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Research Studies in Music Education 2011 33: 3
DOI: 10.1177/1321103X11400501

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Musical tempo stability in mental practice: A comparison of motor and non-motor imagery techniques

Randolph B. Johnson
Ohio State University, USA

Abstract
The ability to maintain steady tempos using two different mental practice techniques was assessed through measurement of excerpt duration fluctuations. Ten musicians of various voice and instrument types participated in a two-part experiment. First, I recorded participants’ metronomic performances of lyrical and technical excerpts, which were selected from their repertoire. Next, participants mentally rehearsed their two excerpts over a total of 12 trials. Participants attempted to imagine a steady tempo that reflected the tempo of their actual performance. During each trial, participants heard a 3-second prompt from their recorded performance; following the prompt, each participant continued to mentally rehearse the respective excerpt while using one of two strategies. Participants engaged in two types of mental practice: non-motor imagery and motor imagery. At the end of each trial, participants rang a call bell to indicate each imagined excerpt’s ending articulation. Analysis of the magnitude and direction of excerpt duration discrepancies showed no significant differences in mean tempo accuracy when using the two different mental practice strategies. Non-motor and motor imagery exhibited differences of tempo variance across the two excerpt types: non-motor imagery was more consistent internally across a broad range of tempos. I also observed two significant interactions between successive mental rehearsals: musical sophistication and excerpt note density. In addition, repeated mental rehearsals of a musical tempo seem to settle into a more precise tempo; and motor imagery might provide support for this phenomenon. Both motor and non-motor forms of imagery may have specific applications to different goals in the mental rehearsal of musical tempo.

Keywords
auditory imagery, mental practice, motor imagery, musical time, music performance, rehearsal techniques, tempo, tempo stability, visualization

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 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 addressed one potential use of musical imagery – increasing the stability of musicians’ tempos. Specifically, I compared 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). I elected to use the term ‘non-motor’ rather than ‘auditory’ (e.g., Highben & Palmer, 2004) because it is 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 investigated 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.

Prior to considering the issue of tempo stability, musicians usually address the choice of tempo. Tempo choice can influence the perceived structure and emotional character of a work. Consequently, there has been much discussion regarding the authenticity of performance tempos (e.g., Badura-Skoda, 1990/1993; Bowen, 1996; Brown, 1999; Hudson, 1994; Philip, 1992). Some musicians might suggest that a ‘note-perfect’ performance nonetheless contradicts a composer’s intention if the tempo is inappropriate. 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.

Once a performer has a conception of a given tempo choice, the replicability of that tempo from rehearsal to rehearsal and on to performances is not necessarily guaranteed. 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 many situations in which musicians may desire tempo stability, I focused on the issue of overall tempo stability. In brief, I explored 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 et al., 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, I 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, 1930; Ristad, 1982, p. 119); thus the term ‘mental’ does not necessarily exclude very small movements of muscles, and involvement from the peripheral nervous system. Some authors have focused on these small movements as an explanation of mental practice’s efficacy. 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.

However, different achievement levels between cognitive and physical goals of mental practice could result – in whole or in part – from an interaction between participants’ experience and task type: 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 well 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 just be a way for musicians to rest physically while continuing to practice mentally. 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,
Eloise Ristad has viewed mental practice as a way for muscle patterns to ‘begin to change and become more dependable, more repeatable, less erratic’ (1982, p. 121). While a number of different mental practice techniques have been identified and researched (e.g., Lim & Lippman, 1991), few studies have compared different types of musical imagery used in mental practice. 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.

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, proper 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 were 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 stratification of practice benefits: for rhythmic accuracy, physical practice was significantly better than either form of mental practice, but 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 into 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% and 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% and 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, I proposed that mental rehearsal of rhythm might be best achieved through imagery of kinesthetic feedback and body motion.
Hypotheses

- Hypothesis 1 – ‘Mental practice type’: The magnitude of tempo alterations during mental practice can be minimized using an imagination strategy that focuses on the performer’s physical movements (motor imagery) rather than just the imagined sound of the piece (non-motor imagery).
- Hypothesis 2 – ‘Tempo flux’: Musicians alter tempo while imagining their own performances of a piece. The direction and magnitude of alteration is inversely related to note density (average number of notes per second (nps)): (1a) ‘technical’ pieces, exhibiting high note density, will tend to slow; and (1b) ‘lyrical’ pieces, exhibiting low note density, will tend to quicken.

