Selected Topics in the Perception and Interpretation of Musical Tempo

Dissertation

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Abstract

Two studies examined the influence of mental imagery type and instruments’ tone-decay times on tempo fluctuations between repeated rehearsals and performances of musical works. The first experimental study tested the predictions that 1) motor imagery—in contrast to non-motor imagery—would lead to smaller discrepancies between imagined and performed tempos; and 2) musical works having high note density would tend to be slowed down when imagined, whereas works having low note density would tend to be sped up when imagined. The second correlational study tested the prediction that the same work would exhibit significant changes of average tempo when performed on instruments having different tone-decay times.

In the first study, musicians performed slow and fast musical excerpts either vocally or on their major instrument. These excerpts were recorded. Then, each participant repeatedly attempted to mentally replicate their excerpts’ tempos by using motor or non-motor imagery. Excerpt beginnings were signaled by three-second prompts from the recordings of each excerpt, and participants indicated excerpt endings by ringing a call bell. Excerpt duration discrepancies were calculated by subtracting the performed excerpt length from the imagined excerpt length. The results did not yield support for either of our hypotheses. There was no significant difference of tempo discrepancies.
when using motor versus non-motor imagery; and there was no significant main effect of variable note density on tempo discrepancies. Post hoc analyses suggested that successive mental rehearsals might lead to smaller and less variable tempo discrepancies across musicians of diverse skill levels. Other post hoc analyses suggested that repeated practice attempts might improve or at least maintain tempo accuracy, except in music exhibiting low note density—below approximately 1.5 notes-per-second. However, musicians do not seem to have immediate conscious access to the gains or losses of tempo accuracy in mental practice.

The second part of the study analyzed the effect of instrument tone-decay time on average-tempo differences among repeated recorded performances of North-American Folk music and Western-Classical music. Recordings were paired in such a way that each piece was represented by performances on two (banjo and guitar) or three similar instruments (harpsichord, fortepiano, and piano). Varying tone-decay time comprised one salient difference within each instrument group. The results failed to support our prediction regarding tone-decay length and tempo differences. There was no significant difference of a work’s average tempo when it was performed on different instruments. Post hoc analyses of the folk songs showed that rhythmic speed was higher in performances on banjo than on guitar. This suggests that works not having a definitive version, as in a musical score, might exhibit faster rhythms when performed on instruments with shorter tone-decay times.
Dedication

This document is dedicated to my wife, Lia.
Acknowledgments

I would like to thank my advisor, David Huron, for his guidance with this and other lines of research. I also am very appreciative for the support from my other committee members: Lora Dobos and David Clampitt—many thanks to all of you, and to the whole Music Department at Ohio State.
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Fields of Study

Major Field: Music
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Study One – Musical Tempo Stability in Mental Practice:

A Comparison of Motor and Non-Motor Imagery Techniques
Introduction

A number of studies have suggested that mental practice using imagery is a useful addition to musicians’ practice routines (e.g., Coffman, 1990; Driskell, Copper, & Moran, 1994; Ross, 1985; Theiler & Lippman, 1995). Musical invention and interpretation involves more than mechanical aspects of musicianship such as having a work “under one’s fingers.” For example, it is also important to have an overall mental conception of a work’s structural form. Imagining musical form is a holistic way to experience a work’s interrelations without having to listen to or perform the work in temporal order. This is possible because although images are representations of perceptions, and subject to information loss—images also preserve perceptions and allow intentional transformation of perceptual content (Denis, 1989/1991). Transformations on images offer “the apparent possibility of variable resolution in musical imagery, meaning that we are probably all capable of zooming in on detail, re-playing some fragment again and again or in slow motion, zooming out, playing ‘fast forward’, etc.” (Schneider & Godøy, 2001, p. 22).

Musical imagery, evoked through mental practice, also has numerous other applications such as enhancing memory and facilitating motor planning. These cognitive boosts may lead to better control over musical parameters such as expressive timing, timbre, and pitch structures (see Godøy & Jørgensen, 2001).
The present study addresses one potential use of musical imagery—increasing the stability of musicians’ tempos. Specifically, we compare *tempo stability* in two types of mental practice: one that focuses on the imagination of sound only (non-motor imagery), and another type that focuses on the imagination of performance movements (motor imagery). We elect to use the term “non-motor” rather than “auditory” (e.g., Highben & Palmer, 2004) because it is probably difficult to suppress auditory imagery while using motor imagery. Ostensibly, both types of imagery call up the sonic characteristics of music—their main difference lies in the motor/non-motor distinction. This study investigates tempo stability in the absence of any auditory or kinesthetic feedback, although participants did have their eyes open to follow the score. The results have potential implications for musicians who are interested in reliable techniques to maintain a desired tempo throughout a rehearsal sequence of a work.

*Considerations of Tempo*

Prior to considering the issue tempo stability, musicians usually address the choice of tempo. The tempo at which a musical work is performed can have a dramatic impact on the work’s character. Faster or slower tempos will influence the emotional flavor of the work, and may also influence the perception of a work’s structure. A note-perfect performance might contradict a composer’s musical intention merely through the choice of an inappropriate tempo. It is not surprising then, that tempo is a topic of considerable debate in authentic performance practice (e.g., Badura-Skoda, 1990/1993; Bowen, 1996; Brown, 1999; Hudson, 1994; Philip, 1992). Authenticity of tempo is an
intriguing and important issue, but other than to say that composers also imagine tempos while composing, tempo authenticity is largely beyond the scope of the present study.

Even when a performer has established an ideal tempo for a particular work, that specific tempo may not be realized from performance to performance. A performer may inadvertently speed up or slow down; the tempo may be influenced by performance anxiety, poor tempo memory, or other unknown sources. For the purposes of this study, variability around the performer’s ideal tempo is referred to as *tempo stability*. Unintentional deviations from the desired tempo might accrue over the course of a rehearsal series and cause a change of tempo. Therefore, it is important for musicians to explore ways to increase their abilities to maintain a steady tempo, and to perceive deviations from that tempo.

As a complement to the choice of overall tempo, deviation in the form of *accelerandi* and *ritardandi* are essential aspects of musical expression (e.g., Repp, 1999). However, depending on the style of music, “noticeable changes in speed that are not demanded by the composer are . . . misrepresentations” (Walter, 1957/1961, p. 32). Even the use of *rubato* does not necessarily call for a manipulation of the basic pulse: Richard Hudson’s (1994) history of *rubato* outlines *early* and *late* types of *rubato*. Early *rubato* involved a steady accompaniment pattern with displacement of a melodic line to create the *rubato* effect (Hudson, 1994).

Since there are situations in which musicians may desire a consistent tempo between performances, we focus on the issue of overall tempo stability. In brief, we
explore the potential for two types of mental imagery to support the goal of a stable tempo in music rehearsal.
Background

Helen Sills has suggested that mental practice is an important rehearsal strategy for professionals such as “athletes, pilots, dancers, [and] surgeons” (Sills, 2005, p. 59). What these professions all share in common is the requirement of coordinated, fine, and accurately timed motor skills. Of these professions, investigations of mental practice in sports have been particularly numerous (e.g., Jones, 1965; Roure, Collet, Deschaumes-Molinaro, Delhomme, Dittmar, Rada, & Vernet-Maury, 1998, 1999). Interest in mental practice is not simply confined to professionals, but has captured wide public interest. Numerous books have been published aimed at a broad audience interest in mental “mastery” techniques, especially in sports and music performance (e.g., Gallwey, 1997; McCluggage, 1983; Ristad, 1982).

As often happens with popular ideas, the notion of mental practice is sometimes diluted. James Driskell, Carolyn Copper, and Aidan Moran (1994) have cautioned that some writings, ostensibly concerning mental practice, include other mental preparation techniques mixed with mental practice proper. Example mental preparation techniques include “positive imagery, psyching-up strategies, attention focusing, relaxation, self-efficacy statements, and other forms of cognitive or emotional preparation prior to performance” (Driskell et al., 1994, p. 481). Despite this potential for confusion, many different types of writings—from journal articles to popular books—have led to sustained
interest in the applicability of mental practice to human activities requiring precise coordination.

Mental practice is commonly referred to as “visualization”; however, mental practice is not limited to the visual mode (see Driskell et al., 1994, for other synonyms for mental practice). In line with Don Coffman’s definition of mental practice, we consider mental practice to be a “covert or imaginary rehearsal of a skill without muscular movement or sound” (Coffman, 1990, p. 187). This definition is consistent with the one used by Driskell et al. (1994): “Mental practice is the symbolic, covert, mental rehearsal of a task in the absence of actual, overt, physical rehearsal” (p. 481).

Mental practice of physical movements may invoke muscular impulses despite lack of gross muscular movements (Jacobson, 1931; Ristad, 1982, p. 119); thus the term “mental” does not necessarily exclude very small movements of muscles, and involvement of the peripheral nervous system. Some authors have focused on these small movements as an explanation of mental practice’s efficacy. However, Driskell et al. (1994) have questioned whether purported movements provide the best explanation for the effectiveness of mental practice. Their results have revealed that the rehearsal of cognitive structures seems to benefit more from mental practice than mental practice of physical elements (Driskell et al., 1994).

However, different levels of achievement between mental practice of cognitive and physical goals could result from an interaction between participants’ experience and task type (cognitive or physical). People who are experienced with a particular cognitive or physical skill exhibit significant improvement from mental practice, while novices
exhibit significant benefits only for cognitive tasks (Driskell et al., 1994). To summarize, mental practice is inner rehearsal of the procedural steps used in skills, and mental practice embraces a wide variety of physical and cognitive skill sets.

Mental practice’s contributions to musical learning are extensively researched, but many questions remain. While exclusive physical practice alone is more beneficial overall than exclusive mental practice (Coffman, 1990; Driskell et al., 1994; Highben & Palmer, 2004), it is not clear if staggering mental and physical practice causes direct improvement over a solely physical practice session. Mental practice might simply be a way for musicians to rest physically while continuing to practice in some form. However, in some cases, such as in the “over learning” stage of memorization, mental practice appears to be superior to physical practice (Coffman, 1990; Rubin-Rabson, 1941). Eloise Ristad has viewed mental practice as a way for muscle patterns to “begin to change and become more dependable, more repeatable, less erratic” (Ristad, 1982, p. 121). While a number of different mental practice techniques have been identified and researched (e.g., Lim and Lippman, 1991), few studies have compared different types of musical imagery used in mental practice.

As noted earlier, one distinction of mental imagery type is between motor and non-motor forms of imagery. Motor mental practice involves imagining physical movements, such as the pressing of keys on a piano or the bowing of a violin. Conversely, non-motor mental practice does not involve imagined movements, but rather imagined modalities such as musical sounds. Caroline Palmer (2006, p. 43) has suggested
that future studies should compare motor and non-motor components of mental practice in order to determine how mental practice benefits motor performance.¹

In addition to the possible modes of mental practice, it is important to consider the relationship between mental practice and specific musical goals. Mental practice may mildly improve many aspects of musical performance, or it may have specific benefits to one or more musical goals: memorization, rhythmic accuracy, emotional expression, pitch intonation accuracy, dynamic flexibility, appropriate phrasing, and contrasts of articulation. Assessing specific outcomes of mental practice is more likely to identify the precise benefits of mental practice.

Serene Lim and Louis Lippman (1991) compared three practice conditions: physical practice, mental practice while listening to recordings, and purely mental practice. Judges rated post-rehearsal performances according to note accuracy, rhythmic accuracy, phrasing/articulation, and dynamics/expression. Their results are consistent with the notion that physical practice is superior to mental practice. Lim and Lippman also demonstrated varying effects of contrasting practice conditions on note accuracy, rhythmic accuracy, phrasing, and dynamics. In the case of note accuracy and dynamics, all three practice techniques had significantly different effects: performances following the physical practice condition received the highest scores from judges, followed by the scores for the mental practice while listening condition, which were followed by the scores for the mental only practice condition.

Other practice conditions did not exhibit the same hierarchy of practice benefits: for rhythmic accuracy, physical practice was significantly better than either form of
mental practice, and there was no significant difference between the two types of mental practice (Lim & Lippman, 1991). These results suggest that mental practice has variable benefits depending upon targeted musical skills. Since mental practice while listening was important in improving note accuracy, perhaps an aural component added to mental imagery was a key factor in practice of pitch relationships. However, in the rhythmic domain, mental practice while listening made no difference over pure mental practice. These results hint that there may be other mental imagery techniques that could improve rhythm.

Rhythmic accuracy in mental imagery also was explored in part of Clemens Wöllner and Aaron Williamon’s (2007) performance feedback study; they investigated the effects of auditory, visual, and kinesthetic feedback on timing and dynamics in piano performance. Auditory and visual feedback deprivation caused inter onset intervals (IOIs) to deviate from normal performance feedback IOIs; these deviations ranged between approximately 0.2% – 9%. Most of the deviations consisted of longer IOIs, which correspond to slower tempos. In contrast, deprivation of kinesthetic feedback had a more marked effect: IOIs varied between approximately 8% – 42%. Again, most of these IOI changes reflected longer note durations. These results suggest that feedback from the body’s movements is important for accurately timed performances. Based on this finding, we propose that mental rehearsal of rhythm might be best achieved through imagery of kinesthetic feedback and body motion.
Hypotheses

_Hypothesis one_ – “Mental practice type”: Differences between imagined and performed tempos can be minimized using an imagination strategy that focuses on the performer’s physical movements (motor imagery) rather than focusing on the sound of the piece (non-motor imagery).

_Hypothesis two_ – “Tempo flux”: Imagined tempo is influenced by note density: “fast” works exhibiting a high note density will be imagined at a slower tempo relative to their performed tempos; “slow” works exhibiting a low note density will be imagined at a faster tempo relative to their performed tempos.

We posited these two hypotheses and selected a significance level ($\alpha = 0.10$) _a priori_. The mental-practice-type hypothesis predicts that motor mental practice of tempo would exhibit smaller tempo discrepancies. The tempo-flux hypothesis predicts specific directions of tempo drift depending upon a piece’s note density (number of notes/total excerpt duration). Note density was chosen as the independent variable, rather than tempo, partly because the feeling of pulse may differ between performers—ambiguities of beat hierarchy frequently arise in music.

Hypothesis one arose from selected, previous research, and introspection of our own musical practice using mental imagery. Indirect and direct evidence from musical studies (Lim & Lippman, 1991; Wöllner & Williamon, 2007) suggested that a motor
component to mental imagery is important for musical rhythm. However, the general research literature on mental imagery does not unanimously support the notion of motor imagery’s advantage.

For example, some types of visual imagery makes use of cognitive representations that can be explored through imagined physical action. Mental maps contain visual cues such as landmarks or overviews of roads (Denis, 1989/1991), which may be explored quite quickly compared to traveling those distances in reality. However, cognitive maps still require mental “movement” across relative distances between representational markers—this process of movement is known as image scanning. Guillot and Collet (2005) have reported on research literature investigating the metrics of image scanning: in general, longer representational “distances” are associated with longer durations of image scanning.

So in the case of imagined performance movements, image-scanning distances might fluctuate according to the instrument or voice type of the musician: a piccolo player’s fingers move very little, thus image scanning would fill only a small interval of time. In contrast, a harp player’s image scanning would involve relatively larger distances because the image would include both hand and foot motions. In this hypothetical situation, mentally imagined tempos are constrained by the form of the body/instrument interface. Given this potentially unsteadying effect of motor imagery, we might wonder if hypothesis one is making the correct prediction.

However, the physical distances traversed when performing an instrument are linked closely to the resulting tempo of a work, and other evidence suggests that motor
Imagery may offer support for musical timing. Repp’s (1999) study of expressive timing in piano playing suggests that internal representations support expressive timing, but that the full range of expressive timing comes from perceptual feedback or actual motor activity. Perhaps if musicians are instructed to imagine the motor components of their performances, then they could accurately produce both the expressive or stable components of tempo as called for by musical context.

In early formulation of hypothesis two, before the formal experiment, we entertained a simpler version: musicians will tend to speed up tempos globally during mental practice. This notion of speeding up tempos was based on introspection on our own mental practice of tempo. Often, it seemed that tempos increased internally, but after some more informal observation, we sensed that these fluctuations depend upon a work’s tempo and rhythmic characteristics. Also, the simple hypothesis was not consistent with evidence from Manfred Clynes and Janice Walker’s (1982) experimental test of the tempo differences between imagined and performed musical excerpts. They measured excerpt-duration fluctuations and found that imagined performances were an average of 8.9% longer than actual performances (Clynes & Walker, 1982, p. 188-91). Wöllner and Williamon’s (2007) mental imagery condition led to lengthened IOIs (associated with slower tempos), which is also contrary to the intuition that imagined tempos are faster.

Evidence from tap continuation studies suggests that a theoretical internal time-keeper tends to accelerate over a continuous range of pulse durations (see review in Collyer, Broadbent, & Church, 1992). However, Collyer et al. (1992) have proposed a
more discrete conception of time: in a tapping task, they found alternating patterns of tempo accelerations/decelerations across tempo regions.

Factors other than tempo also may affect synchronization with a pulse: Vos, Mates, and van Kruysbergen (1995) found that beat duration affects negative asynchrony in tapping tasks. However, tapping tasks are not exactly akin to mental or actual performance of music: Clynes and Walker (1982) observed a 5% acceleration of tempo during a tapping and imagined tapping task, but when their participants imagined a piece of music during tapping, the tempo became stable (p. 176). Given that the musical performance task used in our study is more similar to the tasks studied by Clynes and Walker (1982) and Wöllner and Williamson (2007), we might expect that mental performances of musical excerpts generally exhibit slower tempos.

