc Ainger and Anna Gawboy, for their instrumental criticism and assistance. Additionally, I would like to thank Mark Rudoff, my cello professor, for our conversations that helped me to further connect my own experiences with cello playing to my research interests in music cognition. Lastly, I would like to thank the entire Cognitive and Systematic Musicology Laboratory here at Ohio State for their continual feedback and encouragement.
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Fields of Study

Major Field: Music
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Chapter 1: Introduction

Much of music’s popularity stems from its ability to evoke powerful emotions. Performers, composers, and pedagogues alike have asked the question of how music achieves this affect since antiquity. By way of an answer, musicians have habitually regarded the human voice as a model for emotional expressiveness (e.g. Scherer, 1995). More recently, some music cognition researchers have relied on the common comparison of musical traits to vocal affective cues to understand music and emotion (e.g. Juslin & Sloboda, 2011). For this thesis, three different vocal affective phenomenon are explored in musical contexts. The first study involves sadness, the second examines laughter, and the third discusses the expressiveness of vocal range. Each investigates whether these features are exhibited or emulated in instrumental music.

Study 1 is motivated by the fact that a darker timbre is one of the acoustical characteristics of sad voice (Scherer, Johnstone & Klasmeyer, 2003). String instruments may be played either with open strings (where the string vibrates between the bridge and a hard wooden nut) or with stopped strings (where the string vibrates between the bridge and a performer’s finger pressed against the finger board). Compared with open strings, stopped strings permit the use of vibrato and exhibit a darker timbre (Schelleng, 1973). Therefore, it was predicted that when writing nominally sad music, composers might select keys and notes that inhibit the use of the brighter-sounding, open strings. Specifically, the proportions of
potentially open-to-stopped strings were compared between a sample of slow minor-mode movements and matched major-mode movements. By way of illustration, a preliminary analysis of Samuel Barber’s famous *Adagio* from his Opus 11 string quartet shows that the selected key (B-flat minor) provides the optimum key for minimizing open string tones.

Study #2 is inspired by acoustical elements of laughter. Jankélévitch (1961) observed that the use of pizzicato could be evocative of humor—presumably through its resemblance to the sound of human laughter. This study aims to formally test the hypothesis that composers may produce a perceived humorous effect by writing passages whose acoustical structure resembles human laughter. Specifically, it was predicted that these composers would use staccato in isochronous rhythms. In stating the claim that composers portray laughter, the assumption is made that one can interpret tones from a musical instrument as laughter-like sounds. Therefore, the first step was to verify that it is indeed possible to hear laughter from a musical source other than the human voice. Using Max/MSP (Puckette & Zicarelli, 1990), an interface was created that presented participants with four looped sound samples (cello, horn, flute, voice). Twenty-five participants were instructed to adjust the speed (tempo) and duty cycle (articulation) of looped single tones so as to produce the most laughter-like sound. In the second part of the study, nominally humorous musical works were compared with control works. The sample of potentially humorous works consisted of piano compositions labeled *humoresque, Scherzo, or badinerie*. Compared with control works (works by the same composer exhibiting the same tempo markings), it was hypothesized that
humoresques/Scherzos/badineries would be more likely to contain staccato passages that would also be more likely to exhibit isochronous rhythms.

Study #3 is inspired by observations regarding pitch register in emotional speech. I observed that when aiming to increase emotional intensity, advanced string performers typically prefer to play a passage using a high playing position (closer to the bridge) on a low string rather than playing the same pitches using a low playing position (closer to the scroll) on a high string. It was predicted that this practice might be mimicking a vocal affective cue. Speaking in a high register portrays high emotionality (i.e. fear, rage, excitement) (Scherer et al., 2003). Accordingly, utterances at the identical pitch level will tend to sound more emotional if the speaker is perceived to have a lower vocal range than a higher vocal range. The musical practice of moving to a high position on a lower string might mimic this vocal emotional behavior as a way of conveying a higher emotional intensity. However, identifying pitch register is dependent on knowing vocal range. Humans have been shown to be able to accurately identify the range of a person's speaking voice (Honorof & Whalen, 2005). To investigate this theory of greater emotionality, it was necessary to first determine whether listeners could similarly identify the range of an instrument, specifically cello. To test this ability, the study examined whether participants could reliably distinguish between tones played in high and low playing positions.

Cello tones were recorded in both low playing positions on a high string and in high playing positions on a low string. Participants were briefed on the playing positions on a cello and given sound examples to become familiar with the acoustics of high and low playing positions. Listeners were then asked to identify which of a
pair of recorded tones was played in a high playing position. Next, part two tested the hypothesis that melodies played in a high playing position are perceived as more emotionally intense than the same melodies played in a low playing position. Six short melodies were recorded in both high and low playing positions. In a 2AFC paradigm, listeners chose which of the two versions of the melodies they perceive as more emotionally expressive.

The results of study #1 failed to exhibit the conjectured relationship. Despite the predicted avoidance of open strings being demonstrated in the Barber, examination of a broader controlled sample of quartet movements by Haydn, Mozart and Beethoven was unsuccessful in corroborating these findings. Instead, major-mode movements were found to avoid possible open strings more than slow minor-mode movements.

In study #2, the adjusted tempos were consistent but slower than measures of actual human laughter. Similarly, the adjusted duty cycles were consistent but longer than is evident in human laughter. Despite differing from the hypothesis, the slower tempos and articulations in the results corroborate research on laughter in opera that found that laughter portrayed in music was consistently slower and longer than natural human laughter (Provine, 2001). The results of part two were consistent with the hypothesis in that *humoresques* contain more staccato passages. However, these detached articulations were not more likely to be isochronous as might be expected if emulating human laughter. Overall, the results provide mixed evidence largely consistent with the idea that composers emulate the acoustical structure of laughter when composing certain kinds of humorous passages.
For study #3, consistent with the first hypothesis, the results showed that participants were reasonably able to identify whether a note was played in a low or high playing position. The second hypothesis had a more complicated conclusion. Participants who rated melodies played by Cellist A yielded results consistent with the hypothesis in that they rated melodies played in upper playing positions as more expressive. However, participants who heard Cellist B rated melodies played in a low playing position as more expressive. This difference of opinion may be related to how much time the cellists had to learn the melodies before recording as well as the overall skill level of each of the cellists. In the final chapter, future studies are suggested that focus on further exploring performance choices in relation to vocal affective cues.
Chapter 2: The Use of Stopped Strings in Sad Music

Several acoustic factors are known to contribute to the perception of sadness. One factor is a darker timbre. In the case of speech, Scherer, Johnstone and Klasmeyer (2003) note that sadness is linked to a greater spectral slope—that is, where the rate of energy decline with respect to frequency is greater for sad speech compared with other vocal affects. The darker timbre of sad speech appears to be caused by the relaxation of the zygomatic muscles, which pull the lips away from the teeth (in contrast to smiling where the lips are retracted against the teeth). This relaxation produces a lengthening of the vocal tract resulting in a lower resonant frequency, consequently causing a darker or less bright sound (Ohala, 1980, 1994; Tartter, 1980; Tartter & Braun, 1994).

In the case of music, several studies have identified plausible connections between various musical practices and known properties of sad speech. For example, Schutz et al. (2008) compared the distribution of major and minor modes in the concert repertoires of two similar musical instruments—marimba and xylophone. For the darker sounding marimba, roughly 60 percent of the active tonal repertoire is in the minor mode, whereas only 6 percent of the active tonal repertoire for the (considerably brighter) xylophone is in the minor mode. At face value, this result appears to support the connection between darker timbre and sadness. However, other interpretations are possible.

The marimba and xylophone are not exactly comparable instruments. The
marimba is pitched an octave lower than the xylophone, and the marimba produces longer periods of sustain compared with the xylophone. On the one hand, sad speech also exhibits lower overall pitch, so the association between the marimba and the minor mode might originate in its lower pitch compared with the xylophone. On the other hand, sad speech exhibits a slower syllable rate and tempo, so the association between the marimba and the minor mode might originate in its slower decay compared with the xylophone—which is consequently less able to play at slow tempos. That is, timbre, pitch height, and tempo are confounded when comparing these two instruments.

A similar confound is evident when contrasting music for guitar and banjo. The banjo exhibits a brighter timbre than the guitar. In addition, the banjo exhibits shorter sustain than the guitar. Consequently, the greater association of sad music with the guitar may theoretically be attributable to either or both of those features. Johnson (2010) addressed this issue by comparing the note-rates for performances of the same works on solo guitar and solo banjo. He found that the note rates for banjo renditions of the same work were considerably faster than those for the guitar, suggesting that tempo is an important factor, even apart from the difference in timbre between these two instruments. Both the Schutz et al. (2008) and Johnson (2010) studies demonstrate the difficulty of isolating different acoustical factors in creating nominally sad textures, or any specific emotional textures.

The goal for the current study was to test the “darker is sadder” hypothesis using yet another ecological approach. When performing on stringed instruments some sounds are played on “open” strings, whereas other sounds are played using “stopped” strings in which the player uses a finger from the left hand to press the
string against the fingerboard. Especially in the case of unfretted instruments, performers agree that stopped and open strings produce different timbres. Open strings vibrate the full length between the bridge and the nut, and the hard edge of the nut produces a well-defined end-point for the vibrating string. Conversely, stopped strings are terminated by the fleshy pad of the finger, producing a less well-defined end-point with the finger absorbing high-frequency vibrational energy compared with the nut (Schelleng, 1973). As a result, open strings are widely regarded as brighter sounding than stopped strings.

If stopped strings exhibit darker timbres than open strings, one might expect that nominally “sad” works for stringed instruments might tend to avoid the use of open strings in contrast to nominally “happier” works. At the same time, there are other good reasons why musicians might prefer stopped strings over open strings. Most notably, stopped strings afford the use of vibrato, which in modern orchestral music making is a nearly omnipresent element of preferred performance practice. In the case of orchestral strings, if there appears to be evidence of a preference for stopped strings as opposed to open strings, it is not possible to distinguish between the claims that the goal of this practice is strictly timbre or vibrato related. Here it is acknowledged that this method cannot distinguish between these competing claims. Perhaps future studies may be able to disambiguate the principal motivation for any presumed preference for stopped over open string use. In any event, it is appropriate to test empirically the conjecture that musicians prefer stopped string use over open string use—at least in the case of nominally sad music.

**Preliminary Test**

What motivated the current study was an initial exploratory study that was
carried out on Samuel Barber’s *Adagio* for strings (1936). The *Adagio* was originally written as the middle movement of a string quartet (opus 11) and later arranged for string orchestra. In 2004, the British Broadcasting Corporation’s World Service conducted an international survey where listeners voted for “the world’s saddest music.” Samuel Barber’s *Adagio for Strings* won an outright majority of votes—although empirical research suggests that the *Adagio* may not be as “sad” as commonly supposed (Baumgartner, *et al.*, 2006; Boltz, 2001; Krumhansl, 1997; Nawrot, 2003). The work’s key is unusual (B-flat minor). The work’s key is unusual (B-flat minor). A composer’s choice of key can be influenced by many factors. These include idiomatic factors, such as increasing the playability of a work, or intentionally choosing a difficult key to better convey a sense of struggle, challenge, or anguish. In addition, different keys have different historical associations (“key characteristics”) where certain keys are thought to convey distinctive variations in color (Jorgensen, 1991; Steblin, 2002). For the purposes of this study, however, these other possible influences will not be addressed.

Instead, this preliminary investigation examined the possibility that Barber intentionally aimed to reduce the potential for open strings, either in order to facilitate the use of vibrato or to increase the darkness of the string timbres or both. We tallied the duration of potentially open-to-stopped strings and applied this method to 12 alternative transpositions. The results are displayed in Figure 1 (next page). As can be seen, the results are unequivocal: the key chosen by Barber (B-flat minor) is clearly the best possible key if the aim is to minimize the possibility of playing notes using open strings. This raises the question of whether Barber’s practice might be indicative of a general musical practice—hence motivating the
current study.

**Hypothesis**

Formally, this hypothesis may be stated as follows:

H1. The ratio of open-to-stopped strings will be smaller for sad works compared to non-sad works for strings.

![Figure 1: Effect of Transposition on Total Duration of Potentially Open-String Tones in Samuel Barber’s *Adagio* from His Opus 11 String Quartet. Duration is measured in quarter-note units. Transpositions (in semitones) range from a tritone below (-6) to a tritone above (+6). The original key (0, B-flat minor) exhibits a notable minimum, consistent with the conjecture that Barber aimed to avoid the possibility of instrumentalists playing with open strings.](image)

In order to test this hypothesis, each term was operationalized. For the purposes of this study, only common orchestral stringed instruments - specifically, the violin,
viola, and violoncello - were considered. In playing these instruments, performers have considerable latitude in choosing to play a given tone using an open or stopped string. For example, a violinist can play the pitch D4 using either the open D string, or by playing a stopped tone on the G string. With the exception of the lowest pitch (G3), all of the pitches playable on the violin can be theoretically played using a stopped string. The most accurate way of determining whether a given note is played using an open or stopped string would be to study video recordings with close-ups of the left (fingerboard) hand. However, this approach was deemed impractical since the aim was to calculate the ratio of open-to-stopped strings using a large musical sample. Instead, the study focused on musical notation. In notation, one can distinguish between those pitches that must be played using a stopped string from those pitches that may be played using an open string. While the performer holds some latitude to play potentially open string pitches using a stopped string, one might suppose that a composer, aiming to encourage the use of stopped strings would simply minimize those pitches that could potentially be played using an open string. Accordingly, it was decided that the ratio between “potentially open string pitches” and “stopped-string pitches” would be calculated.

