IMAGINING THE MUSIC:

METHODS FOR ASSESSING MUSICAL IMAGERY ABILITY

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RUNNING HEAD: IMAGINING THE MUSIC

ABSTRACT

Timing profiles of live and imagined performances were compared with the aim of creating a context-specific measure of musicians' imagery ability. Thirty-two advanced musicians completed imagery use and vividness surveys, and then gave two live and two mental performances of a two-minute musical excerpt, tapping along with the beat of the mental performances. Profiles of inter-beat-intervals for each performance were generated; correlations were calculated within and between the two performance conditions and then compared with results from the surveys. All participants achieved a significant correlation between the timing profiles within the live condition, while less than 70% did so within the mental condition and between the two conditions. Significant correlations emerged between the imagery vividness measures and results from the live condition, and self-reported time spent employing imagery significantly correlated with results from the live and mental conditions. This suggests that mental chronometry can offer an indication of imagery ability, warranting further research to facilitate more accurate interpretations of results and refinement of testing procedures.

Keywords: imagery; mental chronometry; mental skills; performance science; music education

INTRODUCTION

Musicians commonly engage in imagery as part of their typical learning and performing routines (Lehmann, 1997) and in doing so stand to derive a number of benefits, such as enhanced expressive and interpretive understanding (Connolly & Williamon, 2004). Imagery can also be employed when physical practice is not possible, due to situational or physical constraints for example, and by substituting for excessive practice can assist in the prevention of performance-related injuries (Nordin & Cumming, 2005). It can also be employed during performance to enhance projection of expressive ideas (Woody, 2006).

While often referred to as mental rehearsal by musicians, imagery has been defined as:

> …an experience that mimics real experience. We can be aware of "seeing" an image, feeling movements as an image, or experiencing an image of smells, tastes or sounds without actually experiencing the real thing…. It differs from dreams in that we are awake and conscious when we form an image (White and Hardy 1998, p. 389).

More in line with music performance, imagery can also be thought of as the:

> …cognitive or imaginary rehearsal of a physical skill without overt muscular movement. The basic idea is that the senses—predominantly aural, visual, and kinesthetic for the musician—should be used to create or recreate an experience that is similar to a given physical event (Connolly and Williamon 2004, p. 224).

Having the capacity to assess imagery ability accurately is of particular benefit for researchers, musicians, and those involved in musicians' training. While the assessment of musical skills has a long history, particularly within settings such as conservatoires, assessment of mental skills that musicians employ, such as imagery, is less well developed. Given that music is a domain largely oriented around sound, one would expect the ability to hear and recreate accurately a particular piece of music in the mind to be a central feature of musicians' ability to engage in imagery. Taken into account within this are the accuracy of the melodic and temporal contours of the music, the vividness of expressive qualities, and the sounds of accompanying instruments or parts. However, musicians not only need to "hear" or recreate each of these elements particular to the music they play but it can also be of particular benefit for them to be able to "see" their score, instrument, or the space in which they are performing and "feel" the emotions and sensations involved during an actual performance, as well as the physical movements required to sing or play their instrument (for a discussion of the various aspects of imagery specific to music, see Godøy & Jørgensen, 2001).

Assessing musicians' imagery abilities

General aspects of imagery ability

One of the most common approaches to assessing imagery has been the use of self-report questionnaires such as the shortened form of *Betts' Questionnaire upon Mental Imagery* (Sheehan, 1967), the *Auditory Imagery Scale* (Gissurarson, 1992), the revised *Vividness of Visual Imagery Questionnaire* (Marks, 1995), and the *Movement Imagery Questionnaire - Revised* (Hall & Martin, 1997). The former three of these questionnaires provide participants with a written stimulus or sensory experience, the latter requests the participants to physically perform a series of movements, following which the participants attempt to imagine or recreate that experience or movement and then give a rating concerning how vivid their experience of it was. Despite their widespread use, there are two challenges inherent in these types of questionnaires when used with musicians. Firstly, they employ self-report ratings which can lead to problems when aiming to compare scores between participants (Guillot & Collet, 2005a). Secondly, none of the sensory experiences included actually bear much resemblance to the types of imagery musicians typically engage in.

Supported by work in human movement sciences which suggests that imagery processes are mediated by neuronal mechanisms similar to those used in perception (Jeannerod, 1994; Kosslyn, Ganis, & Thompson, 2001; Mellet *et al.*, 1998), a number of studies have explored the functional equivalence between a variety of perceived and imagined musical sounds and sound qualities (Halpern & Zatorre, 1999; Janata & Paroo, 2006; Pecenka & Keller, 2009). Participants completed tasks such as making similarity judgments about the timbre of heard or imagined instruments, listening to or imagining pitch intervals, and creating an image of raising a tone or chord stepwise. A similar method was employed by Aleman, Nieuwenstein, Böcker, and de Haan (2000) who required their participants to identify which of two specific notes within a familiar song were of a higher pitch, first by listening to the song and then by imagining the song. Fine and Younger (2004; Fine, 2002) have investigated singers' ability to sight-sing individual intervals or unfamiliar songs, exploring the impact that other parts, such as other singers or accompaniment, and auditory representations have on this ability. Similar to this, other researchers have employed a so called "notational audiation" technique (Brodsky, Henik, Rubinstein, & Zorman, 2003; Brodsky *et al.*, 2008; Highben and Palmer, 2004; Kalakoski, 2007). This approach requires participants to identify a familiar melody embedded within a score of specially-composed music via silent sight reading (for an exhaustive review of research on auditory imagery, see Hubbard, 2010). In general, these types of studies have led researchers to suggest that musicians are capable of producing musical images in real time that contain information concerning melodic and harmonic relationships. Hence, musical images can possess a sensory quality that is similar to the experience of perceiving.

The importance of investigating the accuracy of temporal aspects of musicians' imagery in addition to melodic aspects has been highlighted. For instance, in their investigation of the contribution made by auditory imagery abilities to musicians' sensorimotor synchronization skills, Pecenka and Keller (2009) noted a distinction between melodic and temporal aspects of musicians' auditory imagery. Given the multi-sensory nature of musicians' imagery, together with the range of functions for which imagery can be employed by musicians (e.g. Connolly & Williamon, 2004; Gregg & Clark, 2007; Gregg, Clark, & Hall, 2008), a range of methods is needed in order to assess these different aspects or components of imagery ability. Many assessment methods address only specific elements of imagery (i.e. melodic, temporal, or vividness); few measures if any are comprehensive enough to assess all components.