However, there may be interactions between mental tempo drift and the characteristics of each musical excerpt. One such characteristic is the absolute tempo of the excerpt itself. In the current study, we aim to compare nominally “fast” works with nominally “slow” works. In inviting performers to participate in this experiment, fast and slow were operationalized as “technical” pieces, exhibiting high note density, and “lyrical” pieces, exhibiting low note density. Although we could argue that lyrical excerpts are more difficult than technical excerpts (on artistic grounds such as phrasing or expressivity), or on specific physical grounds (e.g. breath/bow control), there is a strong sense that technical excerpts are simply more difficult than lyrical ones. Technical excerpts exhibit quick successions of notes and require a high degree of flexibility and coordination. Guillot and Collet (2005) have reviewed research on durations of mentally
simulated movement; their work highlights a number of studies that support the notion that greater task difficulty leads to increased durations in mental imaging (p. 12). Consequently, we formulated hypothesis two in such a way that associates tempo fluctuations with difficulty (defined by note density). We predicted that a speeding of tempo (compared to actual performance) would occur in mental practice of low-density excerpts; and a slowing tempos would occur in mental practice of high-density excerpts.  

Briefly, in the current experiment, participants recorded pre-rehearsed musical excerpts, and then attempted to replicate the respective excerpts’ tempos while using motor and non-motor forms of mental practice. The goal of this comparison between motor and non-motor imagery was to 1) test whether motor imagery better matches the tempo of actual performance, and 2) test whether musical characteristics such as note density have an effect on the direction and magnitude of tempo drift.
Method

Participants

Sixteen participants took part in the experiment: fifteen sophomore music students, who participated through Ohio State University’s music subject pool, and one graduate student volunteer. The undergraduate participants selected the present study from one of several offered. We employed an ecological design: musicians of various instrument/voice types were recruited; each participant brought two contrasting excerpts from her repertoire (there were no duplicate excerpts in the study); participants had repeated opportunities to mentally practice the piece during the experiment. Two vocalists and fourteen instrumentalists participated. Instruments represented: saxophone, bassoon, violoncello, string bass, snare drum, clarinet, and piano.

Materials and Procedure

Each participant had been asked to prepare performances of two musical excerpts (each approximately 30 seconds in length) in advance of the experiment. The excerpts were selected by each participant and consisted of one lyrical excerpt—with a slower than average tempo—and one technical excerpt—with a faster than average tempo. The musical excerpts were drawn from participants’ repertoire of technical studies, études, and ensemble music.
Participants were also instructed to bring sheet music for each work to the experiment; the experimenter photocopied the music for later use in calculating note densities; all excerpts used are listed in Appendix A. We calculated note density by counting the number of note onsets\(^4\) in each excerpt and dividing the note-count value by the duration of the respective excerpt. We transcribed note counts aurally in cases where participants played their music from memory, and did not bring sheet music.

When a participant arrived at the experiment he was greeted and given a hearing screening inventory test (Coren & Hakstian, 1992). No participant gave responses that indicated hearing impairment. This test not only measured hearing health, but also gave the participant time to adjust to the lab environment.\(^5\)

Each participant warmed up for a few moments and then performed a “dress rehearsal” of the lyrical excerpt while the experimenter recorded this performance onto a laptop computer. After the first performance, the participant performed a final take of the excerpt. In all cases, the second performance of each excerpt was used in the subsequent stages of the experiment. Participants were instructed to keep their second performance in mind as they imagined performing the piece. The above recording process was repeated for the technical excerpt.

Next, the recordings were transferred to compact disc while the participant filled out the Ollen Musical Sophistication Index “OMSI” (Ollen, 2006). In many psychological studies participant groups have been divided into nominal categories, “nonmusician” and “musician.” The OSMI is a continuous, validated, numerical measure based upon a brief survey considering factors such as years of musical training, weekly
practice time, listening experience, and composition experience. Participants’ OMSI scores ranged from 141 to 917 (mean = 656; SD = 238; [one missing value]).

Empirical research on human behavior can make inferences about internal states through measurement of overt actions. Paradoxically, mental practice is difficult to study because research measurement requires overt behavior that violates the purely mental character of mental practice. Several studies have asked participants to tap in time with mentally imagined music (e.g., Clynes & Walker, 1982; Repp, 1999). Other researchers have reduced potential interference between mental practice and overt action by minimizing the amount of tapping: Wöllner and Williamon (2007) had participants tap at structural points only. In the current study, we attempted to reduce overt behavior further—by distilling participants’ response down to one physical action—one tap.

In the second stage of the experiment, a CD player was used to present participant recordings over loudspeakers while the computer was set to continuously record all participant responses, which consisted of call-bell rings at the end of each excerpt. Participants placed a call bell on their laps; a clipboard under the call bell provided a steady surface. Two baseline trials familiarized participants with the bell ringing procedure, and provided a measure of response latency. During the first baseline trial, the lyrical excerpt was played in its entirety. Participants listened while following along with the score. At the onset of the excerpt’s final note, participants rang the call bell. The next trial repeated the baseline procedure for the technical excerpt. If needed, the baseline trials were repeated until participants were comfortable with the bell and satisfied with their accuracy in indicating the last note’s articulation.
The next 12 trials began with a three-second prompt from the participant’s recorded performance for the respective excerpt; the lyrical and technical excerpts alternated every other trial. The experimenter used a volume control knob to adjust excerpts from a comfortable listening level to silence over the course of the first three seconds. As the excerpt faded to silence, participants continued the excerpts using mental imagery as they followed along with the score. Appendix B contains the precise instructions given to participants regarding the mental imagery tasks. At the end of each trial, participants rang the call bell at the imagined onset of the excerpt’s final note. Participants paused in between each mental practice repetition. During each pause, the experimenter asked them to rate their perceived success at matching their performance tempo, using a 1-10 scale; “10” being a rating of very precise tempo and “1” being a rating of very imprecise tempo.

In order to isolate perception from imagery we did not use a “mental practice with listening” condition⁶ (as in Lim & Lippman, 1991). Through using variations on a “mental practice in silence” condition, the present experiment compared two mental practice techniques with equal amounts of listening and silence: both conditions began with a three-second auditory prompt excerpted from the participant’s own recording, and then the participant mentally practiced in silence. Participants practiced the excerpt mentally in one of two ways: 1) “Imagined Sound” condition—mental imagery of sounds; and 2) “Imagined Movement” condition—mental imagery of body movements. One mental practice condition was used for the first six trials. Then, the participant rested
for one minute while the experimenter described the next mental practice technique. The second six-trial block used the other mental practice condition.

Except for one call-bell tap, the present study did not include any other physical action during mental practice. The experimental manipulation required that both mental practice conditions not involve any overt body movements, and that any motor imagery corresponded with the actual movements of performance. Rather than imagining an abstract movement, such as a conductor’s baton, participants were instructed to imagine the feeling of the movements involved in performing their excerpts. A close correspondence between the motor imagery and the actual physical execution of movements appears to be important in ensuring that the mental practice transfers to physical execution: in their study of volleyball skills, Roure et al. (1998) found that mental imagery, which reflected the steps of a skill’s physical execution, was important for transfer.

The order of mental practice conditions was counterbalanced across participants. The only change within the block of six trials was the excerpt type, which alternated (see Figure 1). Excerpt alternation was an attempt to control for the possible confound of fluctuating arousal levels caused by the music itself. Before each trial, the experimenter briefly reminded participants of the mental practice technique in use at the moment. If necessary, reminders to remain physically still during mental practice were also given.
After the 12 mental practice trials, two more baseline trials were conducted as they were before the mental practice. The experiment ended once these were complete. Then, the experimenter debriefed the participant regarding the specific purpose of the experiment, and discussed any questions and comments with the participant.

The dependent variable, excerpt duration discrepancy during mental practice, “delta,” was calculated for each trial by taking the difference between the performed excerpt length and the imagined excerpt length. For example, if the participant recorded a 30 s excerpt and rang the call bell after 28 s in a mental practice trial, then delta would equal 2 s. This particular order in the subtraction process was chosen so that positive values of delta reflect faster tempos taken during mental practice; negative delta values reflect slower tempos during mental practice.

Data from participants 3-6, 10, and 12-16 were used in the analysis. The data from the first two participants were not used in the analysis. We treated these as pilot
trials because adjustments for consistency were made to the audio recording process and to the verbal instructions given to participants. Additionally, data from four other participants were excluded. Two exclusions were made due to experimenter errors made during the recording process (e.g., accidentally stopping the recording of the experiment while unplugging/plugging in cables for monitoring purposes). Another two participants’ data were excluded because participants made rhythmic errors (e.g., omission of rests) during the recording session, and then fixed the errors during mental practice sessions. In total, the data analysis was performed using recordings from 10 participants (1 graduate student and 9 undergraduates).
Results

Table 1 summarizes each participant’s particular tempo choices during their performances. In addition to the note densities used in the hypothesis test, tempo is offered here for descriptive purposes; they are approximations made by the experimenter using a metronome equipped with tapping pad.8

<table>
<thead>
<tr>
<th>Participant No. (instrument)</th>
<th>Lyrical excerpt</th>
<th>Technical excerpt</th>
<th>Excerpt contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tempo/Density</td>
<td>Tempo/Density</td>
<td>Tempo/Density</td>
</tr>
<tr>
<td></td>
<td>(bpm) (nps)</td>
<td>(bpm) (nps)</td>
<td>(bpm) (nps)</td>
</tr>
<tr>
<td>3 (jazz saxophone)</td>
<td>71 1.46</td>
<td>175 4.53</td>
<td>104 3.07</td>
</tr>
<tr>
<td>4 (bassoon)</td>
<td>42 0.70</td>
<td>140 5.13</td>
<td>98 4.43</td>
</tr>
<tr>
<td>5 (snare drum)</td>
<td>86 4.47</td>
<td>165 6.43</td>
<td>79 1.96</td>
</tr>
<tr>
<td>6 (jazz saxophone)</td>
<td>86 1.38</td>
<td>128 7.13</td>
<td>42 5.75</td>
</tr>
<tr>
<td>10 (violoncello)</td>
<td>60 0.88</td>
<td>126 6.74</td>
<td>66 5.86</td>
</tr>
<tr>
<td>12 (voice)</td>
<td>36 1.01</td>
<td>104 3.07</td>
<td>68 2.06</td>
</tr>
<tr>
<td>13 (voice)</td>
<td>66 2.24</td>
<td>160 2.56</td>
<td>94 0.32</td>
</tr>
<tr>
<td>14 (clarinet)</td>
<td>67 1.45</td>
<td>150 5.83</td>
<td>83 4.38</td>
</tr>
<tr>
<td>15 (snare drum)</td>
<td>60 3.80</td>
<td>118 10.97</td>
<td>58 7.17</td>
</tr>
<tr>
<td>16 (jazz piano)</td>
<td>58 1.53</td>
<td>177 1.98</td>
<td>119 0.45</td>
</tr>
</tbody>
</table>

Table 1: Tempo approximations (bpm) and note densities (nps = notes per second) of participants’ lyrical excerpts (mean = 63 bpm; SD = 16) and technical excerpts (mean = 144 bpm; SD = 25). Differences between the tempos of excerpt one and two are listed in the tempo contrast column (mean = 81; SD = 23).
Figure 2 shows each subject’s excerpt duration discrepancies for all trials (not including baseline trials). The technical excerpts had a significantly lower variance of duration discrepancy than the lyrical excerpts ($t = -2.6, p = 0.017$); this might be expected since the technical excerpts had higher note densities, offering more opportunities for time to be subdivided. Looking more closely, there also were differences of duration discrepancy variance within the two mental practice strategies. In the imagined movement condition, technical excerpts had significantly lower variances of duration discrepancy than lyrical excerpts ($t = -2.1, p = 0.06$); but with the use of the imagined sound condition, there was no significant difference of discrepancy variance between excerpt types ($t = -1.5, p > 0.10$). The relationship between mental practice strategy and the target tempo is tested below.
Musicians experience a wide variety of practice methods, and have markedly different approaches to practicing. During post-experiment interviews with each participant, it was apparent that some musicians were more familiar with using one practice type than the other. In addition to musicians’ familiarity with mental and other practice techniques, there also may have been individual differences in the participants’ quality of imagery. Roure et al. (1999) assessed imagery ability and imagery quality in a volleyball task indirectly through measurements of the autonomic nervous system (e.g.,

![Figure 2: Excerpt duration discrepancies (delta) by participant; no distinction is made between excerpt type and mental practice strategy. Negative delta values reflect mental practice attempts that exhibited slower tempos (longer durations).](image-url)
skin conductance, heart rate, respiratory frequency): athletes exhibited “wide individual differences” in the quality of their imagery (Roure et al., 1999, p. 70).

To illustrate some potential individual differences among our participants, Figure 3 shows the excerpt duration discrepancies for each participant across both excerpt type and strategy.

Figure 3: Excerpt duration discrepancies (delta) by participant; arranged by excerpt type (lyrical or technical) and mental practice strategy. IS = imagined sounds; IM = imagined movements.
Some different patterns emerged from each participant:

• *More tempo consistency with lyrical excerpt, despite strategy (Participant 13).* Participant 13, a vocalist, was more consistent with the lyrical excerpt than the technical excerpt, despite the strategy used. The participant’s two selections had very similar note densities, 2.24 and 2.56 (see Table 1), yet the two excerpts had large differences in rhythmic variety: “Se vuol ballare” is composed mainly of quarter notes, whereas “Wohin?” exhibits quarter, eighth, sixteenth, dotted, and grace notes. The greater variety of rhythms in the technical excerpt may have led to larger deviations in timing.

• *More tempo consistency with technical excerpt, despite strategy (Participant 10).* Participant 10, a cellist, was quite accurate when imagining the technical excerpt, but exhibited larger deviations of tempo with the lyrical excerpt. The lyrical excerpt exhibited one of the slowest and lowest combinations of tempo and note density among all excerpts.

• *Consistent slowing of tempos in all condition (Participants 3, 5, and 16).* Participant 16, a jazz pianist, consistently slowed tempos during mental practice, and was relatively unaffected by excerpt type or strategy. However, on piano, the task of imagining both melody and accompaniment is quite different than purely melodic imagery. The slowing of all tempos regardless of mental strategy is consistent with the theory of higher task complexity causing longer processing times during mental practice (Guillot & Collet,
Participant 3 (jazz saxophone) and participant 5 (snare drum) also exhibited this same pattern of tempo-slowing within mental practice. All three of these participants performed the fastest technical excerpts, but there was no obvious comparison between all three of their lyrical excerpts. The drummer and saxophonist had two of the faster lyrical tempos, but none of these was near 100 bpm—the potential regression point of tempo (e.g., Halpern, 1988).

- **Speeding of lyrical excerpts, and slowing of technical excerpts (Participants 4, 12, 15).** Participant 15, a percussionist, sped up the lyrical excerpt and slowed down the technical excerpt, with little difference of impact from imagination type. This pattern was consistent with our tempo-flux hypothesis. The two excerpts had comparable rhythmic complexity and the greatest difference of rhythmic density among all participants’ excerpts (3.8 nps versus 10.97 nps). Perhaps the large contrast of note density provided a strong enough manipulation to observe the tempo-flux hypothesis’s predicted effect.

Several other participants exhibited similar patterns of tempo-flux:

- **More consistency with imagined-sound strategy (Participants 6, 14).** Participant 6 (jazz saxophone) was quite accurate overall, but exhibited even greater consistency of tempos when using non-motor imagery.

- **More consistency with imagined-movement strategy (Participant 4).** Although participant 4 (bassoon) was very consistent overall, the bassoonist’s use of
imagined-movement imagery was slightly closer to the target tempo and more internally consistent.

Participants’ varying performances with the tempo stability task might indicate individual differences of overall imagery quality between musicians, but also might suggest that musicians’ imagery quality depends on both the type of imagery and the characteristics of the musical excerpt.

Tests of Hypothesis One – “Mental Practice Type”

Hypothesis one predicted that the magnitude of tempo alterations would be minimized through the use of motor imagery in mental practice. Consequently, we conducted this hypothesis test using calculations on the absolute values of participants’ excerpt-duration discrepancies.

Due to the repeated-measures design of the experiment, mean duration discrepancies were calculated for each participant according to the two levels of the independent variable—mental practice strategy (IS and IM). The mean duration discrepancy for the IM strategy was 0.81 s ($SD = 0.35$); duration discrepancy for the IS strategy was 0.86 seconds ($SD = 0.51$). A one-way analysis of variance (ANOVA) found no significant difference of duration discrepancy according to mental practice strategy, $F(1, 18) = 0.062, p = 0.81$. This result is not consistent with hypothesis one. The magnitude of tempo alterations during mental practice using motor imagery was not significantly different than the alterations occurring when using non-motor imagery.

Negative results can arise for many reasons; and the above test of duration discrepancies according to mental practice type made no distinction between excerpt
types or between participants’ imagery ability. The lyrical/technical excerpt categories may have had broad differences that affected participants’ tempo stability. More specifically, each excerpt had unique temporal characteristics that may have affected tempo stability. We measured two such characteristics: tempo (beat rate) and note density. In addition, we measured each participant’s musical sophistication. Although this is not a direct measure of imagery ability, it is reasonable to assume that higher musical sophistication corresponds with better musical imagery ability. In light of these possibilities, these measures gave us the opportunity to compare the magnitude of duration discrepancy not only with mental practice strategy, but also with three between-participant factors: OMSI score, excerpt tempo, excerpt note density.

To test the effects of tempo, density, OMSI score, and practice strategy, we conducted a post hoc multivariate analysis of variance (MANOVA) of duration discrepancy. Like the mean-duration-discrepancy calculations, which were used in the previous ANOVA, the MANOVA test was a way to account for the repeated measurements of duration discrepancy. (Participants made three mental practice attempts for each of the four combinations of excerpt type/imagination strategy—12 responses in total). However, the MANOVA treats each participant response as a separate dependent variable. For example, in the imagined-sound/lyrical-excerpt condition, each participant made three mental rehearsals. At the end of each mental rehearsal a measurement was taken. Through the MANOVA, these three measurements per condition were treated as related, or dependent, because the task was the same for all three rehearsals. In essence,
the MANOVA had the additional feature of showing the possible influence of successive mental rehearsals on tempo stability.

