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Robin Mailly, Craig Turner, Caroline Traube, Fabien Dal Maso, Felipe Verdugo. Embodiment of music expression through muscle activity in expert pianists: A case study. Journées d'Informatique Musicale, May 2024, Marseille, France. hal-04661288v2

**HAL Id: hal-04661288**

**<https://hal.science/hal-04661288v2>**

Submitted on 1 Aug 2024 (v2), last revised 5 Nov 2024 (v3)

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# EMBODIMENT OF MUSIC EXPRESSION THROUGH MUSCLE ACTIVITY IN EXPERT PIANISTS: A CASE STUDY

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## ABSTRACT

From an embodied cognition approach, pianists' gestures might be affected by their expressive intentions while helping shape these intentions during performance. Studies investigating pianists' embodiment of music expression have mainly focused on kinematic analysis. The objective of this case study was to evaluate changes in upper-body muscle activity (a key aspect of gesture) and performance features in relation to pianists' expressive intentions. Two expert pianists (P1, P2) played six excerpts on an instrumented piano under a normal condition and a control condition (performance of the score as objectively as possible). Muscle activity of twelve upper-body muscles was recorded using electromyography. P1 and P2 showed opposed neuromuscular strategies. P1 increased muscle activity in the normal condition, while no clear trend was reported for P2. Both participants modulated performance features in a similar trend. Our results suggest that pianists might embody their expressive intentions through muscle activity. However, the presence and the extent of this embodiment process might depend on their playing approach and experience, on the specific musical context, and on structural and semantic expression features. These findings provide empirical support to the embodied music cognition perspective and are also relevant for literature on musicians' risk factors of injuries.

## RÉSUMÉ

Du point de vue de la cognition incarnée, les gestes des pianistes sont influencés par leurs intentions expressives et contribuent à façonner ces intentions. Les études sur le geste pianistique et l'expression musicale se sont centrées sur l'analyse cinématique. L'objectif de cette étude de cas était d'évaluer l'effet des intentions expressives des pianistes sur leur activité musculaire et les paramètres de jeu. Deux pianistes (P1, P2) ont joué six extraits sur un piano instrumenté dans une condition normale et une condition contrôle (jouer la partition de manière objective). L'activité musculaire de douze muscles du haut du corps a été enregistrée par électromyographie. P1 et P2 ont montré des stratégies

neuromusculaires opposées. P1 a augmenté l'activité musculaire dans la condition normale. Aucune tendance n'a été observée pour P2. Les deux participants ont modulé les paramètres de jeu de manière similaire. Ces résultats suggèrent que les pianistes peuvent incarner leurs intentions expressives à travers l'activité musculaire. Cependant, la présence et l'étendue de ce processus d'incarnation pourraient dépendre de leur approche de jeu, du contexte musical et des paramètres structurels et sémantiques du discours. Cette étude de cas apporte de nouvelles perspectives aux travaux sur la cognition incarnée et sur le risque de blessures en musique.

## 1. INTRODUCTION

In the embodied music cognition approach, the body shapes the way music is perceived and experienced [20]. Through an action-perception coupling, music expression for both listeners and performers would be influenced by individuals' bodily experience [19]: on one hand, expressive properties of music can be linked to sensorimotor associations between sound and musical features, and on the other hand, the physical feeling or mental condition produced by motor, visual, tactile, and vascular sensations [20]. Applied to the case of piano performance, this means that pianists' bodily gestures might be affected by their expressive intentions (i.e., expressive content intended to be communicated to the audience) and might simultaneously help shape these intentions during performance [36].

Communication of expressive intentions is a crucial aspect of musicians' work [21,29]. In piano performance, expressive intentions include at least two interrelated types of features [34]. First are concrete performance features such as rhythm and timing [31], sound intensity [9], articulation [30], and timbre [1]. For instance, timing variations (*rubato*) can evoke a sense of tension or relaxation [6,18]. Moreover, the use of specific articulation techniques, such as *legato* or *staccato*, can convey different emotions. Happiness and surprise are associated with *staccato* melodies, whereas sadness or scariness are associated with *legato* melodies

[4]. Additionally, different types of touch can help evoke different timbre and expression possibilities of piano tones [37]. Second, performers' expressive intentions also include a set of complex features related to both music structure (e.g., phrasing, melodic and harmonic tension [2]) and semantic content (extra-musical ideas, such as a specific narrative, a picture, an emotion, a physical movement, and so on [12,14]). As in Mailly et al. (2024), we use the notion of abstract expression features to refer to this type of complex features [22]. Performance studies investigating pianists' gestures have addressed the link between abstract features and bodily gestures by using different expression conditions (e.g., normal, exaggerated, and deadpan playing conditions [7]). These studies found that normal and exaggerated conditions resulted in more head [24,36] and trunk movements [32,40] compared to the deadpan condition, providing empirical support to the role of the body in human interaction with music, as proposed by the embodied cognition paradigm. In a recent literature review [22], we highlighted that studies investigating the link between gesture and abstract expression features have mainly focused on kinematic analysis. Indeed, only one study addressed physiological features and showed that the normal playing condition ('expressive condition') increased physiological arousal (higher levels of heart rate, sweating rate, and minute ventilation) compared to the non-expressive condition [27]. Therefore, there is currently a lack of research on performers' embodiment of music expression features through physiological parameters such as muscle activity.

Pianists' muscle activity has been addressed by studies in biomechanics investigating the impact of concrete performance features on upper-limb muscle load [8] and fatigue [11]. This is an important issue for musicians, as a majority of professional pianists (ranging from 26% to 93%) will suffer from practice-related musculoskeletal disorders (PRMDs) at some point in their career [3]. This high prevalence, which does not seem to decrease over the years, constitutes one of the major problems in arts medicine [16]. Addressing muscle activity changes in relation not only to concrete performance features but also to abstract features of music expression could be beneficial for at least two reasons. This could improve the understanding of the embodiment process related to expression in music performance, as muscle activity is at the origin of bodily gestures and can be modulated with no apparent kinematic correlate (e.g., isometric contraction) [38,39]. Also, quantification of pianists' muscle load in relation to their expressive intentions could provide a better understanding of their exposure to risk factors of PRMDs.