I posited these two hypotheses and selected a significance level ($\alpha = 0.10$) a priori. The mental practice type hypothesis predicted that motor mental practice of tempo would exhibit smaller tempo discrepancies. The tempo flux hypothesis predicted 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 1 arose from selected, previous research, and introspection of my 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.

Guillot and Collet (2005) have reported that in mental imagery, which uses ‘image scanning’ (p. 10), one would expect that longer scanning durations would be linked to image scanning over longer distances. 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 1 is making the correct prediction.

However, the physical distances traversed when performing an instrument are linked closely to resulting tempo of a work, and other evidence suggests that motor imagery may offer an advantage in musical timing. Repp’s (1999) study of expressive timing in piano playing has suggested 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, they could accurately produce either expressive or stable tempos as called for by musical context.

In early formulation of hypothesis 2, before the formal experiment, I 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 my own mental practice of tempo. Often, it seemed that tempos increased internally, but after some more informal observation, I 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: mean standard deviations of duration were 1.92% when playing, and 3.48% when imagining; imagined performances were an average of 8.9% longer than actual performances (Clynes & Walker, 1982, p. 188–191).

Wöllner and Williamon’s (2007) mental imagery condition led to lengthened IOIs (associated with slower tempos), which also ran contrary to the present study’s early hypothesis. 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 my study is more similar to the tasks in the studies by Clynes and Walker (1982) and Wöllner and Williamon (2007), we would 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 excerpt difficulty. 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, I formulated hypothesis 1 in such a way that associates tempo fluctuations with difficulty (defined by note density). I predicted that a speeding of tempo (compared to actual performance) would occur in mental practice of low-density excerpts; and a slowing tempo would occur in mental practice of high-density excerpts.²

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 (a) ascertain a potential enhancement of tempo stability when imagery content (motor) matches the physical motions used when performing a musical piece, and (b) understand better the effect of musical characteristics such as note density on tempo drift.

Method

Participants

Sixteen participants took part in the experiment. There was 1 graduate student volunteer, and 15 sophomore music students, who participated through Ohio State University’s music subject pool. The undergraduate participants selected the present study from one of several offered studies. I employed an ecological design: musicians of various instrument/voice types were
recruited; each participant brought two contrasting excerpts from his or 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 in the study. Instruments represented were: 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 excerpts.

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 and to create an index of the repertoire used by the participants (see Appendix). I calculated note density by counting the number of notes in each excerpt and dividing the note-count value by the duration of the respective excerpt. I 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 or she was greeted, 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.

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 a survey developed by Joy Ollen – the Ollen Musical Sophistication Index ‘OMSI’ (Ollen, 2006). In many psychological studies participant groups have been divided into nominal categories, ‘nonmusician’ and ‘musician’. The OMSI is a continuous, numerical measure based upon a brief survey considering factors such as years of musical training, weekly practice time, listening experience and composition experience. The OMSI is an important tool in screening for some individual differences between formally trained musicians, and also for studying the musical abilities of people who may not call themselves musicians, yet who have varying degrees of musical ability.

Empirical research on human behaviour can make inferences about internal states through measurement of overt actions. Paradoxically, mental practice is difficult to study because research measurement requires overt behaviour 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, I attempted to reduce overt behaviour further – by distilling participants’ overt behaviour 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 3-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 3 seconds. As the excerpt faded to silence, participants continued the excerpts using mental imagery (detailed below) as they followed along with the score. 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 I did not use a ‘mental practice with listening’ condition (as used 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 3-second auditory prompt excerpted from the participant’s own recording, and then the participant mentally practised in silence. Participants practised the excerpt mentally in one of two ways: (a) ‘Imagined Sound’ condition – mental imagery of sounds; and (b) ‘Imagined Movement’ condition – mental imagery of body movements. One mental practice condition was used for the first six trials. Then, the participant rested for 1 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-second excerpt and rang the call bell after 28-second in a mental practice trial, then delta would equal 2 seconds. 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. I 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