The data structure met Mauchly’s criterion for the assumption of sphericity \( (p = 0.61) \); therefore, we did not use the Greenhouse-Geisser correction. The results of the MANOVA showed no significant effects \( (F(15, 20) = 0.266, p = 0.99) \) arising from the between-participant factors: excerpt tempo, excerpt density, OMSI, and practice strategy. The main effect of number of successive trials also proved not to be significant, \( F(2, 19) = 2.176, p = 0.141 \). Again, these results are not consistent with hypothesis one.

However, the overall test for within-participant interactions was significant; Wilks’s Lambda, \( F(30, 38) = 1.725, p = 0.056 \). In this case, the Wilks’s Lambda test indicates the existence of some significant interactions between number of successive trials and one or more between-participant variables. In brief, two 2-way interactions were significant, one 4-way interaction was significant, and one 5-way interaction was significant.

The interactions involving more than two variables are difficult to conceptualize and articulate verbally, but a closer examination of the 2-way interactions may offer some insights into the relationship between mental practice and musical characteristics: 1) OMSI scores and number of successive trials exhibited a significant, interactive effect on duration discrepancy, \( F(2, 19) = 6.67, p = 0.006 \). This post hoc finding is consistent with the notion that as musicians of varying experience continue to mentally rehearse tempo, their tempo discrepancies become both smaller and more alike. The top panel (“zero successive trials”) in Figure 4 shows participants’ first rehearsal using a given technique.
on an excerpt—the smooth, wavy line shows the varying averages of duration
discrepancy across the spectrum of musical sophistication. As successive trials accrue,
the line becomes less wavy and moves lower on the y-axis. In other words, participants’
timings were most dissimilar at the beginning of mental practice. Over the course of two,
successive trials, participants’ timings became more consistent with each other, and more
stable in relation to the target tempo.

Figure 4: The interaction between successive rehearsals (0, 1, 2) and musical
sophistication was a significant factor of tempo stability, $F(2, 19) = 6.67, p = 0.006$. As
musicians of varying experience continue to mentally rehearse, their tempo fluctuations
become smaller overall and more similar to other musicians’ fluctuations.
2) Excerpt density and number of successive trials also exhibited a significant interaction, $F(2, 19) = 9.84, p = 0.0012$. Figure 5 shows the contrasting drifts of tempo discrepancies for excerpts exhibiting variable densities. Densities ranged from 0.698-10.97 notes-per-second (nps). In the bottom three panels, we can see that repeated mental practice attempts led to either slight improvement or maintenance of timing. In contrast, the top panel shows that low-density excerpts (0.698-1.449 nps) tended to become less temporally accurate with repeated attempts. These post hoc results are consistent with the notion that in low-note density excerpts, timing discrepancies will tend to accrue over repeated mental rehearsals.
In addition to these 2-way interactions there were also higher order interactions:

1) Number of successive rehearsals, OMSI score, excerpt tempo, and excerpt density were a significant 4-way interaction, $F (2, 19) = 7.88, p = 0.0032$; and 2) Number of successive rehearsals, OMSI score, excerpt tempo, excerpt density, and mental practice strategy comprised a significant 5-way interaction, $F (2, 19) = 7.69, p = 0.0036$. These
types of interactions are very difficult to conceptualize, graph, and discuss. However, the 4-way and 5-way interactions give the impression that tempo stability depended highly on each participant’s choice of excerpts and individual differences. These interactions may be an artifact that came from the ecological design of the present experiment.

_Tests of Hypothesis Two – “Tempo Flux”_

In this hypothesis test, we no longer consider only the magnitude of duration discrepancies, but also their direction. Consequently, we used the signed value of duration discrepancies in our calculations. Negative discrepancy values corresponded to instances where imagined excerpts lengthened (slower tempo); positive discrepancy values corresponded to instances where imagined excerpt shortened (faster tempo).

First we conducted a 1-way ANOVA of tempo discrepancies versus excerpt density. We predicted that both the direction and magnitude of tempo discrepancies would be related to excerpt density: lower-density excerpts would tend to be speeded up, and higher-density excerpts would tend to be slowed down during mental practice. In this initial test, we made no distinction between mental practice strategies, but rather calculated mean duration-discrepancy values for each excerpt. The results were not consistent with hypothesis two. The effect of excerpt density proved to be a non-significant effect on the magnitude and direction of tempo discrepancies, $F (1, 18) = 0.38$, $p = 0.545$. As can be seen in Figure 6, as density increases there is no systematic shift of discrepancies from positive to negative values. Rather, the excerpt duration discrepancies are staggered about “zero” through the majority of the data set.
Although the above ANOVA shows a negative result regarding our predicted main effect of mental practice strategy on duration discrepancy, the result is difficult to interpret fully without considering all of the data gathered during the experiment. On one hand, the above model may not account for enough factors. For example, it may be the case that the different mental practice techniques are better suited to contrasting tempo

Figure 6: The relationship between mean duration discrepancy (for each excerpt) and note density (nps) was not significant $F(1, 18) = 0.38, p = 0.545$. Rather than moving from positive to negative error values as density increases, the discrepancy values seem to undulate while hovering close to zero. The dip near “12” is consistent with the prediction, but it is only one data point, and should be considered cautiously. The data loosely reflects the observations (seen in Figure 5) that higher density excerpts undergo less tempo fluctuation.
regions or tempo densities. Or perhaps overall musical experience and sophistication determines tempo stability.

Consequently, we conducted a post hoc MANOVA of duration discrepancy that considered four factors: 1) excerpt note density, 2) excerpt tempo, 3) mental practice strategy, and 4) musical sophistication score (OMSI) for each participant. This test is analogous to the MANOVA conducted for hypothesis one; except in the current test, we used signed duration discrepancy values rather than absolute values of duration discrepancy.

The structure of our data failed Mauchly’s test for sphericity ($p < 0.05$); therefore, we used the Greenhouse-Geisser correction in interpreting the significance tests for model factors. The model as a whole was not statistically significant, $F(15, 20) = 0.57$, $p = 0.865$. In contradiction to our prediction, the effect of mental practice type was not a significant impact on tempo stability, $F(1, 20) = 0.54$, $p = 0.471$. None of the other between-participant factors or interactions were significant. The within-participant factor of “number of successive trials” was not a significant effect on tempo stability, $F(1.56, 31.25) = 2.36$, $p = 0.122$. No interactions between the four tested factors and the number of repeated mental practice attempts were statistically significant.

*Post Hoc Hypotheses*

Two additional questions presented themselves during the data analysis process:
A) How did tempo stability change over the entire course of the twelve mental practice attempts? B) Are musicians able to sense the accuracy of their timing in mental practice without feedback?
Hypothesis A: The number of accumulated mental practice attempts is negatively associated with the absolute value of excerpt duration discrepancies.

Some studies in the mental practice literature have measured the effects of mental practice through a pre-test, mental practice session(s), and post-test format (e.g., Coffman, 1990). This type of evaluation gives insight into the net effects of mental practice, but it does not show the gradual changes that may occur during mental practice. The participants in the present study had the opportunity to repeatedly rehearse excerpt tempos within their imagination; measurements were taken after each trial, giving potential insight into tempo trends during mental practice.

Intuitively, some musicians would agree that mental practice repetition is beneficial: “it is a recognized phenomenon among musicians that in the course of mental rehearsals, the ‘performance’ will become increasingly temporally accurate and settle down to a surprisingly constant performance time” (Sills, 2005, p. 59). If this intuition were true, then musicians could mentally practice with reassurance that their tempos are becoming solidified, rather than straying off course. Additionally, after looking at a number of experiments on mental practice, Driskell et al. (1994) concluded that 20 minutes is an optimal duration for mental practice. During our study, each participant engaged in approximately 20 minutes of mental practice (including breaks for rest while the experimenter gave instructions). This match between the optimal time frame for mental practice and our experiment’s length offers some assurance that participant’s were undertaking productive mental practice, and not becoming overly fatigued.
If an association between mental practice repetitions and tempo accuracy exists, then smaller duration discrepancies would have occurred in later mental practice trials. Pearson’s correlation coefficient (see Figure 7) between the number of successive trials and the magnitude of excerpt duration discrepancy was significant for the IS condition \( (r = -0.30; p = 0.023) \), and not significant for the IM condition. This moderate, negative correlation suggests that as musicians mentally rehearse using the imagined sound strategy, repeated run-throughs tend to settle on the idealized performance tempo.

Figure 7: Magnitude of excerpt duration discrepancy related to accumulated trials according to strategy only; no distinction was made for participants. On the left is the “imagined movement” strategy; on the right, the “imagined sound” strategy. Zero on the x-axis refers to each participant’s initial mental practice trial. Number of successive trials in the imagined sound condition is inversely correlated with the magnitude of duration discrepancy \( (r = -0.30; p = 0.023) \).
This result should be considered cautiously, due to the post hoc nature of this hypothesis test. Also, the graphs in Figure 7 represent an agglomeration of the data from the IS and IM conditions, but each subject did not use one type of mental practice for all 12 trials. So, these results can be interpreted differently: it is possible that the largest gains in temporal accuracy occurred when non-motor imagery was followed by motor imagery. The downward sloping line at far right region of Figure 7 could be evidence that late non-motor practice trials had benefitted from previous motor practice.

To test this alternative interpretation, we examined tempo fluctuations in two groups of participants: 1) those who used six, IM rehearsals followed by six, IS rehearsals ($n = 5$); and 2) those who used six, IS followed by six, IM rehearsals ($n = 5$). As seen in Figure 8, when the mental practice session was organized as IM proceeding to IS, there was no significant change of duration discrepancy over the twelve attempts. On the other hand, when IS was followed by IM there was significant improvement over the course of the mental practice session, $F (1, 58) = 5.18, p = 0.027$. 
These results are consistent with the notion that temporal accuracy improves (or at least stays constant) over the course of a mental practice session, which does not exceed 20 minutes. Neither motor nor non-motor imagery led to worse performance over repeated mental rehearsals of musical tempo. Motor imagery seemed to be relatively more reliable from the beginning of the mental practice session. By the end of either arrangement of practice strategies, discrepancy rates were comparable.

These results shed additional light on the agglomerated data shown in Figure 7, which did not track each participant’s course of practice. When we accounted for the combination of motor and non-motor imagery, the results seemed to indicate that motor
imagery was associated with better tempo consistency. Participants who began their mental practice session using motor imagery exhibited less tempo fluctuation from the start of the session. The overall discrepancy for the IM-IS arrangement of practice was 0.67 seconds. When the IS technique was introduced, then discrepancies remained relatively the same. (Perhaps the mental image of the tempo had already been solidified via the six, IM trials.) In contrast, the IS-IM arrangement exhibited higher overall discrepancy (mean 1.0 seconds). Participants began by using the IS technique; when IM practice followed, there was a significant improvement of tempo stability.

These results suggest that further study of Sills’ intuition is warranted, especially if other types and combinations of mental practice show similar or stronger effects. A future investigation of these notions would benefit from a between-group method in which each participant mentally practices using only one of several mental practice strategies. Then, further studies could test combinations of mental practice strategies using combinations of between-group and within-group designs.

*Hypothesis B:* Participants’ tempo accuracy self-ratings for each trial are inversely related to the absolute value of duration discrepancy in the respective trials.

During the experimental session we did not give participants any feedback regarding their tempo accuracy. In addition to the preceding hypothesis test, there is previous evidence that mental practice can be effective even in situations where no immediate feedback is given (Zecker, 1982). Given feedback or no feedback, are musicians consciously aware of their improvement? Since participants seem to achieve a
more steady performance tempo with repeated mental rehearsal, awareness of improvements could help prevent excessive practice.

In the present study, participants gave an overall, mean self-rating of tempo accuracy equal to 7.6 (SD = 1.7) on a 1-10 scale, ten being a rating of high accuracy. A one-way ANOVA revealed that the imagined sound strategy had higher participant self-ratings, $F(1, 116) = 3.55; p = 0.062$. The mean IS self-rating was 7.9 (SD = 1.9); the mean IM self-rating was 7.3 (SD = 1.4). A Pearson correlation test suggested that excerpt duration discrepancies were not significantly correlated with participants’ ratings of perceived tempo accuracy ($r = -0.07; p = 0.45$). Although participants seem to feel more confident using the imagined sound strategy, this result is consistent with the notion that musicians do not have conscious access to the benefits gained from repeated mental practice. Future studies might want to consider specifically testing different lengths of practice sessions at different times of day in order to identify optimal mental-practice times and distribution with physical practice. Until then, musicians should be aware that combined amounts of mental practice longer than 20 minutes are associated with lower benefits (Driskell et al., 1994).

**Summary of Results**

Detailed discussion of these results follows, but in brief:

- Mental practice of technical excerpts exhibited less variance of tempo discrepancy than lyrical excerpts.
- When musicians used motor imagery, technical-excerpt tempos exhibited less variance of tempo discrepancy than lyrical excerpts.
• However, when musicians used non-motor imagery, technical and lyrical excerpts both had comparable variances of tempo discrepancy.

• Motor and non-motor mental imagery of musical tempos did not have a significantly different impact on the average magnitude of tempo discrepancies across all excerpts. This result was not consistent with our prediction in hypothesis one.

• *Post hoc:* The main effects of musical excerpt characteristics (tempo and note density), musical sophistication, and practice strategy did not significantly affect the magnitude of tempo discrepancies.

• *Post hoc:* However, there were two significant interactions that were interpretable: 1) as musicians of varying experience continue to mentally rehearse tempo, the sizes of their tempo discrepancies become both smaller and more alike; and 2) in low-note density excerpts, timing discrepancies accrue over the course of repeated mental rehearsals; whereas in high-note density excerpts, timing tends to improve or at least stay the same with repeated mental rehearsals.

• Excerpt note density did not significantly affect the magnitude and direction of tempo discrepancies. This result was not consistent with our prediction in hypothesis two.

• *Post hoc:* Number of successive trials, excerpt tempo, excerpt note density, mental practice strategy, and musical sophistication score did not have a significant effect on the magnitude and direction of tempo discrepancies.
• *Post hoc:* Repeated mental practice attempts under 20 minutes in total duration tended to become more temporally consistent. Motor imagery tended to boost timing improvements when added after non-motor imagery. When practice sessions began with motor imagery and ended with non-motor imagery, the tempo discrepancies tended to stay quite small and more consistent.

• *Post hoc:* Musicians do not seem to have conscious access to the benefits conferred by mental practice.
Discussion

The results showing that imagined, technical excerpts exhibited less variance of tempo discrepancy than imagined, lyrical excerpts, seems to confirm the common practice of rhythmic subdivision. Musicians often imagine beat divisions and subdivisions while performing. These sub-articulations of time set up a regular “grid” that seems to help equalize beat durations and align rhythms in their appropriate place. Perhaps the automatic “subdivision” that comes from the faster rhythms helps maintain a more accurate time reference for musical performance. However, we could not have predicted this effect because our experiment involved mental imagery of musical works. The purportedly greater effort involved in imagining technical excerpts could equally have been associated with greater mental tempo fluctuations or a general trend of slowing tempos—we found neither result to be significant in our various hypothesis tests.

When a task is more difficult, imagined performances have been found to exhibit longer durations because it appears as if “image accuracy is more important than temporal characteristics” (Guillot & Collet, 2005, p. 14). We predicted that fast musical tempos would make the task of imagining a musical excerpt more difficult because there is a smaller window of time within which to maintain the integrity of imagined pitches, rhythms, etc. However, the shape of the graph in Figure 6 implies that difficulty might be minimized at moderate levels of note density. At low and perhaps high note density
states, musical tasks appear to become more difficult. However, they may not be difficult in the same way. Excerpts exhibiting low note density may require more effort because musicians tend to focus on timbral and dynamic characteristics of notes while shaping the musical line. This notion would seem to be consistent with our finding that motor imagery led to more variable tempos for lyrical excerpts than for technical ones. Adding vibrato or dynamic changes in performance requires more hand motion, air, etc., thereby causing the motor imagery to become increasingly complex at slow tempos. Non-motor imagery might be less detailed and less complex overall—an attribute that would make it more consistent across a broad range of tempos.

However, our results are difficult to interpret because there is solid backing from previous studies in support of the notion that high note density/tempo excerpts require more effort (at least in physical response tasks). Higher note density in the condition of subdivision seems to require more effort. Carolyn Drake, Amandine Penel, and Emmanuel Bigand’s (2000) study of tapping along with mechanically and expressively performed music confirmed one prediction stemming from Mari Jones’s (e.g., 1987) dynamic attending theory: tapping along with music at the shorter, subdivision level required more effort than tapping at the longer, metrical/supermetrical levels. Results from these previous studies are consistent with the notion that high rhythmic density leads to greater processing effort. In turn, we would expect that greater effort causes a slowing of tempo in the imagination. Our results did not confirm this theory. Thus, it seems as if the requirement for a physical response task or a musical performance may be quite different from imagination of motor action. A fast tempo or quick successions of
notes might remove musicians’ sense of obligation to generate vivid motor imagery. In contrast, slow tempos might create a sense that motor imagery must be vivid—making the imagery “more difficult” in the sense of detail rather than speed.

An alternative explanation for many of our non-significant experimental results is the effect of memory, which seems to cause a regression to a mean tempo. Our experimental design alternated lyrical and technical excerpts. This was intended to control for the possibility of participant’s attentional arousal levels being affected by the characteristics of one, fast or slow musical excerpt. However, it is possible that the tempo of one musical excerpt might have interfered with other excerpt within participants’ memories for tempo.

