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Measurable changes in piano performance of scales and arpeggios following a Body Mapping workshop

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ABSTRACT
Body Mapping is becoming increasingly popular among musicians as an educational approach to improve bodily movement and thereby the audible quality of music performances. This study used MIDI data to quantitatively measure changes in scale and arpeggio piano performance one day before and one day after a Body Mapping workshop. While there were subtle changes in the MIDI data, these changes were generally neither statistically significant, nor a magnitude that would be audible. Based on these findings, we theorise that reports of immediate improvements to music performance originate in visual dominance: audience members observe changes in bodily movement and perceive this as improved sound quality.

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Body Mapping; somatic method; piano performance; MIDI data; music perception

Introduction

In recent years, Body Mapping has grown in popularity as a somatic[1] method which is said to both improve music performance and reduce the risk of injury through education about the body in movement. Body Mapping educators coach students to inquire into their perceptions of their own body, their *body map*, and identify differences between their body map and their actual anatomical structures (Johnson, 2009). As the student corrects and refines their body map, the quality of the body movement is said to improve (Malde et al., 2013) and as a result, the quality of their musical performance is said to improve (Mark, 2003). Some of these changes are said to happen in the immediate term and others in longer periods of study (Knaub, 2002). It is becoming increasingly common for musicians to take lessons and workshops in Body Mapping, due in large part to perceptions of improvements in music performance (Johnson, 2009). In the present study, we focus specifically on musical aspects of piano performance and for this reason, we will not discuss at length the relationship of Body Mapping to injury. To our knowledge, the impact of Body Mapping on music performance-related injury has not yet been investigated.

Anecdotal evidence indicates that musicians studying Body Mapping experience improvements in their music performance. Musicians are said to be better able to handle fast tempi (Harscher, n.d.) and play with greater expressivity (Pearson, 2006), while pianists specifically are said to be able to play with fewer note errors (Mark, 2003). There are many videos of workshops in Body Mapping, taken to record a change in sound quality following instruction (Johnson, 2013; Pearson, 2011) often with audiences who assert that the tone has become fuller, richer, and more beautiful (Blumer, 2014; Breault Mulvey, 2016). Instructional literature echoes this phenomenon of improved tone quality (Conable, 2000; Johnson, 2009), and also asserts that Body Mapping helps promote consistency between performances (Malde et al., 2013; Pearson, 2006), and improvements in the technical facility of both singers and instrumentalists (Harscher, n.d.; Krayer-Luke, 2014; Rennie Salonen, n.d.). It is clear that musicians perceive changes to the sound of music performance following Body Mapping study.[2]

While there are many sources describing the reputed effects of Body Mapping, the research literature on the effects of Body Mapping is currently limited to two

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[1]Thomas Hanna (1988), who brought the term 'somatics' into common use among movement therapists and educators, defined somatic work as that which addresses both the self-awareness of the student, patient, or client, and the observations made by the educator or therapist in the design and execution of the therapy or education.

[2]This study was based on data collected as part of a master's thesis project. Readers may find similarities between this publication and the first author's thesis document, published locally at University of Ottawa.

qualitative studies and one quantitative study. Student participants in the two qualitative studies expressed through reflective journals that Body Mapping allowed them to have the greater facility and, for singers and wind instrumentalists, greater breath control (Knaub, 2002). In semi-structured interviews, the students of a Body Mapping class expressed their experiences of improved focus during the performance and greater capacity for expressivity (Buchanan & Hays, 2014). In the single quantitative study to explore Body Mapping, four of ten pianists received a 50-minute online Body Mapping lesson from a licensed Body Mapping Educator, formerly termed Andover Educator. Judges, blind to condition, rated post-test audio and silent video recordings. Ratings for post-test recordings were generally better than pre-test recordings, but none of the changes to perceived musical quality were statistically significant. While the lack of statistical significance was likely attributable in part to the small sample size, the findings do suggest that the effects of a 50-minute online Body Mapping lesson are not as clearly observable as anecdotal evidence suggests (Wong, 2015). This limited amount of research suggests that when studying Body Mapping with a teacher in person for the length of at least one semester, students report improvements in their performance, but a single hour of instruction through an online interface does not yield easily observable improvements.

