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COORDINATION OF BREATHING AND VARIOUS MOVEMENT MARKERS DURING PIANISTS' PERFORMANCE TASKS[1]

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Summary.—Few investigations have analysed the relations of breathing and pianists' movements. In past studies, however, coordination of breathing with repetitive movements were examined. The current experiment explored the coordinative relations of breathing with three different finger-movement markers (pitch, meter, and thumb passage) during the performance of repetitive exercises at the piano. Eight pianists played the C major scale and arpeggio at different tempi. The Musical Instrument Digital Interface (MIDI) data were collected and the pianists' respiration was simultaneously monitored by inductive plethysmography. Analysis showed that the breathing varied between participants. Other than some exceptional cases for which movement markers coincided with the end of inspiration and the end of expiration of the breathing curve, no coordination or relation occurred between breathing and finger movement.

The relations between breathing and various bodily rhythms are complex since respiration is linked to many motor subsystems by neuronal interactions (Ebert, Rassler, & Hefter, 2000). Coordination is defined as a tuning of temporal patterns during which one oscillator imposes its tempo and phasing onto another oscillator, indicating the entrainment of one rhythm by the other (von Holst, 1939). Coordination is evaluated with the use of phase coupling of cyclical rhythms affecting each other (Kohl, Koller, & Jäger, 1981; Rassler & Raabe, 2003). Coupling analyses are often used in studies of the link between the breathing cycle and various rhythms. Relations have been observed between breathing and other body rhythms which lead to respiratory entrainment in both animals and humans (Bramble & Carrier, 1983). Movement characteristics such as type (Bechbache & Duffin, 1977), frequency (Perségol, Jordan, & Viala, 1991), and workload (Bernasconi & Kohl, 1993) may be associated with the extent of entrainment between movement and breathing. Moreover, factors like familiarity of movement (Bramble & Carrier, 1983) and altitude (Paterson, Wood, Marshall, Morton, & Harrison, 1987) may be associated with entrainment. Research has been done on the entrainment of breathing and larger movements such as those seen during repetitive exercises;

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these studies have established coordination between breathing and walking rhythms (Rassler & Kohl, 1996), running rhythms (Bramble & Carrier, 1983), cycling rhythms (Kohl, *et al.*, 1981), cross-country skiing rhythms (Fabre, Perrey, Arbez, & Rouillon, 2007), and rowing rhythms (Mahler, Shuhart, Brew, & Stukel, 1991).

For actions of smaller muscle groups, there are studies on the entrainment of breathing with limb movements (Agostoni & D'Angelo, 1976), forearm tracking movements (Ebert, *et al.*, 2000), eye and head movements (Rassler & Raabe, 2003) and finger movements (Wilke, Lansing, & Rogers, 1975; Rassler, Ebert, Waurick, & Jaughans, 1996; Rassler, 2000; Rassler, Bradl, & Scholle, 2000). In a study on forearm tracking movements (Ebert, *et al.*, 2000), researchers wanted to determine whether rhythmical tracking can lead to breathing entrainment. Subjects were asked to flex and extend the forearm repeatedly while their respiration was being measured with a pneumotachograph. Sinusoidal graphs of the breathing pattern and the arm motion were obtained and compared to find phase intervals. Using the frequency of coordination as a measure for coupling strength, the study showed that entrainment between breathing and forearm tracking movements occurs. In another article on the mutual neural influences between breathing and precision finger movements, Rassler (2000) discussed the effects of precision, short-term finger tracking on the respiratory cycle and vice versa. The right-handed subjects had to perform short, spontaneous, and pre-determined flexion and extension finger movements while their respiration was being recorded by a pneumotachograph attached to a face mask. The results indicated that there is an association between short-term finger tracking and modulations of the respiratory cycle at different stages of breath.

Accurate finger movements such as flexions, extensions, and tapping movement, examined in some previously mentioned studies (Wilke, *et al.*, 1975; Rassler, *et al.*, 1996; Rassler, 2000) are similar to gestures performed by pianists while playing. Ebert, Hefter, Binkofski, and Freund (2002) addressed the coordination of breathing with mental groupings of piano finger movements during the performance of a piano exercise (Hanon technique piano book) transcribed into five different meters. Since individual pianistic movements are much faster than a normal breathing pattern, the authors wondered if regulation of breathing was according to groupings of notes. Analysis showed that a breath cycle seemed to last the length of a bar (1:1 coordination) when the meter used was 5/4, 6/4, 7/4, and a breath cycle lasted two bars (1:2 coordination) when the meter used was 6/4 or 4/4. Additionally, pooled data indicated that coordination between breathing and finger movement was found more frequently in a 7/4 meter and less frequently with a 4/4 meter. The researchers hypothesized that this is related to increased mental effort required to group music with an asymmetrical meter.

Ebert, *et al*. (2002) show that the relation of breathing with finger-movement markers differed by meter; however, there is no research on the relations of breathing with pitch finger-movement markers or the passage of the thumb. Consequently, this gap in research on the correlation between respiration and finger movements at the piano inspired the present objective, while the surprising exactitude of the results exemplified by Ebert, *et al*. (2002) led to a sub-purpose of this study. The present focus was to assess whether coordination develops between breathing and various finger-movement markers during the performance of a C major scale and arpeggio at different tempi. More specifically, the three finger-movement markers observed were: (1) meter, the typical rhythmic division of a scale or arpeggio, (2) pitch, the top and bottom note of each exercise and (3) passage of the thumb, the notes pressed by the thumb when tucked under the other fingers[2]. Furthermore, a part of this project also replicates Ebert and colleagues' (2002) study to determine if similar results are obtained. The exercises proposed are simple and repetitive; therefore, if there is a relation between breathing and the different movement markers, entrainment should be observed on the phase-interval graphs.

