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Article

Effects of Rehearsal Time and Repertoire Speed on Upper Trapezius Activity in Conservatory Piano Students

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BACKGROUND: Repetitive piano play may overload neck and shoulder muscles and tendons, leading to playing-related musculoskeletal disorders (PRMDs). **METHODS:** In this pilot study (EMG data of the extensor carpi radialis have been published separately), surface electromyography (sEMG) activity of the upper trapezius (UT) was captured in 10 conservatory piano students while playing a fast and a slow music score selected from the individual's repertoire, each 3 minutes long. Measurements were made at baseline and again after 2 hrs and 4 hrs of rehearsal time of the piano études. The amplitude of the sEMG signal was processed by a smoothing algorithm, and the frequency component with a non-orthogonal wavelets procedure. Amplitude of the sEMG was expressed in percent of maximal voluntary contraction (%MVC) at baseline, and the frequency component using median frequency based on the frequency band powers. Statistical analysis encompassed repeated measures ANOVAs for the amplitude and frequency components of the sEMG signal (set at 5%). The students also rated the intensity of rehearsals using a visual analog scale (VAS). **RESULTS:** The median values for the %MVC presented a global mean for the left trapezius of 5.86 (CI90% 4.71, 6.97) and 5.83 for the right trapezius (CI90% 4.64, 7.05). The rehearsals at moderate intensity increased the amplitude of %MVC of the upper trapezius by around 50% and decreased the median frequency. **CONCLUSIONS:** Playing faster presented higher magnitudes of activity of the upper trapezius. The decrease in the median frequency in response to long rehearsals may be a sign of muscle fatigue. *Med Probl Perform Art*. 2022;37(1):1–12.

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PIANISTS are highly at risk for playing-related musculoskeletal disorders (PRMDs) which affect their professional activity. These PRMDs are predominantly located in the upper body.[1–7] Using the ICD-10 codes, Moñino et al. (2017)[5] found that the most frequently diagnosed disorders in pianists were trigger finger (ICD-10 code M65.3, 35.5%), cervicalgia (M54.2, 32.2%), and muscle contracture (M624, 29.5%). Risk factors for PRMD include age, gender, long durations of repetitive practice in unnatural static postures, anthropometric features such as the size of hand, and performance anxiety.[7,8,9–17]

The biomechanical factors that influence the physiological load on the muscles during piano playing have not been fully addressed.[18–26] To the best of our knowledge, only a limited number of studies on piano performance have included an EMG analysis with a tendency to concentrate on the forearm muscles.[19,21,26–33] The long durations of repetitive piano practice in unnatural static postures can cause trigger points in the upper trapezius (UT) up to a condition of trapezius myalgia and cervicalgia.[34,35] In this context, it might be interesting to have an idea of the actual loading of the upper trapezius during performance of piano excerpts.

The activity of the upper trapezius has been assessed in two experimental contexts.[23,32,33] In the study of Degrave et al. (2020),[23] the pianists were asked to perform 4 series of 40 isolated key strokes. In the studies of Yoshie et al.,[32,33] pianists were asked to perform from memory a solo score of their choice for a duration around 6.5 minutes requiring

TABLE 1. Demographic and Playing Characteristics of Participants

Subject	Gender	Age	Handedness L/R	Years of Experience	Years at Conservatory	Days of Piano Playing/ Week	Hours of Daily Practice	Breaks per Practice	Duration of Breaks	Musculo-skeletal Discomfort*
1	M	26	R	20	7	7	5 × 1h	0	No breaks	1
2	F	24	R	16	5	5	2 × 2h	1	Max 5 min	2
3	F	25	R	20	7	6	4 × 2h	3–4	5–10 min	2
4	M	21	R	14	2	7	2 × 2h	Rarely	<10 min (in case of a break)	1
5	F	20	R	13	3	7	2 × 2h	1	5 min	2
6	F	28	R	18	6	7	2 × 2.5h	0	No breaks	2
7	F	24	R	15	5	6	2 × 2h	2	5–10 min	2
8	M	22	R	16	5	7	3 × 2h	2	No breaks	1
9	F	28	L	18	6	7	10 × 30 min	0	No breaks	1
10	F	21	R	13	4	7	3 × 2h	Max 1	5–10 min	2

*Musculoskeletal discomfort measured on a 5-point severity scale.

considerable technical playing skills in a rehearsal or competition context. It is still unclear whether and if so, how muscle fatigue may evolve in the trapezius in response to long hours of rehearsals. In this study, we evaluated the effect on the activity of the upper trapezius of playing fast music excerpts on the piano versus slow music excerpts chosen from the individual's repertoire combined with the effect on it of a repetitive piano practice of 4 hours. The sEMG data on the left and right trapezius presented in this article have been captured in the same project from which the sEMG data analysis on the extensor carpi radialis have been published previously.[29]

METHODS

This study was approved by the Ethical Commission of the Vrije Universiteit Brussel (BUN 143201732690). All participants provided written informed consent. The inclusion criterion for this study was being a student at a conservatory in at least her/his second year of study. The exclusion criterion was the presence of self-reported current or previous severe musculoskeletal injuries which needed medical care (medication, orthopedic intervention).