Temporal aspects

Previously employed methods for addressing temporal aspects of imagery have involved comparisons of timing profiles (i.e., a series of intervals between the onset of particular events) from live and mental performances, a process called mental chronometry which refers to the time course of information processing by the nervous system (Posner, 1978). Early chronometric studies investigated simple motor skills such as locomotion and grasping and manipulating, while more recent studies have employed complex, whole body tasks (Calmels, Holmes, Lopez, & Naman, 2006;

Guillot & Collet, 2005b). Comparisons of the amount of time required to ‘perform’ a piece of music have also been explored (Clynes & Walker, 1982; Gabrielsson & Lindström, 1995; Finney, 1997). These studies were interested in the amount that the total time to perform the actions differed between the two conditions. Results varied considerably between studies and no conclusions remained consistent through repeated studies (for a review of timing studies with musicians see Repp, 2001). In an attempt to explain such inconsistencies, a variety of moderators have been proposed that are believed to influence a person’s ability to perform such tasks. These include imagery ability (Decety, Jeannerod, & Prablanc, 1989; Rogers, Hall, & Buckolz, 1991), level of musical training or experience (Janata & Paroo, 2006; Schendel & Palmer, 2007; Aleman *et al.*, 2000; Keller & Koch, 2008), and the type of imagery employed within the task (i.e. motor vs. non-motor; Holmes & Collins, 2001; Palmer, 2006). While the full impact of these moderators is still not understood, evidence from a growing number of studies now suggests that the temporal structures of melodies are generated during imagery in a manner identical to during live performance, substantiating the use of mental chronometric comparisons (Halpern, 1988, Halpern & Zatorre, 1999; Zatorre & Halpern, 1993, 2005; Zatorre *et al.*, 1996).

In an attempt to develop and employ tasks with greater ecological validity for those being tested than some earlier mental chronometric comparison investigations, and by doing so make the testing procedure more naturalistic and applied, recent studies have begun conducting mental chronometric comparisons on the specific tasks and activities performed by athletes of different sports as well as musicians. Additionally, this research has further developed earlier investigations that only examined the total time required to perform or imagine an activity by breaking the tasks or activities up into stages and comparing the duration of the different segments, rather than just the duration of the entire task (Calmels *et al.*, 2006; Guillot & Collet, 2005b; Reed, 2002). Calmels *et al.* (2006) found that when comparing the time required for gymnasts to perform a complex vault physically and mentally, the temporal organization of the specific components of the movement were different in the two conditions, despite the time to perform the entire movement not differing significantly between the conditions. These results indicate that by only looking at the total duration of a performed action, subtle temporal fluctuations on a smaller scale within the action might be missed.

Work within music has taken this one step further and divided the task up into an even smaller division: beats. This would be equivalent to sport science researchers examining each step or footfall in athletes' imagery. In two studies, Repp (1999a, 1999b) investigated the effects of eliminating auditory and kinaesthetic feedback on expressive performance parameters by looking at the timing profiles of performances under different conditions. Repp's rationale for this approach was that performances with no auditory feedback would allow insight into pianists' "internal representations or mental images of the musical sound structure" (1999a, p. 412).

To explore this, Repp (1999a) asked six pianists to perform the opening of a Chopin etude on a digital piano, first normally and then with no sound (no auditory feedback). When comparing the timing profiles (the series of inter-onset-intervals, IOIs) of the performances from the two conditions, he found that most of the pianists lengthened the penultimate note in the condition with no auditory feedback, but otherwise the performances were similar between conditions. Building upon this, he then asked the same six pianists to tap along with the beat of an imagined performance, so in effect removing both the normal performance auditory and kinaesthetic feedback (Repp, 1999b). He found that the timing patterns were significantly positively correlated for four of the six pianists, leading him to suggest that expressive temporal fluctuations do occur during imagined performances in a manner similar to live performances, just not to the same extent for all musicians.

A similar approach was adopted in a study by Wöllner and Williamon (2007). They proposed that by studying the extent to which musicians rely on auditory, visual, and kinaesthetic feedback while performing, insight could be gained into the content and strength of their mental imagery for the music they play. For this, eight pianists were recruited and requested to perform a piece of their choice within four different conditions: (1) normal performance, (2) no auditory feedback, (3) no auditory or visual feedback, and (4) tapping to indicate the beat of an imagined performance. All eight participants obtained significant positive Pearson correlations (all $p < 0.01$) for the timing profiles between the normal performance and Conditions 2 and 3. With Condition 4, by contrast, only four out of the eight participants achieved significant positive correlations. This led Wöllner and Williamon to suggest that not all musicians, for reasons unknown, are able to produce consistent timing profiles under varying conditions (in particular the removal of kinaesthetic feedback).

The results found in the studies by Repp (1999a, 1999b) and Wöllner and Williamon (2007) provide support for this particular task to be employed as a naturalistic and ecologically appropriate method to examine musicians' temporal imagery abilities. Given that not all of the participants in the studies by Repp (1999a, 1999b) and Wöllner and Williamon (2007) were able to complete all phases of the experiments successfully, musicians' ability to perform this type of chronometric task successfully is still somewhat unclear, as is the range of factors that may help or hinder their ability to do so.

Aims of the present study

The present study sought to expand upon previous mental chronometric comparison studies as an ecologically relevant method for examining musicians' imagery abilities, assessing the temporal consistency between musicians' live and imagined performances in particular. It is not fully understood why some musicians perform better on this type of task than others. Imagery experience, use, and ability and musical experience have been proposed as potential moderators, so their role in musicians' ability to perform this task was also explored. Specifically, profiles of inter-beat-intervals (IBIs) for live and mental performances would be generated, which could then be compared within and between performance conditions, as well as with results derived from standard imagery use and vividness measures.

It was expected that the participants would report employing imagery for a variety of functions and that the specific functions identified and extent to which they were employed would vary depending on the participants' musical background and training. Given the factors that have been proposed to influence temporal consistency within imagery, it was also hypothesised that those participants who reported regularly employing imagery would display greater imagery abilities, as assessed by standard imagery vividness questionnaires and by the mental chronometry task.

METHOD

Participants

For this study, 32 undergraduate and postgraduate music performance students were recruited from the Royal College of Music (RCM; *N* = 24) and Boston University (*N* = 8). The students from Boston University were part of an exchange programme and were based at the RCM during the time of the study. The sample comprised 11 men and 21 women, ranging in age from 20 to 28 years (*M* = 22.29, *SD* = 2.20), except for one participant who was 51 years of age. The median age for the entire sample was 22 years. In terms of the participants' year of study, 4 were Year 1 undergraduates, 6 were Year 2, 14 were Year 3, 4 were Year 4, and 7 were postgraduates. Grouped by instrument, 7 were pianists, 9 were vocalists, 12 were string players, and 4 were woodwind and brass players. The participants' amount of involvement in musical activities prior to performing the study is summarized in Table 1.