Based on past research, hypotheses may be proposed regarding the occurrence of coordination of breathing with the different finger-movement markers. Ebert, *et al*. (2000) had previously conducted a study to assess whether coordination occurs between breathing and forearm movement. Using the frequency of coordination, the study illustrated the occurrence of entrainment between respiration and repetitive opening/closing forearm movements during sinusoidal tracking. Since the repetitive performance of a scale or arpeggio requires a consistent opening and closing movement of the forearm, a similar coordination of breathing with pitch-movement markers during a pianist's performance of both exercises should be observed. In addition, like the results exemplified by Ebert, *et al*. (2002), a coordinative relation of breathing with meter finger-movement markers is anticipated. Lastly, since the passage of the thumb is irregular, it is predicted that this finger movement will not be coordinated with breathing.

Method

Participants

Eight pianists (seven women, one man; ages 18–28 years) whose playing level ranged from Grade 8 of the Royal Conservatory of Music (RCM) of Toronto to a Bachelor of Music in piano performance degree participat-

[2]The passage of the thumb marker is based on the following right hand fingering where 1 is the thumb and 5 is the smallest finger. The bold, underlined numbers indicate the top note (C6) of the scale or arpeggio (see Fig. 2):
Scale: 1 2 3 1 2 3 4 1 2 3 1 2 3 4 **5** 4 3 2 1 3 2 1 4 3 2 1 3 2 1
Arpeggio: 1 2 3 1 2 3 **5** 3 2 1 3 2 1

ed in the study. The Grade 8 and 9 pianist is considered to be an intermediate-advanced player. In order to be admitted to the Bachelor of Music program, the individual must have at least completed the Grade 10 level. Afterwards, a student in this university program takes four years of practical, theoretical, and history classes to complete the degree.

All participants followed classical music training. As seen in Table 1, there is a wide range between the number of years individuals have invested in piano training and the level they obtained, which is not uncommon amongst pianists. Therefore, this heterogeneous sample is an accurate representation of reality in which various training characteristics differ between participants.

Instrumentation

To acquire data from performance conditions as close to normal as possible, a non-invasive inductive plethysmography system (RIPmate Respiratory Effort System) was chosen. This technique has also been commonly used in other studies requiring monitoring of respiration (Clarenbach, Senn, Brack, Kohler, & Bloch, 2005). During the experiment, sound, images, and respiration were recorded simultaneously.

Recording sound and images.—Two methods were used to record sound. In accord with past research on piano performance (Ebert, *et al.*, 2002), participants played on a Yamaha Disklavier Mark III. As explained on the Yamaha Canada Music (2005) website, the 88 key sensing system of this 7 feet, 6 inches grand piano is made of non-contact, optical fiber/grayscale shutters which detect the key position, the keying velocity, and the key re-

TABLE 1
CHARACTERISTICS OF PARTICIPANTS

Participant	Sex	Years Playing the Piano	Highest Level Completed	Year of Completion[a]	Current Piano Activity
1	F	19	Grade 8	1998	Plays occasionally and teaches piano
2	F	20	Grade 9	2004	Practices regularly, takes lessons, and teaches piano
3	F	20	Grade 8	2003	Plays occasionally
4	F	21	BA Music	2005	Plays regularly and teaches piano
5	M	10	Grade 9	2007	Practices regularly, takes lessons, and teaches piano
6	F	21	BA Music	2005	Plays occasionally
7	F	19	Grade 8	2003	Plays occasionally
8	F	25	BA Music	2003	Plays regularly and teaches piano

[a]It is important to note that the experimentation was conducted in June and July 2009.

lease velocity. Data obtained from these sensors during a performance are recorded by an integrated Musical Instrument Digital Interface (MIDI)[3] operating system which also allows replaying of MIDI files. For synchronization purposes, sound data were acquired in a waveform audio format with a microphone (Neumann TLM-103) connected to a Digidesign Digi002 sound card (Digidesign, a division of Avid Technology, Inc., Burlington, Massachusetts).

For overall visual recording of the sessions, experiments were filmed by a vertically moveable, analogue video camera mounted on accordion brackets attached to the ceiling of the laboratory. The video cassettes were available for later viewing to obtain complimentary information during the data analysis.

Recording respiration.—The inductive plethysmography straps [RIPmate Respiratory Effort System (Sleepmate Technologies, Midlothian, Virginia)] surrounded the pianist's rib cage under the armpits and around the abdomen, below the 12th rib. The respiratory effort sensors measured inductance changes represented by voltage output, resulting from the circumference displacements of the upper rib cage and abdomen during inspiration and expiration. The signals from the sensors were converted into digital signals by a data acquisition board [DAQ08-Scireq (Scireq Scientific Respiratory Equipment, Inc., Montréal, Canada)]. Prior to recording the data, calibration was done by simultaneously measuring the circumference displacements (RIPmate) and flow changes through a pneumotachographer (Hans Rudolf-PNPT 3830B-400L/min.) attached to a MicroGard filter. Both were connected to the DAQ08-Scireq.