The goal of the present study was to evaluate changes in both concrete performance features and upper-body muscle activity in relation to pianists' expressive intentions. To do so, we performed an exploratory and interdisciplinary case study using qualitative- and

quantitative-based research approaches. In this article, we present the main results of the quantitative approach.

## 2. METHODS

### 2.1. Participants

Two expert classical pianists (1 female and 1 male) volunteered to participate in this study. Participant 1 (P1) held a doctoral degree in piano performance and was a prize-winner of national and international music competitions. Participant 2 (P2) was enrolled in a doctoral degree in piano performance. None were affected by injuries at the time of the experiment. Sex, handedness, age, and anthropometric characteristics are shown in **Table 1**. After receiving instructions on the experimental protocol, participants read and signed a written informed consent. The protocol was approved by the Université de Montréal's Research Ethics Committee (No. 2021-1380).

Participant	P1	P2
Sex	Female	Male
Handedness	Right-handed	Right-handed
Age (years)	36	28
Body height (cm)	168	183
Upper arm length (cm)	55	60
Hand span (cm)	19.5	24.3

**Table 1.** Characteristics of each participant.

### 2.2. Experimental procedures

First, individual interviews (lasting 1 hour) were conducted to understand pianists' own ideas regarding their expressive intentions. Interview responses and analysis will not be presented in the present article. Participants received the musical scores of six short excerpts from the classical piano repertoire (see **APPENDIX**) and were asked to practice them at least two months before the experiment. The excerpts included four slow excerpts:

- E1. Chopin, *Ballade n. 1 op. 23* [1–9]
- E2. Brahms, *Intermezzo op. 118 n. 2* [17–34]
- E3. Chopin, *Polonaise-Fantaisie op. 61* [181–199]
- E4. Beethoven, *Sonata op. 111* [1–16]

and two fast excerpts:

- E5. Beethoven, *Sonata op. 111* [21–29]
- E6. Brahms, *Piano Concerto n. 1 op. 15, 3rd movement* [1–8]

These excerpts were selected from western classical and romantic repertoire for two main reasons. First, this type of repertoire has been used by previous studies on gestures and pianists' expressive intentions [24].

Second, this repertoire represents the cornerstone of professional classical pianist training. We decided to include six excerpts to investigate our research question in a diversity of musical contexts (slow/lyric and fast/virtuoso excerpts). Participants were asked to perform the excerpts in two different conditions in a randomized order: a normal playing condition (engaging with their expressive intentions) and a control condition oriented on objective sound-production, where they had to play objectively the musical information specified in the score without any personal or subjective interpretation. These conditions were defined according to the analysis of the interviews performed prior to the experiment. More specifically, in the normal condition, participants were asked to perform the excerpt as they would in a concert setting by adding any music expression feature that relate to their personal interpretation of the score. In the control condition, participants were asked to perform the excerpt by focusing only on the musical features written by the composer in the score, to avoid personal or subjective interpretations of the score. In both conditions, participants were allowed to use the sustain pedal as desired, as pedal is a central element of piano tone control, which is usually not specified by composer and its use varies according to the specific acoustical set-up. Each condition was recorded twice (participants could repeat the recordings until they were satisfied), for a total of 24 trials (6 excerpts  $\times$  2 conditions  $\times$  2 trials).

### 2.3. Instrumentation and data collection

Participants played on a Yamaha grand piano (Disklavier DC7X) instrumented to record MIDI data. EMG activity of twelve trunk and upper-body muscles on both the right and left sides were collected using a Delsys Trigno™ Wireless system (Boston, MA, USA) at a sampling rate of 2000 Hz. These included the external oblique, upper trapezius, triceps, biceps, extensor digitorum communis (EDC), and flexor digitorum superficialis (FDS). Electrodes were placed at the estimated motor point respecting the fascicle muscle direction according to SENIAM [35]. To reduce the impedance, the skin was shaved, abraded, and cleaned with 70% isopropyl alcohol prior to the recording.

Before the trials at the piano, participants were asked to perform maximal voluntary contraction tests (MVC) against manual resistance for a 5-second period. MVC tests are required to obtain EMG activation level as the raw EMG amplitude is not interpretable. These included finger isometric flexion and extension against a resistance with the wrist in a neutral position, elbow isometric flexion and extension at 90° of elbow flexion, shoulder isometric elevation with extension, lateral isometric flexion and contralateral rotation of the head, and isometric rotation and flexion of the trunk.

## 2.4. Data processing

### 2.4.1. MIDI data

Onset and offset of respectively the first and last note of the excerpts were used to compute total duration of each trial. Then, only the notes of the leading melody (played by the right hand) were analyzed due to three main reasons. First, by focusing only on the leading melody, it is possible to reduce the complexity of piano performance analysis while addressing key features of pianists' expressive intentions related to timing, articulation, and sound intensity. Second, both participants were right-handed. Third, expert pianists exhibit greater key velocities at right hand notes compared to left hand notes, suggesting that analysis of right hand notes would be more relevant for studying risk factors of PRMDs [15]. Four concrete performance features were extracted from the leading melody notes:

- *Key velocity*: MIDI key velocity from 0 to 127;
- *Legato*: duration of the overlap time between the offset and the onset of two consecutive notes;
- *Detaché*: duration of the gap time between the offset and the onset of two consecutive notes;
- *IOI relative difference*: the relative difference for each inter-onset interval (IOI) was calculated as follows:

$$(1) \quad \frac{\text{IOI normal condition} - \text{IOI control condition}}{\text{IOI control condition}} \times 100$$