Insert Table 1 about here

Materials

A series of questionnaires and performance-related tasks was employed to assess the participants' musical background, previous experience with mental skills, and mental rehearsal and imagery vividness and ability.

Previous mental skills experience

In order to gain an understanding of the participants' previous experience with imagery and mental rehearsal, as well as mental approaches to practising and performing in general, a survey was developed that ascertained the types of mental activities in which the participants engage in relation to their musical activities (see mental practice strategies survey, Appendix 1). Participants were also asked to provide an approximate indication of the amount of time they engage in each type of mental strategy or activity per week, how long they have been using the particular activities, and how skilled or effective they felt they were in using each of them. In order to assess the participants' perceived ability for their particular mental activities or strategies, they were asked to rate themselves on a scale from one to seven, with seven representing "very skilled".

Imagery ability

Imagery ability was assessed using one questionnaire and one performance-related task. The questionnaire employed was the randomized short version of Betts' Questionnaire upon Mental Imagery (Betts' QMI; Sheehan, 1967). This is a 35-item self-report questionnaire in which participants are asked to rate on a seven-point Likert-type scale the strength or vividness of suggested sensory experiences with 1 = Perfectly clear and vivid, and 7 = No image present at all. Seven different senses are addressed, including sight, sound, taste, smell, movement, and interoceptive and exteroceptive sensations. As per the standardised instructions, participants were asked to conjure up or imagine a particular sensory experience and then rate the vividness of the image created. Responses are then summed for a total questionnaire score as well as scores for each of the subcomponents. A lower score indicates a greater level of imagery vividness.

Finally, a mental chronometry task was developed similar to that employed by Repp (1999a, 1999b) and Wöllner and Williamon (2007) with the aim of providing a contextually relevant, empirical measure of imagery ability that extends beyond the aforementioned measures. The full procedure for this task is described in detail below.

Procedure

Each participant was requested to prepare a two-minute extract of their choice that was at public performance standard. A full list of the pieces performed by the participants is provided in Appendix 2. Provided along with the names of the pieces are the tempi at which the participants performed them and the tempo units in which the participants tapped (i.e. quarter note, eighth note). Prior to completing the mental chronometry task, the participants first completed the questionnaires.

Participants next gave two live performances of their chosen extract, rating the accuracy of each performance upon completion on a scale from one to seven, with seven representing “very accurate”. By accuracy, as was explained to the participants, what is referred to is a performance that was accurate relative to the participant’s desired expressive and technical intentions. They then gave two mental performances of the extract, tapping a light metal object upon a desk to indicate the beats of the piece as they imagined themselves performing it. The metal object was selected specifically to present no weight-related burdens on the participants’ tapping motion and to produce a clearly audible and identifiable sound signal. Again, upon completion of the two mental performances the participants were asked to rate the accuracy of the performance they had imagined, as well as the ease with which they were able to imagine themselves performing, also on a scale of one to seven with seven representing “very easy”. For the mental performances, the participants were instructed to “perform” their pieces in a manner identical to their live performances, as equal as possible in terms of tempo and expressivity. They were not given specific instructions as to which modality of imagery to employ, rather they were free to use a strategy that was most familiar and comfortable to them. The participants were also instructed to commence tapping at the onset of the first beat of their excerpt, not necessarily the first note or bar per se. The participants were allowed practice trials during which the process was discussed with the investigator to ensure that the correct procedure was being adhered to. This process also helped ensure that the investigator was aware of where exactly in the score the participants were beginning their tapping. Additionally, the beat subdivision at which the participants tapped was discussed to ensure that the IBIs from the live performance condition represented the same note value as the taps from the mental performance condition (the note values used by each participant are reported in Appendix 2). All performances, live and mental, were recorded using a Tascam Portable Stereo Audio Recorder.

Data preparation

Initial data preparation involved the generation of mean scores and standard deviations for the survey and questionnaire, as well as relevant individual items or subscales within them. For the mental chronometry task, the inter-beat-intervals (IBIs) for each of the four performances were extracted to produce timing profiles using one of two methods. For the live performances, the sound files were imported into the program Sonic-Visualiser (http://www.sonicvisualiser.org). This program allows the user to place markers upon a visual representation of the sound file while listening to the file. Following initial placement, the markers can be adjusted to ensure accurate placement using the auditory and visual data. The amount of time between markers (IBIs) can then be determined and extracted, allowing for the creation of IBI timing profiles. Markers were placed at the beat level for the live performances, corresponding with the beat subdivision at which the participants tapped in the mental performance condition, as opposed to note onset. For the mental performances, the sound files were imported into the program Audacity (http://audacity.sourceforge.net). Also producing a visual representation of the sound file, this program does not allow for the placement of markers while listening to the file, hence it was not appropriate for use with the live performances. Given that the sounds created by the tapping procedure had clearly identifiable visual start points, Audacity was appropriate for use with the mental performances. Audacity also has a function allowing the user to export a set of IBIs automatically, unlike within the version of Sonic-Visualiser employed in this study in which the user must extract the IBIs individually (recent versions of Sonic-Visualiser now include a function that can do this automatically).

To ensure that the two programs employed produced timing profiles in a manner identical to each other, timing profiles for six of the mental performances were also generated using Sonic Visualiser. The two sets of timing profiles from the six mental performances were then correlated with one another, achieving a mean r value of 0.99 ($SD = 0.01$; $p < 0.001$). This indicates that the use of two different programs to create the timing profiles posed no significant complications and therefore was appropriate for the present investigation.

For five of the 32 participants, there were an unequal number of beats or taps between one or two of their performances and their others. In most of those instances, it was apparent that one or two extra beats or taps had been erroneously inserted by the participant, either in the midst or at the end of the excerpt. In cases where such extras were found, those taps or beats alone were removed from the series, with all the others being left. In some cases it was not possible to realign the onsets just by removing one or two erroneous onsets. In those situations, the latest point at which it was clear that the beats or taps were still aligned was found and all other onsets that followed that point were deleted.

Following the creation of timing profiles for each of the live and mental performances, similarity between the IBIs of the two performances within each of the two conditions was assessed using Pearson correlations. Because the objective of the task was for the participants to produce multiple performances identical in terms of their timing profiles, one-tailed significance tests were deemed appropriate. Pearson correlations were next used to assess the similarity of the IBIs between the two conditions.