In light of the increased role of Body Mapping in music education today, its presence in at least 18 post-secondary music institutions (Mollnow Wilson, personal communication, 2015), and wide availability of instructional literature (Andover Educators: Recommended reading, 2017), the presence of only three research studies is insufficient. Although there are a vast number of possible research studies, empirical measurement may be the most urgent. As such, we chose to investigate whether the performance of pianists studying Body Mapping improves musicality in an empirically measurable way. Since many of the improvements in music performance associated with Body Mapping are described in a nonspecific manner, or refer to an instrument other than piano, it is necessary to first define what an improvement in piano performance may be. To do this, we consulted piano pedagogy and performance literature to determine how an improvement in piano performance may be defined. Since there are many contexts in which improvements in performance could be observed, here, we choose to focus specifically on the piano performance of scales and arpeggios. These are common activities which are well automatised in experienced pianists. Many researchers use scales (Beacon, 2015; Jabusch et al., 2004; Wong, 2015) and arpeggios (Yoshie et al., 2008) to examine piano playing under a variety of conditions, and for this reason, the review of literature below places a particular emphasis on concepts of good piano performance as they relate to scales and arpeggios. Having identified which variables these texts describe as good piano performance, we then relate these variables to the best available quantitative empirical measurements.

When discussing concepts of good piano performance which apply to scales and arpeggios, note errors, tone, evenness, tempo, and articulation arise as salient features. Authors emphasise the importance of playing the correct notes, with emphasis on reducing note errors (Ahrens & Atkinson, 1955; Brower, 2003; Chang, 2009; Fink, 1992; Fraser, 2011; Holmberg, 2012; Whiteside, 1997). Authors discuss the need for a strong tone, which they describe as being even in the strength (Ahrens & Atkinson, 1955; Bernstein, 1981; Brower, 2003; Uszler et al., 2000; Whiteside, 1997) and in length of consecutive notes (Ahrens & Atkinson, 1955; Bastien, 1988; Holmberg, 2012). This evenness is said to be important and more difficult in the case of thumb crossings (Agay, 2004; Bastien, 1988; Bernstein, 1981; Hofman, 1976; Whiteside, 1997). Authors advocate an even tempo, particularly in avoiding tempo drift (Bernstein, 1981; Chang, 2009; Holmberg, 2012; Kullak, 1973), as well as evenness of articulation, where the amount of gap or overlap is consistent among consecutive notes (Bastien, 1988; Hofman, 1976; Whiteside, 1997). Based on piano pedagogy and performance literature, an improvement to scale and arpeggio piano performance will include pianists playing the notes accurately and playing with greater evenness in sound intensity, tempo, and articulation. It is difficult to know whether 'strong tone' could be described as an overall increase in sound intensity, or whether this is related to other variables, such as evenness of sound intensity and articulation. For the purposes of this paper, we explore overall sound intensity of scales and arpeggios, but because of this lack of clarity in the piano literature, this measure is exploratory.

MIDI technology yields data on pitch, velocity, and timing. Using MIDI pitch data, we can identify note errors by comparing a written score, which shows the intended pitches, to a printout of the MIDI pitch content, which shows the notes played (Gudmundsdottir, 2002; Mito, 2003). Further exploration of pitch data involves classifying note errors into added notes, called additions, missed notes, called deletions, and incorrectly played notes, called substitutions (Finney, 1997; Palmer & van de Sande, 1993; Yoshie et al., 2008). MIDI velocity data is a measure of sound intensity (Repp, 1997) which researchers have used to quantify evenness of tone by note strength (Repp, 1996; Salmon & Newmark, 1989). Evenness of tone by note length, on the other hand, may be examined using MIDI timing data. The time between

Table 1. Variables measuring improvements in piano performance, described in Body Mapping literature, piano pedagogy and performance literature, and researching using MIDI data.

Category	Body Mapping Literature	Piano Pedagogy Literature	Analysis by MIDI
Note accuracy	Reduced note errors, particularly in thumb crossings	Fewer note errors – especially at thumb crossing	Note errors counted and codified as additions, deletions and substitutions
Sound intensity	– Increased control of dynamic – Improvement in tone – Ability to handle louder dynamics	Strength of tone Evenness of tone by note strength – in thumb – in thumb crossing Evenness of tone by note lengths – in thumb crossing	Overall sound intensity quantified by mean velocity Evenness of tone by note strength (sound intensity) quantified by standard deviation of key velocity Evenness of tone by note length quantified by standard deviation of IOI
Tempo	Greater ability to handle tempo	Avoid tempo drift	Tempo drift quantified by change in IOI between first and last repetitions of a sequence
Articulation	Ability to play in greater legato	Evenness of articulation, particularly across thumb crossing	Evenness of articulation quantified by standard deviation of KOT or KDT