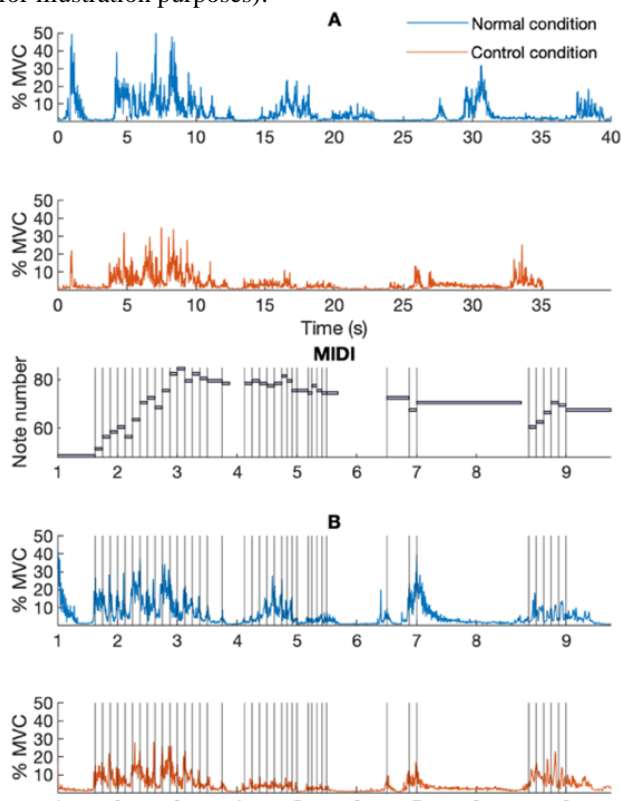
Average MIDI data per note from the two trials of the same condition and excerpt was used to compute these four performance features.

### 2.4.2. Electromyography data

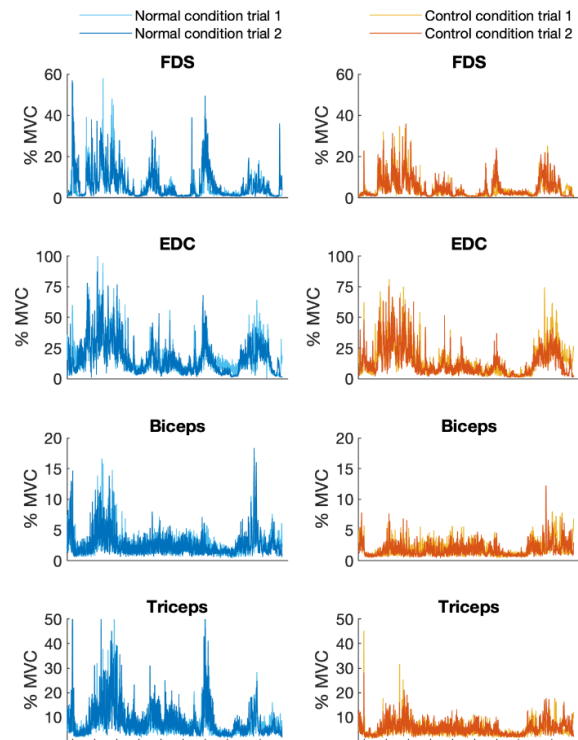
In line with the recommendations of the International Society of Electrophysiology and Kinesiology [26], EMG data (obtained during trials at the piano and MVC tests) were filtered using a 2<sup>nd</sup> order Butterworth band-pass filter with cut-off frequencies of 10–400 Hz. The signal envelope was obtained using a sliding root mean square with a 30 ms window. To normalize these EMG data, the maximum voluntary activation was calculated using the median of the maximum values obtained over a period of one non-consecutive second across all MVC tests performed [8]. The amplitude of the EMG envelope was normalized with respect to the MVC value to obtain EMG activation levels (%MVC). Additionally, EMG data were time-normalized using the onset time of each note of the leading melody of each excerpt (see **Figure 1**).

EMG data from the two trials of the same condition and excerpt were averaged. Prior to this, the repeatability across the two recordings was visually assessed (see example in **Figure 2**). The peak EMG activation between two MIDI onsets was calculated for each condition. We then subtracted each computed peak EMG value of the control condition from the

corresponding value of the normal condition (i.e. positive value = normal > control, negative value = normal < control). Our analysis focused on the average per excerpt of the computed difference values (two non-averaged specific examples are also presented for illustration purposes).



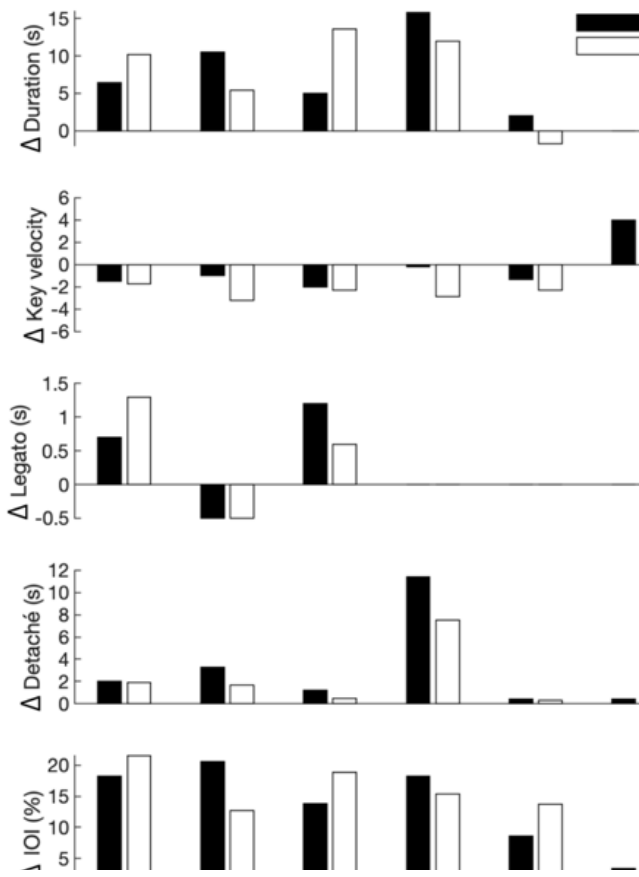
**Figure 1.** Normalized EMG amplitude of flexor digitorum superficialis (FDS) of P1 before (A), and after (B) time-normalization according to each MIDI onset of the leading melody.



**Figure 2.** Example of EMG time-series data of P1's right upper-limb muscles to assess the repeatability across the two recordings. FDS = flexor digitorum superficialis, EDC = extensor digitorum communis.