Concern has been expressed over the use of parametric tests as a means of comparing timing profiles from musical performances (Almansa & Delicado, 2009; Schubert, 2002; Vines, Nuzzo, & Levitin, 2005). Almansa and Delicado (2009, p. 213) suggested that "notes that are closer in the score are more statistically related than those that are farther away". Due to this, it has been argued that IBIs violate the assumption of independence required for parametric tests and that conducting analyses like Pearson correlations could lead to erroneously inflated results. Functional Data Analysis, for instance, has been recommended as a method for dealing with potential autocorrelations resulting from the use of this type of data (Almansa & Delicado, 2009; Vines, Nuzzo, & Levitin, 2005). Vines *et al.* (2005, p. 138) note that "FDA was developed primarily as an alternative to general linear model-based statistics that assume the dependent variables come from independent, discrete observations; FDA treats a curve representing multiple observations as the fundamental unit of analysis". However, given the range of studies that have employed parametric tests within mental chronometric investigations (i.e. Calmels *et al.*, 2006; Guillot & Collet, 2005b; Repp, 1995; 1999a; 1999b; Wöllner & Williamon, 2005),and the fact that the same method of analysis was employed with all participants, Pearson correlations were deemed appropriate for the present investigation.

Dealing with temporal variation

The amount of temporal variation, or deviation from metronomic timing, inherent in a performance may moderate the correlations between the inter-beat-intervals (IBIs) of multiple performances. Repp (personal communication, 9 December 2009) cautioned that greater amounts of deviation from metronomic timing in a particular performance would result in higher correlations, due to the fact that the controlled variations in timing would be large compared with those that are uncontrolled. Because of this, the amount of deviation inherent in each performance would need to be factored out of any analyses employing Pearson correlations when more than one piece of music has been used by the participants. One possible option to address this is to set the correlation between the IBIs of live performances as the upper limit achievable by a particular participant and then to express all other correlations derived from that participant as a proportion of the former. Another option would be to calculate the coefficient of variation of each piece of music performed, also referred to as measures of dispersion. Coefficients of variation can be calculated by dividing the standard deviation of a piece's IBIs by the mean of that piece's IBIs. Once calculated, these could be used as a controlling variable within a partial correlation when comparing results from a mental chronometry task with other measures of imagery ability. This would allow researchers to explore the extent to which mental chronometry-type tasks relate to previously developed imagery ability measures, while controlling for any potential impact of varying levels of deviation from metronomic timing. The potential role of deviation from metronomic timing and methods for accounting for any resulting influence will be explored within the results presented below so as to understand its implications and applications.

RESULTS

Previous mental skills experience

Table 2 provides a summary of the participants' responses to the mental practice strategies survey. No prompts or suggestions were provided within the instructions for this survey; rather, the participants were requested to list any activity in which they engage beyond traditional physical practice as part of their regular musical learning and performing.

Insert Table 2 about here

When asked to identify the types of mental strategies or activities that the participants employ as part of their regular practice activities, mental rehearsal was identified most often (N = 20). Within this, the participants reported singing or hearing their music in their minds, memorizing music away from their instruments, and playing on a surface other than their instrument (or finger practice). The second most mentioned activity was score study away from the instrument. The participants reported engaging in this in order to explore expressive possibilities, to make choices in terms of phrasing, and for thematic analysis. With "Imagining performance", what is referred to here is an inclusive, multi-sensory form of imagery in which the participants reported imagining themselves within a particular performance situation, seeing the auditorium and audience around them and hearing and feeling themselves performing.

Imagery ability questionnaire

For the Betts' QMI, the participants obtained a total mean score of 89.66 (*SD* = 26.09). The potential range for this questionnaire is 35-245, with a lower score indicating greater imagery vividness. A repeated-measures analysis of variance (ANOVA), with the seven subcomponents of the questionnaire as the within-subjects variables, was used to test for differences between the scores. The assumption of sphericity was violated according to Mauchly's test, so the Greenhouse-Geisser correction was applied. The analysis revealed that the scores differed significantly across subcomponents ($F_{4.13,128.05} = 10.68$, $p < 0.001$). As can be seen in Table 3, the participants' ability to imagine sounds (auditory sub-component) and movements (kinaesthetic sub-component) were the senses achieving the greatest vividness on this measure, while the participants' ability to imagine smells (olfactory sub-component) achieved the least amount of vividness. One-way ANOVAs revealed no significant gender differences on any of the scores.

Insert Table 3 about here

The Betts' QMI has published normal population statistics for men and women (Sheehan, 1967). One-sample *t*-tests were conducted to assess the extent of any differences between published norms and participants' sub-component scores, using the male and female norms for each sub-component as the test variable against which the participants' scores were compared. While the study sample reported greater imagery vividness than the norms for all of the subcomponents, these differences were significant only in a few instances. Men and women in the present study reported significantly greater levels of imagery vividness on the subcomponents of auditory (men: $t_{10} = 2.85$, $p < 0.05$; women: $t_{20} = 3.22$, $p < 0.01$), kinaesthetic (men: $t_{10} = 4.10$, $p < 0.01$; women: $t_{20} = 2.89$, $p < 0.001$), and gustatory (men: $t_{10} = 2.27$, $p < 0.05$; women: $t_{20} = 4.43$, $p < 0.001$).

Mental chronometry task

Descriptive statistics for the accuracy and ease ratings that the participants gave their live and mental performances within the mental chronometry task are provided in Table 4. The ratings fell slightly above the midpoint of the scale and there is little variation between them. While the scores suggest the participants felt their performances could have been more accurate, the ratings do indicate a belief that they could perform the task successfully.

When reviewing the technical accuracy scores that the participants gave for their mental performances, in a few cases it was apparent that the participants were aware that something had gone wrong during one of their mental performances, due to a considerably lower accuracy rating on one than the other. Given this, it was deemed that an average of the two mental performances would be less likely to provide a representative indication of their imagery abilities (cf. the finding by Repp (1999b) and Wöllner and Williamon (2007) that not all musicians are able to execute this task equally well). This disparity in accuracy ratings did not occur with the live performances, however, so in all subsequent analyses following the initial within-performance condition correlations (those for the live and mental performance conditions) an average of the timing profiles from the two live performances has been used, while the timing profile from only the one mental performance rated most accurate by each participant was employed (this method was also employed when comparing the timing profiles between the two performance conditions).

Insert Table 4 about here

Examining the total duration of the performances from the two conditions, the mean of the live performances for all of the participants was 86.09 seconds (*SD* = 26.22), while the mean of the participants' most accurate mental performances was 88.68 seconds (*SD* = 25.51). A paired samples *t*-test comparing the two sets of durations revealed no significant difference (t_{31}= 1.79, $p > 0.05$; two-tailed).

To investigate the extent of consistency in the beat-by-beat tempo fluctuations between performance conditions, Pearson correlations between the inter-beat-intervals (IBIs) for the performances within and between the two performance conditions of the chronometry task – live and mental – were calculated. Mean correlations (and standard deviations) for the live performance condition, the mental performance condition, and between the two conditions were, respectively: 0.64 (0.22), 0.28 (0.22), and 0.33 (0.24). All 32 of the participants achieved a significant correlation between the two live performances. When examining the mental performance condition, however, only 17 participants achieved a significant correlation. Comparing the IBIs between the live and mental conditions, 22 of the 32 participants yielded a significant correlation between the two conditions.