Turning next to the term “sad music,” one way of operationally defining sad music might simply be to select works in the minor mode. However, not all works in the minor mode may be reasonably characterized as “sad.” Post and Huron (2009) observed a general association between slow tempo and the minor mode—consistent with the notion that slow tempo contributes to the perception of sadness. However, they found a notable exception in music from the nineteenth century, which exhibits a reverse correlation: in the nineteenth century, on average, music in
the minor mode exhibits faster tempos than major mode works. In order to avoid this possible confound, sad music was operationally defined as music in the minor mode that is also slow in tempo.

**Sample**

As noted earlier, a preference for stopped strings may have several possible motivations. Apart from the pursuit of a darker timbre, stopped strings also enable the use of vibrato. Note that prior to the 20th century, it is thought that vibrato was used in an intermittent or ornamental fashion; the use of constant vibrato throughout the work was not yet mandatory (Norrington, 2004). Accordingly, in this musical sample, only music prior to around 1850 was examined. To this end, a convenience sample of already-existing computer encodings of string quartets from the 18th and 19th centuries was used. The works were available in a database provided by the Center for Computer Assisted Research in the Humanities on kern.ccarh.org (Huron, 1997). The initial candidate sample included a total of 73 string quartets: 46 string quartets by Franz Joseph Haydn, 19 string quartets by Wolfgang Amadeus Mozart, 7 string quartets by Ludwig van Beethoven, and 1 string quartet by Franz Schubert. More specifically, the conventional “slow” movements from these string quartets were selected. Typically, this is the second movement in both three-movement and four-movement works.

**Procedure**

For each string quartet, the various movements were examined to determine whether the prevailing mode was major or minor. The movements of the 73 quartets were divided into three categories: (1) obviously predominantly major, (2) obviously predominantly minor, and (3) not obviously major or minor. Of the slow movements
from these quartets only 11 movements met the a priori selection criterion of being both slow and obviously minor. Five were composed by Haydn, and three each were composed by Mozart and Beethoven. For technical reasons, only 10 of the 11 selected movements were available for analysis.

For each of the 10 minor-mode slow movements, one of the remaining movements from the same quartet was randomly selected as a control. In order to be selected, control movements had to be deemed obviously in the major mode. None of the string quartets failed to include a movement deemed obvious major, so control major-mode movements were available for each of the 10 target minor-mode slow movements. Note that a control movement might have also had a relatively slow tempo marking. For example, one of the control movements was marked “Adagio e cantabile” and a second was marked “Adagio - Allegro assai - Adagio.” However, the majority of control movements were clearly faster in tempo, ranging from Andante to Presto, with a considerable majority exhibiting some type of allegro tempo. Regardless, major-mode movements were retained as controls whether or not the tempo was fast or slow.

For both the target and control movements, the number of notes for each instrument, and also the number of notes that could, in principle, be played using open strings, were counted. Separate tallies were done for each of the target instruments: violin I, violin II, viola, and violoncello. Tied notes were treated as single pitches. In order to maximize data independence, repeats and Da Capos were ignored.

Results

Recall that the hypothesis predicts that the ratio of open-to-stopped strings will
be smaller for nominally sad works compared to non-sad works for strings. In the operationalization, it is assumed that slow works in the minor mode are more likely to express or represent sadness compared with tempo-variable works in the major mode. Accordingly, it is reasonable to expect that slow-minor movements should exhibit fewer potential open strings than for major movements. Combining the data for all of the sampled works, it was found that for slow-minor movements, 17.5 percent of all notes could possibly be played using open strings. By comparison, for tempo-variable major movements 15.9 percent of notes could be played using open strings. In short, the results are exactly contrary to the hypothesis. Major-mode movements have fewer potential open strings than slow-minor movements. No statistical test is necessary since the average scores are skewed opposite to the predicted direction.

Another way to test the hypothesis might compare the original keys with all other possible keys in which a work might be written—as demonstrated in the exploratory study with Barber’s *Adagio*. For example, a work might be written in B minor—a key that affords relatively few opportunities to use open strings, compared with other possible keys. Accordingly, the ratio of potentially open-to-stopped strings for all possible chromatic transpositions could be calculated. Then, the transposed ratios could be compared to the ratio for the actual notated key. To this end, each movement was transposed to 11 different transpositions (ranging from a tritone below the notated key to a perfect fourth above the notated key). For each transposition, the proportion of potentially open and stopped strings was calculated. These transposed versions effectively provide a distribution against which the ratio of open-to-stopped strings in the notated key could be compared. The actual open-
to-stopped ratio can then be expressed as a normalized value or z-score. Positive z-scores would indicate that the actual key provides more open-string opportunities than other possible keys. Table 1 reports the average z-scores for open strings for the two musical samples (slow-minor and tempo-variable major) with independent results shown for each instrument, as well as a combined score.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Slow-minor</th>
<th>Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violin</td>
<td>+0.90</td>
<td>+1.96</td>
</tr>
<tr>
<td>Viola</td>
<td>+2.05</td>
<td>+1.44</td>
</tr>
<tr>
<td>Cello</td>
<td>+2.04</td>
<td>+0.92</td>
</tr>
<tr>
<td>All</td>
<td>+1.59</td>
<td>+0.34</td>
</tr>
</tbody>
</table>

*Table 1. The z-scores for Open-string Notes*

Again, positive z-scores indicate that the actual key involves more open strings than would be expected compared with a random transposition or random key. As can be seen in Table 1, there is a proliferation of positive z-scores. This means that, in general, the notated keys exhibit more open strings than would be expected (were key not considered) for both the slow-minor and major movements. Moreover, the overall z-score for slow-minor movements is higher than for major-mode movements indicating that the open-string tendency is greater for the composer-selected keys in the nominally sadder movements. Once again, these results are contrary to the motivating hypothesis for this study. As before, no statistical tests are necessary since the results are skewed in a direction opposite to the hypothesis.

**Sympathetic Vibration – A Post-Hoc Test**

In discussing the above-mentioned negative results with string players, another possibility was raised: namely, the role of sympathetic vibrations. When one
plays C3 on the cello, the lowest string (C2) will typically vibrate as well. This phenomenon of sympathetic vibration can be observed for all of the lower harmonics, so the C string will tend to vibrate sympathetically for the pitches C3, G3, C4, etc. Similarly, the pitches G3, D4 and G4 will tend to evoke sympathetic vibration from the G (G2) string, and so on. The consequence of these sympathetic vibrations is described by string players as adding brightness to the timbre—analogous to the brightness of open strings. Accordingly, instead of just focusing on the potential open strings, it might be useful to also consider the effect of pitches that could evoke sympathetic vibrations. As a result, the following post-hoc variation to the experimental hypothesis was entertained:

H2. The ratio of possible-open-and-or-sympathetic to stopped-and-nonsympathetic pitches will be smaller for sad works compared to non-sad works for strings.

In brief, the same method and same musical sample described above were employed once again, with the addition of the nominally “sympathetic” pitches. In general, strings will vibrate sympathetically to any concurrent tone that corresponds to a harmonic of that string. The amount of energy of the sympathetic vibration is dependent on the energy of the concurrently sounded tone, as well as the closeness in frequency to the true harmonic. Harmonics 5 and 7 are notably out-of-tune with their equally-tempered counterparts, so most sympathetic vibrations will be limited to harmonics 1, 2, 3, 4, 6, and 8. Of course pitches played below a given string may also activate sympathetic vibration for an open string tuned above. Hence, on the
cello, playing A2 on the G string will tend to engage the open A string (A3).

Applying these observations, Tables 2, 3, and 4 identify the strings for each of the violin, viola and violoncello, as well as the corresponding near-harmonic pitches that are most likely to evoke sympathetic vibrations. In creating these lists, note that a distinction must be made between the evoking pitch and the evoked pitch. For example, playing the G (G3) string on a violin might evoke a sympathetic vibration on the D2 string, corresponding to the third harmonic for G3, namely D5. In this

<table>
<thead>
<tr>
<th>String</th>
<th>Sympathetic tones (2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 6\textsuperscript{th}, 8\textsuperscript{th} harmonics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3</td>
<td>G4, D5, G5, D6, G6</td>
</tr>
<tr>
<td>D4</td>
<td>D5, A5, D6, A6, D7</td>
</tr>
<tr>
<td>A4</td>
<td>(A3), A5, E6, A6, E7, A8</td>
</tr>
<tr>
<td>E5</td>
<td>(E4), (A4), E6, B6, E7, B7, E8</td>
</tr>
</tbody>
</table>

*Table 2. Violin: Plausible Open Pitches and Sympathetic Pitches*

<table>
<thead>
<tr>
<th>String</th>
<th>Sympathetic tones (2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 6\textsuperscript{th}, 8\textsuperscript{th} harmonics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>C4, G4, C5, G5, C6</td>
</tr>
<tr>
<td>G3</td>
<td>G4, D5, G5, D6, G6</td>
</tr>
<tr>
<td>D4</td>
<td>(D3), D5, A5, D6, A6, D7</td>
</tr>
<tr>
<td>A4</td>
<td>(A3), (E5), A5, E6, A6, E7, A7</td>
</tr>
</tbody>
</table>

*Table 3. Viola: Plausible Open Pitches and Sympathetic Pitches*

<table>
<thead>
<tr>
<th>String</th>
<th>Sympathetic tones (2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 6\textsuperscript{th}, 8\textsuperscript{th} harmonics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>C3, G3, C4, G4, C5</td>
</tr>
<tr>
<td>G2</td>
<td>G3, D4, G4, D5, G5</td>
</tr>
<tr>
<td>D3</td>
<td>(D2), D4, A4, D5, A5, D6</td>
</tr>
<tr>
<td>A3</td>
<td>(A2), (E4), A4, E5, A5, E6, A6</td>
</tr>
</tbody>
</table>

*Table 4. Violoncello: Plausible Open Pitches and Sympathetic Pitches*
case, G3 is the evoking pitch and D5 is the evoked pitch. Although it is D5 that is evoked, it is the brightness of the G3 string that is enhanced. Hence, for the purposes of this study, our interest is not the evoked pitch (e.g., D5), but the evoking pitch (G3). In effect, all of the pitches listed in Tables 2-4 were treated like open strings, and repeated the analysis of the Haydn, Mozart, and Beethoven minor-slow and tempo-variable major movements. For simplicity, all of the pitches displayed in Tables 2-4 are collectively referred to as “sympathetic pitches” rather than as “open & sympathetic pitches.”

Combining the data for all of the sampled works, it was determined that for slow-minor movements, 45.1 percent of all notes are “sympathetic” pitches. By comparison, for tempo-variable major movements, 41.9 percent of notes are sympathetic pitches. As before, the results are exactly contrary to the hypothesis. No statistical test was deemed necessary since the average scores are skewed opposite to the predicted direction.

Once again, all of the movements were transposed through 12 different keys—down to a tritone below, and a perfect fourth above, as well as the original key. The proportion of sympathetic pitches for the transposed versions were again used as a distribution against which the actual sympathetic pitch counts could be compared—

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Slow-minor</th>
<th>Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violin</td>
<td>+1.22</td>
<td>+1.81</td>
</tr>
<tr>
<td>Viola</td>
<td>+1.65</td>
<td>+1.83</td>
</tr>
<tr>
<td>Cello</td>
<td>+1.73</td>
<td>+1.75</td>
</tr>
<tr>
<td>All</td>
<td>+0.99</td>
<td>+1.82</td>
</tr>
</tbody>
</table>

*Table 5. The z-scores for Sympathetic Notes*
resulting in a set of normalized z-scores. Table 5 reports the z-scores for sympathetic notes for the two musical samples (slow-minor and major) with independent results shown for each instrument, as well as a combined score. As before, positive z-scores indicate that the actual keys involve more sympathetic notes than would be expected compared with a random transposition or random key. As can be seen, all of the values are positive suggesting that the actual keys involve more sympathetic notes than expected. However, the values for the major mode are bigger than comparable values in the minor mode, suggesting that major-mode movements exhibit a greater tendency to avoid sympathetic notes than slow-minor movements—exactly contrary to the hypothesis.

**Conclusion and Discussion**

As shown, both the original and post-hoc hypotheses failed. It may be appropriate to speculate about possible reasons for this failure. In the first instance, the hypothesis may simply be false. It may be that the results for Barber are unique, a chance result, or that Barber was an idiosyncratic composer interested in reducing the possibility of open-string playing. There are other possibilities as well.

One possibility is that the composers studied here were already aware of the preference string players have for playing stopped strings. In general, string players much prefer to play stopped rather than open strings, so even in a key (such as C major) with the potential for many open strings, players typically choose to play using entirely stopped strings. At the same time, for very rapid passages, open strings may tend to reduce the difficulty. Both Mozart and Haydn were experienced string players and Beethoven was certainly well-versed in string technique (Drabkin, 1995). Perhaps, in writing their works, they were providing more options for string
players: that is, one could choose to play with or without open strings depending on the skill level of the performer or whether the work was being sight-read (Jones, 2003).