the onset of one note and the onset of the following note is called the interonset interval (IOI) and standard deviation of IOI provides a quantitative measure of evenness of tone by note length (Duke et al., 2011; Finney, 1997; Ruiz et al., 2014). As the standard deviation of IOI decreases, the evenness of tone increases. MIDI timing data can also provide a measure of evenness of tempo and articulation. The difference between the mean IOI in the first and last repetitions of a sequence with notes of the same value, such as sequences of eighth notes, can be used to quantify tempo drift (Loehr & Palmer, 2009). Articulation is measured by key overlap time (KOT), defined as the difference in time between the onset of a note and the offset of the previous note. Mean KOT describes the articulation, with positive KOT describing an overlap and negative KOT describing a gap. Standard deviation of KOT is a quantitative measure of evenness of articulation (Beckman, 1994; Bresin & Battel, 2000; Palmer, 1988; Repp, 1994, 1999b).

Having reviewed the claims made about improvements in music performance associated with Body Mapping and how these improvements may be clarified for the context of piano performance, we are equipped to quantitatively measure these improvements using MIDI data. The variables of concern are the number of note errors, overall sound intensity, and evenness of sound intensity, evenness of tempo, and evenness of articulation. See Table 1 for a summary of the relationship of these variables to the three bodies of literature: Body Mapping, piano pedagogy and performance, and research using MIDI.

Research problem

A large body of anecdotal evidence indicates that pianists' music performance improves following the study of Body Mapping, yet we have minimal research evidence to support this perception. There is a particular lack of empirical data, and to date, there have been no studies to examine any aspect of participants' performance before and after attending the course, 'What Every Musician Needs to Know About the Body' (WEM), which Body Mapping Educators are licensed to teach. Six-hour WEM-style workshops are such a common form of Body Mapping instruction, that Body Mapping literature frequently refers to WEM as simply 'the course' (Andover Educators: The Course, 2017). Teaching of the course is one of the most central components in the Body Mapping Educators training process (Bindel, 2013) and as such, music students are most likely to experience Body Mapping through WEM-style workshops.

In this study we address the following question:

- Does the standard six hour Body Mapping workshop improve the note accuracy, evenness of tone, evenness of tempo, and evenness of articulation of scale and arpeggio piano performance as measured by MIDI data?

Given the literature reviewed above, we hypothesise that after the Body Mapping workshop, there will be fewer note errors and tone, tempo, and articulation will be more even. We asked participants to play the scales and arpeggios legato, and therefore an increase in the amount of key overlap will also be considered an improvement in piano performance in this context. These data should be interpreted cautiously, however, as there is little consensus on the amount of key overlap that constitutes good legato in scale and arpeggio performance. We hypothesise that these changes will be quantitatively evident in the MIDI data. We also explore overall sound intensity, but because of the lack of clarity in piano pedagogy and performance literature, there is no hypothesis associated with this exploratory measure.

Method

Participants

We recruited 38 participants (29 female, $M = 26.35$ years, age range = 18–56 years) for this study from four Canadian cities, among those who were currently studying and majoring in piano at an undergraduate or graduate level, or who had previously studied at such a level. As data collected from the intake questionnaires confirmed, all participants were active in playing, performing and/or practicing piano at the time of data collection. No participant had received more than one group workshop or one private lesson in Body Mapping. Some participants had previous experience with other somatic methods including Alexander Technique and Feldenkrais. Two participants reported owning a book about Body Mapping. Independent samples t-tests revealed negligible differences in results between those who had had experience with somatic methods and those who had not.

The methodology of this study received approval from the Office of Research Ethics and Integrity prior to the commencement of data collection.

Procedures

All participants received information about the playing tasks prior to their participation in the study and agreed to prepare adequately for the fluent performance of each task, described below. The day before and the day after their participation in the group intervention activity, participants arrived individually for testing. During each testing session, the participant first completed a consent form and a questionnaire. In the questionnaire, the participant reported their age, gender, left- or right-handedness, number of years of piano lessons, first year of piano lessons, post-secondary piano training, their experience, if any, with somatic methods such as Body Mapping, and their experience, if any, with musculoskeletal injuries. The participant was then seated at an adjustable bench and warmed up at the instrument for at least two minutes before recording began.