### 3. RESULTS

Results of concrete performance features are presented in **Figure 3**. Both participants played the four slow excerpts (*E1-4*) at a slower tempo in the normal than the control condition: P1's average was 9.4 s slower and P2's average was 10.3 s slower (**Figure 3**). Fast (and shorter) excerpts (*E5-6*) showed a similar duration (P1's average was 1 s slower and P2's average was 0.6 s faster in the normal condition). In the normal condition, both participants played with a slightly lower key velocity (1–3 MIDI units) for all excerpts (except for *E6* of P1, where key velocity was higher in the control condition). The duration of *legato* increased in *E1* and *E3* and decreased in *E2*. The duration of *detaché* increased for all excerpts (a remarkably higher increase of 11.4 s for P1 and 7.5 s for P2 was observed in *E4*, and only small increases were reported in *E5* and *E6*). The IOI relative difference was about 10–20% higher in all four slow excerpts as well as in *E5* in the normal condition, and ~5% higher in *E6*.



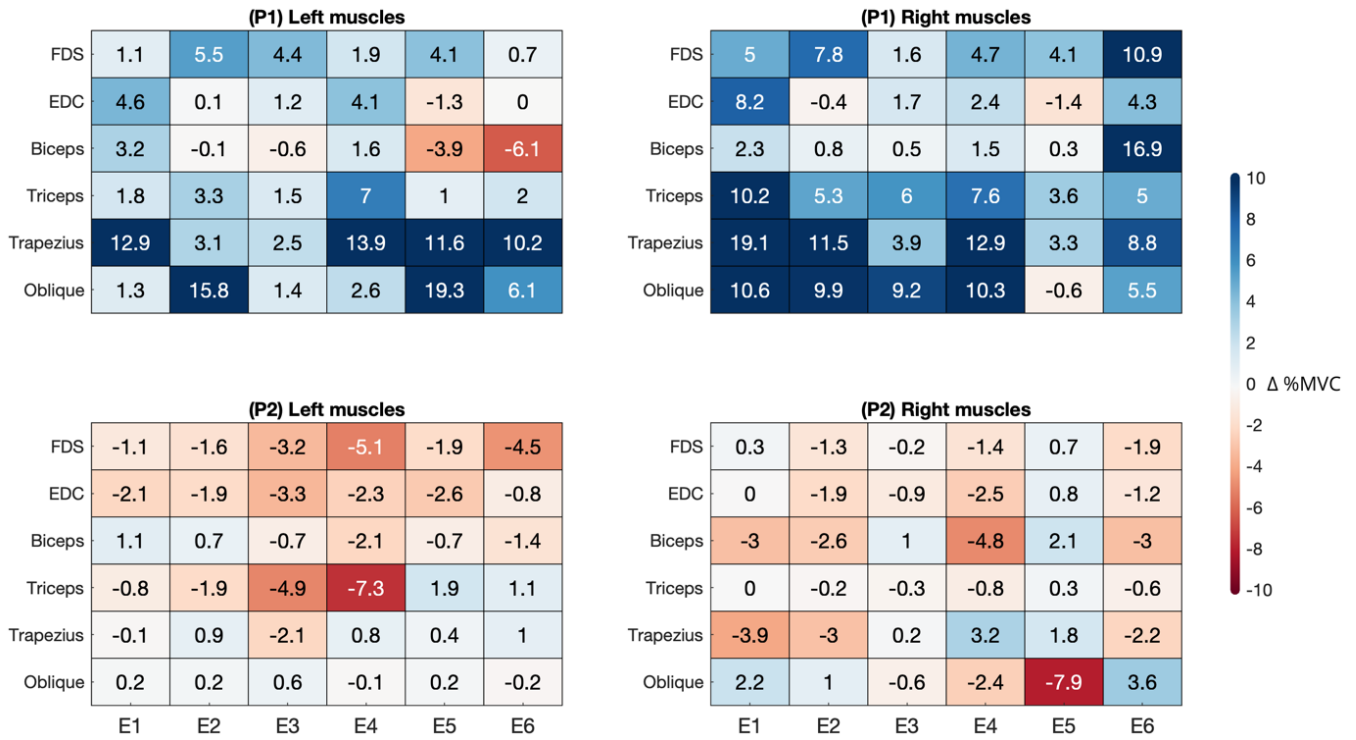
**Figure 3.** Performance features (duration, key velocity, *legato*, *detaché*, IOI relative difference) for P1 and P2. Values represent the difference between conditions (normal minus control; positive value = normal > control).

Average differences between conditions in peak EMG values of each excerpt for the two participants are presented in **Figure 4**. Overall, results differed between participants. P1 upper-body muscle activation levels were higher in the normal condition compared to the control condition (ranging from 0–5% MVC to 10–19% MVC). No clear trend was observed for P2 and the difference values between conditions were smaller compared to P1.

To illustrate the results at a micro level, we present two short passages of *E1* in **Figure 5**. These short passages support overall results (P1 upper-body muscle activations were higher in the normal condition; modulation of concrete performance features showed rather similar trends between participants). However, they also show a specific musical context (**Figure 5**, right panel, measure 7) where P1 and P2 exhibited similarities in the effect of the normal condition on their muscle activity.

#### 4. DISCUSSION

The goal of this case study was to evaluate changes in upper-body muscle activity and concrete performance features in relation to pianists' expressive intentions. P1 and P2 showed opposing neuromuscular strategies in relation to expressive intentions. Both participants modulated concrete performance features in a similar trend. Overall, our results suggest that pianists might embody concrete (performance) and abstract (structural and semantic) features of music expression through changes in trunk and upper-limb muscle activity. However, the presence and the extent of this embodiment strategy might depend on several elements, including: *i*) pianists' playing approach and experience, *ii*) the specific musical context, and *iii*) differences in both abstract expression features and related subtle changes in concrete performance features.