Other possibilities for the failure of these hypotheses might arise because the sample size was too small, or that the sample was restricted to just three composers from the late 18th and early 19th centuries. Note that Barber’s Adagio was written more than a century after the latest work in the sample. So the hypothetical compositional practice of avoiding open strings in nominally sad music might be a comparatively late compositional development. Alternatively, it may be that the use of minor-slow movements as representative of “sadness” or tempo-variable major movements as “non-sad” may be inaccurate or inappropriate.

The results of the post-hoc test duplicate the results of the main hypothesis. Even when the possibility of sympathetic vibration is taken into account, slow-minor movements do not tend to avoid the possibility of open strings more than tempo-variable major mode movements.

Recall that the original motivation for this study was the conjecture that nominally sad musical expressions would tend to exhibit the darker timbres (lower spectral centroids) evident in sad speech. This idea gained further credence in the exploratory study of Samuel Barber’s Adagio, opus 11. However, this single case study did not generalize to a larger sample of string quartets by Haydn, Mozart and Beethoven. This difference in results could be related to a difference in compositional practices between the nominally Classical and Post Romantic eras. Finally, it could be that with the notable exception of Barber’s Adagio for Strings, perhaps sad string timbres are not preferred in nominally sad music.
Chapter 3: The Acoustical Features of Laughter in Music

The second study presented here investigates the possible presence of acoustical characteristics of laughter in nominally comedic musical compositions. To review this study, it is necessary to first examine the role humor plays in Western Art Music.

Many composers have used various devices intended to evoke laughter or amusement among listeners (e.g. Gruneberg, 1969; Moore & Johnson, 2001; Mull, 1949; Walton, 1993). Haydn, in particular, is noted for his various humorous passages (see Wheelock, 1992). For example, in his "Joke Quartet" (Opus 33, No. 2), Haydn makes use of cadential conventions to "trick" listeners into thinking the ending has occurred at several different moments, and then actually ends the work on a tonic moment that would normally presage continuation. In modern times, musical humorists, like Peter Schickele (alias PDQ Bach), have made use of a variety of techniques whose purpose is to evoke audience laughter (Huron, 2004, 2006).

An important distinction is generally made between evoked (or induced) emotion, and portrayed (or represented) emotion. Musical passages (such as those produced by Haydn and Schickele) might evoke laughter without necessarily representing laughter. However, it is also possible for a passage to portray laughter (sound laughter-like) without necessarily evoking laughter in listeners. For the purposes of this study, our focus is solely on represented or portrayed laughter in
music. That is, this study is concerned with laughter-like passages rather than laughter-inducing passages.

Portraying laughter may be achieved musically by mimicking its acoustical features, namely short repetitive articulations. For example, Vladimir Jankélévitch (1961) speaks of "the humor of pizzicatos." Indeed, a quick sequence of pizzicatos does seem to resemble the punctuated exhaling characteristic of laughter.

Inspired by Jankélévitch’s observation, this study aims to test formally the hypothesis that musically humorous passages resemble the acoustical structure of human laughter. Specifically, reported are two experiments (part one and part two) that address this issue using contrasting methods. The first is an experiment in which listeners use the method of adjustment to modify tone sequences so as to sound most laughter-like. The second study is a correlational study examining musical scores. To anticipate the results, nominally humorous passages are shown to indeed exhibit a greater likelihood of employing tones with detached articulation (e.g., staccato) reminiscent of laughter. However, compared with control passages, these staccato passages failed to exhibit the isochronous rhythms characteristic of real laughter.

Acoustical features of human laughter have been described by Bickley and Hunnicutt (1992), Provine (2001), and Bachorowski, Smoski & Owren (2001). Laughter consists of punctuated vocalized exhaling. Each vocalized "ha" is referred to as a "call." Measures of laughter call rates range from 4.37 (Bachorowski, Smoski & Owren, 2001) and 4.7 (Bickley & Hunnicutt, 1992), to 5 calls per second (Provine, 2001), with an average of 4.69. In laughter, each vocalized call is followed by a silent period. Measures of the ratio of call-to-silence range from .33 (Provine, 2001) to .50.
(Bickley & Hunniccutt, 1992), with an average of .42. If certain musical passages are intended to emulate human laughter, one might predict that the music would tend to imitate these acoustical features.

**Study 2, Part 1**

Of course singers can easily produce laughter or laughter-like sounds. Part one of this second study will test whether laughter-like sounds can be produced with musical instruments. Specifically, it aims to determine whether listeners can adjust instrument sounds to emulate laughter, and whether these sounds will exhibit similar acoustical features to real laughter.

**Hypothesis**

Specifically, this part of the study tests the following two hypotheses:

H1. When instructed to emulate a laughter-like effect, listeners will tend to adjust the tempo of tone sequences to roughly 4.69 notes per second.

H2. When instructed to emulate a laughter-like effect, listeners will tend to adjust the duty cycle (articulation) of tone sequences with a tone-to-silence ratio of roughly .42.

**Method**

In brief, the experiment involved the method of adjustment where participants were instructed to "tune" the tempo and duty cycle of four different repeating sounds so as to create the most laughter-like effect.
Participants

For this experiment, 25 participants were recruited from the Ohio State University School of Music participant pool. All of them were enrolled as 2nd year music majors.

Procedure

The experiment made use of a custom-built Max/MSP interface (Puckette & Zicarelli, 1990). The interface included a start/stop button, a save button, a volume control, and two sliders per stimuli, one each for adjusting the repetition rate (tempo) and the duty cycle (articulation/sustain). Participants were asked to adjust five different sounds so as to produce the most laughter-like effect. The first sound consisted of a recorded female voice producing a sustained “ha” syllable. The remaining three sounds consisted of recorded tones produced by a bowed cello (pitch C3), a horn (F4), and a flute (F5). The default setting for the sliders began with the original speed of the recording and a duty cycle of 0.5. The resulting inter-onset interval of the default setting was 1.2 seconds. The tempo and duty-cycle slider positions were reset for each subsequent sound (for images of the interface, see Appendix 1).

Instructions

Participants received the following instructions:

“In this experiment, we're interested in what makes something sound like it's laughing. You'll hear a repeating sound that plays over-and-over again. You can turn the sound "on" by clicking the PINK button here. You can turn the sound "off" by clicking the PINK button again. [DEMONSTRATES]. Here you see three sliders. This grey vertical slide on the left [pointing] is the volume control that you can adjust at any time. This blue horizontal slider [pointing] adjusts how fast the sound repeats - that is, the tempo or speed. This yellow horizontal slider [pointing] adjusts how short or long the sound is.
What we want you to do is very simple: For each sound, we want you to adjust the blue and yellow sliders so as to make the sound as laughter-like as possible. Please aim for a "natural" sounding laughter as possible. There will be four different sounds we want you to adjust. When you have adjusted the sliders so that you're happy with the laughter-like quality, click the buttons at the bottom of the page to save and submit your answers. This experiment won't take any more than five minutes.

Do you have any questions?"

Results

Recall that the motivating hypotheses pertain to both the tempo and duty cycle components of laughter-like sounds. First, consider the tempo responses. Figure 2 shows the distribution of tempos for all five target sounds. In addition, the solid, dotted, and dashed lines indicate the mean laughter tempo values as measured in human laughter by Provine (2001) (solid line), Bickley and Hunniccutt (1992) (dashed line), and Bachorowski, Smoski and Owren, (2001) (dotted line). As can be seen, the mean tempo values in calls/second for all four sound sources are very similar: voice ($M=3.69$, $SD=0.82$), cello ($M=3.63$, $SD=1.0$), horn ($M=3.66$, $SD=1.07$), and flute ($M=3.64$, $SD=1.22$). Paired t-tests between all four sound sources failed to show any significant differences at the 95 percent confidence level. As evident from Figure 2, all the experimental data appear to fall below all three values for actual human laughter as measured by Provine (2001), Bickley & Hunniccutt (1992), and Bachorowski, Smoski & Owren (2001). This observation is confirmed by a statistical test. Combining the tempo data for all of the responses, the aggregate mean ($M=3.66$, $SD=1.03$) falls below the mean of the three human laughter sources ($M=4.69$). A one-sample t-test with the average human laughter value treated as a population mean proved significant ($t(99)=-10.0$, $p<0.0001$). That is, the tempo values
Figure 2. The Distribution of Mean Selected Tempos and Researched Tempos of Actual Human Laughter.

from the experiment are significantly slower than reported values for measured human laughter.

With regard to duty cycle, the distributions for all four sounds are shown in Figure 3. Once again, there appears to be little difference between the four sound types. However, while the mean values are similar, the variances differ notably: voice \((M=0.80, SD=0.15)\), cello \((M=0.95, SD=0.52.)\), horn \((M=0.88, SD=0.44)\), and flute \((M=0.87, SD=0.47)\). Duty cycle values in actual human laughter are reported only by Provine (2001) (solid line) and by Bickley & Hunnicutt (1992) (dotted line). Specifically, the mean values are 0.33 (Provine, 2001) and 0.50 (Bickley and Hunnicutt, 1992). Combining the duty-cycle data from all of the stimuli, the
aggregate data differs significantly from the mean of the Provine and Bickley & Hunnicutt values. A one-sample t-test with the average human laughter duty cycle treated as a population mean proved significant \( t(99) = -10.5, p < 0.0001 \). That is, the duty cycle values from the experiment are significantly longer than reported values for measured human laughter.

By way of conclusion, these results are somewhat mixed. First, contrary to the motivating hypothesis, when asked to adjust repeated instrument tones to produce a laughter-like effect, participants produced event sequences that are both slower and more sustained than published values for actual human laughter. On the other hand,

\[ \begin{align*} 
0.8 & \quad 0.95 \\
0.88 & \quad 0.87 \\
0.5 & \quad 0.33 \\
\end{align*} \]

\textit{Figure 3.} The Distribution of Mean Selected Duty Cycles and Researched Duty Cycles of Actual Human Laughter.
the sounds produced for instrumental tones (cello, horn, flute) proved to be very similar to sequences adjusted for the vocalized "ha" sound. This suggests that participants were attempting to emulate vocal laughter when adjusting the instrument sounds, even though the overall tempi were significantly slower.

**Study 2, Part 2**

Although the mixed results of part 1 suggest that musical instrument sounds can theoretically be used to emulate human laughter, this result does not address the question of whether laughter emulation is actually used in real music making. It would therefore be appropriate to examine actual musical practice.

If a composer intends to create a laughter-like sound, one might expect the passage to exhibit some of the acoustical features associated with real laughter. However, how does one know that a composer intends to create a laughter-like expression? If laughter-like features are used as a way to identify candidate laughter passages, the logic would be entirely circular if we argued that laughter-like passages exhibit laughter-like acoustical features. This study hinges on the issue of how one might know whether a composer intends to represent or express laughter. While recognizing that one can never be certain of a composer's intentions or aims, there are sometimes telltale signs that suggest that a humorous intention might have possibly motivated the composer. Among such telltale signs is the title of a work. Unfortunately, it is uncommon to find overt titles such as "Columbine is Laughing." However, there exist several genres of music whose origins suggest some overt humorous content. Examples include Scherzos, badineries and humoresques.

The word "scherzo" is Italian for "jest" or "joke." The word "badiner" is French for "to joke, tease, trifle, or be flippant," with "badinerie" meaning "teasing or
childishness." The word "humoresque" derives from the Latin "umor" and has a long and convoluted etymology, mostly related to bodily fluids. The earliest musical use of "humoresque" is attributed to Schumann, who apparently used the term in the historical sense, related to the body humors (Brown, 2001). However, later use of the term in music seems more in keeping with a light-hearted or humorous ethos (Apel, 1969).

Although the origin of these different genres suggests humor or jocularity, it should be noted that not all Scherzos, humoresques or badineries are overtly humorous in tone. In the case of the humoresque in particular, scholars have drawn attention to various melancholic aspects (Kennedy, n.d.), such as evident in the Humoresque No. 7 from Dvořák’s set of eight Humoresques for piano (Op. 101, 1894).

Accordingly, it cannot be claimed that any given composition dubbed "Scherzo," "Humoresque" or "Badinerie" is intended to emulate or portray laughter. Rather, the claim made here is that, as a group, such compositions are more likely to exhibit passages that emulate or portray laughter than other musical works.

If laughter-like features are predicted to be more common in these musical genres, the next question is what features might be consistent with an expression of laughter. As noted earlier, laughter exhibits a series of isochronous puffs or "calls." In notated music, one might expect to see a greater use of staccato or pizzicato, and that any such passages would be more likely to exhibit isochronous rhythms.

For the purposes of the second study, the decision was made to focus on notated scores. Specifically, here is predicted that, compared with similar control works, humoresques/Scherzos/badineries are more likely to contain staccato passages
and that sequences of staccato are more likely to be isochronous - consistent with laughter.

**Hypotheses**

Formally, the following hypotheses are proposed:

- **H3.** Compared with similar (non-humoresque/Scherzo/badinerie) passages, *humoresques/Scherzos/badineries* are more likely to contain staccato sequences.

- **H4.** Compared with similar (non-humoresque/Scherzo/badinerie) passages, staccato passages from *humoresques/Scherzos/badineries* are more likely to exhibit isochronous rhythms.