Ten piano students from the Conservatory of Maastricht (Hogeschool Zuyd) volunteered to participate in the study following a meeting explaining the purpose and procedure of the study. Seven of the 10 participants were women. All students presented minor musculoskeletal discomfort of 1 to 2 on a 5-point severity scale. Table 1 presents the characteristics of the subjects.

The activation pattern of the left and right upper trapezius was measured by means of a semi-wireless surface electromyography (sEMG) device (Biosignalplux, Lisbon, Portugal) at a sampling rate of 1,000 Hz (gain 1,000; range ±1.5mV; bandwidth 25–500 Hz; input impedance >100 GΩ; CMRR 100 dB). Surface electrodes (Ambur bluesensor N surface ECG electrodes) were placed following the recommendations of Barbero, Merletti, and Rainoldi (2012).[36] Maximal voluntary contraction (MVC) activity of the upper trapezius was captured with shoulder shrugging against manual resistance sustained over 5 seconds. The reference was defined as the root mean squared (RMS) value of the middle 3 seconds.

The conservatory piano students were previously informed about the goals of the study, accentuating that performance quality was not an issue. The students were given appreciation for their engagement. One researcher prepared and followed the measurements. The participants were not video-recorded. A piano professor who is a known source for performance stress did not attend the sessions. The pianists were asked whether they were at ease and relaxed to start with the protocol. For the evaluation scores, each pianist chose a fast and slow score from his/her repertoire which was evaluated for inclusion by the conservatory piano professor.

After a few minutes of warm-up free play on the piano, the baseline MVC signal was registered. The sEMG measurements were then performed with the pianist playing a fast and a slow music score, chosen from the pianist's individual repertoire, each with a duration of 3 minutes (time point t1). These measurements were repeated after time intervals of 2 hrs (time point t2) and again after an additional 2 hrs of continuous piano rehearsals (4 hrs of rehearsal time, time point t3), together with sEMG capturing of the MVC. These evaluation excerpts were performed in the same order at every time point.

The 2-hr rehearsal sessions encompassed solo practice sessions sequencing a continuous performance of slow excerpts of 25 minutes followed by a 10-minute break and followed with a 25-minute fast excerpt performance. The content of the études covered different excerpts from the individual's repertoire which were different from the scores evaluated by means of EMG. The intensity of the rehearsals was evaluated by the students on a scale from 1 to 10 (1 light, 5 moderate, 10 strenuous).

sEMG Signal Processing

The amplitude of the sEMG data was normalized to the baseline MVC (in %MVC). Amplitude analysis was performed on smoothed data following a second-order Savitzky Golay filter (frame length 15). To analyze the frequency component on the non-stationary sEMG signal, wavelet transform is well suited. Within this study, a real-

TABLE 2. Characteristics of the Frequency Bands of the von Tscharner Wavelets Scalogram[37]

(Hz)	Frequency Band Number 0	1	2	3	4	5	6	7	8	9
Center frequency	6.90	19.29	37.71	62.09	92.36	128.48	170.39	218.08	271.5	330.63
Band-width	9.77	15.63	21.48	27.34	35.16	41.02	46.88	52.73	58.59	66.41

time procedure based on a non-orthogonal wavelet scalogram was used encompassing 10 frequency bands based on von Tscharner[37] (Table 2). These procedures were programmed in a Matlab interface (GUI; Matlab ver. 2019a; MatLab, Natick, MA, USA).

Amplitude Component Output Variables: As checked with Q-Q plotting, the distributions of smoothed amplitude data captured during the piano performances were right skewed for all subjects. Statistical analysis on the smoothed amplitude data was done on the following output variables: percentile 10 (P10), first quartile (Q1), median (Me), third quartile (Q3), and percentile 90 (P90).