Mari Jones and Devin McAuley (2005) discovered that their participants developed a memory of a mean tempo that exerted a sort of “gravitational” effect, pulling faster tempos down towards the running mean, and pushing slower tempos up. Andrea Halpern (1988) also observed a regression effect: when participants imagined songs with tempos below about 100 bpm, those songs tended to be imagined more quickly than they were perceived in a metronome adjustment task. Songs exhibiting perceived tempos above 100 bpm tended to be slowed down when they were imagined. The memory of an overall, running average of music somewhere around 100 bpm could likely lead to drifts according to tempo region.

However, the task-difficulty and the memory effects may not provide a complete account for duration/tempos fluctuations—another potential explanation to consider is the filled duration illusion (FDI). The FDI is a well-known phenomenon from the
psychological research literature. The illusion occurs within perceptual judgments of beat lengths: a constant beat length is perceived as longer when filled with beat sub-articulations than when the beat is not filled. This illusion, along with musicians’ responses to the illusion, is important to examine in studies of music’s temporality. Bruno Repp and Meijin Bruttomesso (Repp, 2008; Repp & Bruttomesso, 2009) explored the musical ramifications of the filled duration illusion. Repp (2008) found evidence in support of the FDI occurring in beat-tempo perception. In Repp’s first two experiments, participants synchronized with presented beats; once the presented beats ended, participants attempted to continue tapping at the same pace. If the presented beats were subdivided by either the computer controller or by the participant, then participants tapped their continuation beats more slowly (on the order of 3-5%) than the presented beats. A third experiment illustrated the FDI in a purely perceptual task; and a fourth experiment suggested that the respective effects of FDI on perceptual and reproduction tasks were not correlated (partly due to differences between the non-musician and musician groups).

A follow-up study by Repp and Bruttomesso (2009) found that musicians compensate for the filled duration illusion during performance: since the FDI leads to densely-filled beats being perceived as longer than empty (or low-density) inter-beat intervals, then in actual performance the dense beats “must be shortened to be perceived as equal in duration” (Repp & Bruttomesso, 2009, p. 114) Again, the effects of the FDI are on the order of 3-5%, but “even relatively slight changes in overall tempo (say 2-3%) noticeably affect the qualities of the music” (Clynes & Walker, 1982, p. 181). Moreover,
compensation for the FDI may be exaggerated by musicians for expressive purposes: “The FDI thus may merely be the germ of a more pervasive tendency to accelerate in dense passages, which musicians sometimes try to avoid but at other times seem to follow quite happily, probably because they find it expressively appropriate” (Repp & Bruttomesso, 2009, p. 129).

We did not observe an interaction between tempo discrepancy and note density that was consistent with the theories of the filled duration illusion. Low-note-density excerpts presumably would have little influence from the FDI (and thus minimal slowing) because there are fewer notes filling-in beats. Rather than a trend to speed up or slow down, our post hoc analysis found that low-density excerpts tended to accumulate timing discrepancies over the course of successive mental rehearsals (Figure 5). Higher-density excerpts tended to stay more constant or even improve over successive mental rehearsals. Therefore, it is difficult to determine whether the FDI affected participants’ mental rehearsals. The FDI may have been completely absent, or it may have been subsumed by a task-difficulty effect: slow music with high note density often has complex, irregular rhythms and embellishments that present challenges to performers. Thus, a slowing and irregular tempo in these situations is not surprising. However, we did not manipulate tempo or density. Future studies might benefit from investigating the possible effect of the FDI on musical performance and mental rehearsal.

If we had observed the presence of compensation for the FDI during mental practice (rather than just the general slowing effect of the FDI in perceptual tasks), this would have suggested that participants were able to simulate an actual performance
through imagery. This is important because although mental images are built up from perception, as Michel Denis states: imagery ultimately allows “individuals to perform computations, simulations, inferences, comparisons, etc., without recourse to formal logic” (Denis, 1989/1991, p. xi). Thus, we would hope that musical imagery shows evidence of being more than just an experience of remembered, fleeting musical perceptions. Observing FDI compensation in mental practice would bolster mental practice as a viable technique to actually rehearse music—not just to recall music.
Conclusion

Summary

We examined the relationship between musicians’ tempo stability and type of mental practice strategy in a performance continuation task. This experimental design was intended to be more ecological in comparison with previous studies that focused on one instrument and only a handful of excerpts. The current experiment included both vocalists and instrumentalists, each performing two, self-selected excerpts—one lyrical and one technical. The musicians had multiple opportunities to rehearse using motor and non-motor forms of mental imagery. Tempo stability was inferred through measurement of excerpt duration discrepancies, which were calculated by comparing the length of each mental rehearsal with the actual performance time.

The results suggest that tempo differences between the target tempos and mental practice tempos are not significantly affected by the use of a motor mental practice strategy versus a non-motor strategy. The magnitude and direction of tempo fluctuations also do not appear to be systematically associated with musical characteristics such as note density or tempo. The magnitude of tempo discrepancies that occurred during mental practice of these excerpts was small (mean, absolute value of excerpt duration discrepancies = 0.83 s; $SD = 0.72$); musicians are quite accurate with this type of task. Additionally, mental practice seemed beneficial in rehearsing not just tempo, but the
music’s rhythmic structure. Perhaps this was most apparent when several musicians mentally fixed rhythmic discrepancies that were committed in their actual performance, such as the omission of rests. During post-experiment interviews participants generally expressed that mental practice was beneficial.

There was some evidence favoring use of the non-motor imagery when mental practice takes place over broad tempo ranges. Participants described non-motor mental practice as easier to invoke; and tempo variation among repeated imagined-sound rehearsals was relatively constant across all of the types of excerpts. Motor imagery exhibited less accurate timing in slow excerpts, compared to fast excerpts. However, there was an overall trend for smaller timing discrepancies when using motor imagery, although this trend was not significant.

In our post hoc analyses, we observed that when motor mental practice followed a period of non-motor practice, there was an improvement of timing accuracy. In the other ordering of practice strategies, motor practice followed by non-motor practice seemed to hold a consistently low discrepancy rate across the entire session. The results suggest that it may be beneficial for musicians to use motor imagery first, when their mental practice follows a period of physical practice. The mental image of physical movements might fade less quickly than the mental image of musical sounds. So, motor imagery may serve to anchor subsequent use of non-motor imagery.

The repeated-measures design of our experiment also yielded some insights into the effects of successive mental rehearsals. In post hoc analyses, there were statistically significant effects between successive trials and musical sophistication: our participants
exhibited varying levels of experience, but as they continued to mentally rehearse tempo, their tempo-discrepancy profiles became both smaller overall and more similar to each other. This result is encouraging because it suggests that the benefits of musical-temporal mental practice may be equally available for musicians of varying skill levels—there does not seem to be any prerequisite for using mental practice, nor any incentive to stop using it as musicians become more experienced.

The other observed post hoc interaction was that timing discrepancies tended to accrue in the lowest-density excerpts (0.698-1.449 nps). Although timing generally improves with successive mental rehearsals, there does seem to be a lower boundary for this effect. Excerpts with very long notes should be approached cautiously when using mental practice.

Future Directions

The present study did not address the question of musicians’ tempo stability when starting a piece without prompting. This question is potentially of great value to musicians involved with conducting, chamber music, and solo performance: starting a work at the desired tempo is a skill that requires perhaps as much practice as the skill of maintaining a steady tempo. A future study could use a similar procedure as the present study, but ask participants to ring the bell (or tap a computer key) when they mentally begin and end the piece; no prompting would be given from their recording.

Although there are other mental practice techniques to be studied, it may be informative to continue the study of the motor/non-motor distinction. In the current study, the task may have been too easy for the musicians. When musicians record a piece and
then immediately engage in mental practice, this introduces some effects of short-term memory. Participants may have been temporally accurate in their imagination simply because they remembered the right tempo. The memory of motor actions seemed less resistant to decay than auditory memory. The lyrical and technical excerpts in the present study were intended to act as mutual distraction tasks, but memory may have fused the sense of their tempos. A future study could split the recording and mental practicing portions of the experiment between two separate days. Alternatively, the mental practice session could be done before the excerpts are recorded, but in this case mental practice may influence the later performance.

The ecological design may have admitted confounding variables that led to differences between participants. For example: practice time, familiarity of excerpt, and instrument type. Future studies could still study diverse instruments, but control for practice time effects by assigning excerpts to participants, and giving participants equal practice times. Alternatively, future studies in tempo and rhythm and imagination could focus on single instrument types at a time, but manipulate practice time and excerpt tempo.

Longitudinal studies of mental practice and tempo may lead to even clearer insights. The present study manipulated mental practice type using a brief verbal lesson on mental practice. Some participants were unfamiliar with mental practice in general, so these verbal instructions could have interfered with their performance. For example, John Jones’s (1965) study of mental practice in athletics found that learning of a novel gymnastic task occurred more quickly when participants were given time to engage in
undirected mental practice, compared to another group that used mostly directed mental practice (instructions given during the mental practice session). It could be argued that the verbal instructions given in the present study were simply distracting; a control group of participants who used undirected mental practice may have revealed potential effects caused by the experimenter’s verbal instructions.

Future studies may benefit from pre-test surveys that identify musicians’ familiarity with mental practice, as well as participants’ quality of imagery. Musicians could then be given mental practice instruction (or no instruction) in a classroom setting over the course of an academic semester. Later, a tempo stability test could assess the differences between mental practice conditions.

Mental practice is widely used by musicians, but it is employed in myriad ways, and likely with varying degrees of success. Perhaps this diversity has led to ambiguity that prevents mental practice from becoming a core component of music instruction. Although mental practice has promises that reach far beyond enhanced musical rhythm and tempo, there are many further considerations just within the interaction of imagery and musical time.

Motor and non-motor forms of mental practice do not seem to differ in their support of achieving a targeted tempo. However, there may be targeted applications for both types of imagery: non-motor mental practice exhibited less variance of duration discrepancy internally across a wide range of excerpts; and motor mental practice may be a useful method to reduce imagery decay during the course of a mental practice session.
In addition, to temporal consistency, musical imagery offers flexibility: “In imaging rhythm one is quite aware whether one is imaging in real time or on some other time scale” (Clynes & Walker, 1982, p. 175). Whether a musician wants to cultivate her sense of absolute timing of a work, or rehearse relative, rhythmic relations in a “time-constrained” rehearsal (Guillot & Collet, 2005) before a performance, mental practice offers a number of benefits to performers. Future research may lead to more specific musical applications and discoveries of the role of imagery in cognition.
Endnotes

1 The ratio of mental practice to physical practice also warrants future investigation, in addition to the practice order of mental and physical modes (see, for example, Ristad, 1982, p. 123).

2 In the present study’s planning stages, the experimental design called for two technical excerpts to minimize possible effects of rubato (from slower excerpts) on performance duration. However, technical excerpts tend to be performed at faster tempi and this could confound the results. Specifically, Vos, Mates, and van Kruysbergen (1997) found that judgments of accelerations and decelerations in tempo are dependent on tempo; decelerations were more salient perceptually in slow tempi (around 60 bpm) and accelerations were more noticeable in fast tempi (240 bpm). In the middle (120 bpm) there was equal ability to detect acceleration and deceleration. Since tempo-change detection tasks show a dependence on overall tempo, then one might expect the direction of tempo drift in imagery to be affected by the speed of an excerpt. Therefore, a within-participant balance of a technical (fast) and lyrical (slow) excerpt was chosen for the present study.

3 Since musicians are often called on to perform contrasting lyrical and technical excerpts in an audition situation, this dichotomous categorization of excerpt type offered a convenient way to describe low- and high-density musical excerpts.
Calculating note densities using this method is appropriate for instruments that are largely constrained to performing one note at a time (e.g. trumpet, clarinet): each note sounds in succession, thus the density calculation corresponds to note onsets in the linear, temporal dimension. In cases where instruments such as the piano or viola (multiple stops) perform chords of notes as well as successive notes, this technique may not be appropriate because it merges simultaneous and successive notes. One such case occurred in the present study included performances from one jazz pianist. Since the lead sheet represented only the melody, to which the pianist added improvised, chordal voicings, we counted both the number of melody notes and the number of chordal articulations. Assuming an average of four notes per chordal articulation, each occurrence of a chord was multiplied by four.

The hearing screening had an additional purpose in the present study because the lab is accessible by stairs or elevator. Climbing five flights of stairs may have impacted participants’ heart rates and overall arousal levels, thus influencing tempo choices. Participants were seated during the screening test and introduction to the experiment. The time period before each recording session was approximately five minutes, giving ample time for heart rates to return to normal.

Participants listened to a professional recording of a piece during mental practice (see also Coffman, 1990).
Actual excerpt lengths and imagined excerpt lengths were calculated using the waveform visualization window and time counter within the GarageBand software program. Excerpt beginnings were operationally defined as the moment where the first tone’s rise begins. Endings were defined as the moment where the last tone’s rise begins.

Beats per minute values were not used as the dependent measure in the experiment. The precise psychological sense of a beat is difficult to measure. In addition, the perception of beats (versus beat divisions, sub-divisions, or beat groups) varies between individuals so experimenter bias could confuse the participant’s perception of a beat with a judgment of a beat division.
Study Two – The Effect of Tone-Decay Time on Tempo:

Two Comparative Studies of Banjo/Guitar and Fortepiano/Harpsichord/Piano
Introduction

Of the many factors that influence performed tempo, two subtle factors are concert-hall acoustics and instrument acoustics. Organists, for example, know to slow down in a highly reverberant hall; otherwise the music might lose definition. The capacity to slow down is enabled by the instrument’s acoustics: where sustaining a long note on a trumpet may prove difficult, an electricity-powered organ has a distinct advantage in playing very slowly. Both concert-hall and instrument acoustics influence or play a role in the choice of tempo.

The fine distinctions of concert-hall acoustics and instrument acoustics can also be difficult to observe. Performance tempo is one musical factor that is sensitive to the sometimes-unpredictable changes of acoustic conditions. Musicians’ meticulous efforts to plan and to manage a work’s tempo can be unduly influenced by non-ideal or simply unexpected performance-space acoustics. Experience and adaptive thinking are a vital skill for performers who travel or lack advance access to the performance space. Even in familiar venues, performers can benefit by considering the factors that cause acoustical shifts. For example, increasing numbers of audience members reduces hall reverberation because clothing and bodies absorbs sound. Also, larger ensembles exhibit an increase in sound propagation distances between performers. In turn, greater distances increase the
amount of reflected sound in the overall *reverberation mix*—the proportion of direct sound to reflected sound (Gardner, 1999).

Effects of musical instrument type on tempo are not immediately obvious and less understood. Potential instrumental influences on tempo might include, for example, the physical constraints of the body/instrument interface. Some instruments such as those in the woodwinds family have a facility at very quick tempos, in comparison to instruments such as the string bass or trombone. A musician’s body must move through larger physical distances when performing these larger instruments. However, the restriction on achieving a targeted tempo diminishes with increasing performer skill, and so physical constraints may not significantly impact moderate and slow tempos.

Attributes of instruments—such as an instrument’s pitch range and attack/decay characteristics—are more likely to have a systematic influence across a broad range of performance tempos. The present study investigates the influence of one characteristic on tempo—tone-decay time. Since musical works are frequently arranged for different instruments, it is important to understand how the inherent qualities of an instrument may affect a work’s interpretation. For example, Thomas Christensen’s study (1999) of piano four-hand transcriptions has illustrated the influence that this medium had on musical listening in the 19th century: “Not only could a piano transcription have taught musicians to listen to the *Eroica* with fresh ears; we could argue that it thereby served to alter the genre of the symphony itself” (Christensen, 1999, p. 288). Since the piano and the drawing room had a transformative effect on ways of performing and listening to symphonies, then to what extent were interpretation characteristics such as tempo
influenced by performances in homes on piano? In order to prepare a foundation for answering this type of question, the present study reviews selected research findings regarding hall-acoustic and instrument-acoustic effects on tempo, and then investigates the influence of instrument type on tempo through analysis of instrumental solo recordings.
Background

Theories of the Effects of Hall-Decay Time on Tempo

An understanding of concert hall characteristics—such as its acoustics and social traditions—not only helps determine appropriate tempo adjustments during performances, but also assists with a musical work’s overall preparation. Depending on the extent of the hall’s reverberation, conductors may need to choose performance tempos with the hall in mind. This is not only practical, but the interaction between hall acoustics and tempo is also a historical consideration.

For example, Denis Stevens (1995) has shown that performance spaces influenced the tempos of Monteverdi’s music. Monteverdi, and those performing his music, carefully chose tempos to suit the varying acoustics in churches and rooms of royal palaces. Even when modern recordings of Monteverdi’s music are made in original halls, they are typically recorded without an audience present. Without the increased sound absorption arising from an audience, slower tempos may result due to longer reverberation time. Live recordings still might fail to encourage a style-appropriate tempo unless audience members were supplied with the “voluminous court costumes” worn during Monteverdi’s time (Stevens 1995, p. 11). Historically accurate tempos in composers’ music can be better re-created using knowledge of the intended performance venue, instrumentation, ensemble size, and appropriate social customs and behaviors.
This discussion of authenticity in musical performance is not intended to suggest that all performances must strive to recreate the conditions of the era in which a piece was conceived, but rather to point out that physical factors arising from concert halls and instruments should not be disregarded by performers who purport to be playing a piece in an authentic style. José Bowen has noted a gap between ostensibly “original” performances and the performance conditions of a particular time period: “Given the plethora of specialists who are skilled in both the theory and practice of earlier eras and our belief that performance style is essential to a musical work, there is remarkably little music-making which imitates both the external sound and the internal philosophy of earlier performers” (Bowen, 1999, p. 427). If we purport to value authentic re-creations of historical performance traditions, then we should invest time into understanding both the physical and aesthetic factors involved in historical performance traditions.