Tempo

Tapping at a faster speed, resulting in smaller IBIs, leaves less room for timing variations due to random, unintentional fluctuations. Arguably, it also leaves less room for intended, expressive timing variations. Unintentional fluctuations within the tapping could create inaccurate timing profiles for the mental performances, resulting in complications when comparing the two performance conditions. In order to examine this, the tempo (speed) at which the participants performed their excerpts was examined to see if it had any impact. Pearson correlations between the tempo and the results obtained from correlating the IBIs of the different performances revealed no significant correlations.

To examine this further, the musicians were allocated to one of three groups depending on the tempo at which they performed their excerpt (Group 1: tempo = 39-76 beats per minute (bpm); Group 2: 77-114 bpm; Group 3: 115-151 bpm). The mean correlations (standard deviations in brackets) from the live performance condition, the mental performance condition, and between the two conditions for each of the three groups are presented in Table 5. A one-way ANOVA with the Pearson correlations between the IBIs of the different performances as the dependent variable and tempo group allocation as the between-subjects factor was performed. Given the differences between the numbers of musicians assigned to each of the three groups, therefore violating the assumption of homogeneity of variance, Welch's (1951) correction was applied. This test revealed no significant differences between the groups in terms of their performance on the mental chronometry task. Specifically, the results from the one-way ANOVA for the scores from the live performance condition, the mental performance, and between the two conditions were, respectively: $F_{(2,3.51)} = 0.021$, $p > 0.05$; $F_{(2,7.37)} = 3.446$, $p > 0.05$; and $F_{(2,2.78)} = 0.368$, $p > 0.05$. Given this, it would appear that tempo had no significant impact on the participants' ability to perform the mental chronometry task.

Insert Table 5 about here

Temporal variation

As discussed above, it has been proposed that the amount of deviation from metronomic timing in a performance can moderate the correlations achievable when comparing the IBIs of multiple performances (Repp, personal communication, 9 December 2009). To determine whether this did in fact occur, coefficients of variation were calculated for each of the pieces performed by the participants. This was done by dividing the standard deviation of the IBIs (as marked by the researchers) from each participant's first live performance by the mean of the IBIs from that performance (the coefficients of variation can be found in Appendix 2). Following this, the coefficients of variation were correlated with the correlation coefficients from the live and mental performance conditions and between the two conditions (these results are presented in Table 6). Given the emergence of significant correlations, this indicates that the amount of deviation from metronomic timing in the performances is indeed linked to the resulting correlations, as previously proposed. Specifically, a greater amount of deviation from metronomic timing correlated with higher correlations between the performances within the live performance condition as well as between the two conditions, giving the impression of facilitating temporal consistency between performances. It is clear, therefore, that the amount of deviation from metronomic timing in a performance is linked to the results achieved, therefore requiring that it be factored out prior to any subsequent analyses.

As mentioned above, one possible option to address this is to set the correlation between the IBIs of two live performances as the upper limit achievable by a particular participant and then express all other correlations derived from that participant as a proportion of the former. However, for six of the participants their correlation from the live performance condition was not actually their highest. This suggests that the correlation they achieved in the live performance condition was not an upper achievable limit for them in terms of temporal consistency. Normalising each of the resulting correlations is not feasible, as that renders them unusable. Instead, the present investigation used partial correlations controlling for each piece's coefficient of variation in subsequent analyses.

Insert Table 6 about here

Comparing the assessment measures

In order to determine whether three sets of correlation coefficients obtained on the mental chronometry task resembled results obtained on the self-report imagery use and ability measures, Pearson correlations were calculated between the results derived from the task and the other instruments. Given that each performance's amount of deviation from metronomic timing was found to be linked to the correlations between the IBIs of the different performances, partial correlations were conducted with coefficient of variation as the controlling variable (these results are provided in Table 7).

To begin, the results from the mental practice strategies survey were examined. The number of minutes per day, the number of years used, and self-rated ability for the activities of mental rehearsal, score study, listening to recordings, imagining performance, and reading about the music and composer were used in this analysis. While a number of other strategies and activities were identified on this survey, they were reported by only one participant, thus ruling them out of this analysis. Of the five strategies that were included, mental rehearsal was the only one from which significant correlations emerged with the mental chronometry task. A significant positive correlation emerged between the number of minutes per day that the participants reported engaging in mental rehearsal and their expressive timing consistency within the live and mental performance conditions. Significant findings also emerged with the total and subcomponent scores from the Betts' QMI. The results from the live performance condition achieved significant negative correlations with total scores from the Betts' QMI as well as the subcomponents of visual, auditory, organic, and gustatory imagery. As lower scores on the Betts' QMI indicate greater levels of imagery vividness, negative correlations indicate a positive connection.

While a number of significant correlations emerged between scores from the live performance condition with imagery vividness as demonstrated by the Betts' QMI, no significant correlations emerged between results from the mental chronometry task and scores from the Betts' QMI. Furthermore, no significant correlations emerged between the between-conditions correlation coefficients and any of the other imagery use and vividness or practice data collected (presented in column three of Table 7).

A series of analyses was also conducted between the three sets of correlation coefficients obtained on the mental chronometry task and the participants' reported amount of daily practice, total amount of practice accrued throughout their musical involvement, and years of playing, but no significant effects were found.

Insert Table 7 about here

DISCUSSION

Expanding upon previous chronometric comparison studies as a method of examining musicians' imagery abilities, the present investigation sought to assess the extent of temporal consistency between live and imagined musical performances. As it is not fully understood why some musicians perform better on mental chronometry tasks than others, the potential influence of imagery experience, use, and ability on musicians' ability to perform this task were also examined. Taking into consideration the proposal that the amount of deviation from metronomic timing inherent in a musical performance can moderate how well a musician performs on this task, this study sought to examine this further.

Participants' imagery vividness and use

As reported on the mental practice strategies survey, the participants identified ten different types of activities that they employed as part of their regular practice activities. Of these different activities, mental rehearsal was identified by 20 of the participants, the most of any activity. Aside from physical practice, mental rehearsal is probably one of the most widely researched learning and practice strategies employed by musicians (see for example Bailes, 2006; Barry & Hallam, 2002; Holmes, 2003, 2005; Lehmann, 1997). The second most identified mental practice strategy was score study, identified by 13 of the participants. Whether or not this was accompanied by some form of concurrent mental audition is unclear, as that was not reported specifically by the participants. Six of the participants also reported regularly imagining themselves in performance situations, both while practicing and outside of their physical practice activities. While Connolly and Williamon (2004) make reference to this form of imagery as a performance preparation strategy, it is perhaps one of the least researched types of imagery.