Frequency Component Output Variables: The combination of frequency, amplitude, and time is called a scalogram. The global amount of %MVC over the 3 minutes of piano performance was called the sEMGpower. The amplitude (in %MVC) in each of the cells of the contingency table combining time with the frequency bands was expressed in a normalized signal (in %): i.e., for each of the frequency bands, the amount of %MVC was summed up over the 3 minutes of piano performance and expressed as a percent of 'sEMGpower.' This distribution of percentages over the frequency bands percentage was termed as the relative *frequency band power* (rFBP). Statistical analysis of the frequency component of the sEMG signal was performed on the median frequency value of the frequency distributions.

A visual representation of the processing of the amplitude and frequency component of the captured sEMG signal is provided in Figure 1.

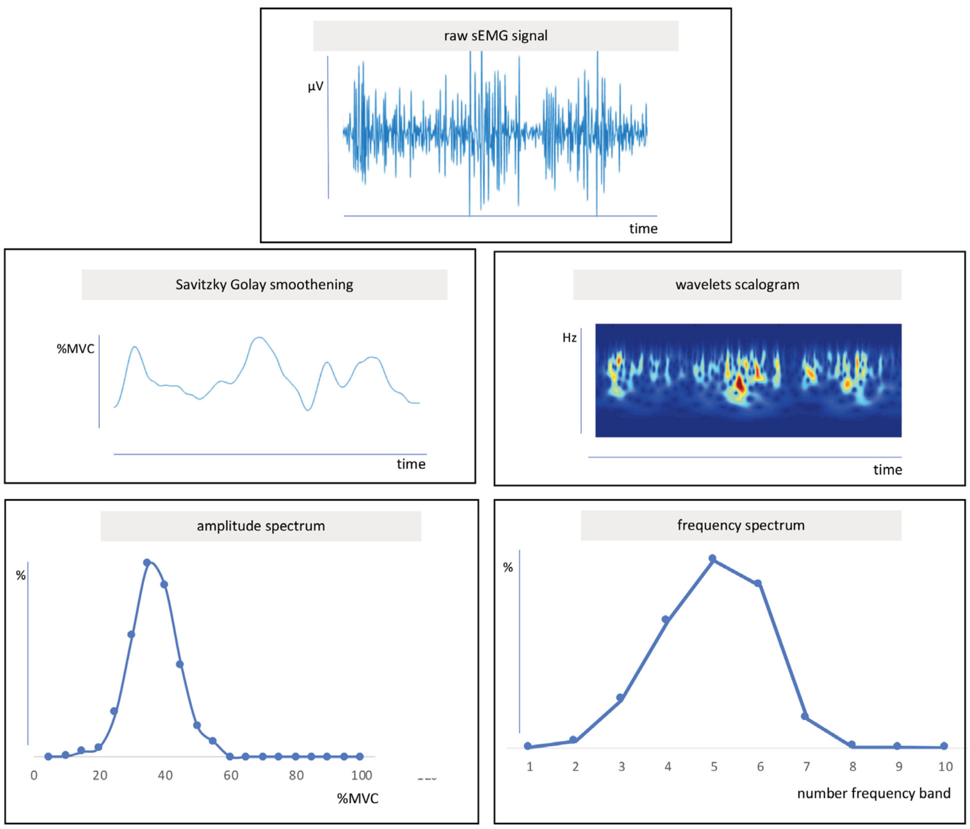

FIGURE 1. Graphs for the amplitude spectrum and FBP distribution over the frequency bands from a 3-minute piano performance of a participating student. The left column represents the processing of the amplitude component of the sEMG signal by means of Savitzky Golay smoothing. The right column represents the processing of the frequency component based on a wavelets scalogram. The colors represent the amplitude level of activity, increasing from blue to red. For clear visualization, the figures for "raw sEMG signal" and the related "Savizky Golay smoothing" and "wavelets scalogram" represent but a few seconds from the total time of 3 minutes of a piano score played.