Performance traditions and social factors also are intertwined with the acoustical characteristics of some halls such as the Amsterdam Concertgebouw. Olaf Post’s (2009) research on audience reception of Mahler and Bruckner’s music at the Concertgebouw, shows that the hall’s long reverberation time and high degree of sound diffusion are ideally suited towards late-Romantic music. Thus, to a significant extent, the long-standing affinity of Amsterdam audiences for Mahler’s music appears to be related to the suitability of the works to the acoustics of the Concertgebouw (Post, 2009).

In addition to social and historical considerations of performance and tempo, there are numerous practical aspects of tempo choice and performance-space acoustics. Jürgen Meyer’s (1972/1978) discussion prioritizes a clearly articulated performance: “ultimately
the tempo itself has to accommodate slightly to the acoustical properties of the hall if the conception of the interpreter is to reach the listener in the auditorium” (p. 216-7). Like Stevens’s view of Monteverdi, Meyer views the hall’s acoustical properties as working in synergy with particular styles of music. To some extent, performers can alter a piece’s usual articulations to compensate for an unmatched acoustic; however, too much alteration of articulations, dynamics, or tone also can transform the character of a work.3

In less than ideal acoustics, Meyer recommends subtle changes of tempo—see Table 2—as a way to help preserve the music’s general character.

<table>
<thead>
<tr>
<th></th>
<th>Slow Movements</th>
<th>Fast Movements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excessive reverberation</strong></td>
<td>Long reverberations are not as much of a problem in slow pieces; reverberations make it easier for performers to sustain long notes. Use regular tempo.</td>
<td>Long reverberation will degrade tone clarity at fast tempos. If clarity is desired, then a slower tempo than normal may be necessary. If a “noisy” or full, diffuse sound are desired, then maintain the quick tempo.</td>
</tr>
<tr>
<td><strong>Too little reverberation</strong></td>
<td>“In slow movements, too short a reverberation causes difficulty in developing an expressive tone.” Dynamic expression is reduced. Use a quicker tempo.</td>
<td>Dry acoustics hinder the musical effect of short notes. Performers may need to use a “slightly firmer and fuller <em>staccato</em>” and perhaps a slower tempo.</td>
</tr>
</tbody>
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Table 2: Summary of Jürgen Meyer’s (1978, p. 217) discussion of the interaction between works’ tempos and halls’ acoustics. Fast tempos may need to be slowed down in both wet and dry acoustics. Slow tempos benefit from large amounts of reverberation; but may need to be quickened in dry acoustics.
Based on Meyer’s framework, we could make some predictions about performance tempos of a particular work performed in different environments. Dry acoustics would tend to encourage a push of the tempos of fast and slow movements so that they converge (i.e., they both become more moderate). Highly reverberant acoustics will tend to encourage faster movements to slow down, but may not affect slow movements’ tempos.

Evidence from Live Performances: A Re-Analysis of Winckel (1962)

Fritz Winckel’s (1962) work with the Cleveland Orchestra has provided some observational evidence pertinent to these influences of acoustics on tempo, as put forward by Meyer. Winckel’s study focused mainly on the orchestra’s ability to maintain very stable dynamic ranges in different halls. However, near the end of his study, he makes some brief observations regarding tempo. Through observing performance-duration fluctuations of the same works performed in different acoustics, he concluded that there appears to be “no unique relation between reverberation time and tempo” (Winckel, 1962, p. 86). This intuition was not supported by any reported, formal analysis by Winckel; only descriptive statistics of halls’ decay times and works’ durations were included (Table I, Winckel, 1962, p. 82-3). This table is quite large—consisting of data on eight works that were performed in 15 different halls; in addition, there are missing decay times and performance durations in cases where it was not possible to collect these data. Consequently, it is fairly easy to read the table in such a way that suits a particular hypothesis about hall decay and durational fluctuation of pieces.
Since Winckel assembled a valuable data source, we offer a statistical analysis of his observations. First, we needed to maximize the number of performance-duration comparisons that could be made based on the table. Six halls had complete decay time data listed in the table (results for an empty and full hall): on average, when a hall was full the decay time was shortened by approximately 0.975 seconds in comparison with an empty hall. The decay times for each individual hall are illustrated in Figure 9.
Figure 9: Hall decay times (seconds) according to whether each hall was filled with an audience or empty. The presence of an audience shortened decay time by an average of 0.975 seconds.

Three other halls had missing values for the full hall condition, so we subtracted the average decay-time reduction (0.975 seconds) from the empty hall values available for these three halls. After this data treatment, we proceeded with an analysis of works’ performance durations using data from 11 halls: six halls with complete decay time data;
two with full hall data measured by Winckel; and three with our extrapolated full hall data. (No decay time values were available for the remaining four halls.) Presumably, Winckel made his measurements of work duration during performances of each work (not rehearsals), so we used only full hall decay times in this re-analysis.

After we established the hall measurements to be used in the analysis, we then excluded musical-work durations based on the following criteria: 1) any duration entry that Winckel annotated as “maximum” or “minimum” was excluded; 2) a duration entry that spanned two movements of a multi-movement work was excluded; 3) duration times of the same work that varied by more than 100 seconds were excluded because they suggested that the work was performed with or without repeats/cuts on different occasions; and 4) if a work was only performed once among all of the compared halls, then it was excluded.

Duration values for each work were averaged together, and then a “duration deviation” value for each performance of a work was calculated by subtracting each work’s average duration from the actual performance times of each work. Figure 10 shows the distribution of performance duration deviations according to decay times of halls. Positive deviations reflect longer performance durations (relative to the average duration); negative deviations reflect shorter performance durations.
Figure 10: Deviation of work durations (compared to a work’s average duration) according to hall decay times. The effect of increasing hall decay time leading to increasing work duration deviation approached significance at the alpha = 0.10 level, $F (1, 54) = 2.65, p = 0.1096$.

We conducted an analysis of variance (ANOVA) of performance duration deviations according to hall decay time. A positive trend of increasing hall decay times being associated with increasing work durations fell just short of statistical significance, $F (1, 54) = 2.65, p = 0.1096$. Although Winckel seems to indicate that his observations run contrary to his original hypothesis that longer hall decay times would be associated with longer performance durations, the present analysis seems more consistent with his original hypothesis. He also concluded that an optimum hall decay time is around 2.0 seconds, and “not more than 2.5 s” (p. 86). With optimum reverberation times there may
be closer “impedance matching” between instruments’ and the hall, and presumably shorter performance times because “it is easier to play an instrument for matched impedance conditions” (Winckel, 1962, p. 86). Our data do not include hall decay times up to 2.5 seconds, but Figure 10 shows that a number of the longer performance duration times occurred near 2.0 seconds of reverberation. Granted, we have made some assumptions about decay times for three halls, and excluded some of the original data, but Winckel’s study does not rule out a small to moderate linear effect of hall acoustics on musical performance durations.

Winckel made some other qualitative observations that could not be tested statistically at present: he observed that “minimum values for duration of music are found particularly in halls having especially good hearing conditions” and “maximum [duration values] are obtained in auditoriums which are especially arranged for public address systems and less for live music performances” (Winckel, 1962, p. 86). These observations suggest that interactions between hall acoustics and musical performance are more complex than the supposed effect of hall reverberation time: there are likely additional acoustic factors that influence chosen performance tempos.

Winckel’s qualitative observations are consistent with Meyer’s observations that lengthening reverberation times may not lead to a linear slowing of tempos. The accord between the reverberation time, ensemble size, and musical work must be considered. These notions illustrate an important distinction between optimum reverberation time and long/short reverberation time: if the widest breadth of tempo expression is achieved in a hall with ideal “hearing conditions” then increased or decreased reverberation times in...
other halls might constrain both fast and slow tempo extremes. So, in the case of large ensembles performing in a large hall, there may not be a simple one-to-one correspondence between tempo and reverberation time. What may be most important is that the performance space matches the musical style’s aesthetic and the ensemble size. Although it is difficult to discern the magnitude and linearity/non-linearity of hall-decay time on tempo, further study of the purported influence of decay time on tempo is warranted.

*Laboratory Evidence*

A more recent laboratory study on tempo’s interaction with reverberation supports Meyer’s theory, and explains reasons why highly reverberant environments may constrain tempo. Graham Naylor (1992) had participants tap in synchrony with repeated, regular^5 tone pulses at different tempos; he simulated reverberation in the sound booth’s fixed acoustic by changing the envelope shapes of the tone pulses. Pulses with long decay tails simulated the sound of a note in a highly reverberant space. Naylor found that envelope shape had an affect on tap synchronization errors: in the long-decay condition, tap errors were in the range of 25 to 45 milliseconds (Naylor, 1992, p. 262). Faster tempos exaggerated the effects of long decay, leading to more overlap of tone envelopes, and thus delaying the “perceptual attack time” (p. 262).

When perceptual attack points are obscured by high reverberation and quick tempos, musicians may struggle to synchronize and play as an ensemble. However, high reverberation does not automatically lead to a slowing of tempo; a slower pace is but one possible choice that the ensemble could make. Naylor offers several practical solutions to
ensure good ensemble synchronization despite high reverberation: 1) play ahead of the beat that is heard, 2) “sharpen attack transients by using a more detached bowing . . . or harder tonguing,” 3) play at a slower tempo, and 4) place players closer together (p. 265). Naylor’s conclusions are consistent with the intuitions and practices of many musicians. Playing ahead of the heard beat is facilitated through visual synchronization with a conductor; and a compact ensemble setup reduces delays due to sound propagation distances. Sharpening attacks may be helpful to an extent, provided the character of the piece is not unduly altered. Slowing the tempo may be the most intuitive reaction to long reverberation.

Ensemble size is another factor that can affect tempo. According to Jürgen Meyer, a “large body of strings allows a slower tempo than a smaller ensemble” (Meyer, 1978, p. 217). In effect, choruses of instruments add virtual reverberation. Larger bodies of instruments not only increase the volume of sound, but they also increase sound propagation distances between players. So, to some degree, larger ensembles also might tend to perform fast tempos more slowly than a smaller ensemble. Increased distance between instruments is analogous to increased reverberation in the overall reverberation mix, and leads to delays of perceived attack time (Naylor, 1992, p. 264).

Instrument-Related Tempo Effects

The effects of hall and ensemble size on tempo are well documented, but are there tempo effects that come from the physical properties of individual instruments? Intuition would suggest that the interpretation of a musical work could be influenced by performances with different instruments. It also seems plausible that the changing
technology of single instrument type could influence interpretive changes of a work over
time. For example: “one must keep in mind the nature of the fortepiano and the general
style of playing cultivated by Mozart. Sounds decayed more rapidly on the instrument of
Mozart’s time and encouraged a highly articulate touch and a highly detailed sense of
phrasing” (Hudson, 1994, p. 165). In contrast, a preponderance of longer more legato
lines in the Romantic era “required an instrument that would not damp the tone
immediately and completely as the classic fortepiano did when a key was released”
(Hudson 1994, p. 198). Richard Hudson’s remarks concern differences of articulation and
phrasing between piano types, but it is possible that tendencies of note and line lengths
also could influence the tempos used in performances.

A recent study by Michael Schutz, David Huron, Kristopher Keeton, and Greg
Loewer (2008) supports the notion that instruments with inherently shorter note length
will be associated with faster tempos. Schutz et al. (2008) examined the frequency of
occurrence of major and minor keys associations in the concert repertoires of xylophone
and marimba. These two mallet percussion instruments differ in a number of ways. For
example, the xylophone tends to have a brighter timbre than the marimba. In addition,
xylophone tones tend to exhibit quicker decay times. Schutz et al.’s (2008) principal
finding was that solo works for xylophone are largely in the major mode. This
phenomenon implies a happier character for the xylophone: faster decay times lend
themselves to faster tempos, which may also contribute to the happier character. The
characteristics of the xylophone parallel happy speech patterns: the xylophone has
“relatively high pitch range . . . bright timbre . . . and short note durations . . . making slow articulation rates impractical” (p. 127).

**Study Overview**

In light of this introduction, the current study attempts to discover potential tempo effects of instruments through analyses of recorded works between contrasting solo instruments: banjo/guitar, and fortepiano/harpsichord/piano. It is not possible to control timbre, tone-decay rate, and pitch height independently and so the results remain correlational, with many alternative interpretations possible. The following hypothesis is proposed:

*Hypothesis one* – Instruments exhibiting shorter tone-decay times will tend to be played at faster tempos than similar instruments exhibiting relatively longer tone-decay times.

**Method Overview**

In brief, each part of this study involved gathering a collection of solo works to be used for comparing instruments. North-American Folk music comprised the songs studied in part one; Western-Classical music comprised the works studied in part two. Multiple recordings, representing performances by contrasting instruments, were collected for each piece. Then, a tempo-tracking procedure was used to calculate tempo attributes such as average tempo and tempo fluctuation. The tempos of each recording were compared in order to determine if a work’s tempo varies significantly in performances with different instruments.
Analytic Sample Overview

Wind instruments and bowed strings provide sustained tones. If the goal is to examine the effect of differing decay times, then it is appropriate to examine percussion and plucked instruments. Therefore, the scope of the present study is limited to selected, plucked and struck instruments. This avoids a potential confound that comes from some instruments, bowed or blown, that are able to sustain notes for longer and variable amounts of time. Most “plucked or struck instruments . . . produce notes without steady-state parts, which begin to decay immediately after the onset” (Rasch, 1979, p. 121). The above hypothesis is tested in two separate studies: first through comparison of banjo and guitar performance tempos; and then a three-part comparison of the fortepiano, harpsichord, and piano.
Part 1 – Banjo and Guitar

Introduction

The five-string banjo and acoustic guitar share basic attributes such as a neck (usually fretted), resonating body, and tension-adjustable strings. Although solo guitar and solo banjo have their own distinct repertoires, they also overlap in certain repertoires such as in folk, country, old time, and bluegrass styles. In general, the two instruments both are performed using various combinations of strumming and picking (plucking): often in complex combinations. For example, banjo picking/strumming styles include the frailing, clawhammer, and picking styles; these are often associated with specific musicians and regional traditions (Baggelaar & Milton, 1976, p. 29). Beyond the practical differences of performing on an instrument with five or six strings, it is difficult to define a specific plucking/strumming style as exclusive to the banjo or guitar. The instruments share and borrow aspects of their physical performance techniques—and some performers are able to switch between both instruments from song to song.

A salient difference between the guitar and banjo is the decay time of their tones. The guitar exhibits longer tone-decay times by virtue of its larger, wooden resonant body. The banjo’s resonant body—the “head”—is sometimes “composed of a parchment skin stretched over a wooden or metal hoop” (Baggelaar & Milton, 1976, p. 28), and exhibits quicker tone decay rates; modern banjo heads often are constructed with plastic in place.
of the parchment skin (Odell & Winans, 2010). To some extent, the resonance of the head is adjustable via screws, which are arranged around the circumference of the head; but head tension adjustments also affect the instrument’s timbre, so there may be performance-tradition norms that discourage a timbre that is too “dull” or “tinny.” By contrast, an acoustic guitar’s resonance is largely fixed. There may be notable differences of resonance between models and brands of guitars, but in general, the guitar’s characteristics promote more resonance and slower decay rates than the banjo.

In addition to the resonance characteristics of the body or head of the respective instrument, there are also differences of pitch range and string construction that affect tone decay and timbre. The five-string banjo’s strings are tuned in a variety of ways depending upon a work’s key or other musical factors: two common tunings are G4-C3-G3-B3-D4 (“C tuning”) and G4-D3-G3-B3-D4 (“G tuning”)6—contrary to most stringed instruments, the shortest open string of the banjo is the fifth string, near the player’s thumb. Using common tunings, the banjo’s open strings’ pitch range spans from C3 (or D3) up to G4. The common acoustic guitar tuning is E2-A2-D3-G3-B3-E4, with its open strings spanning from E2 up to E4. The guitar has a lower pitch range, and also uses three (or four) thicker, wound strings in contrast to the banjo’s one wound string (fourth string). Wound strings will tend to decay more slowly than unwound strings—this is related to aspects such as string tension and gauge. In brief, the difference of pitch ranges between the guitar and banjo contributes to the decay times of the instrument’s tones, though perhaps not nearly as much as the instruments’ body construction.
Despite their differences, the banjo and guitar are a reasonable pairing: they share (or nearly share) the same tuning for four of their strings; the instruments can be performed using various combinations of strumming and picking; and they are both deeply rooted in North-American, traditional musical styles. One of their key differences is that of tone-decay time, which is the focus of the ensuing study.

*Population*

The present study aims to identify differences between the corpus of works for banjo and guitar. Since the solo repertoires for both instruments are relatively small, we focus more specifically on works for each instrument accompanied by a single voice—the voice of the instrumentalist. The selection of this population strongly influenced the styles of music studied: American folk, blues, old-time, and country music. Works for solo singer accompanied by a separate guitar or banjo instrumentalist are not considered. The physical constraints upon a singer accompanying herself with a banjo are much different from those of a solo singer or instrumentalist: the solo genres tend toward more a virtuosic performance style, which may influence performance tempos.

*Sampling*

In order to minimize the number of uncontrolled variables, the sampling process identified single pieces of music for which recordings of both banjo plus voice and guitar plus voice exist. The planning stages of sampling involved searching through several discographies of folk and country music such as Dean and Nancy Tudor’s (1979) discography and the index for the Indiana University Archives of Traditional Music (1975). While these resources are informative, they do not list instrumentation for
specific songs. Tony Russel’s country music discography (2004) does contain instrumentation details, but finding pieces with the desired instrumentation proved to be slow; and many recordings were not readily available. A more practical sampling method made use of a convenience sample assembled from recordings available from a large local university music library containing some 28,000 CDs and 80,000 LPs.\(^7\)

Since there were fewer library holdings of banjo recordings than guitar, we began by searching through the smaller banjo sub-sample. A catalog search for the keyword, “banjo,” yielded 314 recordings that contained banjo. In order to refine these results to match the target population—namely, a musician performing on banjo and voice—the library catalog descriptions for each of the results were examined individually. Albums in which the banjo was one of many instruments in an ensemble were excluded.\(^8\) Solo, duo, and field recordings did not always have detailed catalog listings for each track; therefore, listening to each recording and reading the liner notes helped to determine each song’s inclusion in or exclusion from the sample. This stage of sampling resulted in a master list of recordings of works for banjo plus voice.