**Musical Sample**

A convenience sample was provided through the International Music Score Library Project (IMSLP) website (Mullin, 2010). A search for the words "humoresque," "Scherzo," "badineries" uncovered 3,757 works/movements. Most of the identified works were marked *Scherzo,* somewhat fewer *humoresques,* with only a small number of *badineries.*

In analyzing any musical work, it is necessary to consider what features are simply musical commonplaces before concluding that some feature is characteristic or unique to a given work or genre. Accordingly, this study contrasts each target musical work with a matched control. Specifically, in order to determine how staccato is used, one must contrast *humoresque,* *Scherzo* or *badineries* passages with non-*humoresque*/Scherzo/*badinerie* passages.
Apart from the conjectured use of staccato to emulate laughter, the use of staccato is apt to be influenced by many other musical concerns. In the first instance, staccato is unlikely to occur in slow musical passages, so it would be inappropriate to compare the use of staccato in *humoresque/Scherzo/badinerie* passages with works that differ dramatically in tempo. In addition, the use of staccato may vary by musical style, by instrumentation, and by individual composer. Some composers may be more likely to use staccato. Similarly, staccato may be more common for some instruments (e.g., piano), compared with other instruments (e.g., trombone). Finally, notational practices change over history. Earlier periods in music history were less likely to notate staccato in musical scores.

A further consideration is dynamic level. Perhaps it is important to ensure that the control movements are matched for dynamic level. However, the relationship between dynamic level and laughter is not obvious. Laughter itself spans a wide range of loudness levels from quiet giggling to boisterous guffaws. It is not clear that failing to control for dynamic level would bias the results in some way. Given the task of finding matching passages by the same composer, for the same instrument, and at the same tempo, the additional aim of matching dynamic levels was regarded as unduly burdensome. Consequently, it was decided *a priori* not to explicitly match dynamic levels in the controls.

Accordingly, in selecting control passages, the objective was to match each *humoresque/Scherzo/badinerie* passage with a passage written for the same instrument, written by the same composer, and having the same notated tempo. Musical notation rarely includes detailed metronome markings. Instead, descriptive (Italian) terms are commonplace. These include terms such as *Adagio, Andante, Allegro*, etc.
The target and control works were deemed to exhibit matched tempos if they employed the same tempo term. In many cases, these tempo terms include an adjective or modifier, such as Allegro assai. For the purposes of this study, the modifiers - with the exception of moderato, were ignored. For example, Allegro assai was considered equivalent to Allegro. Appendix 2 provides a complete list of the tempo terms used in the sample.

In examining the available online materials, nearly two-thirds appeared to consist of solo piano music. In order to simplify the task of finding matching control passages, it was determined a priori to sample only solo piano music. With this instrumentation constraint, a search for the words "humoresque," "Scherzo", "badineries" uncovered 2,684 works/movements. 85% of these movements are "scherzo", 14% are humoreque, and only a handful (1.2%) are "badineries."

Finally, in order to reduce the workload to a manageable level, a goal was set a priori of reaching a sample of 300 works – 150 Scherzo/humoresques/badineries and 150 matched control movements.

**Sampling procedure**

From the randomly-ordered list of piano works dubbed humoresque/Scherzo/badinerie, each score was examined in order to identify whether a tempo marking was present. Several works did not include a tempo designation and so were excluded from the sample. Of the remaining humoresques/Scherzos/badineries, the tempo designation was determined and a control piano work was sought by the same composer containing the same tempo designation. For some relatively obscure composers, no other piano works were available, and so the target humoresque/Scherzo/badinerie was discarded from the sample. Having identified
candidate piano works by the same composer, the tempo markings were then examined in order to find a match. As noted above, some leeway was permitted in pairing tempo markings, so that allegro and allegro assai were deemed to constitute a matched set (see Appendix 2). Once again, in several cases, it was difficult to find a suitable matched control work/movement, and so the target work was discarded. This procedure was continued until 300 works were identified - 150 pairs of works matched for composer, instrument, and tempo.

**Analysis procedure**

Having assembled the corpus of matched target and control works/movements, each work/movement was scanned from the beginning for staccato passages that were at least four notes in succession. If any staccato passage was located, the first such passage was then characterized as either isochronous (a pattern of consistent lengths occurring at equal intervals) or anisochronous (no pattern of regular lengths and/or occurrences at irregular intervals) rhythms. For example, an isochronous rhythm might consist of an eighth note followed by an eighth note rest that is repeated whereas an anisochronous rhythm would contain a break in the pattern or notes of unequal lengths (such as a quarter note followed by an eighth note). Notice that a long sequence of notes is statistically less likely to consist of equivalent-duration notes than a short sequence of notes. In order to avoid confounds introduced by especially long or short staccato passages, the judgment of isochronicity was determined by considering only the first four notes in the relevant passage. That is, if a passage contained 10 successive staccato notes, if the first four notes were equivalent in duration than the passage was operationally deemed “isochronous.”
Results

The results are summarized in Table 6. Roughly 81.3 percent of the *humoresque/Scherzo/badinerie* movements exhibited the presence of a staccato sequence, whereas only about 68.7 percent of the matched control movements included staccato passages. A chi-square test shows that this difference is statistically significant ($\chi^2(1)=5.76, p<0.02$ with Yates continuity correction applied). The results are consistent with hypothesis 3: that is, *humoresque/Scherzo/badinerie* movements appear to exhibit more use of staccato.

<table>
<thead>
<tr>
<th></th>
<th>Staccato present</th>
<th>Staccato absent</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Humoresque/Scherzo/badinerie</em> movements</td>
<td>122</td>
<td>28</td>
</tr>
<tr>
<td>Control movements</td>
<td>103</td>
<td>47</td>
</tr>
</tbody>
</table>

*Table 6. Ratio of Staccato Present to Staccato Absent*

With regard to hypothesis 4, the initial staccato sequences, 122 from *humoresque/Scherzo/badinerie* movements and 103 from control movements, were examined for isochronous rhythms. As noted earlier, a passage was deemed to be isochronous if the first four notes of the initial staccato sequence exhibited the same notated duration. The results are shown in Table 7. Roughly 77.8 percent of initial staccato passages in *humoresque/Scherzo/badinerie* movements exhibited rhythmic isochrony, whereas only about 73.8 percent of the initial staccato passages in the matched control movements exhibited isochrony. Despite the skew in the predicted direction, a chi-square analysis found no significant difference between the target and control movements ($\chi^2(1)=0.311, p=0.577$; with Yates continuity correction applied).
Conclusion and Discussion

In part 1, participants were asked to tune vocal and non-vocal instrumental tones to produce a laughter-like effect. Using the method of adjustment, participants produced call rates that were comparable, but slower, than actual laughter rates. With regard to duty cycle, the sounded portions were also comparable, but longer (less staccato articulation) than actual laughter. These results are somewhat consistent with the suggestion that laughter-like acoustical features are recognizable using tones produced by musical instruments. In part 2, a body of musical works were examined whose genres suggested that the composer might have had a jocular or humorous musical aim. Compared with matched controls by the same composer, exhibiting the same instrumentation and tempo, it was shown that *humoresque/Scherzo/badinerie* were more likely to contain staccato sequences, although these sequences were not more likely to exhibit isochronous rhythms.

The principal anomaly in this study is the unexpectedly slow tempi and long articulations produced by our participants. Why did our participants choose rates 22% slower than measures of spontaneous human laughter? Two possibilities come to mind. First, various observations suggest that fake or staged laughter tends to be slower than normal laughter. Such staged laughter can be found in various operatic recordings. Provine (2001), for example, examined 20 opera scores for instances of

<table>
<thead>
<tr>
<th></th>
<th>Isochronous staccato</th>
<th>Anischronous staccato</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humoresque/Scherzo/badinerie</td>
<td>95</td>
<td>27</td>
</tr>
<tr>
<td>Control movements</td>
<td>76</td>
<td>27</td>
</tr>
</tbody>
</table>

*Table 7. Ratio of Isochronous/Anischronous Staccato Passages*
laughter. He measured the musical tempi and duty cycles of the laughter and found similar results to the current study. Remarking on this finding, Provine has written: "Although this exercise was frustrating and fraught with musicological uncertainty, we found that most composers overestimated the duration of laugh notes ("ha") and inter-note intervals ("ha-ha"). Whether due to artistic constraints (musical context) or perceptual error composers usually made laughter slower (longer) than it really is" (2001).

Another factor likely to influence laughter rate is body size. Rates of respiratory oscillation are strongly related to body size (Straub, 1998). Children produce faster laughter rates, whereas large individuals are likely to exhibit a slower (Santaesque) ho-ho-ho sound. It is possible that musical sounds, or the sounds produced using synthesized envelopes, connote a heavier or larger sound source. Consequently, this would have led our participants to adjust the laughter rate to a slower value that might have been deemed to be more appropriate for the perceived size.

Recall that each of the presented studies is inspired by the concept that some music might imitate vocal affective cues. The results of the current studies lend further partial support to this view - at least in the case of expressions of human laughter.
Chapter 4: The Affect of String Register

Study 3, presented in this chapter, is inspired by the observation that high emotionality (e.g. fear, rage, excitement) is typically portrayed through speaking within the upper pitch register (Scherer et al., 2003). Specifically, this study explores the possible presence of this technique in string playing.

For string players, one of the important musical decision that must be made when approaching a piece of music is the fingering, or how the string player will position their hand in order to play the notes on the score. There are two important aspects to consider when deciding on the fingering of a musical passage. One is playability. A certain location on the fingerboard, or hand position, could facilitate fingering a certain musical passage better than another, especially for a passage with many string crossings or chords. The second aspect to consider is musical expression. When interpreting musical passages, string players need to decide on an emotional intention for each musical moment, melodic line, section, etc. With an emotional intention in mind, a string player must then decide on how best to communicate it using expressive musical tools such as timbre, vibrato, and dynamics.

Related to this, I made the observation that string players, specifically cellists, move the fingering up the fingerboard (away from the scroll towards the bridge) to a high playing position when they aim to make a passage sound more expressive. For
this study, an ecologically based theory is presented that could explain this observed behavior.

When communicating more intense emotions (such as panic, elation, and despair), humans tend to speak higher in their range than for less intense emotions (such as contempt, boredom, and shame) (Banse & Scherer, 1996). Humans are highly effective at predicting where in one’s voice someone is speaking (Honorof & Whalen, 2005). It may be possible to perceive this information from instruments as well. If one can hear cues of location in range from a string instrument, this could support why using high playing positions might communicate a higher level of emotional intensity. In this study, part one tests whether or not it is possible to recognize pitch register from an instrument. Part two then studies whether there is an effect for emotional intensity based on high or low playing positions.

**Hypotheses**

The first part of this study tests whether it is possible to hear the range of an instrument, specifically cello, and identify the pitch register of a tone. This ability was investigated by testing whether participants were able to sort cello tones into high and low playing position categories. For this, the following was hypothesized:

H1. When asked to compare individual cello notes to recorded examples of high and low playing position notes, participants will be able to identify which notes are played in which registers.
An appropriate follow-up question might be whether string players are more sensitive to these timbre differences than non-string players. Accordingly, the following hypothesis was also considered:

H2. String players will be more successful at identifying the register of notes than non-string players.

In order to test this hypothesis, it was decided that demographic data would be acquired about whether or not participants have played a string instrument and for how long.

Pilot Method

As stated above, the aim of part one of this study is to determine whether listeners can identify if a pitch is played in the upper or lower range of a string instrument, specifically on the cello. Initially, to avoid possibly confusing the listeners, the experiment was structured in such a way that avoided the need to provide an explanation of instrument register versus pitch register. When participants began the pilot study, there was a pop-up window and a main screen. The pop-up contained two recordings, one of a melody played in the low register of the cello and one in the high register of the cello (played by the same cellist). These were labeled “Performance 1” and “Performance 2”. Participants were prompted to familiarize themselves with the performances before beginning the study. They were then given 20 different recordings of whole notes played by a cellist (again, all by the same cellist), one note at a time. For each note, they were asked to indicate if it
sounded more like Performance 1 or Performance 2 by pressing 1 or 2 on their computer keyboard.

After running a few participants for the pilot, the results showed that the task was more difficult than anticipated. Therefore, the method and the structure of the interface were revised for the main study.

Revised Method

Originally, participants were only asked whether or not they played a string instrument, and if so for how long. The reasoning behind this question was to test the hypothesis that string players would perform more accurately on part 1 than non-string players. However, a pilot participant pointed out that wind players are also highly sensitive to timbre changes and therefore may also perform well on the task. In response to this comment, additional demographic questions were added about whether participants played a brass instrument, a woodwind instrument, or piano or a percussion instrument, and for how long. This addition expands the initial H2 to include wind players:

Revised H2: For part 1, string players will perform better than wind players who, in turn, will perform better than non-string/non-wind players.