During recording, participants played four-octave C major scales and arpeggios, ascending and descending, repeating without pauses until asked to stop. Asking the participant to repeat the task continuously allowed the participant's attention to be devoted to the playing task and not counting repetitions. The research assistant ensured that 5 repetitions of the scale or arpeggio were recorded before stopping the participant. Participants performed the scale with right hand only first, followed by scale with left hand only, followed by four-octave C major arpeggios with the right hand only and then with the left hand only. The research assistant gave the participant an auditory metronome stimulus at 120 bpm for the scale, asking the participant to play in eighth notes, and 84 bpm for the arpeggio, asking the participant to play in sixteenth notes. As soon as the participant began to play, the research assistant silenced the metronome. Participants performed at least one trial run of the scale and arpeggio before recording.

Mark (2003) describes that pianists learning Body Mapping may discover that their habituated bench height or distance from the piano is ill-suited to their body size and shape. To explore whether pianists change their bench height or distance from the piano after a Body Mapping workshop, we recorded the participants' chosen bench height and distance after each testing session.

Intervention

Participants received a six-hour WEM-style Body Mapping workshop which was taught by a licensed Body Mapping Educator and tailored for pianists. The workshop was similar to other Body Mapping workshops taught by licensed Body Mapping Educators, in that it included group instruction and a masterclass in which each participant worked individually with the instructor. To control for the amount of individual attention given to each participant by the instructor, a maximum of six participants were allowed in each workshop, and 15–20 minutes of masterclass time was allotted for each participant.

Measurements

To examine note accuracy, and evenness of tone, tempo, and articulation of pre-test and post-test scale and arpeggio recordings, we collected MIDI data during testing and then analysed the data using a programme designed for this study. At the Piano Pedagogy Research Laboratory, we collected the MIDI data using a Yamaha Disklavier from the Mark III series, while in other centres, we used a comparable MIDI-equipped keyboard instrument. We designed a programme for analysis that first separated the repetitions of scale or arpeggio, and then detected whether any note errors were present. The programme then discarded repetitions with note errors and analysed key velocity and timing data of error-free repetitions. This data provided the measurements of sound intensity, tempo, and articulation. We then exported the resultant data for comparison between pre-test and post-test.

While the programme described above was capable of identifying the presence of errors in each repetition, it was not able to classify them into the categories of addition, deletion, and substitution. The primary researcher and two research assistants conducted this note error classification by manually counting note errors using music scores generated from the MIDI files and then coding them as addition, deletion, or substitution. Where differences between analyses were found, the researcher and research assistants consulted to conclude the correct number of additions, deletions, and substitutions.

Results

Using Statistical Package for the Social Sciences (SPSS), we first assessed each of the data sets for normality of distribution. Following the standard deviation based method of trimming data described by Field (2013), we identified outliers as any participant's datum which yielded a z-score of more than 2.58 standard deviations from the mean and these data were eliminated. In data sets where outliers were eliminated, these eliminated values constituted 1%–3% of the data set. If a participant's datum was considered an outlier in the pre-test, we ignored the parallel datum in the post-test. Where the data were normally distributed, parametric tests were appropriate, and where we could not achieve normality of distribution, we used nonparametric tests and did not trim any of the outliers.

Note errors. Once the researcher and research assistants had counted and coded note errors, we calculated a note error rate: the total number of note errors divided by the number of repetitions recorded. Error rates varied widely among participants, and as such, normal distribution of data could not be obtained by removing outliers. For this reason, we used a nonparametric test, Wilcoxon signed ranks test, which uses median as the measure of average. Median error rate was 0 note errors per repetition in both the pre-test and the post-test in right-hand ($Z = -2.03$, $p = 0.04$) and left-hand scales ($Z = -.77$, $p = 0.44$). Right-hand arpeggio note error rate decreased from a median 0.50 errors per repetition in pre-test to 0.44 errors per repetition in the post-test ($Z = -.11$, $p = 0.91$). Left-hand arpeggio recordings had a median of 0.38 note errors per repetition in both pre-test and post-test ($Z = -1.32$, $p = 0.19$). We also examined the rate of additions, deletions, and substitutions. The rate of additions per repetition increased slightly from 0.71 in the pre-test to 0.76 in the post-test ($Z = -.86$, $p = .39$), while the median deletions per repetition remained 0 in pre-test and post-test ($Z = -.20$, $p = .84$). Substitutions decreased slightly from 0.13 substitutions per repetition in pre-test to 0.11 substitutions per repetition in the post-test ($Z = -1.60$, $p = .11$). While there were some small changes in note accuracy between pre-test and post-test, there was no clear pattern and none of the measured differences reached statistical significance.