The next step of the sampling process entailed searching the library catalog using a combination of the keyword, “guitar,” and each of the banjo songs’ titles (and title variants).\(^9\) In total, this search yielded 19 pieces that were represented by at least two recordings: one for guitar and one for banjo. The sampled songs are listed in Appendix C. Some songs had more than two recordings available: in these situations, the banjo recording was matched with the guitar recording with the nearest recording date.\(^10\) In other situations where multiple banjo and guitar recordings were available for a song, a
guitar version was randomly selected, and then matched with a banjo version with the closest recording date. Some songs—having the same title—bore few musical similarities. These songs were excluded from the final sample.

 Tempo Data Collection

An operational definition of tempo was necessary to test the tempo/tone-decay hypothesis. Since tempo is a multi-dimensional musical element, it can be measured in many ways: for example, measurement of duration, average tempo, starting tempo (or the tempo of another section), or degree of tempo fluctuation. If we calculate the mean tempo, then we are making a statistical assumption that a piece has relatively little tempo fluctuation. If the assumption is correct, then the calculated average tempo is an accurate reflection of the overall tempo.

The sampled songs were approximately three minutes in length, and performed with a relatively steady tempo; consequently, average tempo was deemed an appropriate calculation. Average tempo calculations are not always appropriate measures for tempo, depending on the repertoire of music studied. In longer works with structural changes of tempo, average tempo will blur over tempo fluctuations; these situations demand bar-by-bar averages, sectional average tempos, or “initial tempo” calculations, for example (see Bowen, 1996).

Average tempos were calculated using data collected while tapping along with each song. A computer program (see Appendix E), written in the ChucK audio-programming language, converted a computer keyboard into a tap-pad. At the instant of each key press, the program outputted the clock time value to the screen; these time
values were copied and saved into a plain text file. A spreadsheet software program was used to calculate beat durations: successive time values were subtracted from each other. Several descriptive statistics—average beat duration, average tempo, and standard deviation—also were calculated. Average tempo values (expressed as beats per minute) were used in the hypothesis test below.

Results

Of the 19 pieces sampled, there were ten instances in which the tempo for the banjo was faster than the tempo for guitar; the guitar’s tempo exceeded the banjo’s tempo in the remaining nine songs. Table 3 summarizes the results for each piece.
Table 3: Average tempos (bpm) for each piece’s banjo or guitar renditions. The banjo tempo exceeds that of the guitar in ten songs; the guitar tempo exceeds that of the banjo in nine songs.

<table>
<thead>
<tr>
<th>Piece</th>
<th>Banjo Tempo--Beats per Minute (bpm)</th>
<th>Guitar Tempo (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down in the Valley</td>
<td>41.52</td>
<td>44.4</td>
</tr>
<tr>
<td>So Long, It’s Been Good to Know You</td>
<td>64.29</td>
<td>73.84</td>
</tr>
<tr>
<td>Midnight Special</td>
<td>73.78</td>
<td>93.04</td>
</tr>
<tr>
<td>In the Evening When the Sun Goes Down</td>
<td>80.73</td>
<td>67.04</td>
</tr>
<tr>
<td>This Land is Your Land</td>
<td>86.3</td>
<td>105.25</td>
</tr>
<tr>
<td>Jimmie Crack Corn</td>
<td>99.63</td>
<td>81.08</td>
</tr>
<tr>
<td>Spoonful</td>
<td>99.78</td>
<td>73</td>
</tr>
<tr>
<td>T. B. Blues</td>
<td>100.58</td>
<td>98.86</td>
</tr>
<tr>
<td>Old Reuben</td>
<td>100.85</td>
<td>123.3</td>
</tr>
<tr>
<td>Ain’t it a Shame</td>
<td>102.48</td>
<td>103.49</td>
</tr>
<tr>
<td>Skip to My Lou</td>
<td>110.18</td>
<td>111.77</td>
</tr>
<tr>
<td>Stagolee</td>
<td>110.37</td>
<td>107.27</td>
</tr>
<tr>
<td>Golden Vanity</td>
<td>111.7</td>
<td>76.15</td>
</tr>
<tr>
<td>What a Beautiful City</td>
<td>112.54</td>
<td>99.96</td>
</tr>
<tr>
<td>Talking Blues</td>
<td>114.76</td>
<td>123.07</td>
</tr>
<tr>
<td>St. James Infirmary</td>
<td>116.8</td>
<td>122.24</td>
</tr>
<tr>
<td>Georgie Buck</td>
<td>122.69</td>
<td>142.32</td>
</tr>
<tr>
<td>Cumberland Gap</td>
<td>126.45</td>
<td>123</td>
</tr>
<tr>
<td>St. Louis Blues</td>
<td>133.49</td>
<td>130.98</td>
</tr>
</tbody>
</table>

The banjo recordings’ average tempo was 100.46 bpm, having a standard deviation (SD) of 22.71 bpm. Banjo tempos ranged from 41.52 to 133.49 bpm. The guitar recordings had a nearly identical average—100.00 bpm (SD = 25.44 BPM)—and a range of tempos from 44.50 to 142.32 bpm. The tempos of the banjo and guitar works were also
highly correlated ($r = 0.789$): pieces performed faster on the guitar tended to be performed faster on the banjo; similarly, pieces performed slowly on the guitar tended to be performed more slowly on the banjo. This positive correlation provides an index of reliability for the final sample because it suggests that the two, recorded versions of a work are likely the same work—not two different works that happen to have the same name. If sampled songs had been paired freely across styles such as folk, be-bop, and heavy metal, for example, then one might expect a relatively weak correlation of tempos between different versions of the purported same song. The high positive correlation is consistent with the notion that the sampling procedure gathered songs from the same style of music, or at least quite similar styles.

Other descriptive statistics revealed that the distribution of banjo tempos was not a normal distribution, but rather a negatively skewed distribution: specifically, there was a predominance of moderately fast tempos compared to relatively few moderate-to-slow tempos.\textsuperscript{12} Since the banjo distribution did not meet the criterion of a normal distribution, which is assumed when running a paired-samples $t$-test, a Wilcoxon Signed Ranks Test was chosen for the test of statistical significance.\textsuperscript{13} A significance level ($\alpha = 0.10$) was selected, \textit{a priori}, for tests upon this sample.\textsuperscript{14} The Wilcoxon test indicated that the observed mean tempo difference was non-significant ($z = -0.080$, $p = 0.936$). This result is inconsistent with our prediction in hypothesis one. According to the present sample, it appears that decay rate, and other differences between the two instruments, does not significantly influence the beat rate in folk music performances.
Discussion

Although tone-decay rates do not appear to be correlated with tempo differences in folk works for guitar and banjo, the above hypothesis test defined tempo as the beat rate of a musical piece. In the folk repertory, songs are not viewed as fixed “texts” to the same degree as some western-classical works; and there is less of a distinction between the folk music composer and performer. Therefore, other tempo attributes in addition to beat rate, such as note density, can vary considerably between different performances of ostensibly the same work. Although the above results demonstrate that beat rate did not differ significantly between the banjo and guitar, rhythmic patterns in each piece varied between guitar and banjo performances. The varying densities of note articulations in each piece may contribute to a sense of significantly faster or slower tempos, even when small differences of beat rate occur.
Part II – Banjo/Guitar Post Hoc Hypothesis

Introduction

The most common conception of tempo is that of beat rate; however, tempo is a more complex, multi-dimensional phenomenon—interacting with harmonic rhythm, phrasing, rhythmic density, and emotional characteristics of the music. For example, two works performed at the same beat rate might be perceived as having markedly different speeds if one work uses rapid rhythms that fill the divisions and sub-divisions of the beat. In response to hypothesis one, the following post hoc hypothesis is proposed:

*Hypothesis two* – Instruments exhibiting faster tone-decay rates will tend to be played using faster note rates than similar instruments exhibiting relatively slower tone-decay rates.

Sampling

The sample from hypothesis one was used to test this hypothesis. Ideally, a new sample would be sought, but the initial sampling process exhausted the local university library’s holdings of pieces with both a banjo and guitar version of each song. Since this is a post hoc hypothesis and the second hypothesis test performed on the same sample, the results below should be interpreted with caution. However, statistical measures are taken in the proceeding test to reduce the chances of accepting hypothesis two as true when it is actually false.
Method

Each work’s ostinato accompaniment pattern was analyzed aurally. The number of strummed/picked rhythmic values within one beat was counted. The ostinato pattern was defined as the steady pattern that occurred once the performer began singing in the first verse of the song—this excluded variations of rhythm that occurred between phrases and in introductions, interludes, and codas; the accompaniment pattern of the first verse was the only one considered. In addition, melodic doubling of the vocal line by the guitar or banjo was excluded in the rhythmic articulation count.

In general, the performers represented by this sample maintained steady accompaniment patterns while they sang, and added more rhythmic activity at phrase ends. The articulations-per-beat count does not factor in the embellishing material. In some cases where the ostinato accompaniment pattern varied frequently in sung portions of the song, the average number of articulations was deemed representative of the overall accompaniment. For example, a regular alternation between duple and triple divisions of the beat was counted as 2.5 articulations per beat; four sub-divisions of a beat were counted as 4; and so on.

After the ostinato articulations were counted, they were multiplied with the beats per minute values from the first hypothesis test. The resulting articulations-per-minute (a/m) values reflected the approximate note densities of the accompaniment patterns used by banjo and guitar—taking both beat rate and number of articulations per beat into account.
Results

Performances on the banjo exhibited faster articulation rates in their accompaniment patterns. The banjo a/m rate exceeds the guitar in 16 songs; the guitar’s rate exceeds the banjo’s in 3 songs. This difference between the banjo and guitar is statistically significant—(z = -3.582; p < 0.05) in a Wilcoxon test of the articulation rates shown in Table 4.15
Table 4: Columns two and three show the number of rhythmic articulations per beat in *ostinato* accompaniment patterns of the guitar and banjo. Columns four and five show articulations per minute, which is a weighted value of beat rate multiplied by articulations per beat.

**Discussion**

Although performances of the banjo and guitar do not exhibit significantly different beat rates, banjo accompaniment patterns exhibit a significantly faster note-
articulation rate. The banjo’s proclivity towards note rapidity is consistent with the notion that instruments with shorter tone decay times will tend to be performed more quickly than instruments with longer tone decay times. These results are based upon correlational evidence, and it is difficult to rule out a number of alternative explanations for the differences between banjo and guitar accompaniment patterns. For instance, the banjo’s arrangement of strings in an “out-of-order” pitch sequence with the highest string near the thumb may encourage the use of quicker, alternating finger picking styles, in contrast to a strumming style associated with the guitar.

The non-significant difference between the beat rates used when performing these two instruments is difficult to interpret. If the post hoc test had turned out to be non-significant as well, then the combined result would have implied that there is little grounding for the tone-decay/tempo hypothesis. However, given that there is some evidence in favor of the hypothesis at the level of note-articulation rates, this idea warrants further investigation. Additionally, the banjo/guitar sample was not an ideal representation of purely instrumental performances: when the voice of the performer is combined with her performance on the guitar or banjo, there may be a constraint of vocal style or mechanics that limits the beat rate of songs. Ideally, we would have sampled purely instrumental works for banjo and guitar, but this was not practical considering the high frequency of works for voice and banjo/guitar, and our desire to sample randomly from substantial library holdings of folk music.

Next, the tempo/tone-decay hypothesis was tested in a different population: works in the Western-Classical tradition for early piano, modern piano, and harpsichord.
Part III – Fortepiano, Harpsichord, and Piano

Introduction

This part of the study investigates the association between tone-decay time and performance tempo for three additional instruments—the fortепiano, harpsichord, and piano. We examine performance tempos in Western-Classical music, a musical corpus which offers an additional control when making tempo observations: the pitch and rhythmic content of a classical work remains relatively unchanged between repeated performances, whereas the pitch and rhythmic content of a piece of North-American Folk music can vary markedly. Consequently, we focus on the beat-rate dimension of tempo rather than note rate, which is not free to vary independently of beat rate.

In several respects, the fortепiano, harpsichord, and piano are more similar to each other relative to the similarities between the banjo and guitar. The gross finger mechanics used when performing on keyboard instruments are less variable than the various picking/strumming styles of the guitar and banjo: keyboard players may have individual styles of fingering, but they usually use all ten fingers. Each pitch on a keyboard instrument is only performable via one key, whereas a given pitch can be performed on different strings of a guitar or banjo.

The same work performed on these different keyboard instruments is also less stylistically variable compared to another work performed on guitar and banjo. Keyboard
works in the Western-Classical tradition were usually written with a specific keyboard instrument in mind, but these works have been performed on other keyboard instruments as this family of instruments has evolved. When a work originally written for harpsichord is performed on a piano, pitch and rhythmic content does not change substantially. In contrast, differing guitar and banjo idioms offer different ways to render a musical work on each instrument.

Another factor that is known to lead to significant differences of tempo choice is performance practice. As a work ages, its “performance history” also changes (e.g., Bowen, 1993; Leinsdorf, 1981). Changes of performance practice are largely bounded by the time period of the performers. We assume that the performers represented in our sample belong to the modern performance tradition; and so the influence of time period should be equally distributed among all of the recordings sampled. Thus, if we observe systematic differences of tempo between performances on different instruments, then this would support the notion that instrument tone-decay time can influence tempo choices.

Despite the similarities of time period between performers and similarities of repertoire between the fortepiano, harpsichord, and piano, these instruments exhibit differences of tone-decay time that might be substantial enough to impact aspects of musical performance. For the purposes of this study, we will rank order the three instruments from shortest to longest decay time: harpsichord, fortepiano, and piano. This ordinal classification is not as ideal as taking acoustical measurements from specific instruments. For example, early pianos were less standardized and evolved rapidly: a Walter piano or a Stein piano that was dated too early might not match the particular
piano sound that Mozart had known (Latcham, 1996). However, our sampling method necessitated that we examine recordings of many different performers and instruments. Thus, it was deemed more practical to classify the fortepiano categorically as an acoustic transition between the harpsichord and piano (Gätjen, 1996), rather than taking measurements from actual instruments. Some further considerations regarding differences between these instruments are discussed below.

Turning first to modern-day pianos and early pianos (fortepianos), these instruments have several differences, which influence tone-decay time. The piano has undergone many innovations since its invention c. 1700 by Bartolomeo Cristofori. A number of changes of construction have led to the modern piano’s longer decay times: 1) the modern piano’s soundboard is more strongly reinforced with metal, allowing for more string tension 2) modern pianos employ solid hammers in contrast to the hollow hammers used in some early pianos.

Comparing the piano and harpsichord, the harpsichord has a smaller pitch range—consisting of approximately four and a half octaves, spanning from around A1 to F6 (Fletcher & Rossing, 1998, p. 341). In addition, the harpsichord’s strings are set into vibration by a plectrum rather than a hammer; timbre can be manipulated in some harpsichords equipped with additional plectra types and damper settings (Fletcher & Rossing, 1998, p. 342). Some harpsichords can perform at different dynamic volumes, but this is due to additional manuals, which add effectively more voices—the intensity of the plectra strokes does not change, and neither do the strings’ tone-decay times. The harpsichord’s tone-decay times range from “about 20 s for the lowest notes to 5 s for the
highest” (Fletcher & Rossing, 1998, p. 346). The piano exhibits tone-decay times ranging from 50 s to 0.2 s (Fletcher & Rossing, 1998, p. 384). Across most pitches, the piano is generally more resonant that the harpsichord (ignoring changes of dynamics for the time being), but above F5 (approximately) the piano’s decay times are less than 5 s—the shortest decay time for the harpsichord. In the harpsichord’s highest octave (F5-F6), the harpsichord exhibits longer decay times than the piano’s pitches above F5. The dominant pitch content for Western-Classical musical works ranges from E2-G5, with a center around D#4 (Huron, 2001). The pitch dominance region for Western-Classical music lies below F5, so keyboard music will typically exhibit longer decay times when played on the piano compared with the harpsichord. Thus, we can predict that the modern piano generally is performed using slower tempos than the harpsichord. This prediction may not fully encapsulate the relationship between pitch height and tempo, but rather than making a handful of predictions, the present study will use the broad notion that the piano exhibits longer decay times than the harpsichord.

Despite a purportedly consistent effect of pitch on decay time across the pitch dominance region, we cannot make the same assumption in the case of dynamics. Tempo predictions between the pianos and the harpsichord depend on particular works because the harpsichord has a relatively constrained dynamic range. Since the dynamic flexibility of the piano and fortepiano alters tone-decay time, we can expect that for “loud” pieces the harpsichord’s tempo will exceed the pianos’ tempos: at loud dynamics the tone lengths for the pianos are longer than the harpsichord. For “soft” pieces the tempo differences between pianos and harpsichord will be minimized, because the harpsichord
exhibits no change of tone decay for the ostensibly “soft” pieces while the pianos are able to play softly, thus reducing tone lengths. These predictions are summarized in the hypothesis statement below:

*Hypothesis three* – Musicians will tend to use faster tempos when performing on instruments exhibiting shorter decay times. Thus, the fortepiano and piano generally will tend to be performed at slower tempos than the harpsichord; and the piano will tend to be performed at a slower tempo than the fortepiano. Since dynamic levels influence decay times in some instruments such as the fortepiano and piano, we also expect an interaction between instrument type and dynamics: softer dynamics will lead to shorter decay times, and louder dynamics encourage longer decay times. Consequently, soft dynamic levels will minimize the differences of tempos between performances on these three instruments; and loud dynamic levels will maximize differences of tempo between instruments.