Experimental Set-up and Data Synchronization

The DAQ08-Scireq recorded data from four sources: (1) RIPmate abdominal respiratory belt, (2) RIPmate thoracic respiratory belt, (3) flow, and (4) pressure. While flow data and pressure data were only recorded during the calibration and synchronization stages of the set-up, respectively, respiratory data from the belts was recorded throughout the experimental session. A double synchronization setup was used to synchronize the participant's respiratory data and the MIDI data from the piano. The first step was to synchronize the waveform audio file (Fig. 1, Sound 1) with the analogue signal by using sound and pressure peaks. This was accomplished by striking a polyvinyl chloride tube which created a pressure wave detected (with a negligible resolution of 865 μsec.) by a pressure sensor and a microphone connected to the Digidesign Digi002 sound card. This wave created a peak in the pressure recording and a peak in the audio file. The second synchronization step was accomplished by synchroniz-

[3]MIDI is an electronic musical instrument specification that represents musical information in a digital format.

ing the MIDI data (Fig. 1, Sound 2) and Sound 1. A key was played on the piano which launched the MIDI recording and would be detected by the microphone, connected to the Digidesign Digi002 sound card, creating another peak in the audio file. MATLAB algorithms were subsequently coded into a Graphical User Interface to detect these three peaks (pressure, Sound 1, and Sound 2) and align them in time, resulting in synchronization of the system.

Procedure

Participants were given an information package containing the presentation letter, the consent form, and the musical scores required in preparation for the experimental session. In the letter, participants were asked to practice beforehand so they would be able to perform the required task with ease. While it did not directly divulge the purpose of the study, given the nature of the experiment and the equipment used to collect the data, participants were aware that their breathing was being measured.

On the day of the testing session, participants came to the Piano Pedagogy Research Laboratory at the University of Ottawa at their appointed time. For demographic purposes, participants answered a questionnaire. The information is provided in Table 1.

Before starting the experiment, a two-step equipment calibration pro-

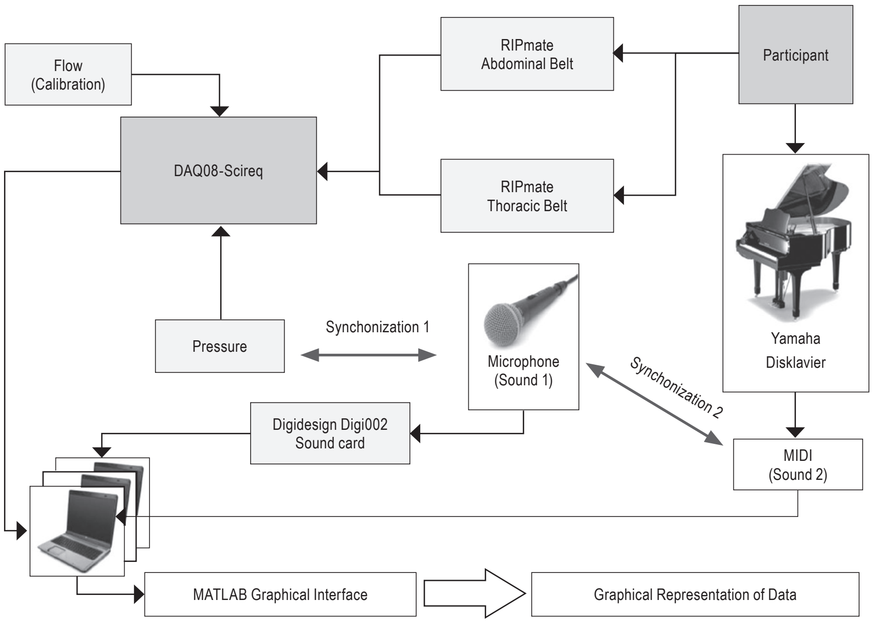

FIG. 1. Experimental set-up illustrating the double synchronization method.

cedure, based on the literature (Konno & Mead, 1967; Sackner, *et al*., 1989; Banzett, *et al*., 1995) was completed. The nose of each participant was plugged, and each was asked to breathe in a pneumotach, always keeping the hands on the piano in a natural playing position. The two calibration steps were: (1) breathing at rest for 2 min., which is referred to as quiet breathing hereafter and (2) vital capacity (VC), i.e., taking a breath to maximum capacity and exhaling to maximum capacity (repeated twice). Then, participants were asked to perform various musical tasks as they would during a normal piano lesson. This experiment was part of a larger experimental session[4] which lasted approximately 45 min. and included exercises as well as repertoire pieces. However, the focus of this paper is on the performance of two exercises, the C major scale and the C major arpeggio. Between musical tasks, breathing at rest was measured during which participants were asked to read a preselected text of random facts which served as a distraction.

Scale.—Participants were asked to play repeatedly for 1 min., two octaves of the C major ascending and descending scale with the right hand in eighth notes at three tempi: 60, 120, and 184 bpm. The metronome was used to set the tempo for the first 10 sec. of this task and was then turned off for the rest of the performance.

Arpeggio.—Participants were asked to play repeatedly for 1 min., two octaves of the C major ascending and descending arpeggio with the right hand in eighth notes at three tempi: 80, 120, and 160 bpm. The metronome was used to set the tempo for the first 10 sec. of this task and then was turned off for the rest of the performance.

Data Acquisition

With a Graphical User Interface created in MATLAB, it was possible to obtain a graphical representation of the MIDI recording and of the respiration (Fig. 3).

Piano roll.—A MIDI toolbox created by Schutte (2009) was used to visualize the MIDI data recorded by the Yamaha Disklavier. Using a piano roll format, the performance was graphically illustrated across time by squares representing each note of the musical excerpt in Fig. 3. The position and size of each square denote the pitch played and its duration, respectively.

Respiration curve.—The RIPmate belts are sensitive to circumference

[4]During the complete experimental session, the participants were asked to perform five pianistic tasks in this order: (1) C major scale (right hand) at 60 bpm, 120 bpm, and 184 bpm, (2) C major arpeggio (right hand) at 80 bpm, 120 bpm, and 160 bpm, (3) Hanon five-finger exercise (right hand) at 170 bpm, (4) Minuet in G major by J. S. Bach at 80 bpm, 120 bpm, and 160 bpm, and (5) Für Elise by L. Beethoven at 100 bpm, 140 bpm, 180 bpm. Full data can be obtained in the thesis *Breathing patterns of advanced pianists while executing four performing tasks* (Nassrallah, 2010).