For the main task of the pilot, asking participants to decide where single notes were played on the cello without any context proved to be unreasonably difficult and unrealistic. In a real performance choice situation, in my experience, a string player will often directly compare the sound of a note in one position and then another before deciding which fingering communicates the desired sound best.
Therefore, participants should similarly be allowed to hear the same pitch played in two different places on the instrument and directly compare them. An argument against this approach could be that in live performance, listeners encounter notes without a context to help identify where they are in the instrument register. Should the hypothesis be true, they still need to be able to attain range information in order to experience range-related emotional cues. However, sometimes in live performance, passages and notes played in different registers can be compared directly to one another. For instance, when musical phrases are repeated, musicians often aim to give the repeated statement a different emotional tone. For this, they may decide to play the same theme in a different place on the instrument from where they played it the first time. For example, examine this excerpt from Variations on a Slovakian Theme by Bohuslav Martinu (Variation 3, mm.125-130):

![Figure 4. Excerpt from Martinu’s Variations on a Slovakian Theme.](image)

The first statement of this melody can be played in a low playing position on the A string (as indicated by the roman numeral I under the notes) and the second statement can be played in a high playing position on the D string (as indicated by the roman numeral II under the notes). The numbers above the notes indicate the fingering. In the performance, listeners would hear these two contexts directly compared with the intended effect of emotional or timbral contrast. Therefore,
although there are situations in which a pitch is heard without direct comparison to contextualize where the note is played in the instrument’s register, this example demonstrates that occasionally a direct comparison might be available. Also, it could be that when listening to real music, people are more accurate at perceiving cues related to range than they are able to report in this kind of task. In other words, hearing range and taking emotional cues from range could be a more subconscious task than anticipated.

Also, in the pilot, string register is referred to with the operationalized terms “high register” versus “low register”. After the pilot, the decision was made that the use of the word “register” too closely related to pitch for this task and might confuse participants. Therefore, for the purposes of this study, the operationalization of where the note is played on the cello was changed to either a note played in a “low playing position” or a “high playing position”.

Participants

The 47 participants for this study were mostly undergraduate and graduate music majors from Ohio State University and Illinois Wesleyan University between the ages of 18-30. Additional participants were between the ages of 18-40 and were a mixture of musicians and non-musicians.

Materials

To ensure that the predicted phenomenon did not apply only to specific instruments or cellists, four cellists were recorded playing the notes for part one and two cellists for the melodies for part two. In string performance, another factor that influences timbre is whether a given pitch coincides with the harmonic of an open string. The resulting resonance due to sympathetic vibration can produce a marked
change in timbre, as discussed in Chapter 2. Accordingly, both sympathetic pitches and non-sympathetic pitches were used as stimuli. Specifically, half of the stimuli involved sympathetic pitches and half were non-sympathetic pitches. The initial hypothesis for this part of the study predicts success for both sympathetic and non-sympathetic pitches. However, another secondary hypothesis \textit{a priori} predicts the following:

\textbf{H3:} Participants will be better able to discriminate non-sympathetic pitches into different registers on the instruments than sympathetic pitches.

The selected pitches also covered a large range on the cello and used each of the four strings. Each pitch had a low and high playing position note. Twelve pitches total were selected for part one of this study (for the pitch, hand position, playing position category, string, and sympathetic category information, see Appendix 3). The tones were recorded and edited using Audacity. The cellists who were used to record the notes were given the following instructions:

“Below are 24 notes which are voiced twice, one in a low string register and one in a high string register. On the headphones, a metronome will be clicking. Set the metronome for the tempo markings indicated before playing the notes. All the notes will be recorded in a single take. During the take, announce which note you are about to play and then start the note on whatever beat you like and hold it out for the full whole note value. Between notes, feel free to find the note and practice playing it to achieve the best sound possible before announcing and playing the actual recording. Please play each of these notes as musically as possible with a full, rich sound.”

The tones recorded from each of the four cellists were used in the study. A different interface was created for each set of recordings. Eight additional tones were
recorded to give to participants as examples of how high and low playing positions sound (for information on these tones, see Appendix 4).

**Interface**

Javascript and Jspsych were used to create the interface for this study (Flanagan, 2006; De Leeuw, 2015). When emailed the link for the study, participants were asked to please take the study in a quiet space and with the best quality headphones available. When they clicked on the first link for part one, a main window and a pop-up window appeared. The pop-up window contained the audio examples of notes played in a high playing position and notes played in a low playing position. The main window thanked them for participating and then proceeded to the demographic questions. After these, participants were briefly informed of what playing positions were on the cello and asked to familiarize themselves with the examples in the pop-up window as much as they liked throughout that part of the study (for the full interface, including diagrams and illustrations, see Appendix 5). Here are the instructions for the participants below:

“ In the pop-up window, we provide two, whole-note listening examples of a cellist playing pitches in a low playing position and in a high playing position. Before we begin, please familiarize yourself with these examples. Listen for aural cues in the example notes that might help you to differentiate between the playing positions. We recommend comparing Example 1 to Example 3 and Example 2 to Example 4.

You will be presented with 12 pairs of recordings of single whole notes played on the cello. For each pair of notes, we would like you to indicate which note you believe is played in a high playing position by pressing 1 or 2 on your computer keyboard (1 = Note 1, 2 = Note 2). Some note pairs will be repeated but not necessarily in the same order. You may listen to the audio examples in the pop-up window throughout the study as needed. Please remember what aural cues you use to make your decisions during this task because we will ask you to report them at the end. This part of the study will take about 5 minutes. Click next to begin.”
Following these explanatory windows, participants viewed the following instructions with each pair of tones presented:

“Press the appropriate number (1 or 2) on your computer keyboard to indicate which note is played in a high playing position (1 = Note 1, 2 = Note 2). In other words, which note sounds more like examples 3 and 4? If you wish, you can re-listen to the examples in the pop-up. If you have closed the pop-up window, you can reopen it by clicking here.”

The notes pairs were randomized in their appearance. At the end of the study, participants were asked to list what information they used to determine which tone was played in the playing position.

Results

Recall that the first hypothesis predicted that participants would be able to hear a difference between the same notes played in a low playing position versus a high playing position. This ability was investigated by asking participants to listen to a pair of notes and choose which one was played in a high playing position. Each participant heard 12 pairs of notes. Therefore, if the hypothesis is true, the resulting mean of scores should be higher than chance (6). Conducting a simple t-test, the results are consistent with our hypothesis in that participants on average scored significantly higher than 6 (M=7.96, SD=2.86, t(46)=4.69, p<.0001).

Presented earlier were also several hypotheses on the effects of main instrument and whether or not tones were sympathetic pitches. For main instrument, the hypothesis predicted first that string players would score the highest, followed next by wind players, and then finally by all non-wind and non-string players. Upon running an independent means t-test on the scores from part one for string instruments players and non-string instruments players, the results
found were inconsistent with the hypothesis. Non-string instrument playing participants scored higher ($M=8.03$, $SD=2.55$) than string instrument players ($M=7.81$, $SD=3.47$), although this difference is not statistically significant. Running the same test with the combined results of wind instrument players (brass and woodwind) and string instrument players versus participants who identified with all other instrument families, the results were still inconsistent with the hypothesis. Participants who were non-wind players and non-string players performed better ($M=8.67$, $SD=2.5$) than wind and string players ($M=7.79$, $SD=2.94$), however this difference is not statistically significant.

Regarding sympathetic strings, the third hypothesis predicted that participants would more successfully identify pitches in the upper playing positions if they were non-sympathetic notes rather than sympathetic pitches. This prediction is based on the idea that sympathetic notes cause open strings to vibrate. This addition to the overall timbre might make it more difficult to hear the range location of the note. An independent means test was conducted. While the results were skewed in the direction of our hypothesis, results for non-sympathetic pitches were only slightly higher ($M=4.02$, $SD=1.51$) than results for sympathetic pitches ($M=3.96$, $SD=1.61$) and were not statistically significant.

**Part Two Hypotheses**

Given that part one establishes the possibility of hearing pitch register from instrumental tones, part two tests the conjecture that playing in the upper register is perceived as more expressive. In brief, participants were asked in a 2-alternative
forced choice design to listen to pairs of cello melodies and decide which one was more expressive.

H4: When exposed to a cello melody played once in the lower string register and once in the upper string register, participants will select the upper register version as the more expressive recording.

Participants

The same 47 participants from part one also took part two of the study. They entered a unique identifier in both parts of the study so that it would be possible to compare results.

Materials

The four cellists who recorded the notes for part one also recorded the melodies for part two. The instructions they received for recording are below:

“Below are 6 short 8 measure-long-melodies which are voiced twice, one in a low string register and one in a high string register. On the headphones, a metronome will be clicking. Set the metronome for each of the tempo markings indicated before playing the passage. For the melodies, we will record each one at a time. Please announce the number assigned to that melody and begin on whatever beat you like playing the whole melody through in tempo. Feel free to practice the melodies between recordings. The strings and fingerings are a suggestion. For the initial rendition of melodies, the intention is to play it in the lowest string register possible without sacrificing the musicality of the passage. Feel free to alter the fingerings, but do not move up beyond second position on any string. For the second rendition of the melody, the intention is to play in the highest register possible while maintaining the musicality of the passage. The fingerings are a strong suggestion but you may change them to ease your ability to play the melodic lines cleanly. Use harmonics as sparingly as possible, only to ease the musicality of the melodic lines. Please play each of these excerpts as musically as possible.”
To avoid possible demand characteristics, the cellists were told nothing about the purpose of the study beforehand. In the instructions, it was asked that they play the sample as musically as possible in order to encourage a full, performance-style sound without giving any direct emotional objective. Five of the melodies were chosen from Suzuki, Book Three and one was chosen from Suzuki, Book Four (to see the actual melodies and notes presented to the cellists for recording, see Appendix F). The selection titles, measure numbers, keys, and composers are listed below:

1) Berceuse - m.1-8 (G Major) - F Schubert
2) Gavotte - m.1-8 (d minor) - J.B. Lully
3) Gavotte in C minor - m.1-8 (c minor) - L van Beethoven
4) Humoresque - m.25-32 - (d minor) - A. Dvorak
5) La Cinquantaine - m.53-64 (A Major) - G. Marie
6) Sonata in C Major, Rondo grazioso - m.1-8 (C Major) - Jean Baptiste Breval (Book 4)

It was deemed practical to equally represent both major and minor mode because of their opposite emotional connotations. Therefore, three of the pieces picked were in a major mode and three were in a minor mode. The minor mode is often associated with sadness, as mentioned in Chapter 2 (Post & Huron, 2009). In my experience, cellists seem to move into the upper register more often for a sad expressive musical passage than for a happier one. Therefore, the prediction was made that participants would select the high playing position melodies as more expressive more often for the minor mode selections than major mode selections:

H5: Participants will select the melodies played in a high playing position as more expressive for minor mode melodies more often than for major mode melodies.
Initially, two cellists were recorded playing at the tempi indicated by the original music. However, for the second melody played in the upper register, the fingerings are much more difficult. Therefore, at the given tempos, the cellists were distracted by the technical difficulties and the musicality of the passages suffered. This would directly impact how participants would perceive these upper register melodies and could completely invalidate the study. Therefore, for the next two cellists, all the tempi were slowed down to around half the original tempo. This allowed for much more expression even during difficult passagework for the upper register melodic renditions. Therefore, for this part of the study, only the recordings by the last two cellists were used to make the materials instead of all four.

**Interface**

The interface for part two was also created using Javascript and Jspsych (Flanagan, 2006; De Leeuw, 2015). The page that was emailed to participants for part one had a link to part two which they were instructed to click after finishing part one. Participants were given the following instructions upon opening the tab:

“In this part of the experiment, you will be presented with a series of 12 pairs of recordings of a melody. You will be asked to indicate which recording of the melody you believe was played more expressively or emotionally by pressing the appropriate number (1 for the first recording or 2 for the second recording) on your keyboard. You will hear each pair of melodies twice. This part of the study will take about 20 minutes. Please use the best quality headphones that you have access to for this study. Click next to begin.”

Upon reading these instructions and hitting next, participants were then exposed to the 6 melodies (shown twice) in a random order. The melodies were counterbalanced in their presentation. Specifically, half the participants heard the melody in a low playing position before the one in a high playing position whereas
the other half heard the high playing position one first (or vise versa). The instructions for each pair of melodies are shown below:

“Press the appropriate number (1 or 2) on your computer keyboard to indicated which recorded melody you think is played more expressively or emotionally.”

After going through all 12 pairs of melodies, participants were asked to list the information in the music they used to make their choices (for the full interface, see Appendix 7).

**Part 2 Results**

Our second main hypothesis (labeled as H4) predicted that melodies played in mostly upper playing positions would be perceived as more expressive than those played in lower playing positions. To test this, participants heard 12 pairs of melodies, one version played with higher playing positions and one with lower playing positions. They were asked to select which of the two was more expressive. The results were coded so that selecting the melody played in an upper playing position was a “correct” answer. Therefore, should the hypothesis be correct, the expected results would be a mean of scores higher than 6, which would be chance.

Initially it could appear that our results are inconsistent with our hypothesis \((M=5.96, SD=2.7)\). However, upon closer examination, these results still provide an interesting picture.

Below is a distribution of the frequencies of the results for part two of this study (Figure 5). As you can see, there are two swells in the data. Participants either scored mostly below 6 (showing a preference for melodies played in a low playing position) or mostly above 6 (showing a preference for melodies played in a high playing position). Few participants actually scored around chance (6). To test the
The significance of this phenomenon, a post-hoc test was run. To verify that the means of each half of the data were significantly different than chance, six was subtracted from each of the scores and the absolute value was taken. A t-test was used again, this time with a test value of zero since zero represented participants lacking a strong preference for either low or high playing positions. The results are consistent with the idea that participants had an opinion that either low playing position melodies or high playing position melodies were more expressive rather than playing position having no affect ($M=2.28, SD=1.44, t(46)=10.84, p<.0001$).