*Sampling*

Although Western-Classical works were often written for a specific keyboard instrument in mind (e.g. virginal, harpsichord, clavichord, fortepiano, or piano), modern-day performance practice (combined with the limited availability of some instruments) allows musicians flexibility to perform these pieces on their choice of instrument. The choice is most often between piano and harpsichord, and there also has been a resurgence of interest in the fortepiano. Accordingly, this study focuses on comparisons of recordings representing these three common keyboard instruments.
We used a sampling procedure similar to the banjo/guitar sampling. Due to the larger library holdings of keyboard music, we were able to assemble a more diverse sample—with representation by 26 different composers and 39 different performers. The sampling process proceeded in three stages:

- **Stage 1:** Works performed on fortepiano were identified through searching the online catalog of a university music library, and the Naxos Online Music Library. We used the search keyword, “fortepiano,” and limited the results to sound recordings. Then, we extracted the solo keyboard works from these results. In a list format, we noted each composer represented by these available recordings of solo keyboard works.

- **Stage 2:** For each composer, we randomly sampled\(^{17}\) one of the fortepiano recordings from either the library’s holdings or from Naxos. (Hereafter, the words “sampled” or “sampling” refer to the random sampling we conducted at every stage of this study.) Next, we sampled a work from each recording; if the work had multiple movements, then a movement was sampled from within the respective piece. Piano and harpsichord (when available) versions of each work were then sampled.

- **Stage 3:** One, random minute was sampled from the fortepiano version of each work. Because of tempo differences, the corresponding piano and harpsichord excerpts usually started and ended at different clock times than the fortepiano version. Therefore, we aurally matched musical locations in the different recorded versions.
The sampling procedure resulted in each work having representation from either two recordings (fortepiano and piano) or three recordings (fortepiano, piano, and harpsichord). A total of thirty works \((n = 30)\) comprised the sample. Every work was represented by piano and fortепiano recorded versions, and nine works \((n = 9)\) were represented by harpsichord as well. Appendix D lists the sampled works, along with performers, instruments, and record label number.

In addition to the aforementioned modern resurgence of interest in period instruments, performance practices of specific musical eras also influences the existence of performances by these three instruments. For example, due to the harpsichord’s decline in use during the 19\(^{\text{th}}\) century, it is difficult to find recordings of Romantic works performed on harpsichord. Other works written during the birth of the early pianos in the early 18\(^{\text{th}}\) century, such as Scarlatti’s sonatas and J. S. Bach’s suites, preludes, and fugues have been performed on all three instruments.

We should note that this study of harpsichords, early pianos, and modern pianos does not reflect the entirety of keyboard instruments used throughout the history of Western-Classical music. For example, Carl Philipp Emanuel Bach wrote many of his keyboard sonatas with the clavichord in mind,\(^{18}\) and a number of modern recordings on clavichord are available. The clavichord is an “early piano” in some respects: it is capable of dynamic changes within its relatively soft overall dynamic range. However, we did not include recordings of clavichord in the present study because the clavichord’s construction and performing technique differs from the piano. For example, early “fretted” clavichords were arranged so that each unison string pair produced up to four
different pitches—this arrangement precluded performing any two of these four notes simultaneously (Ripin et al., 2010).

**Tempo Data Collection**

The works studied in this part of the study included diverse musical forms such as sonata, variations, and rondo—all of which may exhibit tempo changes between formal sections. Therefore, the assumptions required for an average tempo analysis of the entire work were not met. For example, consider a hypothetical variations form (consisting of a theme statement, slow variation, and fast variation) that is performed with markedly different tempos for each section from performance to performance. Depending on the chosen tempos, the overall average tempos for two performances could all be the same. In one rendition of the piece, a performer might choose more moderate tempos for both the fast and slow variations. A different performer might choose more extreme fast and slow tempos—in either case the overall average could be the same because the second performer used a faster fast tempo that was balanced by a slower slow tempo. Sectional performance tempos have been shown to balance each other in some cases (e.g., Clynes & Walker 1982; Bowen, 1996). In other words, average tempo calculations for an entire work with multiple sections does not necessarily represent the tempo of each section within the work. Consequently, a modified form of the banjo/guitar data collection process was used for the present sample.

Average tempos calculations were based upon tapping beats while listening to each excerpt. A short computer program (see Appendix E) printed absolute time values of successive keyboard taps (the “shift” key was used to avoid character output to the
screen); the values were printed to the computer screen. Once the musical excerpt ended, the time values were copied into subtracted from each other, yielding running tempo calculations from beat to beat. The average tempo for each excerpt was calculated from the running tempo calculations.

Dynamic levels for each piece were determined by listening to the piano version of each piece. We chose a single dynamic level that reflected the overall average dynamic from the one-minute excerpt. Dynamics ranging from $pp - ff$ were encoded on a numerical scale of 1–6. Experimenter bias may have been introduced by this operational definition of dynamics. We chose to begin with this operational definition because of its convenience. If any of the hypotheses involving dynamics were found to be significant, then we would ask other musicians, who did not know our hypothesis, to rate dynamic levels of each piano excerpt.

**Results**

For ease of comparison, the average tempos for each work are listed in Table 5. The missing values in the harpsichord column represent works for which no harpsichord recording was available.
<table>
<thead>
<tr>
<th>Work</th>
<th>Harpsichord</th>
<th>Fortepiano</th>
<th>Piano</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tempo</td>
<td>MAD</td>
<td>Tempo</td>
<td>MAD</td>
</tr>
<tr>
<td>Bach, CPE</td>
<td>120.83</td>
<td>9.98</td>
<td>105.35</td>
<td>9.48</td>
</tr>
<tr>
<td>Bach, JC</td>
<td>138.26</td>
<td>5.29</td>
<td>191.96</td>
<td>9.85</td>
</tr>
<tr>
<td>Bach, JC</td>
<td>62.13</td>
<td>1.97</td>
<td>60.72</td>
<td>3.21</td>
</tr>
<tr>
<td>Bach, JS</td>
<td>44.08</td>
<td>4.45</td>
<td>55.17</td>
<td>1.73</td>
</tr>
<tr>
<td>Bach, JS</td>
<td>79.89</td>
<td>3.88</td>
<td>73.01</td>
<td>2.48</td>
</tr>
<tr>
<td>Beethoven, L</td>
<td>-</td>
<td>119.32</td>
<td>8.66</td>
<td>97.82</td>
</tr>
<tr>
<td>Chopin, F</td>
<td>-</td>
<td>44.32</td>
<td>4.63</td>
<td>44.81</td>
</tr>
<tr>
<td>Clementi, M</td>
<td>-</td>
<td>46.24</td>
<td>9.24</td>
<td>51.69</td>
</tr>
<tr>
<td>Czerny, C</td>
<td>-</td>
<td>96.29</td>
<td>7.66</td>
<td>96.82</td>
</tr>
<tr>
<td>Diabelli, A</td>
<td>-</td>
<td>61.49</td>
<td>9.98</td>
<td>77.51</td>
</tr>
<tr>
<td>Dussek, JL</td>
<td>-</td>
<td>49.15</td>
<td>5.5</td>
<td>43.65</td>
</tr>
<tr>
<td>Farrenc, L</td>
<td>-</td>
<td>97.12</td>
<td>12.07</td>
<td>102.95</td>
</tr>
<tr>
<td>Field, J</td>
<td>-</td>
<td>71.62</td>
<td>9.68</td>
<td>65.01</td>
</tr>
<tr>
<td>Gottschalk, LM</td>
<td>-</td>
<td>54.61</td>
<td>4.91</td>
<td>37.92</td>
</tr>
<tr>
<td>Handel, GF</td>
<td>106.58</td>
<td>7.32</td>
<td>131.39</td>
<td>12.21</td>
</tr>
<tr>
<td>Harrison, L</td>
<td>-</td>
<td>43.87</td>
<td>4.06</td>
<td>52.08</td>
</tr>
<tr>
<td>Haydn, J</td>
<td>-</td>
<td>120.29</td>
<td>7.76</td>
<td>93.01</td>
</tr>
<tr>
<td>Haydn, J</td>
<td>50.57</td>
<td>2.40</td>
<td>53.74</td>
<td>2.96</td>
</tr>
<tr>
<td>Hummel, JN</td>
<td>-</td>
<td>29.04</td>
<td>7.19</td>
<td>33.01</td>
</tr>
<tr>
<td>Kraus, JM</td>
<td>-</td>
<td>50.62</td>
<td>7.43</td>
<td>35.03</td>
</tr>
<tr>
<td>Liszt, F</td>
<td>-</td>
<td>128.52</td>
<td>19.90</td>
<td>141.23</td>
</tr>
<tr>
<td>Lithander, C</td>
<td>-</td>
<td>95.19</td>
<td>8.01</td>
<td>107.17</td>
</tr>
<tr>
<td>Lithander, F</td>
<td>-</td>
<td>57.99</td>
<td>5.49</td>
<td>47.34</td>
</tr>
<tr>
<td>Mendelssohn, F</td>
<td>-</td>
<td>84.27</td>
<td>10.32</td>
<td>82.12</td>
</tr>
<tr>
<td>Mozart, WA</td>
<td>-</td>
<td>146.69</td>
<td>10.26</td>
<td>149.46</td>
</tr>
<tr>
<td>Scarlatti, D</td>
<td>161.32</td>
<td>8.94</td>
<td>154.48</td>
<td>10.34</td>
</tr>
<tr>
<td>Scarlatti, D</td>
<td>133.07</td>
<td>6.86</td>
<td>128.52</td>
<td>4.96</td>
</tr>
<tr>
<td>Schubert, F</td>
<td>-</td>
<td>137.05</td>
<td>11.38</td>
<td>138.02</td>
</tr>
<tr>
<td>Schumann, R</td>
<td>-</td>
<td>76.25</td>
<td>6.91</td>
<td>112.1</td>
</tr>
<tr>
<td>Soler, A</td>
<td>123.19</td>
<td>16.11</td>
<td>106.82</td>
<td>16.54</td>
</tr>
</tbody>
</table>

Table 5: Average tempos (bpm) and mean absolute deviations (MAD) of one-minute excerpts from each work recorded by harpsichord, fortepiano, and piano. Works are listed according to the composer’s name. Dynamic level is from 1-6, representing pp-ff.
Turning first to the two pianos, summary statistics are listed in Table 6. The average tempo for performances on fortepiano was just higher (approximately 2 bpm) than the piano average tempo. In contrast, the piano median tempo is approximately 14 bpm higher than that of the fortepiano. (The median is a measure of central tendency that is less influenced by extreme values.) However, in a statistical analysis, the fortepiano and piano distributions of tempo were not significantly different (Wilcoxon Signed Ranks Test; \(Z = -0.627; p = 0.530\)). This result is not consistent with our prediction in hypothesis three. The differing decay times for the fortepiano and piano do not seem to influence performance tempos.

<table>
<thead>
<tr>
<th>Tempos (bpm)</th>
<th>No. of Works</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fortepiano</strong></td>
<td>30</td>
<td>89.55</td>
<td>40.76</td>
</tr>
<tr>
<td><strong>Piano</strong></td>
<td>30</td>
<td>87.52</td>
<td>37.88</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fortepiano</strong></td>
<td>29.04</td>
<td>191.96</td>
<td></td>
</tr>
<tr>
<td><strong>Piano</strong></td>
<td>33.01</td>
<td>165.56</td>
<td></td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Percentiles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fortepiano</strong></td>
<td>54.39</td>
<td>80.26</td>
<td>122.75</td>
</tr>
<tr>
<td><strong>Piano</strong></td>
<td>51.12</td>
<td>94.92</td>
<td>118.45</td>
</tr>
</tbody>
</table>

Table 6: Descriptive statistics of tempo for 30 works, each with a piano and fortepiano recorded version. Tempo values are listed as beats per minute (bpm). The mean fortepiano tempo is marginally higher than that of the piano. The median tempo is less affected by extreme values (outliers) and is substantially higher for the piano, suggesting that at moderate tempos, performance tempos may outpace those of the fortepiano. However, these differences are not statistically significant.
Only nine of the above works were performed on the harpsichord, so the average harpsichord tempo cannot be directly compared with the two other averages for all thirty works. In addition to the piano and fortepiano comparison above, we tested the tempo differences between the remaining instrument-pair combinations: 1) the Wilcoxon Signed Ranks Test comparing the tempo distribution for harpsichord and fortepiano was not statistically significant ($Z = -0.30; p = 0.77$); and 2) nor was the difference between harpsichord and piano ($Z = -0.42; p = 0.68$). These results also are not consistent with our prediction. Overall, there were no statistically significant differences of performance tempos between the harpsichord, fortepiano, and piano.

Hypothesis three also predicted an interaction between dynamics and instrument type: soft dynamics may essentially equalize decay times across instruments, resulting in a minimization of differences between performance tempos. We tested this possible interaction by conducting several two-way Analyses of Variance (ANOVA). These two-way ANOVAs examined two factors that may have influenced the observed performance tempos: 1) instrument type, 2) dynamic level, and 3) the interaction between instrument type and dynamic level. We expected that decay time differences (and perhaps performance-tempo differences) between instruments would be most exaggerated at loud dynamics, and minimized at soft dynamics.

First, we conducted an ANOVA comparing the fortepiano and piano across all thirty works. Like the findings from the above Wilcoxon tests, the main effect of instrument type did not have a statistically significant effect on tempo ($F (1, 59) = 0.059; p = 0.81$). Again, this was not consistent with hypothesis three. However, the main effect
of dynamics did have a statistically significant effect on tempo: softer dynamics were associated with slower tempos and louder dynamics were associated with faster tempos \( (F(1, 59) = 28.61; p < 0.0001). \) The interaction between instrument type and dynamics was not significant \( (F(1, 59) = 0.23; p = 0.63). \) The lack of an interaction is consistent with the notion that both the fortepiano and piano have a related capacity to modulate dynamic level in proportion with tempo: as dynamics become louder or become softer, the performance tempos on both instruments seem to move in parallel.

We expected to observe the strongest interaction between instrument type and dynamics when comparing harpsichord and the pianos. The dynamic capacity of the harpsichord differs markedly from the pianos. To test this prediction, we conducted another two-way ANOVA comparing all three instruments across the nine works for which complete data were available. Again, instrument type was not a statistically significant predictor of tempos \( (F(2, 26) = 0.073; p = 0.93), \) nor was the interaction between dynamic level and instrument type \( (F(2, 26) = 0.038; p = 0.96). \) These results were not consistent with our prediction in hypothesis 3. However, like the ANOVA for the piano and fortepiano, dynamic level was found to be a statistically significant effect on tempo \( (F = 12.8964; p = 0.0017). \)

Additionally, we conducted a post hoc test for a potential correlation between dynamic level and tempo differences among instruments. The tempo differences between the multiple recordings of a piece were quantified using a mean absolute deviation (MAD).\(^9\) The MAD for each piece was calculated by 1) averaging the mean tempos of each recording for a piece—resulting in a “piece average,” 2) subtracting the “piece
average” from each recording’s tempo—resulting in “deviations,” and 3) calculating the average “deviation” value by adding all deviations (while ignoring negative signs) and dividing by the number of recordings—resulting in the “mean absolute deviation.”

Dynamic levels were encoded on a scale of 1-6 (1 = pianissimo and 6 = fortissimo). The results, shown in Figure 11, exhibit no significant correlation between dynamic level and tempo differences among different versions of works. As dynamic levels increase, the tempo differences between performances by harpsichord, fortepiano, and piano appear to stay the same, $F(1, 28) = 0.047, p = 0.83$. 
Figure 11: Each work’s mean absolute deviation (in bpm) according to dynamic level. Dynamic level is encoded from 1 to 6 (soft to loud). The straight line is the line of fit (regression line). As can be seen, there is no significant \( F(1, 28) = 0.047, p = 0.83 \) relationship between dynamic level and instruments’ tempo differences. The density contours are read like a topographic map, the higher “altitudes” represent areas were higher percentages of the points are clustered together.

Up until this point, the results have dealt with average tempo calculations that were derived from one-minute musical excerpts. If we examine the mean absolute deviations of tempo within each excerpt (Table 5), then there might be some additional insights related to tempo fluctuations around each mean tempo. While listening to the sampled pieces, we noticed a tendency for some performances on fortepiano to use more frequent acceleration and deceleration than the other instrumental performances. For
other pieces, the piano seemed to be performed with more varied tempos. To assess the possibility of a broad trend of tempo flexibility connected with an instrument, we conducted paired $t$-tests on the mean absolute deviation values for each instrument. None of the instrument pair-comparisons exhibited significantly difference mean absolute deviations of tempo. This result suggests that while there are certainly differences of tempo flexibility used by different performers, these patterns are not related overall to performance on a particular instrument type.

Discussion

Contrary to our first prediction from hypothesis three, we found no significant difference of average tempos between repeated performances of each work on harpsichord, fortepiano, and piano. The second prediction regarding dynamic/instrument effects on tempo also was not statistically significant.

These negative results may be due to a number of factors. Although it seemed plausible that variations in tone-decay length could explain tempo variation between performances of the same work on different keyboard instruments, perhaps this purported effect of tone decay is overshadowed by other differences between the instruments and the performers. For instance, the evolution of the piano has not only introduced differences of tone sustain, but also a refinement of the piano’s mechanical operation. It is also plausible that the technical advantages offered by the modern piano (such as more efficient key action) facilitate the attainment of faster tempos. However, all of the recordings we studied were modern-day recordings; and the fortepianos have benefitted from modern-day restoration and replication. Further, our data show that musicians
performing on fortepianos are by no means limited with their choice of tempo: the maximum fortepiano tempo exceeded that of the piano (192 bpm compared to 166 bpm).