FIG. 2. The C major scale and the C major arpeggio participants were asked to perform.

changes from the thorax and abdomen, but also other torso or limb movement may be detected by the sensors. Therefore, before quantitatively analyzing the respiratory patterns it was necessary to verify that patterns and peaks in the respiratory curve did represent the respiratory changes and not participants' abrupt movement. Since the experimental sessions were filmed, abnormal curves in the breathing pattern were verified by watching the video of the experimental session for upper body movements or arm movements.

From MATLAB, the breathing curve for each participant during ev-

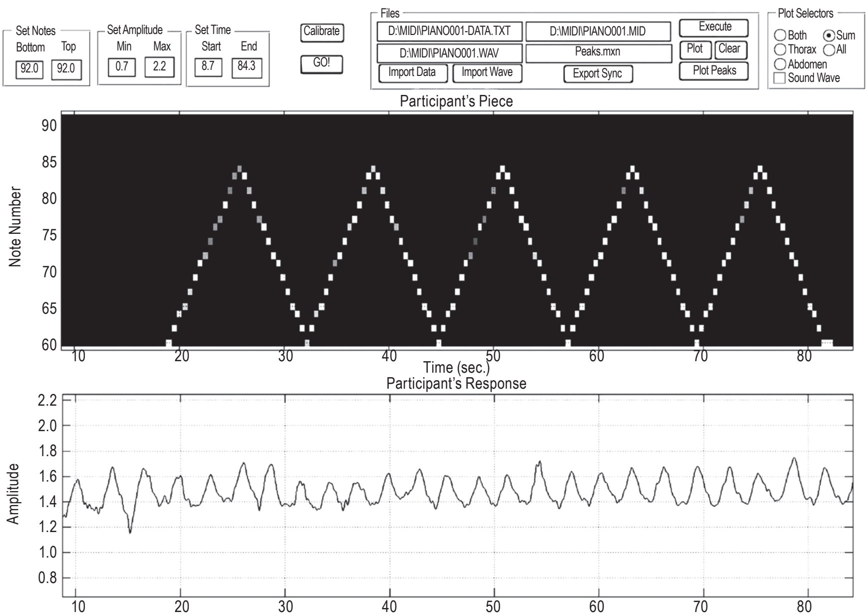

FIG. 3. A piano roll (upper graph) showing the performance of a scale and the breathing curve (lower graph) as represented in MATLAB.

ery activity was traced, based on 2 × thorax + 1 × abdomen as described by Banzett, *et al*. (1995). For respiration to be graphically represented in terms of litres across time, it was first necessary to convert respiration data from voltage to litres. This was achieved by comparing the respiration flow values (in litres) obtained with the pneumotach during the calibration step to the electrical signals (in volts) output from the RIPmate System. A conversion factor between the two sets of data allowed representation of the amplitude changes in litres. Afterwards, by finding the vital capacity for each participant, the *y* axis of the respiration graphs was converted to percentage of vital capacity thereby permitting comparisons among participants.

Data Analysis

To find phase coupling and frequency coupling, the time at which each note was pressed during the performance of the scale and arpeggio was extracted from the MIDI data. Then, the time value of each movement marker event, corresponding to a specific note played, was selected. Three sets of movement markers were established: (1) meter marker, i.e., the onset of every fourth note. The meter markers were regular; (2) pitch marker, i.e., the onset of the bottom note (middle C) and the top note (C6) of the scale and arpeggio. The pitch markers are based on the first and last notes of the scale and arpeggio and occurred at regular intervals; (3) passage of the thumb marker, i.e., the onset of every note pressed by the thumb as it is tucked under the hand. With the standard fingering used during the performance of a scale or arpeggio, this marker occurs at irregular intervals. As shown in Fig. 4 and Fig. 5, the three different marker types only correspond in time at the beginning of the performance of a scale or arpeggio.

Phase coupling.—To study coordination, phase coupling and frequency coupling are typically used (Kohl, *et al*., 1981; Ebert, *et al*., 2000; Ebert, *et al*., 2002; Fabre, *et al*., 2007). Phase coordination was determined by finding the time difference between a specific point of the movement cycle and

FIG. 4. Location of the different markers in the C major scale. It should be noted that the position of the passage of the thumb markers is based on the assumption that the correct fingering was used during the performance of the scale.

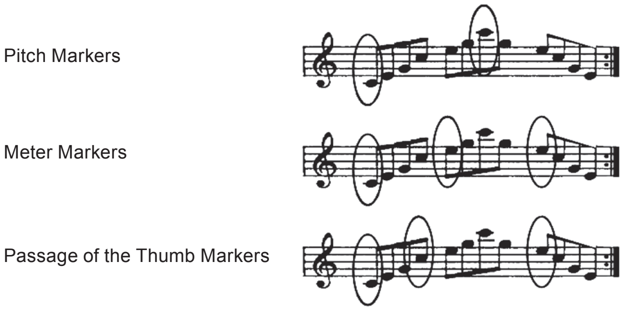

FIG. 5. Location of the different markers in the C major arpeggio. It should be noted that the position of the passage of the thumb markers is based on the assumption that the correct fingering was used during the performance of the arpeggio.

a specific point of the respiratory cycle, such as expiration or inspiration. Therefore, to assess coordination between breathing and movement, the time period between a movement marker and the closest breathing marker that represented the end of expiration was considered (Fig. 6). This was accomplished by obtaining the time points of the end of expiration in DIAMOV, a MATLAB-designed program created at the Laboratory of Biomedical Technologies (Politecnico di Milano, Milan, Italy) in which it is possible to visualize data and to get specific values within a selected window (Fig. 6).