Recall that for this part of the experiment, two cellists were used. Half of the participants heard one cellist (Cellist A) play all of the melodies and half of them heard the other (Cellist B). Comparing resulting scores with an independent means t-test shows that there is a significant difference between responses to melodies played by Cellist A ($M=7.67, SD=1.99$) and responses to melodies played by Cellist B.
Participants who heard Cellist A showed a significant preference for melodies played in the upper register ($t(23)=4.1$, $p<.0001$) and participants who heard Cellist B showed a significant preference for melodies played in the lower register ($t(22)=-4.1$, $p<.0001$). Theories behind this difference in results are examined in the discussion section.

The fifth and final hypothesis predicted that participants would select melodies played in a high playing position as the more expressive melody if the melody was in the minor mode rather than in the major mode. An independent means t-test was conducted. The results were consistent with the hypothesis in that, for both cellists, melodies in the upper playing positions were rated as more expressive more often when they were in the minor mode ($M=3.4$, $SD=1.66$) than in the major mode ($M=2.53$, $SD=1.6$, $t(92)=-2.59$, $p=.011$).

**Conclusion and Discussion**

The results of the first part of the study were consistent with the prediction that listeners would be reasonably able to sort cello pitches into high and low register categories. However, the hypotheses predicting effects of instrument and whether tones were sympathetic or non-sympathetic pitches did not produce significant, corroborating results. The data gave no indication that what instrument the listener played affected their level of accuracy in this task. There was also no indication that whether or not the tones played were sympathetic or non-sympathetic pitches might make any difference in the responses as well.

The results of the second part of the study were partially consistent with the second main hypothesis. Participants who heard recordings by Cellist A, on average, rated the melodies played in high playing positions as more expressive. However,
participants who heard Cellist B’s recordings, on average, rated the melodies played in low playing positions as more expressive. Given that the ability to play musically successfully in the upper register of the cello requires a high level of skill, it is worth noting that Cellist A was at a more advanced playing level than Cellist B. Cellist A had just completed a bachelor’s degree in cello performance and was applying to graduate programs. Cellist B had just finished their sophomore year of undergraduate studies in cello performance. This could perhaps explain the difference in results. Looking at the written responses, both the highest scores for each cellist indicate that dynamic variation, timbre, rubato, and vibrato were all factors in their responses. This might indicate that Cellist A was able to execute these variables well in a high playing position while Cellist B was less able to. For Cellist B, responses also mentioned intonation and emotion as part of their response possibly indicating that in the upper register, Cellist B played more robotically and less in tune. Perhaps results would have been different had the cellists been able to practice the melodies before the recording session.

Considering the positive results for Cellist A, it is worthwhile to discuss other reasons why cellists might prefer the upper register of the instrument when aiming to play more expressively. One reason is that vibrato changes as one moves up the fingerboard. In research, vibrato has been found to increase in both width and rate when moving from a low playing position to a high one, or when moving from the scroll towards the bridge. Allen, Geringer, & MacLeod found that the rate of vibrato

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The explanation for why vibrato widths and rates increase as one’s hand moves up the fingerboard is partially related to physics while also being effected by cello technique and characteristics about the instrument. Generally, vibrato width increases as one moves up the string because the string length shrinks causing the physical distance between the notes to diminish as well (Macleod, 2008). Because of this, pedagogues generally encourage students to use a smaller vibrato width as they move up the
of a professional violinist increased from a mean of 5.7 Hz in first position to a mean of 6.3 Hz in fifth position, and that their vibrato width increased from 40 cents in first position to 108 cents in fifth position (2009). This finding extends beyond that single-case example. Macleod found in another study with high school and university violin and viola players that the vibrato width was wider in the upper register with a mean of 58 cents as compared to 34 cents in the lower register, and that the rate was also faster in the upper register (2008). Similarly, David A. Pope measured vibrato characteristics of high school and college level cellists and found that vibrato rates increased from a mean of 5.07 Hz in first position to a mean of 5.33 Hz in fourth and thumb positions, and that the width increased from 23 cents in first position, to 34 cents in fourth position, to 43 cents in thumb position (2012). The consequential vibrato alterations of shifting hand positions may factor into why a string player would opt for one hand position over the other for expressive reasons.

In order to predict why a string player might chose a wider, faster vibrato, it is necessary to consider what the emotional impressions are of various vibrato widths and rates. Research in vocal vibrato, which is comparable in range and width to string vibrato (Seashore, 1931), gives insight into the affective information of vibrato widths and rates. Dromey, Holmes, Hopkin, & Tanner analyzed recordings of graduate vocalists and found increased vibrato rates for selections that were rated as more emotionally intense (2015). Other studies by Sundberg found the same

instrument (Macleod, 2008). Executing a thinner vibrato width results in a reduction of the width of the oscillating motion of the hand. Consequently, the time it takes to complete a full oscillation is also reduced resulting in a faster vibrato rate (Macleod, 2008). This phenomenon is further complicated by changes that hand position and vibrato technique go through as one moves to higher hand positions. For example, when moving into fourth position, the neck of the instrument ends and the body of the instrument partially obstructs the hand as it vibrates thereby shrinking the vibrato width. The restrictions of upper hand positions could also potentially explain why vibrato rates also increase.
correlation between vibrato rate and emotional intensity as well as some suggestion of vibrato width being positively correlated as well (1994; Sundberg, Iwarsson, & Hagegård, 1994). Assuming that vibrato could carry the same emotional meaning for instruments other than voice, perhaps string players move to higher playing positions for a wider, faster vibrato to give a passage a higher emotional intensity.

Given this research, it is hard to say which would be the dominant reason for moving in to the higher register: to use a high pitch register to portray high emotionality or to achieve a wider, faster vibrato to portray high emotionality. Also, it may be that the two are intertwined. Perhaps a wider, faster vibrato is part of the cue for high register, which communicates high emotionality. On the other hand, perhaps high register portrays a greater emotionality because of the wider, faster vibrato. This study cannot provide a conclusive answer to this relationship. Perhaps future work will be able to differentiate between these possible factors and determine any possible causality.

Another potentially expressive device, timbre, may be affected by fingering decisions as well. Open (un-fingered) strings have been found to have a brighter timbre than stopped (fingered) strings because the finger on the string dampens the higher harmonics (Schelleng, 1973). If a string player wants to avoid the brightness of the open strings, they may be tempted to move to a higher playing position to facilitate playing the closed versions of those notes. There may also be a timbral difference between notes played on a high string in a low playing position and those played on a low string in a high playing position. No measurements of timbre-related acoustical features were taken for this paper. However, in the future, it would be helpful to examine the spectral differences of each register given that our
results indicate an audible difference.

Results were also consistent with hypothesis five, that participants would more often prefer upper playing position melodies when in the minor mode compared to the major mode. It could be that playing in the upper register has a darker timbre than in the low register. Recall that, as mentioned in study #1, a darker timbre has been found to be an element of sad speech (Scherer, Johnstone & Klasmeyer, 2003). The minor mode is also associated with a sad affect (Juslin & Sloboda, 2011). Therefore, perhaps if the upper register indeed has a darker timbre, participants found the sadder minor mode melodies to be more suited to that upper playing position.

As mentioned earlier, it is impossible to declare exactly which musical element of the upper range of the cello might have contributed to the perceived higher level of emotional intensity for Cellist A. While vibrato and timbre are certainly a part of the equation, both parts of this study provide strong evidence for the conjecture that using high playing positions on the cello might communicate a higher emotionality by mimicking the similar vocal affective cue.
Chapter 5: Conclusion and Future Studies

All three studies presented were inspired by different features of vocal emotion and found mixed results. Study 1 was motivated by the observation that research has shown a darker timbre to be a characteristic of sad speech (Scherer, Johnstone & Klasmeyer, 2003). Given that open (un-fingered) strings have a brighter timbre than closed (fingered) strings (Schelleng, 1973), it was predicted that composers writing for nominally sad music might choose keys or notes that inhibit the ability to use open strings. Specifically, the proportions of possible-open-to-stopped strings were compared between nominally sad (slow tempo, minor mode) and nominally happy (major mode) quartet movements.

Study 2 examined the possible presence of acoustical features of laughter in nominally humorous compositions in the form of staccato, isochronous passages. To substantiate the possibility of hearing laughter-like sounds from a musical instrument other than the voice, the first part of the study asked participants to adjust the tempi and articulation of single looped musical tones to sound the most like laughter. The second part of the study compared the number of staccato, isochronous passages found in nominally humorous piano music (including Scherzo, badinerie, and humoresques) compared to matched control works.

The final study presented here, study 3, was inspired by the phenomenon that speaking high in one’s range portrays a higher level of emotionality (Scherer et al., 2003). Interpreting pitch register is dependent on knowing vocal range. However,
research has demonstrated that humans are fairly accurate at identifying vocal range (Honorof & Whalen, 2005). The first part of the study verified that this ability translates to instruments, specifically to cello, by asking listeners to identify which tone - in a pair of recorded tones - was played in a high playing position. The second part of the study tested whether melodies played in the upper register of the instrument would convey a higher level of emotionality, similar to the voice. This was tested by asking listeners to decide which of a pair of melodies - one recorded in low playing positions and one recorded in high playing positions - was the most expressive.

The results of each of these studies are mixed. Study #1 failed to show any consistency between darker timbre and the use of stopped versus open strings in string compositions. Study #2 involved four hypotheses and also produced mixed results. The first part, which employed the method of adjusting tones to sound like laughter, corroborated Provine’s findings that laughter is often portrayed in music at slower tempos and longer articulations than found in natural laughter (2001). However, the second part of study #2 found that while staccato notes are used more in nominally comedic genres, isochronous rhythms are not. These findings partially support the hypothesis that composers might imitate the acoustical structure of laughter when writing for humorous genres. Study #3 also produced mixed but largely positive results. The results of part one indicated that participants were reasonably able to hear and identify which pitch was played in a high playing position. The results of part two were divided. Those who heard Cellist A mostly rated melodies played in high playing positions as more expressive whereas those who heard Cellist B mostly rated melodies played in low playing positions as more
expressive. It could be that our hypothesis only applies to specific instruments or cellists. Otherwise, perhaps the playing abilities of the cellists may have influenced these results.

Given this possibility, I plan on re-running this study using more advanced cellists to create the recordings. These more advanced players would also be given time to decide on ideal fingerings and practice the passages before the recording session. Additionally, while there was a significant time benefit to distributing the study online, there was no control over how subjects listened to the audio samples in the study. The differences between the recordings could be considered fairly subtle. Therefore, the results may have lost a great deal of power if participants were mostly using earbuds or their laptop speakers to take the tests. The next run of this study would better control the audio quality of the samples by running participants in soundproof booths with noise-canceling headphones.

Inspired by the results of the third study, here are proposals for several experiments that will continue examining performance choices related to imitation of vocal affective cues. One future study will continue the investigation of using string register to communicate emotional arousal by collecting data from performer annotations on scores, specifically fingerings. A melody will be selected that can be comfortably performed in low or high playing positions in its entirety. The melody will then be annotated with one of two expressive playing instructions. The first instruction will suggest a low emotionality with words such as “calm, light, dreamy, peaceful”. The second instruction will suggest a high emotionality with words such as “expressive, intense, brooding, upset”. Both melodies will be set at the same tempo. These short melodies will be distributed via email to college-level string
players. They will be asked to write in how they would choose to finger the passages. The hypothesis for this study is that participants, in order to communicate a higher emotionality, will write fingerings in high playing positions more often for the “expressive, intense, brooding, upset” melody than in the “calm, light, dreamy, peaceful” melody.

In relation to the above-mentioned study, it would be of interest to create a corpus of performance annotations from scores of orchestral, chamber, and solo repertoire. The data collected could reveal further trends in performance related to mimicking vocal affective cues.

Lastly, as mentioned during the discussion of study 3 in Chapter 4, given the positive results of part one and the partially positive results for part two, it would be valuable to conduct a full spectral analysis of pitches and passages played in the upper and lower register of the cello. The results strongly suggest that there is some audible difference. It could be that this difference is mostly related to vibrato widths and rates. However, written responses from participants mention timbral aspects often enough as a factor in their ability to hear the different registers that a spectral investigation seems necessary. Another possible motivation behind fingering choices for expressive reasons could have to do with resonance. Perhaps playing in the upper range of a string instrument improves the resonance of the notes and makes playing in that location feel more pleasant for the musician. In the future, it could be valuable to examine what resonance might mean for playing positions as well.
References


Barber, S. (1936). *String Quartet in B minor, op.11, Molto adagio*.