The mean length of the lyrical excerpts was 28.6 seconds (SD = 5.8 s); the mean technical excerpt length was 21.3 seconds (SD = 7.5 s). The average tempo of the technical excerpts performed by all participants was 144 beats per minute (bpm); the average tempo of lyrical excerpts was 63 bpm. The tempos chosen by participants ranged from approximately 36 bpm to 86 bpm for lyrical excerpts and 104 bpm to 177 bpm for technical excerpts. Participants’ OMSI scores ranged from 141 to 917 (mean = 656; SD = 238 (one missing value)).

Table 1 summarizes each participant’s particular tempo choices. In addition to note density, tempo is offered here for descriptive purposes. The tempos are approximations made by the experimenter using a metronome equipped with tapping pad.8

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),

<table>
<thead>
<tr>
<th>Trial Sequence:</th>
<th>IS1</th>
<th>IS2</th>
<th>IS1</th>
<th>IS2</th>
<th>IS1</th>
<th>IS2</th>
<th>IM1</th>
<th>IM2</th>
<th>IM1</th>
<th>IM2</th>
<th>IM1</th>
<th>IM2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counterbalanced Sequence:</td>
<td>IM1</td>
<td>IM2</td>
<td>IM1</td>
<td>IM2</td>
<td>IM1</td>
<td>IM2</td>
<td>IS1</td>
<td>IS2</td>
<td>IS1</td>
<td>IS2</td>
<td>IS1</td>
<td>IS2</td>
</tr>
</tbody>
</table>

Table 1. Mental practice trial sequence and counterbalanced sequence: Imagined sound (IS) and Imagined movement (IM). The lyrical excerpt (1) and technical excerpt (2) were interleaved.
but with the use of the imagined sound condition, there was no significant difference of discrepancy variance between excerpt types ($t = -1.5, p > 0.10$). This suggests that the imagined sound strategy may result in greater internal consistency of durations across lyrical as well as technical excerpts. The relationship between mental practice strategy and the target tempo is tested below.

Musicians receive a wide variety of training, and have markedly different approaches to practising. During post-experiment interviews with each participant, it was apparent that some musicians were more familiar with using a particular mental practice type than the

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)

<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></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>

Figure 2. Excerpt duration discrepancies (delta) by participant; here, no distinction is made between excerpt type and mental practice strategy. Negative delta values reflect mental practice attempts that exhibited slower tempos (longer durations)
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., skin conductance, heart rate, respiratory frequency): athletes exhibited ‘wide individual differences’ in the quality of their imagery (Roure et al., 1999, p. 70). The results not only indicate individual differences of overall imagery quality between musicians, but they suggest that musicians’ imagery quality may depend upon both the type of imagery and the characteristics of the musical excerpt.

To illustrate these individual differences, Figure 3 shows the excerpt duration discrepancies for each participant across both excerpt type and strategy.

Some different patterns emerged from each participant:

**Better tempo consistency with lyrical excerpt, despite strategy (Participant 13)**

Participant 13 (voice) was more accurate 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.

![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](image-url)
Better tempo consistency with technical excerpt, despite strategy (Participant 10)
Participant 10 (cello) 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 lowest combinations of tempo and note density among all excerpts.

Consistent slowing of tempos in all conditions (Participants 3, 5 and 16)
Participant 16 (jazz piano) consistently slowed tempos during mental practice, and was relatively unaffected by excerpt type or strategy. However, the task of imagining both melody and accompaniment is quite different from 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, 2005). Participant 3 (jazz saxophone) and participant 5 (snare drum) also exhibited this same pattern 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 speed of tempo regressions to the mean (e.g., Halpern, 1988).

Speeding of lyrical excerpts, and slowing of technical excerpts (Participants 4, 12 and 15)
Participant 15 (percussion) speeded up the lyrical excerpt and slowed down the technical excerpt, with little difference of impact from imagination type. This pattern was consistent with my tempo-flux hypothesis. The 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: participants 4 (bassoon) and 12 (voice).

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

Better 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.