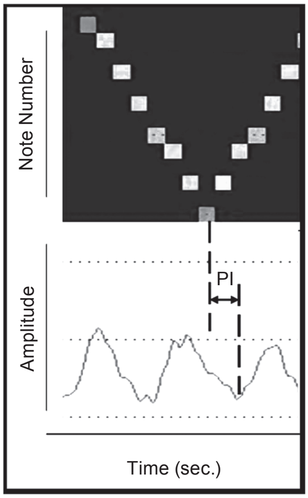

FIG. 6. A section of piano roll (upper representation) and the breathing curve (lower graph). The phase intervals (PI) are calculated by finding the time difference between each movement marker and the closest end of expiration point on the breathing curve.

Results

Phase Coupling Between Breathing and Movement Markers

Observations have been made with regard to phase relations and breathing during the performance of the scale and arpeggio. The phase interval plots of the scale and arpeggio illustrate an independent relation between breathing and movement for all eight participants.

Scale.—For two participants, the plots of pitch markers and metric markers presented groups of points aligned diagonally, especially at the slower tempo (60 bpm). As the tempo increased, the time difference (phase interval) between a movement marker and the closest breathing marker decreased, therefore, the points get closer to the zero.

Arpeggio.—The pitch marker plots of a single participant clearly illustrated groups of points aligned in a diagonal pattern at the slower tempo; however, these patterns are not observed in the plots of the other seven participants.

Markers and Breathing Curve

Graphs showing the positioning of the different markers on the breathing curve were also plotted for further analysis. Amongst all the graphs, the plots of only four participants presented interesting patterns between the meter and pitch markers and the breathing curving (Fig. 8 and Fig. 9). On the graphs of the other four participants, there was no clear pattern observed between the markers and the breathing curve. The plots of breathing and the passage of the thumb did not illustrate any patterns for all participants (Fig. 10).

Scale.—In the graphs for seven of the eight participants no particular patterns were noted between the different markers and the breathing curve. The plot of only one participant (Participant 1) illustrated a noteworthy pattern between the meter markers and the breathing curve during the individual's performance of the C major scale at 120 bpm (Fig. 8). On this graph, the markers mainly corresponded to the major peaks (minimums and maximums) of the breathing pattern.

Arpeggio.—Similarly to the observations made on scale performance, most graphs obtained from arpeggio playing do not illustrate evident relation between the breathing curve and the different markers. An exception, however, is shown in Fig. 9 in which pitch markers clearly coincide with the minimums and maximums of the breathing curve before and after the big peak at 118 sec. while the participant is playing the arpeggio at 120 bpm. This pattern between the pitch markers and the breathing curve during the performance of the arpeggio was observed for Participants 4, 5, and 6 at this same tempo.

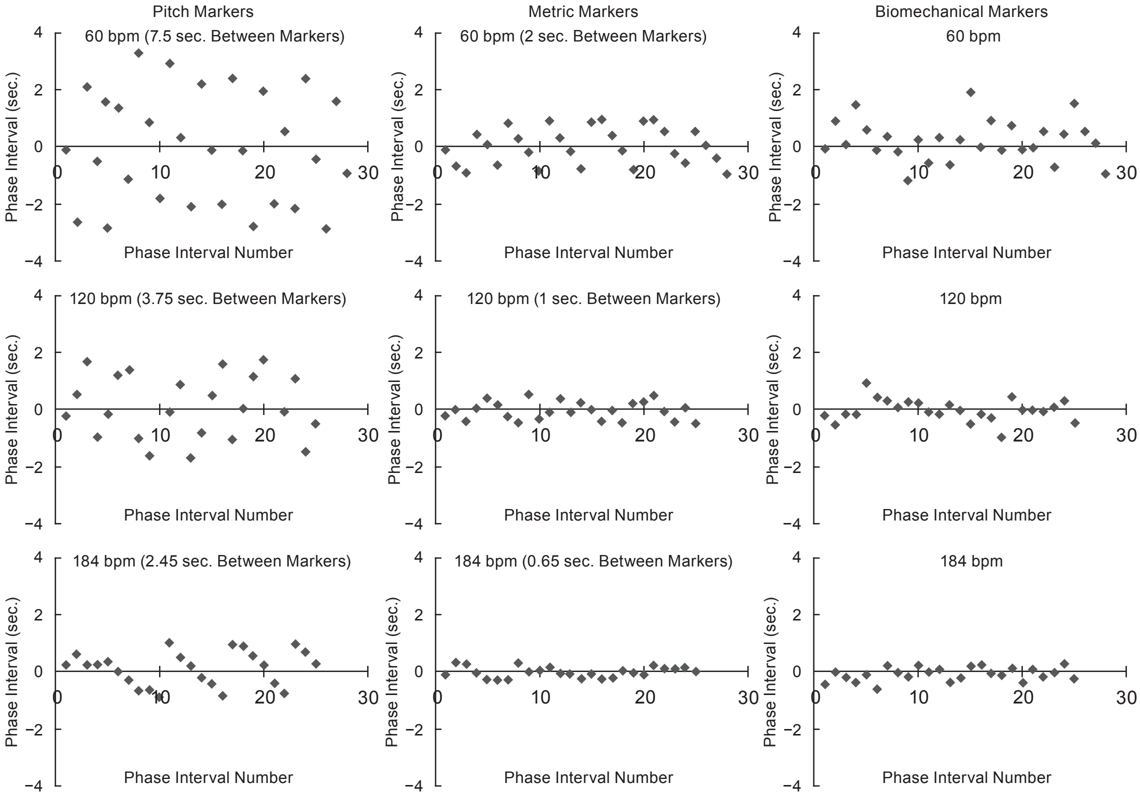

FIG. 7. Plots of phase interval relation between onset of inspiration and onset of movement for the three markers (pitch, meter, passage of the thumb) at different tempi for Participant 6 during the performance of the C major scale. Extraneous points were removed from the plots.