**Figure 4.** Average peak EMG during leading melody notes per musical excerpt of the targeted right and left trunk and upper-body muscles for P1 and P2. Values are expressed as percentage of maximum voluntary contraction (%MVC), and they represent the difference between conditions (blue gradient being EMG activation levels higher in normal than in control condition, while red gradient being EMG activation levels higher in control than in normal condition). FDS = flexor digitorum superficialis, EDC = extensor digitorum communis, Trapezius = upper trapezius, Oblique = external oblique.

#### 4.1. Muscle activity and music expression features

Studies in biomechanics and motor control have shown differences in pianists' upper-limb muscle activity in relation to concrete performance features. Greater muscle activity have been documented when playing louder [28], *staccato* [8], and faster [10]. In our study, only P1 showed a systematic increase of trunk and upper-limb muscle activity in relation to her expressive intentions. However, there was no clear relation between this increase in muscle activity and the assessed concrete performance features. P1 played with a higher average key velocity in the normal condition only in one excerpt (*E6*), which can explain higher activations at right FDS, biceps and upper trapezius due to louder tones. Nevertheless, the five other excerpts showed slightly lower key velocity values. Therefore, the reported higher muscle activations of P1 cannot be explained by key velocity (a central parameter for loudness control of piano tones). In relation to articulation, *legato* and *detaché* showed different trends in different excerpts, making it difficult to identify a clear effect of these performance features on P1's muscle activity. In relation to tempo and timing, P1 played slower in the normal than the control condition, suggesting that higher muscle activation could not be associated with faster tempi. In addition, P2 showed similar trends in the modulation of all assessed concrete performance features, with no clear overall effect on muscle activations. Our results suggest first that muscle activity changes in relation to music expression cannot be fully explained by focusing on concrete performance features. Second, they show that embodiment of expressive intentions through muscle activity might relate to other musical and individual factors, including abstract expression features and pianists' playing approach. This provides novel empirical support to the embodied music cognition perspective and highlight the fact that upper-limb muscle activation (a risk factor of PRMDs) might increase due to abstract expression features.

Performance studies on pianists have reported increases in pianists' movements at the head [5,24] and trunk [32,36] in normal and exaggerated playing conditions ('normal' and 'exaggerated' in relation to participants' personal expressive intentions). In our study, the reported increase of P1's muscle activity was in general higher at more proximal muscles: upper trapezius (located at the upper back) and external oblique muscles (located at the abdominal area). Therefore, our findings support the idea of the central role of proximal segments in the embodiment of pianists' expressive intentions. However, changes in P1's muscle activity were also reported at distal muscles controlling the fingers and the elbow. In this sense, embodiment of music expression features can also occur at pianists' distal segments, even if spatiotemporal constraints are higher compared to proximal segments.

Despite the lack of an overall trend in P2 muscle activity changes in relation to his expressive intentions, there were specific musical contexts where changes

were found. We showed in **Figure 5** two contrasting excerpts: a loud passage with several eight notes (measures 1–3), and a softer passage which includes a crescendo in long notes (measures 6–8). If no clear effect could be depicted in the eight-notes loud passage for P2, this participant showed higher muscle activity at the external oblique, the biceps, and the EDC in the longest note of the softer passage. This is the last note of a *crescendo* passage, and it is expected that pianists imagine a longer sound sustain or even a *crescendo* after the note is played (an effect that pianists might give the impression of doing but cannot effectively produce as piano tones cannot be manipulated after the attack). P1 showed the same effect but in a higher extent and in almost all the targeted muscles (this phenomenon can be also seen in the EMG time-series values shown in **Figure 1** and in **Figure 2** [at measure 7]). This selected example suggests that imagined aspects of music expression can in specific contexts impact pianists' muscle activity in a greater manner than performance features that can actually be manipulated. In other words, pianists might tend to embody through muscle activity the imagined or psychological dimension of music expression, rather than effectively controlled performance features. This idea relates to the findings of Nakahara et al. [27], where a higher physiological arousal was associated with the integration of expressive intentions while performing.

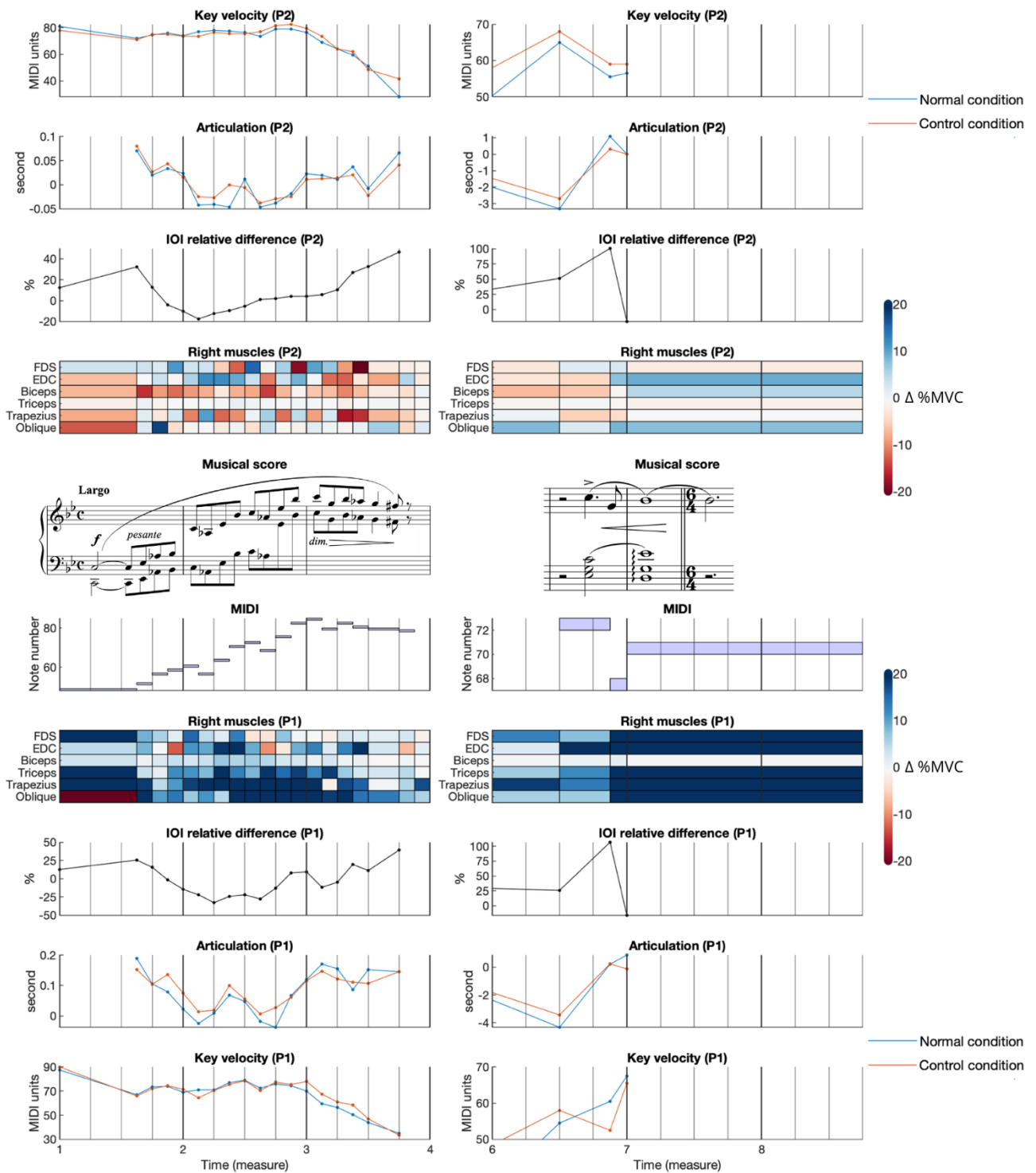
#### 4.2. Performance features of music expression