Overall sound intensity. We quantified sound intensity by mean key velocity of the MIDI data. Key velocity values are presented in the arbitrary units (a.u.) found in MIDI data which range from 0 to 127 and are closely related to sound intensity measured in decibels (Goebl & Bresin, 2003; Repp, 1997). Velocity data were normally distributed and parametric tests were used. Mean velocity in right-hand and left-hand scales and arpeggios are presented in Table 2 with the results of the paired samples t-tests. While mean velocity increased in the right-hand scale, it decreased in the left-hand scale and both arpeggios. These changes, however, were all less than one unit of key velocity. Based on preliminary results from a study which the authors are currently conducting, a difference in key velocity of less than 2%, which in this case would be just over one unit of key velocity, is a magnitude of change that most human listeners would not be able to perceive. Thus, the changes between pre-test and post-test were not at an audible level. To investigate individual fingers, particularly the thumb, we coded the collected data by finger number, given conventions of scale and arpeggio fingering laid out by the Royal Conservatory of Music. We do not present the detailed findings pertaining to individual fingers here because the changes were consistently lower than one unit of key velocity and there was no strong trend of increases or decreases for any of the finger numbers or any of the playing tasks.

Evenness of tone by note strength (sound intensity). Standard deviation of key velocity is a measure of evenness of tone by note strength, or sound intensity, with a decrease in standard deviation indicating greater evenness, which is considered an improvement in performance. Changes in group means, presented in Table 3, are all smaller than one unit of MIDI velocity, and none of the changes were statistically significant. These results show no clear trend in key velocity between pre-test and post-test of any scale or arpeggio.

Evenness of tone by note length. Interonset interval (IOI) is defined as the time between the beginning of one note and the beginning of the following note. Standard deviation of IOI provides a measure of evenness of tone by note length, with a decrease in standard deviation indicating greater evenness of tone by timing, and therefore an improvement in performance. Timing data were normally distributed and thus we used parametric statistical tests. Results of these tests, which can be found in Table 4,

Table 2. Overall sound intensity, quantified by mean MIDI velocity.

	Pre-test (a.u.)	Post-test (a.u.)	Difference	*T*	*df*	Sig (2-tailed)
RH scale	57.17	57.85	0.67	−1.49	37	0.15
LH scale	55.29	54.82	−0.47	0.96	37	0.34
RH arpeggio	61.12	60.94	−0.19	0.48	37	0.63
LH arpeggio	58.45	58.17	−0.29	0.74	37	0.46

Table 3. Evenness of tone by note strength (sound intensity) quantified by standard deviation of MIDI velocity.

	Pre-test (a.u.)	Post-test (a.u.)	Difference	*T*	*Df*	Sig (2-tailed)
RH scale	5.58	5.62	0.03	−0.27	37	0.79
LH scale	5.13	5.23	0.10	−0.82	37	0.42
RH arpeggio	7.14	7.25	0.11	−0.41	37	0.68
LH arpeggio	7.15	7.16	0.02	−0.09	37	0.93

Table 4. Evenness of tone by note length, quantified by standard deviation of MIDI interonset interval (IOI).

	Pre-test (ms)	Post-test (ms)	Difference	*T*	*df*	Sig (2-tailed)
RH scale	12.98	12.99	0.01	−0.01	37	0.99
LH scale	14.24	14.10	−0.15	0.31	37	0.75
RH arpeggio	12.69	13.17	0.47	−1.06	37	0.29
LH arpeggio	14.92	14.60	−0.32	0.61	36	0.55

show that changes in mean IOI were consistently less than one millisecond (ms). Research has shown that musicians are capable of hearing changes in IOI of 20 ms and greater (Repp, 1999a). It is therefore unlikely that observers would be able to perceive reductions in the standard deviation of IOI that were less than 1 ms. Paired samples *t*-tests reveal that none of these changes were statistically significant.