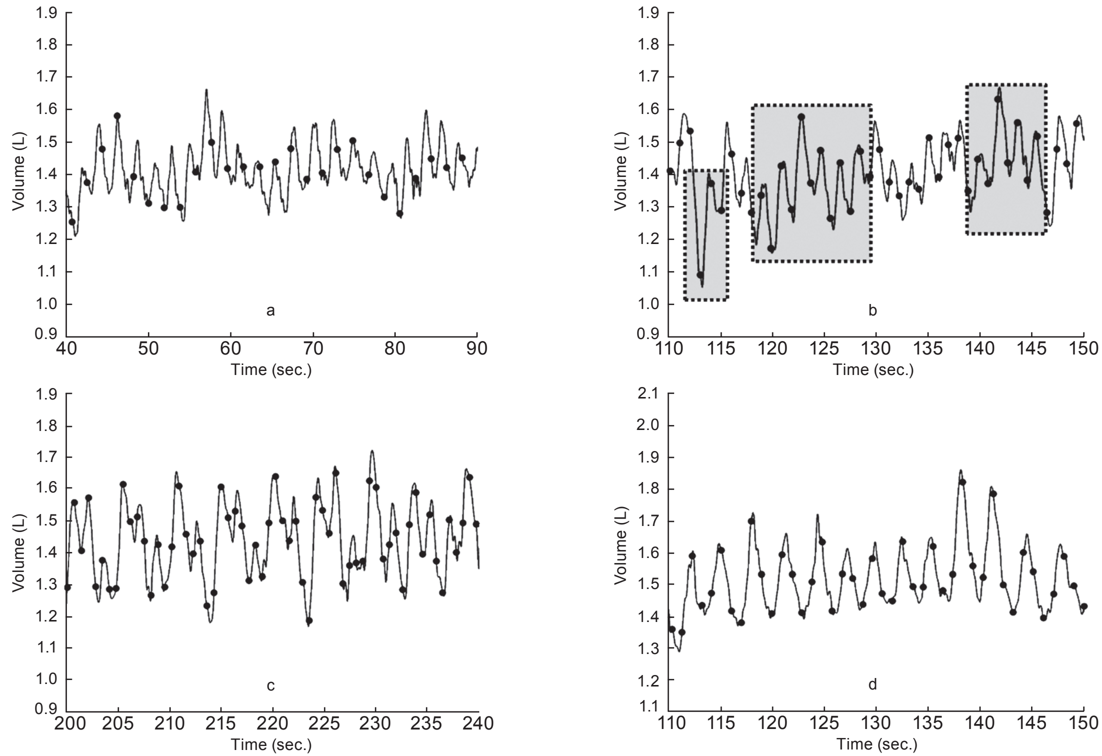

FIG. 8. Breathing curve (—) with juxtaposed meter movement markers (•) during the performance of the C major scale. a) Participant 1 playing at 60 bpm. b) Participant 1 playing at 120 bpm. The areas where the meter markers occur on the maximums and minimums of the breathing curve are marked in grey. c) Participant 1 playing at 184 bpm. d) Participant 4 playing at 120 bpm. With this figure it is possible to compare the graphs of the same participant playing the scale at different tempi. Additionally, comparisons can be done between two different participants (1 and 4) playing the scale at the same tempo. While the graph (b) of Participant 1 exemplifies a pattern, the graph (d) of Participant 4 does not.