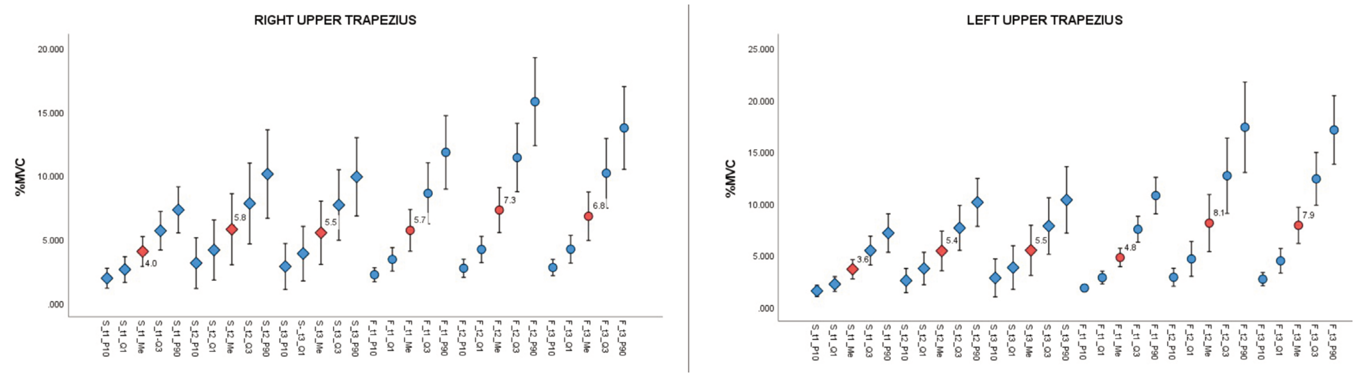

FIGURE 2. Plots of the mean and 90% confidence intervals of the relative amplitude variables (in %MVC) of the left and right upper trapezius for the different music score performances. F, fast music score; S, slow music score; t1, initial baseline measurement; t2, measurement after 2 hrs of repetition; t3, measurement after 4 hrs of rehearsals.

Statistical Analysis

Statistical analysis was performed with SPSS (ver. 27, IBM SPSS, Armonk, NY, USA). The means of the P10, Q1, median, Q3 and P90 variables of the amplitude data arrays as well as the median frequencies of the 10 participants were distributed normally for all sessions as checked by means of Q-Q plotting and Shapiro Wilk test.

The output variables were organized over three factors. A factor "Type" with two levels ('Fast' and 'Slow') divided the measurements between the fast and slow scores. The factor for rehearsals ("Reps") encompassed three levels: level t1 for the initial baseline measurements, level t2 for the measurement after 2 hrs of rehearsal of études, and level t3 for the measurements after 4 hrs of rehearsal. The factor "Side" separated the data between left and right upper trapezius. For inferential statistics, models of repeated measurements analysis of variance (RM ANOVA) were used. In case the sphericity condition was violated (evaluated with the Mauchley's test of sphericity), the alternative of the epsilon pathway by means of Huynh-Feldt was followed. For post hoc pairwise comparisons, the Benjamini-Hochberg procedure was used to cope with the False Discovery Rate.

With this study being an exploratory pilot, significance level was set at 0.10. Confidence intervals at 90% (CI90%) were calculated by means of boot strapping (1,000 samples).[38]

RESULTS

The distributions of smoothed EMG data captured during the piano performances were right skewed for all subjects.

EMG Amplitude Component

The descriptive statistics (mean and CI90%) of the median, first quartile (Q1), third quartile (Q3), percentile 10 (P10) and percentile 90 (P90) related to the data arrays of the %MVC for the different levels of piano playing within the factors Type, Reps are plotted in Figure 2. (Appendix Table A1 presents the statistics in detail.)

Starting from a 3-way-RM-ANOVA, the ANOVA procedure through the post hoc pair-wise comparisons presented the following summarized results (detailed statistics of the ANOVA outputs are presented in Appendix Tables A2 to A7). None of the output variables presented significant interaction for Side*Reps*Test. For the output variables Q3 and P90, interaction was presented between Type*Reps.

- **P10** presented a significant main effect for **Reps** from 1.9 %MVC at t1 to 2.8 %MVC at t2 and from t1 to 2.8 %MVC at t3; i.e., relative increases of respectively 50% and 48%.
- No significant main effect for **Type** could be demonstrated for the **P10** variable.
- **Q1** presented a significant main effect for **Reps** from 2.8 %MVC at t1 to 4.2 at t2 and from t1 to 4.1 at t3; i.e., relative increases of respectively 53% and 48%.
- No significant main effect for **Type** could be demonstrated for the **Q1** variable.
- The **median** presented significant main effects for **Reps** from 4.5 %MVC at t1 to 6.6 at t2 and from t1 to 6.4 at t3; i.e., relative increases of respectively 47% and 42%.
- The **median** presented significant main effects for **Type** with the Fast type of piano performance presenting a higher marginal mean of 6.7%MVC as compared to the Slow type with a marginal mean of 5.0%MVC. The %MVC was 36% higher for the Fast type than the Slow type.
- **Q3** presented interaction between Type*Reps.
  - ✧ For **Q3**, the **Fast** type of performance presented a significant increase from a mean of 7.5 %MVC at t1 to 12.7 at t2 and 12.4 at t3, respectively 61% and 59%.
  - ✧ For **Q3**, the **Slow** type of performance presented a significant increase from a mean of 5.4%MVC at t1 to 7.6 at t2 and 7.8 at t3, a relative increase of 40% and 43% respectively.
  - ✧ For **Q3**, significant higher magnitudes in %MVC of upper trapezius activity for the **Fast** Type were presented through all levels of Reps, respectively 31% at t1, 36% at t2, and 31% at t3.
- **P90** presented interaction between Type*Reps.
  - ✧ For **P90**, the **Fast** type of performance presented a significant relative increase from a mean of 10.8 %MVC at t1 to 17.4 at t2 and 17.1 at t3, respectively 61% and 59%.