Before attempting to assess musicians' imagery vividness and abilities via new and untested methods, it was deemed important to employ existing measures to provide a means of comparison for new measurement tools. As determined by the Betts' QMI, the participants rated their auditory and kinaesthetic imagery as being the most vivid out of seven possible sensory modalities. In a comparison with norm scores, the study participants reported greater levels of imagery vividness for all of the subcomponents, with these differences achieving significance for the subcomponents of auditory, kinaesthetic, and gustatory imagery for both men and women.

It is possible that the participants' regular use of mental rehearsal, as reported on the mental practice strategies survey by 63% of participants who indicated employing it for an average of 25.95 minutes per day, may have contributed to greater levels of imagery vividness. If such were the case, one would presume that significant correlations would have emerged between the results from the mental practice strategies survey and the Betts' QMI, but this was not the case. One possible explanation is that the participants interpreted self-rated ability, as asked on the mental practice strategies survey, as something other than imagery vividness. It may also have occurred because of the domain-specific versus domain-general nature of the two measures, the open- versus closed-response format distinguishing them, the retrospective nature of the mental practice strategies survey, or the lack of an objective standard of vividness against which participants could compare their own imagery when completing questionnaires such as the Betts' QMI. Further research exploring possible connections is warranted.

Participants' ability to perform the mental chronometry task

Previous research indicates that musicians are capable of performing works with similar timing profiles across repeated performances (Clarke, 1995; Repp, 1995; Shaffer, 1984). In the present study, 100% of the participants achieved a significant Pearson correlation when comparing the inter-beat-intervals of the two live performances, which is in line with previous research.

Repp (1999b) and Wöllner and Williamon (2007) found that while some musicians were able to give multiple temporally similar performances in the absence of typical music- or instrument-specific auditory and kinaesthetic feedback, others were less able. In the present study, only 17 of 29 participants (59%) were able to give two performances with significantly similar timing profiles within the mental performance condition, in which there was no auditory or kinaesthetic feedback. Given that the participants demonstrated an ability to give multiple temporally similar performances within the live performance condition, the possibility is raised that for some musicians the strength of their memory or mental representation of a piece of music may be dependent, at least in part, upon the auditory or kinaesthetic feedback they receive when playing. While Wöllner and Williamon (2007) found that the removal of auditory feedback had little impact on the ability of their participants to produce performances with consistent timing profiles, the removal of both auditory and kinaesthetic feedback had a greater impact. When comparing the timing profiles between the live and mental conditions, 22 of the 32 participants (69%) did achieve a significant correlation.

There is the possibility that challenges associated with the task, rather than participants being unable to access a stable internal representation of their music, may have contributed to fewer participants than expected achieving a significant correlation between the performances within the mental performance condition, which subsequently impacted the correlations between the two conditions. The cognitive demands associated with maintaining focus and concentration while accessing an internal representation of a two-minute extract twice without the benefit of any form of sensory feedback could arguably be greater than those required to perform physically that same extract twice. Limitations in terms of the participants' ability to cope with such demands might have contributed to the fact that only 59% of the participants achieved a significant correlation within the mental performance condition. Such limitations might also have impacted the number of participants (69%) who achieved a significant correlation when comparing the two conditions.

Methodological issues in mental chronometry investigations with musicians

It is important to note that no significant differences emerged when comparing the total durations of the performances from the live and mental performance conditions, in contrast to the considerable amount of individual variation found when analysing the beat-by-beat fluctuations within the performances. Had the analysis of the mental chronometry task been restricted to the more global level of total duration, this would have provided an inaccurate indication of the participants' ability to perform this task. In future studies investigating temporal consistency between live and mental performances, it is advised that researchers investigate beat-by-beat tempo fluctuations, rather than the total duration of a performance.

Given the emergence of a significant positive correlation between the amount of deviation from metronomic timing in each of the pieces performed and the results from the mental chronometry task, it is not possible to state with certainty whether the percentages of the number of participants achieving significant correlations between the timing profiles of their performances within and between the two conditions reported above (100% for the live performance condition, 59% for the mental performance condition, and 69% when comparing the two performance conditions) accurately reflect individual participants' ability to perform the different parts of this task successfully. As was proposed earlier, it would appear that deviation from metronomic timing is linked and has the potential to moderate the extent of achievable correlations when comparing the IBIs of multiple performances. To account for this influence, the present investigation employed partial correlations when comparing the results obtained from the mental chronometry task with those obtained by other imagery use and vividness measures. When assessing imagery ability through any means, it is important that the task be relevant and of importance to those being tested in order for them to be dedicated to the procedure. If employing this sort of task within a mental skills ability profiling process, having all participants perform the same piece of music would not be feasible given differences in terms of the participants' primary instrument.

There is the concern that having participants tap along with the beat of their imagined performance turns the mental performance task into an indication more of motor control than imagery ability. While this approach has been previously employed within sport sciences research (i.e. Calmels *et al.*, 2006; Guillot & Collet, 2005b) as well as music (Repp, 2001), moderation due to varying levels of motor control is a possibility worth bearing in mind. To address this, future studies could incorporate some form of synchronization task in order to assess each participant's motor control ability. Following this, motor control ability could then be controlled for or factored out of any subsequent analyses, ensuring that the results achieved on the different components of the mental chronometry task do indeed provide an accurate indication of imagery ability alone (for a review of sensorimotor synchronization studies, see Repp, 2005). Pecenka and Keller (2009) incorporated such a task in their investigation of the contribution of auditory imagery ability to musicians' sensorimotor synchronization skills. To do this, they had participants tap along with a stable and moving metronomic pulse. Perhaps more appropriate, Keller, Knoblich, and Repp (2007) had pianists perform duets with recordings of themselves and others to explore ensemble synchronization abilities. A version of this latter task in which musicians tap along with recordings of themselves prior to tapping along with a mental performance might shed further light upon any effects due to varying levels of motor control ability and possible differences due to challenges associated with extracting beats with temporal precision.

Mental performances as an indicator of imagery vividness

Exploring for links between the assessment tools, significant Pearson correlations emerged between the minutes per day that the participants reported engaging in mental rehearsal as reported on the mental practice strategies survey and the correlation coefficients from the live and mental performance condition. This suggests that those musicians who engage in mental rehearsal the most also possess a greater ability to give multiple performances with comparable timing profiles, even in the absence of sensory feedback. Previous research has also found a link between increased imagery ability relative to use of imagery. Surveying the imagery use and ability of 348 novice and elite rowers, Barr and Hall (1992) found that elite rowers reported more structure and regularity of use of imagery compared to novices. Additionally, elite rowers reported greater imagery ability in terms of the vividness of their imagery compared to novices, which included elements such as their blade, muscles, parts of the stroke, and the boat and its action in the water. This led Barr and Hall to suggest that engaging in greater amounts of imagery can enhance imagery ability.