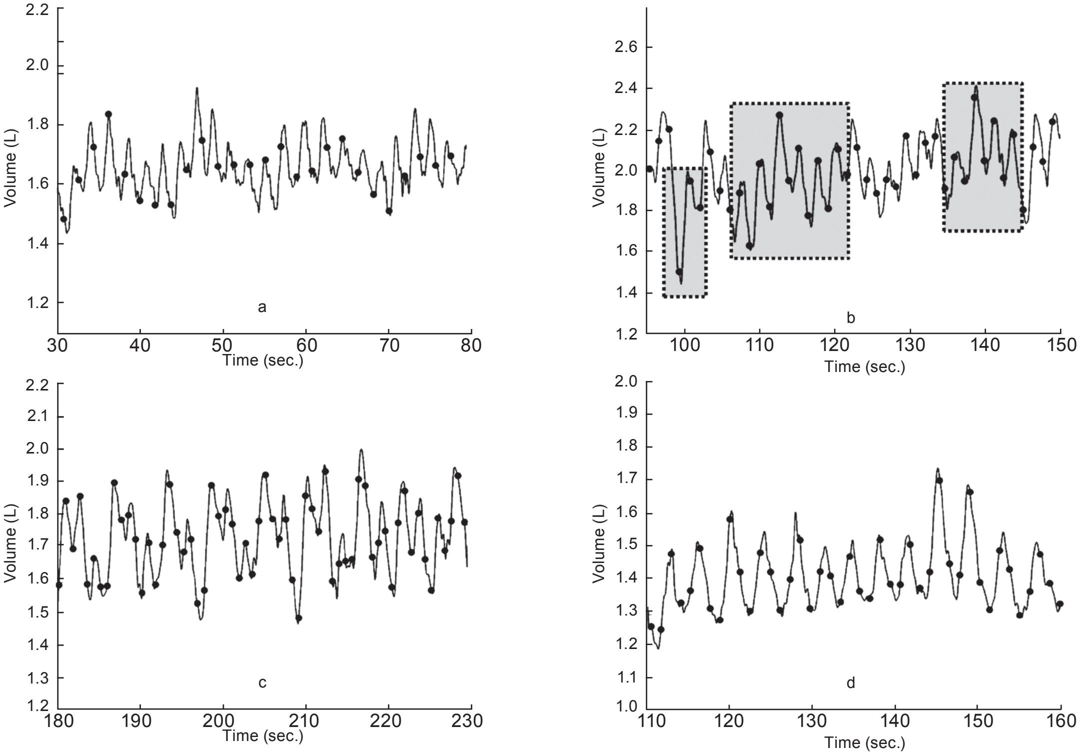

FIG. 9. Breathing curve (—) with juxtaposed pitch movement markers (■) during the performance of the C major arpeggio. a) Participant 4 playing at 80 bpm. b) Participant 4 playing at 120 bpm. The areas where the pitch markers occur on the maximums and minimums of the breathing curve are marked in grey. c) Participant 4 playing at 160 bpm. d) Participant 1 playing at 120 bpm. With this figure it is possible to compare the graphs of the same participant playing the arpeggio at different tempi. Additionally, comparisons can be done between two different participants (4 and 1) playing the arpeggio at the same tempo. While the graph (b) of Participant 4 exemplifies a pattern, the graph (d) of Participant 1 does not.

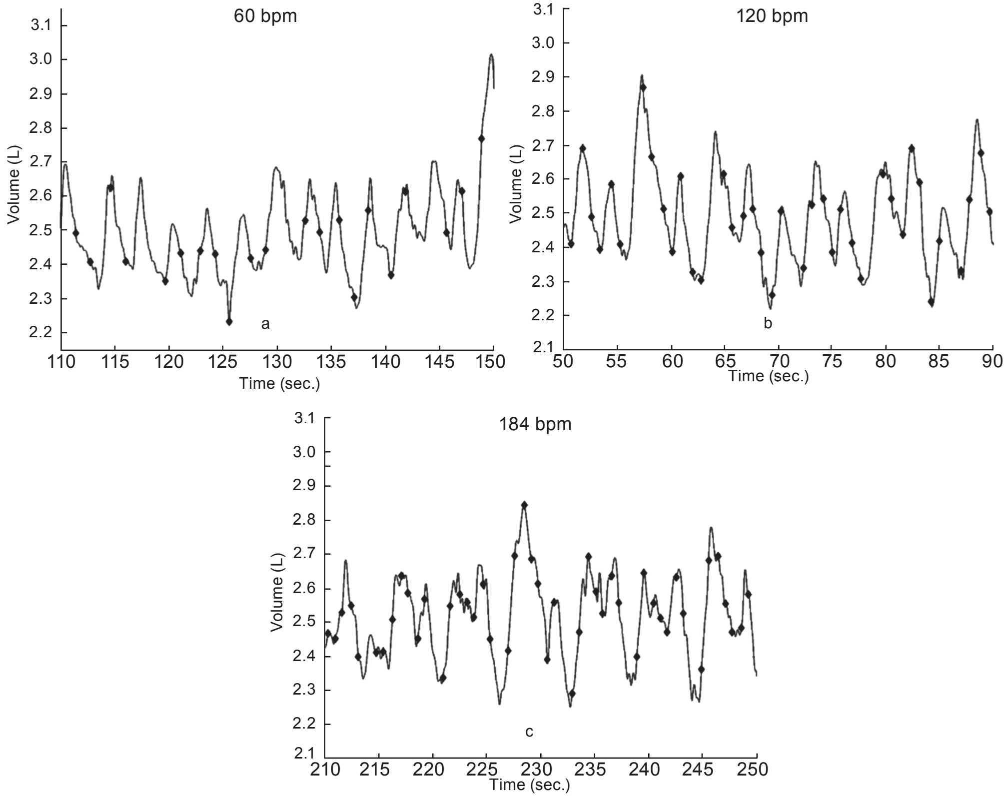

FIG. 10. Breathing curve (—) of Participant 7 with juxtaposed passage of the thumb movement (♦) markers during the performance of the C major scale. No consistent pattern is observed between the peaks in the breathing curve and the thumb movement markers.

Discussion

To investigate coordination between breathing and hand movement based on different markers during the performance of a C major scale and a C major arpeggio, we hereby present several comments on the analysis of the phase-interval plots and breathing curves for the participants during performance.

Performance of the Scale

Pitch markers.—Participants were asked to repeatedly perform the C major scale with the right hand at three different tempi for 1 min. No recognizable patterns were noted for most participants. The phase interval graphs for the pitch markers of two participants displayed intriguing diagonal groupings. The graphs of one of these two participants (Participant 6) are given as an example in Fig. 7. In this figure, diagonal patterns by pitch markers at the three tempi are clear. It was concluded that these diagonal graphical patterns do not indicate coordination between breathing and movement, but are more likely representing independence between the two. The scattered points shaping into a diagonal line signify that the pitch markers were progressively getting closer and further from the breathing markers. In opposition to the previously stated hypothesis, we concluded that these diagonal, graphical patterns do not indicate coordination between breathing and movement, but are more likely representing independence between the two. Based on Ebert, *et al.*'s (2000) results of clear coordination between forearm tracking and breathing, it was expected that coordination between breathing and pitch movement markers would occur during the performance of the scale. In this experiment, the forearm flexion and extension in the repetitive performance of the scale does not lead to coordination between breathing and movement as seen in Ebert, *et al*. (2000).