The sampling procedure used in testing the tempo/tone-decay hypothesis for the keyboard instruments was designed to include a wide diversity of performers. We wanted to make sure that any observed effects of instrument type would not be conflated with a particular artist’s style. If we had only examined recordings by a handful of performers, then the sample would not be representative of the wide diversity of fortepianists and pianist who perform; and it would have been difficult to discern the difference between the influence of a performer or an instrument. Our sample included recordings from 39 different musicians, so we could be relatively assured that any observation of tempo variation was due to different instrument type. Unfortunately, this sampling diversity cannot be fully encapsulated by a categorical classification of instruments (i.e., harpsichord, piano, fortepiano). Each category of keyboard instruments exhibits within-category variations. Different models and makes of instruments exhibit varying sound, feel, and response—so much so that particular composers have been associated with specific makes of pianos (Hudson, 1994). So a future study of tempo and tone decay may want to seriously consider measuring both tempo and tone decay on a continuous scale.

There likely were other untreated variables that influenced tempo to a larger degree than instrument type. Indeed, none of our hypotheses predicted a direct relationship between dynamic level and tempo, but dynamics were included in the ANOVA model, which revealed a statistically significant relationship between tempo and dynamics: “slower-softer” and “faster-louder”. The ANOVA model did not include
potential factors related to the sampled music, such as year of composition, year of
performance, or overall pitch range. In particular, the lowness/highness of each musical
excerpt’s pitch range may have been a potential influence on tempo: decay length varies
across a keyboard instrument’s pitch range. So without accounting for pitch range in our
data collection and hypothesis testing, we may have introduced a significant degree of
random fluctuation in decay that was simply not accounted for by an analysis that hinged
on instrument differences.
General Conclusion

This study tested the notion that instrumental tone decay time is a potentially important influence on performance tempos. This idea was inspired partly by acoustics research (Meyer, 1978; Naylor, 1992; Winckel, 1962) that supports the notion that hall-acoustic decay can influence musical performance tempos to some degree. Additionally, musicological viewpoints have identified instrument and concert hall characteristics as an important factor in period and contextually relevant performances (Christensen, 1999; Post, 2009; Schutz et al., 2008; Stevens, 1995). In line with findings from pre-existing research, we hypothesized that one instrument-acoustic characteristic—tone-decay time—would be associated directly with tempo: shorter decay times would tend to encourage faster performance tempos and longer decay times would tend to encourage slower performance tempos.

The present study focused on tempos used when performing plucked or struck stringed instruments. We collected tempo data from recordings of North-American Folk music and Western-Classical music. Our results indicated that performances on the banjo and guitar exhibited no significant difference of average beat rate. However, the same songs performed on the banjo exhibited significantly faster note rates in comparison with the guitar. Since the banjo/guitar sample consisted of works for a single musician that both sang and played the guitar or banjo, it is possible that the performer’s chosen of beat
rate was influenced by the presence of the voice. A future study may want to investigate
tempo differences between solo guitar and solo banjo music. It may not be possible to
find matched guitar and banjo versions of each song, but a sufficiently large sample may
show differences between the tempo distribution of the guitar and banjo.

The third part of the study compared the harpsichord, fortepiano, and piano. We
found that when the same work was performed on these different instruments, there was
no significant difference of average beat rate. In addition to average tempo, we tested for
differences of tempo flexibility as might be expected if performers on early instruments
emulated performance aesthetics of earlier eras (Bowen, 1996, 2001; Hudson, 1994;
Philip, 1992). We did not observe a significant difference overall of tempo flexibility in
modern performances on early and modern instruments. Despite the overall findings
regarding instrument type, there were noticeable interpretive differences between
individual performers.

Repeated musical performances of works inevitably lead to changes of
interpretation over time. Scores, instruments, and performance spaces have undergone
numerous transformations throughout history. The resulting arrangements of works,
performances on different instruments, and changing performance venues all potentially
impact interpretive aspects such as tempo. Our study’s tempo/tone decay hypothesis was
an attempt to explain one purported influence on performance tempos. Based on intuition
and previous research, it seemed like instrument tone decay time would be an important
factor when considering variations of a work’s tempo in multiple performances. We
found evidence consistent with the notion that works without a fixed text (e.g., folksongs)
will be performed with faster note-articulation rates when performed on instruments with shorter decay times. However, both fixed-text works and non-fixed-text works did not exhibit significant changes of beat rate when performed on different instruments. These results suggest that tone decay time may have an impact on speeds of embellishments or improvised patterns, for example, but that decay time likely does not influence overall beat rates of musical performance.

Other factors likely contribute larger effects on performance tempos. One major influence on tempo is from individual performers. Performers exhibit wide ranges of technical proficiency, but equally gifted performers may have refreshingly different artistic visions of the piece. Another factor that is known to affect performance tempos is performance tradition. Even in the relatively short period of musical history since recording technology, we have witnessed changing performance traditions. For example, Robert Philip’s study (1992) has demonstrated that there are differences of tempo interpretation between pre-WWII recordings and post-war recordings. Among a number of differences, Philip observed relatively fast tempos and a higher degree of tempo flexibility in early recordings (Philip, 1992, p. 6). The present study, however, examined fairly recent recordings. Their recent date of release may be responsible for our observations of relatively homogeneous tempos; they all loosely belong to the modern performance tradition.

However, it is also plausible that musicians who choose to perform on early instruments intend to distance themselves from mainstream interpretations. While this may be true for certain performers, our observations did not show an overall association
between performance on fortepiano and faster, more flexible tempos. Some musicians might adopt both the timbres and interpretive philosophies of earlier music traditions, while other musicians might prefer to use a traditional timbre to add a fresh tone color to modern interpretation.
Endnotes

1 Although tempo is a multi-faceted phenomenon, the present study uses the word “tempo” in reference to the most common conception of tempo—beat rate. Other aspects of tempo are considered in parts two and three.

2 Reverberation can be measured in several ways, and is thus quasi-subjective. Reverberation is but one important factor in hall acoustics—others factors include: early lateral reflection, diffusion, and absorption.

3 Some might argue that changes of tempo also alter the expressive character of a work.

4 We attempted to fit Winckel’s data using several non-linear functions (quadratic and cubic), but these did not fit as well as the linear solution.

5 In some conditions, Naylor embedded irregular pulses within the sequence to determine participants “recovery time”—the time required to regain synchronization with the regular beat.

6 There are many potential banjo tunings: Dick Weissman (1989) lists 67 different tunings for the five-string banjo.

7 A number of these LPs were not listed in the online catalog, but rather in a card catalog. The card catalog was not consulted in part one of this study because the
catalog was arranged largely by composer name. Considering that many folk songs are not attributable to a single composer, and that the sampling procedure matched songs according to name, we deemed it appropriate to use the online catalog solely. Later, in part three, we consulted the card catalog for our sample of Western-Classical works.

8 It is possible that his may have excluded a few works for banjo solo; sometimes ensembles might feature a song in which the band rests while the banjoist performs a solo while singing. Examples such as this were not sought out or included in the sample.

9 Many songs have multiple name variants; these were considered while searching for potential recordings to pair with the banjo recording. Two sources were used to locate song title variants: liner notes to Pete Seeger’s *American Favorite Ballads*; and Ray Lawless (1960, p. 451-484).

10 This was an attempt to control for differences of interpretation that occur as a song is passed down through generations. It could be argued that generational changes to songs’ tempos are not as great as the influence of the performer’s age on tempo choice. For example, Paul Badura-Skoda (1993) observed that during J. S. Bach’s youth, Bach “preferred extreme tempo indications in both fast and slow movements, possibly in order to be better able to demonstrate his virtuosity” (p. 80). Regarding the actual execution of tempos, José Bowen’s tempo research (1996, p. 130) has provided some evidence showing that conductors use
remarkably similar tempos for a work performed across years and in different concert halls. However, the effect of aging on performance tempos is not understood fully (Bowen, 1996, p. 116, n. 19). Additionally, regional variations among American folksongs may be yet another factor that weighs on interpretive aspects such as tempo.

11 ChucK is an audio programming language that achieves real-time accuracy and synchronization of synthesized musical voice streams. It has applications for both composition and analysis. See http://chuck.cs.princeton.edu for resources.

12 Many sampled distributions will have some degree of skewness, but a relatively small amount of skewness that will not unduly affect any statistical tests which assume a normal distribution. A skewness score that exceeds twice the value of the standard error is one criterion for determining the presence of significant skewness. In the case of the banjo, the skewness value was -1.085, more than twice the standard error of 0.524.

13 The Wilcoxon Signed Rank Test not only measures the number of higher, lower, and tied scores between a paired distribution; but it also factors in the magnitude of higher and lower scores.

14 The alpha (α) level is the cutoff point for accepting or rejecting the hypothesis. The selected value of 0.10 signifies a probability of one in ten that a study’s results could be due to chance. Probability values for a hypotheses test that are smaller than 0.10 pass the significance test, and the hypothesis is then accepted.
Typically, more stringent alpha values of 0.05 or 0.01 are used in medicine and other sciences when the consequences of accepting a false hypothesis are serious, potentially threatening someone’s life. However, with research in the arts and humanities, an alpha value of 0.10 may be appropriate, especially when approaching a new path of research that may be followed by more conservative tests if initial studies are fruitful.

15 Since this was a post hoc hypothesis test on the same sample of pieces from hypothesis one; the Bonferroni correction was used to reduce the chance of each hypothesis being accepted in cases where the results were actually due to chance.

16 In modern usage, the term *fortepiano* is used to distinguish the modern piano from early pianos made in the 18\textsuperscript{th} and 19\textsuperscript{th} century.

17 Random sampling was used throughout the study to determine not only the works included in the sample, but also the performing artists and specific locations within the works. Numbers were generated using http://www.random.org—a random number service provided by Mads Haahr of the School of Computer Science and Statistics at Trinity College, Dublin.

18 Ripin et al. (2010) note that the presence of dynamic markings in some C. P. E. Bach’s keyboard scores suggests that they were conceived to be performed on clavichord (despite their indication “for harpsichord”).

19 The mean absolute deviation (MAD), like standard deviation and range, is a measure of a distribution’s dispersion. Using MAD is more appropriate than using
range in small samples. In non-normal distributions, outliers influence MAD less than SD (Gorard, 2005).
References


Indiana University Folklore Institute, Archives of Traditional Music. (1975). A catalog of phonorecordings of music and oral data held by the Archives of Traditional Music. Boston: G. K. Hall.


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Appendix A: Participant-Selected Musical Excerpts

<table>
<thead>
<tr>
<th>Composer</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baermann, C.</td>
<td><em>Variations</em> – No. 25, var. 1</td>
</tr>
<tr>
<td>Bartók, B.</td>
<td><em>Concerto for Orchestra</em> – mvt 1, mm. 488-514</td>
</tr>
<tr>
<td>Brandt, A., &amp; Haymes, B.</td>
<td>‘That’s All’ – mm. 1-8</td>
</tr>
<tr>
<td>Brown, C.</td>
<td>‘Joy Spring’ – mm. 1-15</td>
</tr>
<tr>
<td>Cirone, A. J.</td>
<td><em>Portraits in Rhythm</em> – No. 3, No. 4, No. 18</td>
</tr>
<tr>
<td>Davis, M.</td>
<td>‘Donna Lee’ – mm. 1-16</td>
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<td>Dennis, M., &amp; Brent, E.</td>
<td>‘Angel Eyes’ – mm. 1-8</td>
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<td>Dietz, H., &amp; Schwartz, A.</td>
<td>‘Alone Together’ – mm. 1-4, with repeat</td>
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<td>Ginastera, A.</td>
<td><em>Variaciones Concertantes</em> – mvt. I, mm. 1-7</td>
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<td>‘Body and Soul’ – mm. 1-16</td>
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<td><em>Berenice</em> – ‘Si, tra i ceppi,’ mm. 1-24</td>
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<td>Mozart, W.</td>
<td><em>Marriage of Figaro</em> – Overture, mm. 1-18</td>
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<td>Mozart, W.</td>
<td><em>Marriage of Figaro</em> – ‘Se vuol ballare,’ mm. 1-20</td>
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<td><em>Sound of Music</em> – ‘Edelweiss,’ mm. 1-16</td>
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<td><em>Sonata for Clarinet and Piano</em>, Op. 167, mvt. 1, mm. 1-11</td>
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<td>Schubert, F.</td>
<td><em>Die schöne Müllerin</em> – ‘Wohin?,’ mm. 2-18</td>
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<td>Tchaikovsky, P.</td>
<td><em>Symphony No. 6</em> – mvt. I, mm. 1-6</td>
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Appendix B: Script used in the Mental Practice Experiment

*note: Instructions for the experimenter are given in brackets – [ ]

[Introduction]

Thank you for participating in this experiment and for preparing your musical excerpts in advance of this session. [If participant is an instrumentalist, then ask her to unpack and assemble her instrument now.] I know that this took some hard work, but I hope that it was useful in your practicing of your instrument/voice. In a minute you will have some time to warm up, but first I would like to give you an overview of this experiment.

[Experiment, part one overview]

In this study, I am interested in investigating musicians’ abilities to maintain a steady tempo; including how well musicians can imagine a piece in a steady tempo. In the first stage of the experiment, we will record two takes of your lyrical excerpt. Your main goal in this recording is to give a performance in a steady tempo with accurate pitches and rhythm; please do not add any expressive accelerations or decelerations. The first take will be a dress rehearsal and the second take will be the example we actually use in the next stage of the experiment. We will also do two recordings of your technical excerpt and again we will use your second performance. Later in the experiment, we will listen to your second performance of each excerpt, so please keep this one in mind as your point of reference.

[Begin the first part of the experiment]

When you are ready, go ahead and play a few notes to warm up. Then, we will start with your lyrical excerpt. [Begin recording and sound check. Participant warms up, performs excerpt, and ends. If participant does not make it through the excerpt, then keep the tape rolling and allow for a restart.] Thank you. Now, let’s do the second and final take. [Record second take. Allow for up to three restarts. If none of those are acceptable, then take whatever version (first or second) is acceptable.] Thank you, that is all for the first part of this experiment. Please fill out this survey [Ollen Musical Sophistication Index] while I burn your recording to CD. [Do CD burn. Check microphone to make sure it is on. Put recorded CD into CD player and then put another blank CD into the CD recorder. Put CD recorder into record mode.]
In this part of the experiment, you will be listening to the beginning three seconds of your recorded excerpts. Then, the audio will fade to silence while you continue to imagine the continuation of the piece. During this whole process please keep your body as still as possible and follow along with the score, both of which will help you maintain a steady, internalized performance of the piece. At the imagined onset of the last note of the excerpt, ring the bell sharply. Let’s do a test trial for the bell while you listen to the entire excerpt. Don’t worry about imagining the piece right now: just focus on ringing the bell at the onset of the last note. Do you have any questions? [Record bell ring baseline trial lyrical1, then record bell ring baseline trial technical1]

Over the course of the next twelve trials you will use two different imagination strategies. One strategy is what I call the Imagined Sound strategy. With this technique you internally re-produce and “hear” the sonic qualities of your piece as it unfolds in time. The other strategy is dubbed the Imagined Movement strategy. With this technique you will imagine the body movements that occur during a performance of your piece. You won’t actually move any part of your body, you will just internally re-produce the motions and physical sensations that take place when performing your piece. Whichever imagination technique you are using, try to make it as vivid and close to reality as possible. We will start with six trials of the [IS or IM, depending on the counterbalanced order] condition. Over the course of these six trials you will use the same imagination technique as you imagine the lyrical and technical excerpt in alternation. Do you have any questions?

For these trials you will be using the [IS or IM] strategy. Take a moment to acclimate yourself to that mode of thinking. Are you ready? Here is your lyrical excerpt. [check playback volume, play appropriate track through the player, fade out over the course of 3 seconds of the excerpt, once the bell ring occurs the trial is over] Now, here is your technical excerpt. [repeat same procedure as above] Next, we will do two more repetitions of each piece. [repeat]

In the next six trials you will be using the [IS or IM] strategy. Do you have any questions about the new strategy? Take a moment to switch and adjust to that mode of thinking. Are you ready? Here is your lyrical excerpt. [check playback volume, unpause recorder, play appropriate track through the player, fade out over the course of 3 seconds of the excerpt, once the bell ring occurs the trial is over, hit pause on the recorder and then the player] Now, here is your technical excerpt. [repeat same procedure as above] Next, we will do two more repetitions of each piece. [repeat]

For the final two trials I’d like you to just listen to your entire excerpt and then ring the bell on the final note as you did in the first two test trials. [Record bell ring
Thank you very much; the experiment is over.

[Debriefing]

I greatly appreciate your participation in this study. Before I answer any questions that you may have, please let me ask you a few questions and then tell you about the background and motivations for this study.

- What do you think this experiment is all about?
- How difficult was it to imagine the sound of your piece?
- How did that task compare to imagining the movements of performing your piece?
- With either of your imagination techniques did you feel a part of your body, such as your arm or voice box, tense up, or prepare to move, or actually move?
- How well prepared did you feel when performing your excerpts?
- Do you have any questions about this study? [Field a few questions.] Thank you for your participation. Have a great day. [Small talk, etc.]
### Appendix C: Sampled Banjo and Guitar Solo Works

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Appendix D: Sampled Harpsichord, Fortepiano, and Piano Works

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</table>
// the device number to open
0 => int deviceNum;

// instantiate a Hid object
Hid hi;
// structure to hold HID messages
HidMsg msg;

// open keyboard; exit if no kybd detected
if( !hi.openKeyboard( deviceNum ) ) me.exit();

// successful! print name of device
<<< "keyboard ", hi.name(), " ready " >>>;

// infinite event loop
while( true )
{
    // wait on event
    hi => now;

    // get one or more messages
    while( hi.recv( msg ) )
    {
        // check for action type
        if( msg.isButtonDown() )
        {
            // print value of current time in seconds
            <<< now/second >>>;
        }
    }
}