Further to this, significant negative correlations emerged between the results from the live performance condition of the mental chronometry task and the total score and subcomponents of auditory, visual, organic, and gustatory imagery from the Betts' QMI. The strongest of these was with the auditory subcomponent. If an ability to give multiple performances with comparable timing profiles is dependent upon the musician possessing a strong mental representation of their music, as suggested by Repp (1999b), it would make sense for this to be reflected in greater vividness scores for auditory imagery, as is the case here. Lehmann (1997, p.143) furthered this point by proposing that "the most important goal of performance is to match a highly vivid representation of the desired performance with the current execution", which is also supported by these results.

No other significant links emerged between the rest of the results from the mental practice strategies survey or other practice and musical involvement data with the mental chronometry task. While previous studies have found a link between a participant's level of musical experience and imagery ability (i.e. Aleman *et al.*, 2000; Keller & Koch, 2008; Schendel & Palmer, 2007), the results from the present investigation do not support this. That said, previous investigations have involved participants with a considerable range of musical experience, some having no experience at all. The participants in the present investigation were all studying music performance at conservatoire level and, hence, all had high levels of musical ability and experience. Other studies finding these distinctions typically compare novices and experts (e.g. Milton, Solodkin, Hluštítk, & Small, 2007), which was not the case in the present study.

The finding that the between conditions correlation coefficients did not achieve any significant correlations with the imagery use and vividness measures was unexpected. However, the fact that no significant correlations emerged may have been due to different factors. As discussed in the introduction, the objective behind employing this mental chronometry task was to attempt to find a more ecologically valid means of testing a process that traditional imagery vividness questionnaires were not addressing. If a number of significant correlations emerged between all of the results from the mental chronometry task and existing imagery vividness questionnaires, there would be little point in devising new testing procedures as the standard questionnaires would be sufficient.

Conclusions

The present investigation has explored the efficacy of a context-, and participant-, specific method for assessing musicians' imagery abilities. The findings warrant further research to facilitate a more accurate interpretation of the results, as well as the refinement of appropriate testing procedures. Within this, further research is required to validate proposed links between the timing profiles of musicians' live and mental performances and their imagery use and abilities. There is the very real possibility that even if musicians do routinely engage in imagery as part of their practice activities, striving to "hear" their music temporally accurately may not be their primary objective (this highlights the importance of clear instructions for these types of studies). Recent work exploring imagery use by musicians has identified a wide range of functions, many of which do not necessarily involve temporally-accurate representations of their music (e.g. Connolly & Williamon, 2004; Gregg & Clark, 2007; Gregg, Clark, & Hall, 2008). A more thorough understanding of the function and content of musicians' imagery would be of great benefit for this area of research.

Possessing high levels of vividness and control over imagery has implications for learning and performing and should be of great importance for musicians. If lacking in either vividness or control, a musician runs the risk of rehearsing mistakes when using imagery, thereby rendering it a self-handicapping activity. Of particular interest to both researchers and musicians is the potential impact that imagery ability may have on performance quality. While previous research has suggested that higher levels of imagery ability enhances performance quality (MacIntyre, Moran, & Jennings, 2002), the learning of novel piano pieces in the absence of auditory feedback (Highben & Palmer, 2004), and interpersonal coordination during duet piano performance (Keller, 2008), this also needs to be explored more fully.

The present findings support recommendations for a mixed-methods design when investigating imagery ability. Effective imagery ability research, Guillot and Collet (2005a) suggest, should strive to comprise behavioural indices, psychological tests, and mental chronometry within its design. Based on the current results, a suggested first step would be to acquire information on the range of functions for which musicians employ imagery at the time of investigation, together with an indication of the amount of time spent employing the various functions. Such information could be gathered retrospectively as well as through the use of practice diaries in which musicians keep track, during a particular length of time, of the specific types of activities they engage in and the amount of time they spend doing so. Imagery ability could be assessed through use of standardized questionnaires together with a mental chronometry task such as that employed in the present study.

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TABLES

Table 1

Descriptive statistics for the amount of involvement in musical activities for the participants.

	Mean	**Standard deviation**
Number of years playing principal instrument	13.28	7.35
Number of hours of individual practice per week	18.44	10.61
Number of hours of ensemble rehearsal per week	4.75	3.77
Number of performances given per term	6.79	5.29

Table 2

Responses and means (SD in brackets) for the mental practice strategies reported by the participants.

Skill or Strategy	**Number of responses**	**Minutes per day used**	**Years used**	**Self-rated ability**
Mental rehearsal	20	25.95 (28.54)	6.48 (5.87)	4.80 (1.28)
Score study	13	11.62 (7.86)	5.31 (2.78)	5.08 (1.26)
Listening to recordings	12	19.58 (18.24)	6.25 (6.15)	5.46 (1.47)
Imagining performance	6	9.17 (6.46)	4.33 (5.57)	4.00 (2.00)
Reading about music or composer	4	10.00 (7.07)	7.00 (6.98)	5.25 (0.50)
Attending concerts	2	7.50 (3.54)	17.00 (9.90)	7.00 (0.00)
Relaxation techniques	1	10.00 (n/a)	1.00 (n/a)	3.00 (n/a)
Alexander technique	1	10.00 (n/a)	7.00 (n/a)	4.00 (n/a)
Associating words for expressivity	1	5.00 (n/a)	3.00 (n/a)	5.00 (n/a)
Aural training	1	10.00 (n/a)	2.00 (n/a)	4.00 (n/a)

Note. The range for the ability ratings is from 1 to 7, with 7 indicating a greater ability. n/a = not applicable.

Table 3

Descriptive statistics for the subcomponents of the Betts' QMI. The potential range for the total score of this questionnaire is 35-245, with a lower score indicating greater imagery vividness. Potential range for the subcomponents is from 5 to 35 (N = 32).

	Mean (standard deviation)
Total score	89.66 (26.09)
Visual subcomponent	12.25 (4.81)
Auditory subcomponent	11.28 (4.79)
Olfactory subcomponent	16.88 (5.27)
Gustatory subcomponent	11.53 (4.54)
Organic subcomponent	13.59 (5.55)
Kinaesthetic subcomponent	10.97 (3.81)
Cutaneous subcomponent	13.16 (5.04)

Table 4

Accuracy and ease ratings provided by the participants following each of their live and mental performances ($N = 32$).

		Mean	**Standard deviation**
Live performance 1	Accuracy	4.63	1.06
Live performance 2	Accuracy	5.00	0.98
Mental performance 1	Accuracy	4.92	1.38
	Ease	4.38	1.61
Mental performance 2	Accuracy	5.29	1.12
	Ease	5.04	1.16

Note. Accuracy and ease ratings ranged from 1 to 7, with 7 indicating greater accuracy or ease.