Evenness of tempo. We calculated tempo drift by subtracting the mean IOI of the sixth repetition from the mean IOI of the first repetition in each pre-test and post-test recording of scales. Following piano pedagogy and performance literature, we considered a decrease in amount of tempo drift to be an improvement in performance. We could not calculate tempo drift in recordings of arpeggios due to the high prevalence of errors in the first and sixth repetitions. For right-hand scales, the mean tempo of pre-test recordings slowed by 10.38 ms from first to sixth repetition and in the post-test, the mean tempo slowed by 10.59 ms. This yielded a difference of 0.20 ms ($t(37) = 0.249$, $p = 0.99$). For left-hand scales, the tempo of the pre-test recording slowed by 9.71 ms from the first to sixth repetition, and in the post-test, the tempo slowed by 9.48 ms. This yielded a difference of mean IOI of 0.22 ms ($t(37) = -0.184$, $p = 0.86$). Neither of these differences between pre-test and post-test were statistically significant following a paired samples *t*-test. Considering that the metronome stimulus for scales was 120 bpm, and the scale played in eighth notes, the expected IOI would be 250 ms. In this context, we can see that a tempo drift of 10 ms of IOI would be small and that a reduction in this tempo drift of less than 1 ms is negligible.

Legato articulation. Key overlap time (KOT), defined as the time between the beginning of one note and the end of the previous note, is a measure of articulation. Where there is a detachment between notes, KOT is negative, and where there is an overlap between notes, KOT is positive. Because we asked participants to play the scales and arpeggios legato, we would consider an increase in KOT to be an improvement in performance. Table 5 presents the mean KOT of all playing tasks, which increased in each of the playing tasks from pre-test to post-test. A paired samples *t*-test indicated that only the increase in KOT of the right-hand scale was statistically significant. To examine the size of effect, we calculated Cohen's *d* (Cohen, 1992), which was 0.30, indicating that the Body Mapping workshop had a small effect on articulation.

Evenness of articulation. Standard deviation of KOT is a measure of evenness of articulation, with a decrease in standard deviation indicating greater evenness of articulation which we would consider being an improvement in performance. Table 6 presents the standard deviation of KOT of each scale and arpeggio. As you can see, standard deviation of KOT increased in each of the scales and arpeggios, indicating that there was less evenness of articulation in the post-test. Only the difference between pre-test and post-test values of the right-hand scale was statistically significant. Cohen's *d* for this measure was 0.45, which indicates a small effect size. These changes were less than 4 ms, which is unlikely to be audible to listeners.

Bench height and distance. There were no significant differences between pre-test and post-test bench height, as the mean bench height across all participants in the

Table 5. Legato articulation, quantified by mean key overlap time (KOT).

	Pre-test (ms)	Post-test (ms)	Difference	*t*	*Df*	Sig (2-tailed)
RH scale	9.01	13.39	4.38	−2.47	36	0.018
LH scale	3.93	4.96	1.03	−1.27	37	0.21
RH arpeggio	−20.33	−18.35	1.98	−1.59	37	0.12
LH arpeggio	−16.55	−16.23	0.32	0.65	34	0.52

Table 6. Evenness of articulation, quantified by standard deviation of key overlap time (KOT).

	Pre-test (ms)	Post-test (ms)	Difference	*t*	*Df*	Sig (2-tailed)
RH scale	24.43	27.95	3.52	−3.655	34	0.001
LH scale	24.24	25.34	1.09	−1.602	37	0.12
RH arpeggio	42.60	43.03	0.43	−0.301	37	0.76
LH arpeggio	37.86	38.31	0.44	0.688	36	0.50

pre-test was 49.34 cm and in the post-test was 49.24 cm (t (35) = 0.30, p = .77). Mean bench distance from the piano increased slightly from 58.81 to 60.14 cm, but this was not found to be statistically significant (t (34) = −2.0, p = 0.052).

Discussion

The results of this study indicate that although there were some differences in scale and arpeggio piano performance between MIDI recordings taken before and after the Body Mapping workshop, these differences were small and demonstrated no clear trend of improvements. We hypothesised that after the Body Mapping workshop, the pianists would make fewer note errors, that sound intensity and articulation would become more even, and that there would be less tempo drift. Contrary to these hypotheses, we found little change in these measures. The changes that we observed did not demonstrate a clear trend of improvements, and even those that were measured were small and likely not aurally perceptible to listeners. The only statistically significant changes were to articulation, but these were decreases in evenness of articulation that were not nearly at a level which would be audible to listeners. Despite many anecdotal examples of musicians experiencing improvements in their performance, including to specifically technical elements (Conable, 2000), to rate of note error (Mark, 2003), to tone (Johnson, 2009), to tempo (Harscher, n.d.), and to articulation (Breault Mulvey, 2016), we did not find such improvements in pianists immediately following a Body Mapping workshop.