Tests of Hypothesis 1 – ‘Mental practice type’
Hypothesis 1 predicted that the magnitude of tempo alterations would be minimized through the use of motor imagery in mental practice. Consequently, I 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 seconds ($SD = 0.35$); mean 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 consistent with the notion that the magnitude of tempo alterations during mental practice using motor imagery is the same as the alterations occurring when using non-motor imagery.

The above test of duration discrepancy 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. I measured two such characteristics: tempo (beat rate) and note density. In addition, I measured each participant’s musical sophistication using the OMSI survey. 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 combination, these measures gave me the opportunity to compare the magnitude of duration discrepancies 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, I conducted a 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 rehearsal on tempo stability.

The data structure met Mauchly’s criterion for the assumption of sphericity ($p = 0.61$); therefore, I 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 was not significant, $F(2, 19) = 2.176, p = 0.141$. 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 successive trials and one or more between-participant variables. In brief, two two-way interactions were significant, one four-way interaction was significant, and one five-way interaction was significant.

The interactions involving more than two variables are difficult to conceptualize and articulate verbally, but a closer examination of the two-way interactions may offer some insights into the relationship between mental practice and musical characteristics:

1. OMSI scores and successive trials exhibited a significant, interactive effect on duration discrepancy, $F(2, 19) = 6.67, p = 0.006$. This interaction 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 discrepancies.
Research Studies in Music Education 33(1)

16

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 discrepancies (delta) become smaller overall and more similar to other musicians’ fluctuations 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.

2. Excerpt density and successive trials also were 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 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 results are consistent with the notion that in low-note density excerpts, timing discrepancies accrue over repeated mental rehearsals.

In addition to these two-way interactions, there were also higher order interactions: (a) number of successive rehearsals, OMSI score, excerpt tempo and excerpt density were a significant four-way interaction, $F(2, 19) = 7.88, p = 0.0032$; and (b) number of successive rehearsals, OMSI score, excerpt tempo, excerpt density, and mental practice strategy comprised a significant five-way interaction, $F(2, 19) = 7.69, p = 0.0036$. These types of interactions are very

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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 discrepancies (delta) become smaller overall and more similar to other musicians’ fluctuations.
difficult to conceptualize, graph and discuss. However, the four-way and five-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 artefact that came from the ecological design of the present experiment – participants played different excerpts on different instruments.

Tests of Hypothesis 2 – ‘Tempo Flux’

In this hypothesis test, I no longer considered only the magnitude of duration discrepancies, but also their direction. Consequently, I used the signed value of duration discrepancies in my 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 I conducted a one-way ANOVA of tempo discrepancies versus excerpt density. I 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, I made no distinction between mental practice strategies, but rather calculated mean duration-discrepancy values for each excerpt. The results showed a non-significant effect of excerpt density 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 my 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 regions or tempo densities. On the other hand, perhaps overall musical experience and sophistication determines tempo stability.

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

![Figure 6](image)

**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 discrepancy values as density increases, the discrepancy values seem to undulate while hovering close to zero. The dramatic 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.
The structure of my data failed Mauchly’s test for sphericity ($p < 0.05$); therefore, I 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 agreement with the first ANOVA, 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 was 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, 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 my 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 the experiment’s length offers some assurance that participants were undertaking productive mental practice, and not becoming overly fatigued.

If an association between mental practice repetitions and tempo accuracy exists, 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.

This result should be considered cautiously because of the post-hoc nature of this hypothesis test. The graphs in Figure 7 represent an agglomeration of the data from the IS and IM conditions, but subjects 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 the 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, I examined tempo fluctuations in two groups of participants: (a) those who used six IM rehearsals followed by six IS rehearsals (n = 5); and (b) 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 12 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 I 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, discrepancies remained relatively the same. (Perhaps the mental image of the tempo had already been solidified by the six IM trials.) In contrast, the IS–IM arrangement exhibited higher overall discrepancy (mean 1.0 s). Participants began by using the IS technique; when IM practice followed, there was a significant improvement of tempo stability.