In this case study, both participants exhibited similar trends in each of the concrete performance features assessed. Participants performed the four slow excerpts slower in the normal condition compared to the control condition (differences ranged from 5 s to 15 s). A similar results have previously been shown by Thompson & Luck [36] and Massie-Laberge et al. [24], where deadpan conditions were played faster, while exaggerated conditions were played slower. The latter study included slow excerpts of the romantic period (equivalent to *E1–3* in our study), while our study extends these results to the late classical period (*E4*). In the case of the two fast excerpts (*E5–6*), there was no clear differences between conditions in terms of overall duration. This difference between slow and fast excerpts was expected, as pianists' interpretation choices are linked not only to style but also to the specific musical context (*E5* and *E6* limit timing or rhythmic modulations compared to slower excerpts).

P1 and P2 also showed the same strategy in relation to key velocity, by playing with a slightly lower key velocity in the normal condition (except for *E6* of P1). These results put into perspective previous findings in the related literature. Massie-Laberge [23] showed that pianists played with faster key velocities of around 5–10 MIDI units in a normal condition, compared to an immobile condition where pianists were asked to perform as objectively as possible the musical information given by the composer in the score. This



included taking into account basic dynamics indications (e.g., *p*, *f*, etc.) and changes (e.g., *cresc.*, *dim.*).



**Figure 5.** EMG and concrete performance features results for two passages of *E1* (Chopin's Ballade n. 1 op. 23) measures 1–3 (left) and measures 6–8 (right) for P1 (bottom) and P2 (top). EMG data are expressed as percentage of voluntary contraction (%MVC) and represent the difference between conditions (blue gradient being EMG activation levels higher in normal than in control condition, while red gradient being EMG activation levels higher in control than in normal condition). FDS = flexor digitorum superficialis, EDC = extensor digitorum communis, Trapezius = upper trapezius, and Oblique = external oblique. Positive articulation value = *legato*, negative articulation value = *detaché*.

Therefore, our results on key velocity of the leading melody suggest that pianists might tend to play (on average) not louder but slightly softer when integrating their personal interpretation of the score. Considering reported differences in key velocity between right and left hands [15], the discussed results may also be relevant for the notes played by the left hand. In a study of Lazarov et al. [17], one pianist played ‘*Capriccio, Bach [1–48]*’ in a romantic, modern, and rhetorical style. They showed that the pianist played with a slower key velocity of 3–4 MIDI units in the romantic style, compared to the two other styles. This is consistent with our findings, as the excerpts of the present study were from the late classical and romantic repertoire.

Lazarov et al. [17] found that the romantic interpretation of the cited Bach piece was played with twice as much *legato*, compared to the modern and rhetorical styles. In our study, the two participants increased *legato* in the normal condition in two (*E1* and *E3*) of the relevant three slow excerpts (*E4* did not contain important *legato* passages). Contrary to *E1* and *E3*, the right hand of *E2* must not only play leading melody notes but also other notes to complete chords and polyphonic textures. This might explain why P1 and P2 decreased *legato* in the normal condition, as they could adapt their playing as desired. *Detaché* values were greater for both participants in the normal condition (with a remarkable increase in *E4*). Taken together, our findings suggest that not only late release of *legato* tones (i.e., increased *legato*) but also early release of not *legato* tones (i.e., increased *detaché*) are important tools used by pianists to convey their expressive intentions. However, this idea only applies to slower excerpts, as no clear trend was observed in the two fast excerpts.

IOI relative difference was greater for all excerpts (particularly for the four slow excerpts where IOI relative difference ranged from 10–20%). In music, groove is linked with syncopation (i.e., a disturbance or interruption of the regular flow of rhythm) [33]. Additionally, music with a rhythm that is too predictable (each note falling on a beat) or too complex (each note being shifted in an unpredictable way) showed lower pleasure ratings [25]. Music with an optimal rate of syncopation (and with a medium rhythmic complexity) showed greater overall pleasure ratings [25], highlighting the importance of rhythmic elements in shaping the listener’s experience. In another study, a musical performance without rubato was not perceived to be as musical as one with appropriate variations in timing [13]. Indeed, rubato may help support tension-relaxation changes in the musical discourse [6,18]. Our findings support the importance of rubato in music expression, as IOI relative difference was a key expressive feature that distinguished normal and control conditions in the present study.