Let us now consider the potential of ceiling effects, starting with those measurements which were likely affected by the pianists' high level of playing proficiency. Pre-test note accuracy values had a median of 0 errors per repetition in scales and less than 1 error per repetition in arpeggios. This suggests that the pianists in our study were already playing the tasks at a high level of note accuracy, implying that they had little room for improvement in this measure. Changes in tempo generally need to be at least 2% of the baseline IOI to be audible (Friberg & Sundberg, 1995; Repp, 2001). The baseline IOI for scales in our study was 250 ms. The tempo drift in pre-test data was around 10 ms, not nearly high enough to constitute an audible shift in tempo. It is likely, then, that our inability to reject the null hypothesis for measures of note accuracy and evenness in tempo were affected by a ceiling effect.

When considering changes in evenness of tone by sound intensity, it unlikely that a ceiling effect is involved. Based on pilot data from a study on perceptions of changes in sound intensity, we have reason to believe that changes in key velocity as small as about 5% of the baseline MIDI velocity can be detected by most listeners. A 5% change from the mean MIDI velocity would be 2.89 a.u. for right-hand scales, 2.76 a.u. for left-hand scales, 3.06 a.u. for right-hand arpeggios and 2.92 a.u. for left-hand arpeggios. The standard deviation of MIDI velocity in the pre-test data was well above these numbers, indicating that there were deviations in the MIDI velocity that would render audible unevenness in some pre-test scales and arpeggios. This suggests that a ceiling effect was not at play for evenness of tone by sound intensity.

Evaluating the risk of a ceiling effect in measures of timing requires an understanding of timing perceptions. Looking at evenness of tone by timing, the standard deviation of IOI in pre-test was at its lowest in right-hand scales, at 12.98 ms, and at its highest with left-hand arpeggios, at 14.92 ms. As previously mentioned, trained musician listeners have been found to be able to identify changes in IOI as small as 20 ms (Repp, 1999a). This threshold of 20 ms is around 1.5 standard deviations from the mean in the present data (1.5 standard deviations from the mean in pre-test data would be 19.47 ms in right-hand scales and 22.38 ms in left-hand arpeggios). Since the present data are normally distributed, 86.6% of points will be within 1.5 standard deviations of the mean. This indicates that very few of the notes that pianists played in the pre-test were audibly uneven in timing. It is difficult to tell whether it would have been possible for the pianists to improve in their evenness of timing given these pre-test values, however, the timing data is certainly not as strongly indicative of a ceiling effect as that of note accuracy. Researchers should use caution in interpreting changes in standard deviation of IOI in such an advanced pianist population. When considering evenness of tone by articulation, the lowest standard deviation in pre-test data was 24.43 ms, which is above the auditory threshold for changes in timing identified by Repp (1999a). Thus, while a ceiling effect could be a consideration for evenness of tone by timing, the same cannot be said for evenness of articulation.

It is important to consider study design when interpreting the above considerations on a potential ceiling effect. The likelihood of a ceiling effect in measures of note accuracy and tempo drift demonstrates that the participants were playing piano at an advanced level, such that they had little room for improvement. This does not mean that we sampled poorly. Rather, the population sample is representative of some of the more common participants in Body Mapping workshops. The fact that the participants in this study could not have improved in these measures suggests that technical skills of note accuracy and tempo drift are unlikely to improve in this population at all, whether in an experimental or naturalistic context. Researchers should take this into consideration when deciding whether to use these parameters as measurements of improvements in piano performance in such an advanced pianist population. The measures we chose to study were highly technical in nature, but they were selected based on specific variables described in instructional and promotional literature on audible improvements in music performance following a Body Mapping workshop. The potential of a ceiling effect in note accuracy and tempo drift may explain the null findings in these measurements, but it does not explain why there exist perceptions that Body Mapping workshops yield such results. Further, the lack of evidence of a ceiling effect in other measures, such as those of sound intensity, supports that a ceiling effect is not solely responsible for our inability to reject the null hypothesis.