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 discrepancies ($r = -0.30; p = 0.023$).
These results suggest that further study of Sills’s 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 I 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 (see 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, 10 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).
Results summary

Detailed discussion of these results follows, but in brief:

- Mental practice of technical excerpts exhibited less tempo variance than lyrical excerpts.
- When musicians used motor imagery, technical-excerpt tempos exhibited less tempo variance than lyrical excerpts.
- However, when musicians used non-motor imagery, technical and lyrical excerpts both had comparable tempo variances.
- 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.
- 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.
- However, there were two significant interactions that where interpretable: (a) as musicians of varying experience continue to mentally rehearse tempo, the sizes of their tempo discrepancies become both smaller and more alike; and (b) 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 stay the same with repeated mental rehearsals.
- Excerpt note density did not significantly affect the magnitude and direction of tempo discrepancies.
- Number of successive trials, excerpt tempo, excerpt note density, mental practice strategy and OMSI 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 tend to become more temporally consistent. Motor imagery tends to boost timing improvements when added after non-motor imagery. When the practice session begins with motor imagery and ends with non-motor imagery, the tempo discrepancies tend to stay constant, and as small as the final state of non-motor followed by motor imagery condition.
- 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 tempo variance than imagined, lyrical excerpts seems to confirm the common practice of 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, I could not have predicted this effect because the experiment involved mental imagery of musical work. The purportedly greater effort involved in imagining technical excerpts could have been associated with greater mental tempo fluctuations or a general trend of slowing tempos – I found neither result to be significant in the 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). I 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 suggests that difficulty is minimized at moderate levels of note density. At low and perhaps high note density states, musical tasks appear to become difficult. They may not become 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 the 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, the 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. The results did not confirm this theory. Thus, it seems as if the requirements for a physical response task or musical performance are 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 the non-significant experimental results is the effect of memory, which seems to cause a regression to a mean tempo. The experimental design called for alternation of lyrical and technical excerpts. This was intended to control for the possibility of participants’ 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 excerpts 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 be a complete account for duration/tempo fluctuations – another potential explanation to consider is filled duration illusion (FDI). 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, which is a well-known phenomenon from the psychological research literature. 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, 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 because of 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, 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).

I 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 few notes filling in beats. Rather than a trend to speed up or slow down, I 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, I did not manipulate tempo or density. Future studies might benefit from investigating the effect of the FDI on musical performance and mental rehearsal.

If I 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**

I 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
several 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 tempo 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 relatively small (mean, absolute value of excerpt duration discrepancies = 0.83 s; SD = 0.72); musicians are quite accurate with this type of task.

There was some evidence favouring use of imagined-sound strategy 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.

I 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 may 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 the experiment also yielded some insights into the effects of successive mental rehearsals. There were statistically significant effects between successive trials and musical sophistication: the participants exhibited varying levels of experience, but as they continued to mentally rehearse tempo, their tempo-discrepancy profiles become both smaller overall and more similar to each other. This result is encouraging because it suggests that the benefits of musical-temporal mental practice are equally available for musicians of varying 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 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 of 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.
It is important to conduct further studies upon mental practice. Despite my observation of a number of non-significant differences between motor and non-motor forms of mental practice in the present study, there were some subtle differences. Participants also seemed to have gained some benefit from the experiment's mental practice. Perhaps this was most apparent when several musicians mentally fixed rhythmic errors that were committed in their actual performance, such as omission of rests. During post-experiment interviews, participants generally expressed a view/belief that mental practice was beneficial.

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 practising 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, 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. For example, conductors and instrumentalists who use mental practice might better achieve a high level of tempo accuracy from performance to performance.
In addition, interpretive decisions could be made depending on knowledge concerning a composer’s method for determining a work’s tempo. Clive Brown has proposed that ‘reasonable arguments, based on psychological and experiential ground, might lead to the plausible conclusion that composers’ perceptions of tempo in their imagination may have been faster than they would require in performance and that this often results in metronome marks at the upper limit of ‘practicable tempo’ (Brown, 1999, p. 288); Brown speculates that there is probably not a huge margin of error between imagined tempos and ‘practicable’ tempos. However, composers likely use different types of imagery.