## 5. LIMITATIONS AND FUTURE RESEARCH

This study presents some limitations. As we only included excerpts from the late classical and romantic period, results might only apply to these specific music styles. We also assessed only a limited set of performance features, related mostly to the leading melody. Other performance and expression features might potentially have affected the reported differences in peak EMG values. Furthermore, this was a case study on two participants. Future research should therefore test the presented results in a population of pianists. Additionally, future research could provide an in-depth analysis of pianists’ neuromotor strategies in relation to music expression by incorporating neuroscience techniques (electroencephalography) in the experimental protocol. Lastly, while this study explored the embodiment of expressive intentions through muscle activity, it did not investigate the impact of these intentions on audience perception. Therefore, future studies could include perception tests to determine the link between performers’ expressive intentions, embodiment, and audience appreciation.

## 6. CONCLUSION

This case study investigated pianists’ changes in their upper-body muscle activity, as well as the management of concrete performance features in relation to their expressive intentions. Both participants showed opposing neuromuscular strategies in relation to expressive intentions: expressive intentions increased overall muscle activity of P1 while no clear trend was reported for P2. Both participants modulated concrete performance features in a similar trend, showing that similar overall changes in music expression features might have different impacts on muscle activity. The results of this study suggest pianists might embody their expressive intentions through trunk and upper-limb muscle activity. However, the presence and the extent of this embodiment process might depend on pianists’ playing approach and experience, on the specific musical context, and on structural and semantic expression features. This study provides empirical support to the embodied music cognition perspective and to pianists’ exposure to risk factors of injuries in relation to music expression.

## 7. FUNDING

This work was supported by the Social Science and Humanities Research Council of Canada (Insight Development Grant 430-2021-00384).

## 8. ACKNOWLEDGMENTS

We would like to thank the volunteers for their participation in the study, and the Piano department of the University of Montreal for its support in this study.

## 9. COMPETING INTERESTS

The authors have no conflict of interest to report.

## 10. REFERENCES

- [1] M. Bernays, C. Traube, Investigating pianists' individuality in the performance of five timbral nuances through patterns of articulation, touch, dynamics, and pedaling, *Front. Psychol.* 5 (2014).
- [2] E. Bigand, R. Parncutt, Perceiving musical tension in long chord sequences, *Psychological Research* 62 (1999) 237–254.
- [3] P. Bragge, A. Bialocerkowski, J. McMeeken, A systematic review of prevalence and risk factors associated with playing-related musculoskeletal disorders in pianists, *Occupational Medicine* 56 (2006) 28–38.
- [4] N.R. Carr, K.N. Olsen, W.F. Thompson, The Perceptual and Emotional Consequences of Articulation in Music, *Music Perception* 40 (2023) 202–219.
- [5] G. Castellano, M. Mortillaro, A. Camurri, G. Volpe, K. Scherer, Automated Analysis of Body Movement in Emotionally Expressive Piano Performances, *Music Perception: An Interdisciplinary Journal* 26 (2008) 103–119.
- [6] E.C. Chiang, Rubato and Climax Projection in Two Piano Sonatas by Scriabin, (2013).
- [7] J.W. Davidson, Qualitative insights into the use of expressive body movement in solo piano performance: a case study approach, *Psychology of Music* 35 (2007) 381–401.
- [8] V. Degraeve, F. Verdugo, J. Pelletier, C. Traube, M. Begon, Time history of upper-limb muscle activity during isolated piano keystrokes, *Journal of Electromyography and Kinesiology* 54 (2020) 102459.
- [9] C. Drake, C. Palmer, Accent Structures in Music Performance, *Music Perception* 10 (1993) 343–378.
- [10] S. Furuya, T. Aoki, H. Nakahara, H. Kinoshita, Individual differences in the biomechanical effect of loudness and tempo on upper-limb movements during repetitive piano keystrokes, *Human Movement Science* 31 (2012) 26–39.
- [11] E. Goubault, C. Turner, R. Maily, M. Begon, F. Dal Maso, F. Verdugo, Neuromotor variability partially explains different endurance capacities of expert pianists, *Sci Rep* 13 (2023) 15163.
- [12] I. Héroux, M.-S. Fortier, Expérimentation d'une nouvelle méthodologie pour expliciter le processus de création d'une interprétation musicale, *sqrm* 15 (2015) 67–79.
- [13] C.M. Johnson, Effect of Rubato Magnitude on the Perception of Musicianship in Musical Performance, *Journal of Research in Music Education* 51 (2003) 115–123.
- [14] P.N. Juslin, D. Västfjäll, Emotional responses to music: The need to consider underlying mechanisms, *Behav Brain Sci* 31 (2008) 559–575.
- [15] S. Kim, J.M. Park, S. Rhyu, J. Nam, K. Lee, Quantitative analysis of piano performance proficiency focusing on difference between hands, *PLoS ONE* 16 (2021) e0250299.
- [16] L.M. Kok, B.M.A. Huisstede, V.M.A. Voorn, J.W. Schoones, R.G.H.H. Nelissen, The occurrence of musculoskeletal complaints among professional musicians: a systematic review, *Int Arch Occup Environ Health* 89 (2016) 373–396.
- [17] V. Lazarov, S. Rennotte, C. Traube, De l'intention musicale au jeu instrumental. Développement d'un protocole de recherche pour l'analyse qualitative et quantitative de trois styles d'interprétation d'une oeuvre de J.-S. Bach au piano, *rmo* 6 (2019) 113–141.
- [18] A.C. Lehmann, J.A. Sloboda, R.H. Woody, Expression and Interpretation, in: *Psychology for Musicians*, 1st ed., Oxford University Press New York, 2007: pp. 84–106.
- [19] M. Leman, P.-J. Maes, The Role of Embodiment in the Perception of Music, *EMR* 9 (2015) 236.
- [20] M. Leman, P.-J. Maes, L. Nijs, E. Van Dyck, What Is Embodied Music Cognition?, in: R. Bader (Ed.), *Springer Handbook of Systematic Musicology*, Springer Berlin Heidelberg, 2018: pp. 747–760.
- [21] B. Lortat-Jacob, Le texte affecté: Vers une théorie de l'expression musicale, *Cahiers d'ethnomusicologie* 23 (2010) 11–28.
- [22] R. Maily, C. Turner, E. Goubault, F. Dal Maso, F. Verdugo, Impact of music expression features on pianists' gestures: A systematic review, *Under Review* (2024).
- [23] C. Massie-Laberge, Kinematic, Kinetic and Perceptual Analyses of Piano Performances, (2019).
- [24] C. Massie-Laberge, I. Cossette, M.M. Wanderley, Kinematic Analysis of Pianists' Expressive Performances of Romantic Excerpts: Applications for Enhanced Pedagogical Approaches, *Front. Psychol.* 9 (2019) 2725.
- [25] T.E. Matthews, M.A.G. Witek, O.A. Heggli, V.B. Penhune, P. Vuust, The sensation of groove is affected by the interaction of rhythmic and harmonic complexity, *PLoS ONE* 14 (2019) e0204539.
- [26] R. Merletti, Standards for Reporting EMG Data, *Journal of Electromyography and Kinesiology* 9 (1999) 3–4.
- [27] H. Nakahara, S. Furuya, P.R. Francis, H. Kinoshita, Psycho-physiological responses to expressive piano performance, *International Journal of Psychophysiology* 75 (2010) 268–276.
- [28] N. Oikawa, S. Tsubota, T. Chikenji, G. Chin, M. Aoki, Wrist Positioning and Muscle Activities in the Wrist Extensor and Flexor during Piano Playing, *Hong Kong Journal of Occupational Therapy* 21 (2011) 41–46.
- [29] C. Palmer, Mapping Musical Thought to Musical Performance, (1989).
- [30] B.H. Repp, Acoustics, perception, and production of *legato* articulation on a digital piano, *The Journal of the Acoustical Society of America* 97 (1995) 3862–3874.
- [31] B.H. Repp, A microcosm of musical expression. I. Quantitative analysis of pianists' timing in