Meter markers.—In another study, Ebert, *et al.* (2002), the alignment of the rhythmical, musical finger movement by meters and breathing was examined. These researchers reported that a clear coordination occurred between breathing and finger movement at various time signatures. Interestingly, this phenomenon seemed to be more common between breathing and asymmetrical meters and less common between breathing and a 4/4 meter. The researchers proposed that the persistent coordination between breathing and asymmetrical meters (3/4, 5/4, or 7/4) may represent increased mental effort by the performers.

Contrastingly, in the present plots of meter markers juxtaposed on the breathing curve, no clear relation was observed between breathing and these markers. For only one pianist (Participant 1) meter markers coincided with minimum and maximum peaks of the breathing curve during the individual's performance of the scale at 120 bpm (Fig. 8). In this figure, a graph from another individual (Participant 4) is also presented (d). The latter exemplifies a graph with no pattern as a contrast with the graph of Participant 1 (b) where a pattern is evident. Based on the similarity to Ebert, *et al*.'s (2002) study, a coordinative relation between breathing and the meter finger-movement markers was previously hypothesized. Although the analysis from the graph of a single participant might support this hypothesis, the overall observations are contradictory to the results of Ebert, *et al*. While those results were clear, and illustrated a relation between meter markers and breathing in all their participants, the present data did not confirm their results.

The work of Ebert, *et al.* (2002), was closely examined in an attempt to understand the contrasting results with regard to coordination between meter and breathing. Firstly, in the 2002 study, participants were asked to perform a Hanon exercise and in the present study participants played a C major scale. Unlike the Hanon exercise, the performance of the C major scale requires participants to cross the thumb with the other fingers. The different musical pattern and movement requirements could be an explanation of the different results. Secondly, the Hanon exercise used in the Ebert, *et al.* (2002) study was transcribed in different meters. They found that a clear coordination seemed to be more common between breathing and asymmetrical meters and less common between breathing and a 4/4 meter. As a result, these researchers proposed that the persistent coordination between breathing and asymmetrical meters (3/4, 5/4, or 7/4) may represent an increased mental effort by the performers. Perhaps the performance of the C major scale in the present study does not require the same mental effort, thus yielding contrasting results. Thirdly, while in the Ebert, *et al.* (2002) study subjects were asked to perform at the most comfortable and spontaneous tempo on each trial, in this current study, participants were given a set tempo. The setting of a specific tempo could also lead to differences in the results since the pre-set tempo may not be as natural as a spontaneous one.

Thumb markers.—Analogous findings were noted for the passage of thumb markers. No relation or pattern could be seen for the breathing curve with the passage of the thumb markers based on graphs for all participants. Passage of the thumb markers and the breathing curve seemed to be consistently independent as shown for Participant 7 in Fig. 10. This confirms the hypothesis that since the passage of the thumb is irregular, this finger movement would not be coordinated with breathing.

Performance of Arpeggios

After playing the scales, participants were asked to repeatedly perform the C major arpeggio with the right hand for 1 min. at three different tempi. The phase-interval plots differ radically among participants from which one infers no coordination occurred. However, in the breathing graphs of three of the eight participants the pitch markers occurred simultaneously with the main minimums (ends of expiration) and maximums (ends of inspiration) on the breathing pattern during the performance at the second tempo of 120 bpm. As an example, Fig. 9 displays the graphs of one of these three (Participant 4) performing the arpeggio at different tempi. The second graph (b) presents the pattern observed at 120 bpm. Although coordination of the markers was interrupted by an unexpected peak in the breathing curve, the concurrence of both elements resumes shortly thereafter. In comparison, the fourth graph (d) of Fig. 9 is from Participant 1 for whom no pattern was observed. In sum, the specific observations described here accord with the hypothesis that coordination would be expected between breathing and pitch markers but for three of the eight participants only.

Limitations and Future Studies

Certain behaviours such as tempo variations and inconsistent use of accentuated notes could have influenced these results. Further work could isolate each marker, while asking pianists of the same level (e.g., professionals, or all Grade 8 and 9 students) to perform the scales and arpeggios. Several closer tempi could be chosen and controlled by use of a metronome. It would also be interesting to repeat the present sequence while requiring participants to play the same exercises in several sessions to assess patterns.

This research is part of a limited collection of projects on breathing and finger movements at the piano, therefore, expanding such knowledge could generate interesting questions. There are several examinations of the relation of breathing with different finger movements (Wilke, *et al*., 1975; Rassler, *et al*., 1996; Rassler, 2000; Rassler, *et al*, 2000). When analyzing the influence of breathing on precise movement, Rassler (2000) found that during late expiration, flexion movements were less precise whereas during late inspiration, extension movements were less precise. Knowing this, it is of interest whether late breathing could influence precision in piano playing. A similar coordination study could be used to test this, while analyzing accuracy of performance. Also, coordination has been studied on breathing with head or eye movement (Rassler & Raabe, 2003), which could be the basis for similar research with pianists to evaluate a possible association of head, eye, and torso movements with breathing during piano performance.

Conclusion

In past research, the relation of breathing and meter has been explored but the present study is innovative because focus was on the coordinative relations of breathing with specific pianistic movement markers.

By looking at the breathing curve graphs, for most of this small group, breathing seemed independent of finger movements. For only one participant, many finger movements related to the simultaneous onset of meter markers with peaks in the breathing pattern during the performance of the C major scale. Similarly, the breathing seemed independent of the finger movements during performance of the arpeggio. For three of the eight participants, the pitch-marker movements occurred on peaks of the breathing curve during this exercise. Since these observations were not common to all participants, no relationship of breathing with movement markers during performance of a scale or arpeggio was noted. Continued research is required to warrant a better understanding of the unconscious relation of breathing with fast extremity movements.

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