How would a work’s ideal tempo/tempo range be impacted if a composer worked in one of the following ways? For example: (a) use of a metronome to determine precise MM markings during actual rehearsals of the work in a concert hall; (b) use of a metronome with performance of a reduced version of the work on piano; (c) imaginary, ‘at the composer’s desk,’ rehearsals of a work assisted by a metronome; or (d) mental comparison of the newly composed work with pre-existing pieces with a specific tempo expression (e.g., allegro maestoso). Controversies surrounding composers’ tempo markings abound. With further understanding of musicians’ working methods, specifically the potential biases introduced during mental practice, we may eventually come to a better understanding of a piece’s intended character.

Mental practice is a legitimate way for musicians to rehearse music with particular attention to its temporal structure. Although much imagery research has focused on visual and linguistic modes of imagery (see review in Denis, 1989/1991), musical imagery – consisting of either auditory or kinesthetic modalities or both – offers a powerful tool to musicians who wish to add variety to their practice routine, or who wish to lessen the strain of solely physical practice. Overall, the participants in this study were quite successful in reproducing their music mentally with little disturbance in tempo. The observed fluctuations of tempo were small.

Motor and non-motor forms of mental practice did not significantly 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 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.

Acknowledgements

This study is drawn from the author’s dissertation, which was submitted to Ohio State University in partial fulfillment of a PhD in music theory.

Notes

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) upon performance duration. However, technical excerpts tend to be performed at faster tempi and this could confound the results.
Specifically, Vos et al. (1995) found that judgments of accelerations and decelerations in tempo are dependent upon 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 upon 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. As musicians are often called upon 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.

4. 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 as it included performances from one jazz pianist. Since the lead sheet represented only the melody, to which the pianist added improvised, chordal voicings, I 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.

5. 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 5 minutes, giving ample time for heart rates to return to normal.

6. Participants listened to a professional recording of a piece during mental practice (see also Coffman, 1990).

7. Actual excerpt lengths and imagined excerpt lengths were calculated using the waveform visualization window and time counter within Apple’s GarageBand software program (GarageBand is a trademark of Apple Inc., registered in the US and other countries). 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.

8. 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, subdivisions, 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.

References


**Author biography**

**Randolph B. Johnson** is a recent recipient of a PhD in music theory from Ohio State University, USA. His recent research has used cognitive and systematic techniques to address issues in 19th-century orchestration, facial expression and singing, and the intelligibility of musical lyrics. He is an active teacher and performer.

**Appendix: 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>
</tr>
<tr>
<td>Dennis, M., &amp; Brent, E.</td>
<td>‘Angel Eyes’ – mm. 1–8</td>
</tr>
<tr>
<td>Dietz, H., &amp; Schwartz, A.</td>
<td>‘Alone Together’ – mm. 1–4, with repeat</td>
</tr>
<tr>
<td>Ginastera, A.</td>
<td><em>Variaciones Concertantes</em> – mvt. I, mm. 1–7</td>
</tr>
<tr>
<td>Green, J.</td>
<td>‘Body and Soul’ – mm. 1–16</td>
</tr>
<tr>
<td>Handel, G.</td>
<td><em>Berence</em> – ‘Sì, tra i ceppi,’ mm. 1–24</td>
</tr>
<tr>
<td>Mozart, W.</td>
<td><em>Marriage of Figaro</em> – Overture, mm. 1–18</td>
</tr>
<tr>
<td>Mozart, W.</td>
<td><em>Marriage of Figaro</em> – ‘Se vuol ballare,’ mm. 1–20</td>
</tr>
<tr>
<td>Rogers, R., &amp; Hammerstein, O.</td>
<td><em>Sound of Music</em> – ‘Edelweiss,’ mm. 1–16</td>
</tr>
<tr>
<td>Saint-Saëns, C.</td>
<td><em>Sonata for Clarinet and Piano</em>, Op. 167, mvt. 1, mm. 1–11</td>
</tr>
<tr>
<td>Schubert, F.</td>
<td><em>Die schöne Müllerin</em> – ‘Wohin?,’ mm. 2–18</td>
</tr>
<tr>
<td>Tchaikovsky, P.</td>
<td><em>Symphony No. 6</em> – mvt. I, mm. 1–6</td>
</tr>
</tbody>
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