Appendix A: Images of Max/MSP Interface
Appendix B: Tempos Used in Matching Control to Test Works

Appendix C: List of Cello Pitches, Playing Positions, and Strings

<table>
<thead>
<tr>
<th>Pitches</th>
<th>String</th>
<th>Hand Position</th>
<th>Playing Position</th>
<th>Symp/NonSymp</th>
</tr>
</thead>
<tbody>
<tr>
<td>E4</td>
<td>A string</td>
<td>2nd</td>
<td>Low</td>
<td>Symp</td>
</tr>
<tr>
<td>E4</td>
<td>D string</td>
<td>Thumb</td>
<td>High</td>
<td>Symp</td>
</tr>
<tr>
<td>C4</td>
<td>A string</td>
<td>1st</td>
<td>Low</td>
<td>Symp</td>
</tr>
<tr>
<td>C4</td>
<td>G string</td>
<td>Thumb</td>
<td>High</td>
<td>Symp</td>
</tr>
<tr>
<td>E3</td>
<td>D string</td>
<td>1st</td>
<td>Low</td>
<td>Symp</td>
</tr>
<tr>
<td>E3</td>
<td>C string</td>
<td>Thumb</td>
<td>High</td>
<td>Symp</td>
</tr>
<tr>
<td>A2</td>
<td>G string</td>
<td>1st</td>
<td>Low</td>
<td>Symp</td>
</tr>
<tr>
<td>A2</td>
<td>C string</td>
<td>Thumb</td>
<td>High</td>
<td>Symp</td>
</tr>
<tr>
<td>Bb3</td>
<td>A string</td>
<td>1st</td>
<td>Low</td>
<td>NonSymp</td>
</tr>
<tr>
<td>Bb3</td>
<td>G string</td>
<td>Thumb</td>
<td>High</td>
<td>NonSymp</td>
</tr>
<tr>
<td>Ab3</td>
<td>D string</td>
<td>2nd</td>
<td>Low</td>
<td>NonSymp</td>
</tr>
<tr>
<td>Ab3</td>
<td>G string</td>
<td>Thumb</td>
<td>High</td>
<td>NonSymp</td>
</tr>
<tr>
<td>F3</td>
<td>D string</td>
<td>1st</td>
<td>Low</td>
<td>NonSymp</td>
</tr>
<tr>
<td>F3</td>
<td>C string</td>
<td>Thumb</td>
<td>High</td>
<td>NonSymp</td>
</tr>
<tr>
<td>C#3</td>
<td>G string</td>
<td>2nd</td>
<td>Low</td>
<td>NonSymp</td>
</tr>
<tr>
<td>C#3</td>
<td>C string</td>
<td>Thumb</td>
<td>High</td>
<td>NonSymp</td>
</tr>
</tbody>
</table>
Appendix D: Example Cello Pitches for High and Low Positions

<table>
<thead>
<tr>
<th>Pitches</th>
<th>String</th>
<th>Hand Position</th>
<th>Playing Position</th>
<th>Symp/NonSypm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3</td>
<td>D string</td>
<td>2nd</td>
<td>Low</td>
<td>Symp</td>
</tr>
<tr>
<td>C#4</td>
<td>A string</td>
<td>1st</td>
<td>Low</td>
<td>NonSymp</td>
</tr>
<tr>
<td>A3</td>
<td>G string</td>
<td>Thumb</td>
<td>High</td>
<td>Symp</td>
</tr>
<tr>
<td>C#4</td>
<td>D string</td>
<td>Thumb</td>
<td>High</td>
<td>NonSymp</td>
</tr>
</tbody>
</table>
Appendix E: Interface Images and Syntax for Study 3, Part One

Index with links to both studies:

Click here to begin Part 1 of the study.

Click here to begin Part 2 of the study.

Part 1, screen 1:

Thank you for participating in this experiment. Before beginning, we ask that you check that you are using the best quality headphones available to you for this experiment. You can end this experiment at any time by closing the browser window. Data will only be saved upon completing each of the two parts of this experiment and the post-experiment survey questions.

To begin, we would like to ask you a few questions about your musical background.
Part 1, example demographic question slide:

Do you play a woodwind instrument?

Yes  No  Decline to respond

Submit Answers

Part 1, example additional demographic question slide:

If yes, for how many years have you played?

I don’t play a woodwind instrument  Less than a year  1-3 years  4-7 years  More than 7 years  Decline to respond

Submit Answers

Part 1, unique identifier slide:

Please enter a unique (anonymous) identifier. This information will allow us to anonymously connect the data for parts 1 and 2 of this experiment. You will be asked to re-enter this number in part 2.

Submit Answers
Part 1, instructions slide:

Please carefully read the following:

On the cello, notes are played on each of the 4 strings by pressing down on the fingerboard from the scroll (top of the instrument) towards the bridge (See Figure 1).

Figure 1
The notes played closer to the scroll are considered low playing position notes. The notes played closer to the bridge are considered high playing position notes. Cellists also refer to these locations by hand positions. For this study, we call low playing position notes any notes within half to 2nd position and we call high playing position notes any notes from 5th position up into thumb position (See Figure 2).

**Figure 2**
Part 1, instructions slide continued:
Part 1, instructions slide continued:

The same pitch can often be played in both a low playing position on one string and a high
playing position on another string. For example, as shown circled in red in Fig. 2, a cellist can
play the pitch E3 in a low playing position on the D string or in a high playing position on the G
string. Because these two notes are the same pitch, we are interested in why a cellist might
elect to play one or the other. As part of this question, we want to know how possible it is to
hear whether a note is played in a low or high playing position. In other words, can you hear a
difference between E3 on the D string and E3 on the G string?

Instructions:

In the pop-up window, we provide two, whole-note listening examples of a cellist playing
pitches in a low playing position and in a high playing position. Before we begin, please
familiarize yourself with these examples. Listen for aural cues in the example notes that might
help you to differentiate between the playing positions. We recommend comparing Example 1
to Example 3 and Example 2 to Example 4.

You will be presented with 12 pairs of recordings of single whole notes played on the cello. For
each pair of notes, we would like you to indicate which note you believe is played in a high
playing position by pressing 1 or 2 on your computer keyboard (1 = Note 1, 2 = Note 2). Some
note pairs will be repeated but not necessarily in the same order. You may listen to the audio
examples in the pop-up window throughout the study as needed. Please remember what aural
cues you use to make your decisions during this task because we will ask you to report them at
the end. This part of the study will take about 5 minutes.

Click next to begin.

Part 1, example of a slide with stimuli:

Note 1

Note 2

Press the appropriate number (1 or 2) on your computer keyboard to indicate which note is
played in a high playing position (1 = Note 1, 2 = Note 2). In other words, which note sounds
more like examples 3 and 4? If you wish, you can re-listen to the examples in the pop-up. If you
have closed the pop-up window, you can reopen it by clicking here.
Part 1, pop-up window with examples:

Low Playing Position Examples
These are notes played in half-2nd positions.

Example 1

Example 2

High Playing Position Examples
These are notes played in 4th-thumb positions.

Example 3

Example 4

Interface syntax, index:

```html
<!doctype html>
<html>
<head>
<title>
Performance choices study
</title>
</head>
<body>
<h4>Click <a href="study1.html" target="_blank">here</a> to begin Part 1 of the study.</h4>
<p>
</p>
<h4>
Click <a href="study2_A.html" target="_blank">here</a> to begin Part 2 of the study.
</h4>
```

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Interface syntax, part 1, pop-up examples:

<body>

<h2>Low Playing Position Examples</h2>
<p>
These are notes played in half-2nd positions.
</p>
<h3>Example 1</h3>
<p><audio controls>
<source src="audio/positionexamples/C_4_1.mp3" type="audio/mpeg">
Your browser does not support the audio element.
</audio></p>

<h3>Example 2</h3>
<p><audio controls>
<source src="audio/positionexamples/C_8_1.mp3" type="audio/mpeg">
Your browser does not support the audio element.
</audio></p>

<h2>High Playing Position Examples</h2>
<p>
These are notes played in 4th-thumb positions.
</p>
<h3>Example 3</h3>
<p><audio controls>
<source src="audio/positionexamples/C_4_2.mp3" type="audio/mpeg">
Your browser does not support the audio element.
</audio></p>

<h3>Example 4</h3>
<p><audio controls>
<source src="audio/positionexamples/C_8_2.mp3" type="audio/mpeg">
Your browser does not support the audio element.
</audio></p>

</body>
Interface syntax, part 1:

```html
<!doctype html>
<html>
<head>
  <title>Caitlyn Trevor's experiment Part 1</title>
  <script
    src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
  <script
    src="https://ajax.googleapis.com/ajax/libs/jqueryui/1.10.3/jquery-ui.min.js"></script>
  <link href="https://ajax.googleapis.com/ajax/libs/jqueryui/1.10.3/themes/black-tie/jquery-ui.min.css" rel="stylesheet" type="text/css">
  <script src="jsPsych-master/jspsych.js"></script>
  <script src="jsPsych-master/plugins/jspsych-text.js"></script>
  <script src="jsPsych-master/plugins/jspsych-instructions.js"></script>
  <script src="jsPsych-master/plugins/jspsych-survey-text.js"></script>
  <script src="jsPsych-master/plugins/jspsych-survey-likert.js"></script>
  <script src="jsPsych-master/plugins/jspsych-single-audio.js"></script>
  <script src="jsPsych-master/plugins/jspsych-single-stim.js"></script>
  <link href="jsPsych-master/css/jspsych.css" rel="stylesheet" type="text/css">
  <script type="text/javascript">
    function poponload() {
      testwindow = window.open("audioFiles.html", "mywindow", "location=1,status=1,scrollbars=1,width=400,height=575");
      // testwindow.moveTo(0, 0);
    }
  </script>
  <script type="text/javascript">
    function saveData(filename, filedata) {
      $.ajax({
        type: 'post',
```
var welcome_block = {
  type: 'instructions',
  pages:[
    '<p>Thank you for participating in this experiment. Before beginning, we ask that you check that you are using the best quality headphones available to you for this experiment. You can end this experiment at any time by closing the browser window. Data will only be saved upon completing each of the two parts of this experiment and the post-experiment survey questions.</p> <p>To begin, we would like to ask you a few questions about your musical background.</p>',

    show_clickable_nav: true
  ]
}

// defining groups of questions that will go together.
var page_1_questions = ['Do you play a string instrument?'];
var page_2_questions = ['If yes, for how many years have you played?'];
var page_3_questions = ['Do you play a brass instrument?'];
var page_4_questions = ['If yes, for how many years have you played?'];
var page_5_questions = ['Do you play a woodwind instrument?'];
var page_6_questions = ['If yes, for how many years have you played?'];
var page_7_questions = ['Do you play piano or a percussion instrument?'];
var page_8_questions = ['If yes, for how many years have you played?'];
var page_9_questions = ['How old are you today?'];
var scale_1 = ["Yes", "No", "Decline to respond"];  
var scale_2 = ["I don't play a string instrument", "Less than a year", "1-3 years", "4-7 years", "More than 7 years","Decline to respond"];  
var scale_3 = ["Yes", "No", "Decline to respond"];  
var scale_4 = ["I don't play a brass instrument", "Less than a year", "1-3 years", "4-7 years", "More than 7 years","Decline to respond"];  
var scale_5 = ["Yes", "No", "Decline to respond"];  
var scale_6 = ["I don't play a woodwind instrument", "Less than a year", "1-3 years", "4-7 years", "More than 7 years","Decline to respond"];  
var scale_7 = ["Yes", "No", "Decline to respond"];  
var scale_8 = ["I don't play piano or a percussion instrument", "Less than a year", "1-3 years", "4-7 years", "More than 7 years","Decline to respond"];  
var scale_9 = ["18-22", "22-30", "30-40", "40-50", "50+", "Decline to respond"];  

var likert_block = {  
  type: 'survey-likert',  
  questions: [page_1_questions, page_2_questions, page_3_questions, page_4_questions, page_5_questions, page_6_questions, page_7_questions, page_8_questions, page_9_questions],  
  labels: [scale_1, scale_2, scale_3, scale_4, scale_5, scale_6, scale_7, scale_8, scale_9],  
  intervals: [3, 6, 3, 6, 3, 6, 3, 6, 6],  
};  

var unique_identifier= ["Please enter a unique (anonymous) identifier. This information will allow us to anonymously connect the data for parts 1 and 2 of this experiment. You will be asked to re-enter this number in part 2."];  

var survey_block = {  
  type: 'survey-text',  
  questions: [unique_identifier]  
}
/* define welcome message block */
var instructions_block = {
    type: 'instructions',
    pages:[
        '<h4> Please carefully read the following: </h4> ' +
        '<p> On the cello, notes are played on each of the 4 strings by pressing down on the fingerboard from the scroll (top of the instrument) towards the bridge (See Figure 1). ' +
        '<p> Figure 1 </p> <img src="images/CelloDiagram.png" style="width:936px;height:585px;" > ' +
        '<p> The notes played closer to the scroll are considered low playing position notes. The notes played closer to the bridge are considered high playing position notes. ' +
        'Cellists also refer to these locations by hand positions. For this study, we call low playing position notes any notes within half to 2nd position and we call ' +
        'high playing position notes any notes from 5th position up into thumb position (See Figure 2). ' +
        '<p> Figure 2 </p> <img src="images/CelloPositionsImage_withtext_andHL.png" style="width:490px;height:701px;" > ' +
        '<p> The same pitch can often be played in both a low playing position on one string and a high playing position on another string. ' +
        'For example, as shown circled in red in Fig.2, a cellist can play the pitch E3 in a low playing position on the D string or in a high playing position on the G string. ' +
        'Because these two notes are the same pitch, we are interested in why a cellist might elect to play one or the other. ' +
        'As part of this question, we want to know how possible it is to hear whether a note is played in a low or high playing position. ' +
        'In other words, can you hear a difference between E3 on the D string and E3 on the G string? ' +
    ]
};
Instructions:

In the pop-up window, we provide two, whole-note listening examples of a cellist playing pitches in a low playing position and in a high playing position.

Before we begin, please familiarize yourself with these examples. Listen for aural cues in the example notes that might help you to differentiate between the playing positions. We recommend comparing Example 1 to Example 3 and Example 2 to Example 4.