Table 5

Mean (standard deviation) correlations from the live performance condition, the mental performance condition, and between the two conditions for each of the three groups as allocated by tempo of piece performed.

Group	**Live Performance Condition**	**Mental Performance Condition**	**Between Conditions**
Group 1 (39-76 bpm; *N* = 17)	0.64 (0.20)	0.28 (0.27)	0.31 (0.21)
Group 2 (77-114 bpm; *N* = 13)	0.65 (0.26)	0.29 (0.18)	0.37 (0.29)
Group 3 (115-151 bpm; *N* = 2)	0.67 (0.22)	0.13 (0.06)	0.20 (0.27)

Table 6

Correlations between the coefficients of variation for each of the pieces performed and the correlations obtained in the mental chronometry task.

Performance condition	Coefficient of variation
Live performance condition	0.52**
Mental performance condition	0.33
Between the two performance conditions	0.39*

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Note. A higher coefficient of variation indicates greater amounts of deviation from metronomic timing inherent in the music.

Table 7

Pearson correlations between the imagery use and vividness measures with the correlation coefficients obtained on the mental chronometry task.

Questionnaire	**Live performance condition**	**Mental performance condition**	**Between conditions**
Mental rehearsal: Minutes per day used	0.40*	0.40*	0.16
Mental rehearsal: Years used	0.13	0.20	-0.24
Mental rehearsal: Self-rated ability	0.33	0.28	0.16
Betts' QMI Total	-0.43*	-0.17	-0.02
Betts' QMI Auditory	-0.53**	0.01	-0.09
Betts' QMI Visual	-0.46*	-0.11	0.06
Betts' QMI Organic	-0.38*	-0.26	0.01
Betts' QMI Gustatory	-0.40*	-0.12	-0.25
Betts' QMI Olfactory	-0.23	-0.03	0.07
Betts' QMI Kinaesthetic	-0.11	-0.23	0.09
Betts' QMI Cutaneous	-0.23	-0.16	-0.08

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Note. Lower scores on the Betts' QMI indicate greater imagery vividness; therefore negative correlations with the components of the mental chronometry task are desirable.

APPENDICES

Appendix 1

Mental practice strategies survey

Aside from traditional physical practice, what other strategies or methods do you use when learning or memorizing music and preparing for a performance?

a. ____________________

b. ____________________

c. ____________________

d. ____________________

How many minutes/hours do you engage in them each day/week (please circle)?

a. ____________________

b. ____________________

c. ____________________

d. ____________________

How long have you been using them for, or when did you start?

a. ____________________

b. ____________________

c. ____________________

d. ____________________

In reference to the specific skills you identified above, how effective or skilled do you feel you are at them? (Please rate each with 1 = not at all, 7 = very skilled)

	Not at all					Very skilled	
a. ____________________	1	2	3	4	5	6	7
b. ____________________	1	2	3	4	5	6	7
c. ____________________	1	2	3	4	5	6	7
d. ____________________	1	2	3	4	5	6	7

Who introduced you to mental skills? How did you learn about them?

a. ____________________

b. ____________________

c. ____________________

d. ____________________

Appendix 2

Pieces performed by the participants

Participant	Composer, piece, movement/section	Bars played	Note unit*	Units per min	CofV**
P1	Shostakovich, Piano Concerto No. 1, Mvt. I	1 - 23	Q	119	0.097
P2	Haydn, Trumpet Concerto, Mvt. I	37 - 83	H	64	0.088
P3	Chopin, Scherzo No. 2	1 - 129	H.	94	0.193
P4	Mendelssohn, Piano Concerto No. 1, Mvt. I	7 - 36	Q	151	0.134
P5	Rachmaninoff, Piano Concerto No. 3, Mvt. II	100 - 132	Q	77	0.540
P6	Haydn, Trumpet Concerto, Mvt. I	37 - 83	Q	60	0.099
P7	Ireland, Hawthorne Time	2 - 33	H	80	0.180
P8	Bach, Prelude, Fugue, and Allegro, Prelude	1 - 30	Q.	75	0.114
P9	Bach, Lute Suite No. 4, Minuet	1 - 34	Q	108	0.162
P10	Handel, Oboe Sonata in G minor, Allegro	1 - 43	Q	102	0.116
P11	Schumann, An meinen herzen	1 - 34	Q.	57	0.082
P12	Beethoven, Piano Concerto No. 3, Mvt. I	111 - 172	H	64	0.103
P13	Bacri, Sonata Breve	1 - 59	Q	104	0.378
P14	Prokofiev, Violin Concerto No. 1, Mvt. I	3 - 59	Q.	41	0.171
P15	Bach, Violin Sonata in E minor, Allemande	1 - 32	Q	79	0.125
P16	Schubert, Erlkönig	15 - 78	H	72	0.139
P17	Mozart, Horn Concerto No. 3, Mvt. I	22 - 51	Q	109	0.209
P18	Fauré, Fantaisie Op. 79	2 - 39	Q.	53	0.116
P19	Doyle, Weep You No More Sad Fountains	5 - 52	Q	92	0.092
P20	Bach, Cello Suite No. 2, Prelude	1 - 40	Q	67	0.097
P21	Beethoven, Ich liebe Dich	1 - 39	E	97	0.294
P22	Schubert, Nacht und Träume	5 - 28	Q	74	0.153
P23	Mozart, Piano Sonata No. 10, Mvt. III	1 - 68	Q	85	0.074
P24	Gluck, O Del Mio Dolce Ardor	2 - 19	Q	58	0.163
P25	Schubert, Frühlingsglaube	5 - 24	Q	64	0.181
P26	Fauré, Elegie Op. 24	1 - 43	Q	64	0.169
P27	Schubert, Ganymed	11 - 78	Q	81	0.095
P28	Prokofiev, Violin Sonata in D major, Mvt. I	1 - 38	Q	83	0.123
P29	Vieuxtemps, Élégie	7 - 40	Q	73	0.171
P30	Dowland, Queen Elizabeth Galliard	1 - 33	Q	91	0.070
P31	Chopin, Scherzo No. 3 Op. 39	1 - 151	H.	113	0.227
P32	Franck, Violin Sonata, Mvt. II	5 - 31	Q	55	0.175

Note. E = Eighth note, Q = Quarter note, Q. = Dotted quarter note, H = Half note, H. = Dotted half note.

**Note*. CofV = Coefficient of variation. A higher coefficient of variation indicates greater amounts of deviation from metronomic timing in the performance. These were calculated by dividing the standard deviation of the IBIs from each participant's first live performance by the mean of the IBIs from that performance.