Let us now explore some possible explanations for our inability to reject the null hypothesis, even in those measures where we can be confident that a ceiling effect was not implicated. The first logical explanation is that Body Mapping does not have an effect on these specific measures of piano performance. It is possible that the effects of Body Mapping on audible aspects of piano performance, if there are any, are related to different variables or different contexts. Perhaps if we had used a different musical task, such as one that involves expressivity, or a different instrument, such as one that requires the use of breath, the measures may have been different and thus the outcomes may have been more indicative of improvements in performance in expressivity or use of the breath. Still, there remain claims about Body Mapping's effects on these specific aspects of music performance that were not supported by the present findings. Another explanation of the present findings could be about the amount of Body Mapping training that is required before changes would be measurable. The two previous qualitative studies conducted on Body Mapping found that students reported improvements in their performance following a semester of classes (Buchanan & Hays, 2014; Knaub, 2002). It could be that changes in the specific aspects of piano performance that we measured only arise after several months of Body Mapping instruction and are not evident immediately following a single workshop. This does not explain, however, audience perceptions of immediate improvements to music performance during Body Mapping workshops.

A comparison of the present findings with the overwhelming unanimity of anecdotal evidence invites a number of questions. While it is tempting to conclude that audience perceptions of improvements are simply wrong, it is important to acknowledge that audience perceptions are central to the art of music performance. If it is the case that a Body Mapping workshop has no immediate effect on the sound of piano performance, and yet audience members perceive a change, there must be some reason for these perceptions. What the results of the present study suggest is that audience perception of immediate changes in piano performance have its origin in aspects other than the note accuracy, sound intensity, tempo, and articulation. These perceptions could originate from confirmation bias: audience members expect to hear a change, and their biases create a perception that the sound has changed. The perception is real but is not measurable. The origin may be more complex, however, as we consider the impact of visual aspects of music performance.

Since Body Mapping trains movements of the body (Johnson, 2009), it is possible that in masterclass and workshop settings, audience members visually observe a change in the body movements of the performer and this is perceived as being a change in musical sound. Certainly, the visual aspect of music performance has a major impact on audience perception. Researchers have found that visual information is dominant in perceptual reports (Posner et al., 1976) and that evaluations of musical quality are influenced by visual aspects, such as the body movements of the performer (Siddell-strebel, 2007). In one study, judges were more reliably able to select the winner of a music competition from a series of silent video clips than by a series of audio clips, in spite of their own assertions that musical quality is more important than visual quality (Tsay, 2013). Similarly, in Wong's (2015) study of the effects of somatic lessons on piano performance, the results showed that judges were more frequently able to correctly identify the post-test recordings by video than by audio. Considering the visual dominance of observers, Wong's findings support the hypothesis that something visually had changed. This could mean that perceptions of improvements in music performance immediately following a Body Mapping workshop are more strongly related to visual aspects than to audible ones.

Conclusion

The results of this study provide important insight for musicians, music teachers, and Body Mapping instructors. We found that one day after a standard six-hour WEM-style Body Mapping workshop, the advanced pianists in our study demonstrated little measurable change in note accuracy, sound intensity, tempo, and articulation of scale and arpeggio performance. These results cannot support any claims that Body Mapping can immediately improve these specific aspects of piano performance. While it is possible that Body Mapping strategies can be employed over time to improve these aspects of performance, music educators and Body Mapping instructors should not claim that note accuracy, sound intensity, tempo, or articulation of piano performance will improve immediately following a workshop. While the changes we expected to see in the MIDI data were not empirically measurable, the null findings propel some interesting new research questions. We propose that perceptions of immediate changes in piano performance following a Body Mapping workshop are attributable to changes in visual aspects.

The limitations of this study highlight directions for future research. The playing tasks studied here are limited to scales and arpeggios, and it may be possible that we would see some improvements in repertoire performance. In this study, we specifically looked at note accuracy, sound intensity, tempo, and articulation, and it is possible that there may be some other measurable improvements in music performance following a Body Mapping workshop, such as expressivity. Future research should consider using playing tasks that are repertoire-based, and use methods that examine the expressivity of the performances. In this way, we can examine whether Body Mapping has an impact on the expressivity of music performance, as is claimed in some Body Mapping pedagogical literature (Pearson, 2006) and participant reports (Buchanan & Hays, 2014). This study and the study of Wong (2015) were limited to short term interventions, with participants receiving Body Mapping instruction on only one day. In Knaub (2002), participants reported that while some changes happened dramatically in a short period of time, others emerged after prolonged study. It is possible that Body Mapping studied over a longer period of time may have a measurable impact on note accuracy, sound intensity, tempo, and articulation of music performance, whereas one day of instruction does not. Finally, this study was limited to pianists. Many of the claims associated with Body Mapping relate to other instruments and voice types, and it is possible that while pianists do not experience immediate improvements in these measures immediately, that other instrumentalists and singers do. Further research is required to fully understand the impact that Body Mapping has on music performance.

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