You will be presented with 12 pairs of recordings of single whole notes played on the cello. For each pair of notes, we would like you to indicate which note you believe is played in a high playing position by pressing 1 or 2 on your computer keyboard (1 = Note 1, 2 = Note 2).

Some note pairs will be repeated but not necessarily in the same order. You may listen to the audio examples in the pop-up window throughout the study as needed.

Please remember what aural cues you use to make your decisions during this task because we will ask you to report them at the end.

This part of the study will take about 5 minutes.

Click next to begin.
var test_stimuli = [
    {
        type: 'single-stim',
        stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_2_1.mp3" type="audio/mpeg"></audio>', '<p> Note 2
        <p> <audio controls><source src="audio/C_2_2.mp3" type="audio/mpeg"></audio>'],
        data: { response: '2' },
        prompt: "Press 1 or 2",
        is_html: true
    },
    {
        type: 'single-stim',
        stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_2_2.mp3" type="audio/mpeg"></audio>', '<p> Note 2
        <p> <audio controls><source src="audio/C_2_1.mp3" type="audio/mpeg"></audio>'],
        data: { response: '1' },
        prompt: "Press 1 or 2",
        is_html: true
    },
    {
        type: 'single-stim',
        stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_3_1.mp3" type="audio/mpeg"></audio>', '<p> Note 2
        <p> <audio controls><source src="audio/C_3_2.mp3" type="audio/mpeg"></audio>'],
        data: { response: '2' },
        prompt: "Press 1 or 2",
        is_html: true
    },
    {
        type: 'single-stim',
        stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_5_2.mp3" type="audio/mpeg"></audio>', '<p> Note 2
        <p> <audio controls><source src="audio/C_5_1.mp3" type="audio/mpeg"></audio>'],
        data: { response: '1' },
        prompt: "Press 1 or 2",
        is_html: true
    },
];
type: 'single-stim',
stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_6_1.mp3" type="audio/mpeg"></audio>', '<p> Note 2 <p> <audio controls><source src="audio/C_6_2.mp3" type="audio/mpeg"></audio>'],
data: { response: '2' },
prompt: "Press 1 or 2",
is_html: true
},

type: 'single-stim',
stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_9_1.mp3" type="audio/mpeg"></audio>', '<p> Note 2 <p> <audio controls><source src="audio/C_9_2.mp3" type="audio/mpeg"></audio>'],
data: { response: '2' },
prompt: "Press 1 or 2",
is_html: true
},

type: 'single-stim',
stimuli: ['<p> Note 1 <p> <audio controls><source src="audio/C_10_2.mp3" type="audio/mpeg"></audio>', '<p> Note 2 <p> <audio controls><source src="audio/C_10_1.mp3" type="audio/mpeg"></audio>'],
data: { response: '1' },
prompt: "Press 1 or 2",
is_html: true
}
stimuli: ["<p>Note 1</p><audio controls><source src="audio/C_11_1.mp3" type="audio/mpeg"></audio>", ",<p>Note 2</p><audio controls><source src="audio/C_11_2.mp3" type="audio/mpeg"></audio>"],[
    data: { response: '2' },
    prompt: "Press 1 or 2",
    is_html: true
],
{
    type: 'single-stim',
    stimuli: ["<p>Note 1</p><audio controls><source src="audio/C_11_2.mp3" type="audio/mpeg"></audio>", ",<p>Note 2</p><audio controls><source src="audio/C_11_1.mp3" type="audio/mpeg"></audio>"],
    data: { response: '1' },
    prompt: "Press 1 or 2",
    is_html: true
],
{
    type: 'single-stim',
    stimuli: ["<p>Note 2</p><audio controls><source src="audio/C_12_1.mp3" type="audio/mpeg"></audio>", ",<p>Note 2</p><audio controls><source src="audio/C_12_2.mp3" type="audio/mpeg"></audio>"],
    data: { response: '1' },
    prompt: "Press 1 or 2",
    is_html: true
],
{
    type: 'single-stim',
    stimuli: ["<p>Note 2</p><audio controls><source src="audio/C_12_2.mp3" type="audio/mpeg"></audio>", ",<p>Note 2</p><audio controls><source src="audio/C_12_1.mp3" type="audio/mpeg"></audio>"],
    data: { response: '1' },
    prompt: "Press 1 or 2",
    is_html: true
],
}];
/*
var test_stimuli = [
    {
        type: 'single-audio',
        stimuli: ['audio/1_1.mp3'],
        data: { response: '1' },
        prompt: "Press 1-6"
    },
];

var all_trials = jsPsych.randomization.repeat(test_stimuli, 1, true);

var post_trial_gap = function() {
    return Math.floor( Math.random() * 1200 ) + 750;
}

var test_block = {
    type: "single-stim",
    stimuli: all_trials.stimuli,
    prompt: "<p>Press the appropriate number (1 or 2) on your computer keyboard to indicate which note is played in a <b> high </b> playing position (1 = Note 1, 2 = Note 2). In other words, which note sounds more like examples 3 and 4? If you wish, you can re-listen to the examples in the pop-up. If you have closed the pop-up window, you can reopen it by clicking <a href='javascript:poponload()'>here</a>.</p>",
    is_html: all_trials.is_html,
    choices: ['1', '2'],
    data: all_trials.data,
    timing_post_trial: post_trial_gap
};

/* define debrief block */

var page_1_questions_end = ['"<p>Thank you for completing part 1 of the experiment! Return to the homepage tab and click on part 2 to continue.</p>" <p>We are interested in knowing what information in the notes you used to make your determination of which note was played in a high playing position. Please list the most important information first."'];
var post_test_survey_block = {
    type: 'survey-text',
    questions: [page_1_questions_end],
};

/* create experiment definition array */
var experiment = [];
experiment.push(welcome_block);
experiment.push(likert_block);
experiment.push(survey_block);
experiment.push(instructions_block);
experiment.push(test_block);
experiment.push(post_test_survey_block);
today = new Date();

/* start the experiment */
jsPsych.init({
    display_element: $('#jspsych-target'),
    experiment_structure: experiment,
    on_finish: function(data){
        saveData(today, jsPsych.data.dataAsCSV())
        alert('Please move on to part 2');
    }
});

</script>

</html>
Appendix F: Melodies Recorded for Study 3

Stimuli Score: Melodies

[Sheet Music Image]

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Appendix G: Interface Images and Syntax for Study 3, Part Two

Part 2, introduction slide:

Thank you for continuing to part 2 of this experiment! You can end this experiment at any time by closing the browser window. Data will only be saved if you complete the entire experiment and the post-experiment survey question.

Next >

Part 2, unique identifier slide:

Please enter the unique (anonymous) identifier you used for the last study.

Submit Answers
Part 2, instructions slide:

In this part of the experiment, you will be presented with a series of 12 pairs of recordings of a melody. You will be asked to indicate which recording of the melody you believe was played more expressively or emotionally by pressing the appropriate number (1 for the first recording or 2 for the second recording) on your keyboard.

You will hear each pair of melodies twice. This part of the study will take about 20 minutes. Please use the best quality headphones that you have access to for this study. Click next to begin.

Next>

Part 2, example of slide with stimuli:

Recording 1

Recording 2

Press the appropriate number (1 or 2) on your computer keyboard to indicate which recorded melody you think is played more expressively or emotionally.

Interface syntax, part 2:

```html
<!doctype html>
<html>
<head>
  <title>Caitlyn Trevor's experiment Part 2</title>
  <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
</head>
<body>

</body>
</html>
```
Thank you for continuing to part 2 of this experiment! You can end this experiment at any time by closing the browser window. Data will only be saved if you complete the entire experiment and the post-experiment survey question.
// defining groups of questions that will go together.

var likert_block = {
  type: 'survey-likert',
  questions: [],
  labels: [], // need one scale for every question on a page
  intervals: [] // note the intervals and labels don't necessarily
need to match, but probably should
};

var unique_identifier = "Please enter the unique (anonymous) identifier you used for the last study. "]

var survey_block = {
  type: 'survey-text',
  questions: [unique_identifier]
};

/* define welcome message block */
var instructions_block = {
  type: 'instructions',
  pages: [
    '<p>In this part of the experiment, you will be presented with a series of 12 pairs of recordings of a melody. You will be asked to indicate which
    ' +
    'recording of the melody you believe was played more expressively or emotionally by pressing
    ' +
    'the appropriate number (1 for the first recording or 2 for the second recording) on your keyboard.</p> +
    '<p> You will hear each pair of melodies twice. This part of the study will take about 20 minutes. Please use the best quality headphones that you have access to for this study. Click next to begin.'</p>
  ],
  show_clickable_nav: true
}

/* define test block */

/* var test_stimuli = {
  type: 'single-stim',
  stimuli: ['audio/1_1.mp3','audio/1_2.mp3','audio/2_1.mp3','audio/2_2.mp3'],
  choices: ['h','s']
} */
var test_stimuli = [

{
    type: 'single-stim',
    stimuli: ['<p> Recording 1 <p> <audio controls><source src="audio/melodies/C_M_M1_1.mp3" type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio controls><source src="audio/melodies/C_M_M1_2.mp3" type="audio/mpeg"></audio>',
    data: { response: '2' },
    prompt: "Press 1 or 2",
    is_html: true
},

{
    type: 'single-stim',
    stimuli: ['<p> Recording 1 <p> <audio controls><source src="audio/melodies/C_M_M2_1.mp3" type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio controls><source src="audio/melodies/C_M_M2_2.mp3" type="audio/mpeg"></audio>',
    data: { response: '1' },
    prompt: "Press 1 or 2",
    is_html: true
},

{
    type: 'single-stim',
    stimuli: ['<p> Recording 1 <p> <audio controls><source src="audio/melodies/C_M_M3_1.mp3" type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio controls><source src="audio/melodies/C_M_M3_2.mp3" type="audio/mpeg"></audio>',
    data: { response: '2' },
    prompt: "Press 1 or 2",
    is_html: true
},

{
    type: 'single-stim',
    stimuli: ['<p> Recording 1 <p> <audio controls><source src="audio/melodies/C_M_M4_1.mp3" type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio controls><source src="audio/melodies/C_M_M4_2.mp3" type="audio/mpeg"></audio>',
    data: { response: '1' },
    prompt: "Press 1 or 2",
}]}
is_html: true
|
|

type: 'single-stim',
stimuli: ['<p> Recording 1 <p> <audio
controls><source src="audio/melodies/C_M_M5_1.mp3"
type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio
controls><source src="audio/melodies/C_M_M5_2.mp3"
type="audio/mpeg"></audio>'],
data: { response: '2' },
prompt: "Press 1 or 2",
is_html: true
|
|

type: 'single-stim',
stimuli: ['<p> Recording 1 <p> <audio
controls><source src="audio/melodies/C_M_M6_2.mp3"
type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio
controls><source src="audio/melodies/C_M_M6_1.mp3"
type="audio/mpeg"></audio>'],
data: { response: '1' },
prompt: "Press 1 or 2",
is_html: true
|

{ type: 'single-stim',
stimuli: ['<p> Recording 1 <p> <audio
controls><source src="audio/melodies/C_M_M1_1.mp3"
type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio
controls><source src="audio/melodies/C_M_M1_2.mp3"
type="audio/mpeg"></audio>'],
data: { response: '2' },
prompt: "Press 1 or 2",
is_html: true
|

{ type: 'single-stim',
stimuli: ['<p> Recording 1 <p> <audio
controls><source src="audio/melodies/C_M_M2_2.mp3"
type="audio/mpeg"></audio>', '<p> Recording 2 <p> <audio
controls><source src="audio/melodies/C_M_M2_1.mp3"
type="audio/mpeg"></audio>'],
data: { response: '1' },
prompt: "Press 1 or 2",
is_html: true
|

{ type: 'single-stim',}
var test_stimuli = [

];
var all_trials = jsPsych.randomization.repeat(test_stimuli, 1, true);

var post_trial_gap = function() {
  return Math.floor( Math.random() * 1200 ) + 750;
}

var test_block = {
  //
  //  type: "single-audio",
  type: "single-stim",
  stimuli: all_trials.stimuli,
  prompt: "<p>Press the appropriate number (1 or 2) on your computer keyboard to indicated which recorded melody you think is played more expressively or emotionally. ",
  is_html: all_trials.is_html,
  choices: ['1', '2'],
  data: all_trials.data,
  timing_post_trial: post_trial_gap
};

/* define debrief block */

var page_1_questions_end = ["<p>Thank you for completing the experiment! If you are interested in more about the experiment please email <a href='mailto:trevor.5@osu.edu'>Caitlyn Trevor</a>.</p>
<p>We are interested in knowing which information in the music you used to make your determination of which melody was played more expressively or more emotionally. Please list the most important information first."];

var post_test_survey_block = {
  type: 'survey-text',
  questions: [page_1_questions_end],
};

/* create experiment definition array */
var experiment = [];
experiment.push(welcome_block);
experiment.push(likert_block);
experiment.push(survey_block);
experiment.push(instructions_block);
experiment.push(test_block);
experiment.push(post_test_survey_block);

today = new Date();

/* start the experiment */
jsPsych.init(
    display_element: $('#jspsych-target'),
    experiment_structure: experiment,
    on_finish: function(data){
        saveData(today, jsPsych.data.dataAsCSV());
        alert("Task completed at " + today + ", please print this screen and email a copy to trevor.5@osu.edu (or copy and paste the following text into the email: " + today + ")");
    }
);

</script>
</html>