- the initial measures of Chopin's Etude in E major, *The Journal of the Acoustical Society of America* 104 (1998) 1085–1100.
- [32] H. Shoda, M. Adachi, The Role of a Pianist's Affective and Structural Interpretations in his Expressive Body Movement: A Single Case Study, *Music Perception* 29 (2012) 237–254.
- [33] G. Sioros, M. Miron, M. Davies, F. Gouyon, G. Madison, Syncopation creates the sensation of groove in synthesized music examples, *Front. Psychol.* 5 (2014).
- [34] J.A. Sloboda, Individual differences in music performance, *Trends in Cognitive Sciences* 4 (2000) 397–403.
- [35] D.F. Stegeman, H.J. Hermens, Standards for surface electromyography: the European project "Surface EMG for non-invasive assessment of muscles (SENIAM)", *Roessingh Research and Development: Enschede* (2007) 108–112.
- [36] M.R. Thompson, G. Luck, Exploring relationships between pianists' body movements, their expressive intentions, and structural elements of the music, *Musicae Scientiae* 16 (2012) 19–40.
- [37] C. Traube, M. Moulin, F. Verdugo, Controlling piano tone by varying the « weight » applied on the key, *The Journal of the Acoustical Society of America* 141 (2017) 3874–3874.
- [38] F. Verdugo, A. Ceglia, C. Frisson, A. Burton, M. Begon, S. Gibet, M.M. Wanderley, Feeling the Effort of Classical Musicians - A Pipeline from Electromyography to Smartphone Vibration for Live Music Performance, in: *NIME 2022*, PubPub, The University of Auckland, New Zealand, 2022.
- [39] F. Verdugo, S. Kokubu, J. Wang, M.M. Wanderley, MappEMG: Supporting Musical Expression with Vibrotactile Feedback by Capturing Gestural Features through Electromyography, (2020).
- [40] G.K. Wong, G. Comeau, D. Russell, V. Huta, Postural Variability in Piano Performance, *Music & Science* 5 (2022) 205920432211378.

# 11. APPENDIX

The beginning and/or end of the sections played are marked by red brackets.

## E1. Chopin, Ballade n. 1 op. 23 [1-9]

à Mr. le Baron de STOCKHAUSEN.

*Largo.*  
*f pesante*

*Moderato.*

## E2. Brahms, Intermezzo op. 118 n. 2 [17-34]

*cresc.* *legato* *espress.* *p dim.* *calando* *dolce*

Edition Peters. 94889

E3. Chopin, Polonaise-Fantaisie op. 61 [181-199]

(lento) *ten.* *a tempo*  
*pp* *p* *cresc.* *dim.* *p cresc.*  
*p cresc.* *pp* *poco a poco cresc.*

E4. Beethoven, Sonate op. 111 [1-16]

L. van Beethoven, Op. 111.  
 Komponiert am 13. Januar 1822.

Maestoso.

32. *f sf* *f* *p* *cresc.* *f*

*p* *dim.* *pp* *sempre pp*

10 15

*cresc.* *f* *p*

*pp*

<sup>40</sup> The fingering in italics and the pedal indications are Beethoven's.

E5. Beethoven, Sonate op. 111 [21-29]

Musical score for Beethoven's Sonata op. 111, measures 21-29. The score is in B-flat major and 3/4 time. It features a complex rhythmic pattern with many sixteenth and thirty-second notes. The dynamics range from *f* (forte) to *mezzo piano* and *a tempo cresc.* (gradually increasing tempo). The tempo is marked *poco riteneute* (slightly slowing down). A red bracket highlights measures 21-22, and another red bracket highlights measures 28-29. A circled number '25' is placed above the staff in measure 25.

E6. Brahms, Piano Concerto n. 1 in D minor, op. 15, 3rd movement [1-8]

Musical score for Brahms' Piano Concerto n. 1 in D minor, op. 15, 3rd movement, measures 1-8. The score is in D minor and 2/4 time. It is marked **Rondo** and *Allegro non troppo*. The dynamics are *f* (forte) and *(non legato)*. The tempo is marked *Allegro non troppo*. The score features a complex rhythmic pattern with many sixteenth and thirty-second notes. A red bracket highlights measures 7-8. The score is arranged in three systems, with the first system containing measures 1-4 and the second system containing measures 5-8.