- ✧ For **P90**, the **Slow** type of performance presented a significant increase from a mean of 7.1 %MVC at t1 to 10.1 at t2 and 10.3 at t3, a relative increase of 42% and 45% respectively.
- ✧ For **P90**, significant higher magnitudes in %MVC of upper trapezius activity for the **Fast** Type were presented through all levels of Reps, respectively 36% at t1, 39% at t2, 34% at t3.
- For **Reps**, no significant differences could be demonstrated between t1 and t3 on neither of the variables.

EMG Frequency Component

Throughout all Reps*Type scores, the highest **FBP** was observed in frequency band 3 (center frequency 62.09 Hz) with a global mean of 37.60% (CI90% 36.97, 38.12). Frequency bands 2–4 (62.09–128.48 Hz) contained 87.28% (CI90% 86.67, 87.82) of sEMG power over all levels of performance. (For details, see Appendix Table A8.)

- The means (and 90% confidence intervals) of the **median frequency** of the different performance levels are presented in Table 3. The ANOVA results are as follows (for statistical details, see Appendix Table A9):
  - ✧ For **median frequency**, ANOVA presented no significant 2-way or 3-way interactions (Appendix Table A9).
  - ✧ For **median frequency**, no significant main effect was observed for **Side**
  - ✧ For **median frequency**, no significant main effect was observed for **Type**.
  - ✧ For **median frequency**, **Reps** presented a significant main decrease from 61.76Hz at t1 to 60.77 at t2 and from t1 to 60.00 at t3; i.e., a relative decrease of 2% and 3% respectively.
  - ✧ For median frequency, **Reps** did not present a significant main decrease from t2 to t3.

TABLE 3. Median Frequency of the Upper Trapezius Activation During the Different Piano Performances

Median Frequency	Mean (Hz)	CI 90% (Bootstrapping)
Left trapezius		
F1	62.56	60.26, 64.85
F2	61.79	59.97, 63.61
F3	60.72	58.88, 62.65
S1	61.04	58.56, 63.51
S2	60.39	58.68, 62.45
S3	60.16	58.25, 62.44
Right trapezius		
F1	61.25	57.30, 65.40
F2	60.69	57.91, 64.50
F3	59.32	56.17, 64.20
S1	62.18	57.75, 67.32
S2	60.21	56.09, 64.96
S3	59.83	56.74, 63.55

F, fast music score; S, slow music score.

DISCUSSION

Amplitude Magnitude Component

The median values for the %MVC presented a global mean for the left trapezius of 5.86 (CI90% 4.71, 6.97) and for the right trapezius 5.83 (CI90% 4.64, 7.05). Detailed data related to the %MVC of the trapezius during piano performance are limitedly presented in peer-reviewed journals.[23,32,33]

Yoshie et al. (2009)[32] asked 18 highly trained pianists to perform, for around 6.5 minutes on an acoustic grand piano, a solo piece of their choice requiring considerable playing skills. Participants attended a practice and competition session on two separate days. MVC of the left upper trapezius (UT) was captured with the sustained shoulder shrug. Data of the %MVC of the UT during the performances were not presented, but from the box and whisker plot (Fig. 4 in Yoshie et al.[32]), the median (Q1; Q3) of the %MVC of the UT for the practice session was around 12%MVC (Q1 5; Q3 22) which increased significantly to around 22%MVC (Q1 12; Q3 28) for the competition session. The considerable increase in heart rate and sweat rate from the practice to competition condition reflected the sympathetic activity.

In a second report, Yoshie et al. (2009)[33] extended the study with 7 pianists with an undergraduate level of skills.Data of the %MVC of the left UT during the performances were not presented, but from the box and whisker plot (Fig. 1 in Yoshie et al.[33]), the median (Q1; Q2) of the %MVC of the UT for the practice session was around 16%MVC (12; 22) which increased significantly to around 19%MVC (18; 21) for the competition session.

Our results are comparable to the studies of Yoshie et al.[32,33] in terms of free choice of piano piece from the individual's repertoire. Yoshie et al.[32,33] evaluated the performance in a rehearsal and a competition context, whereas we evaluated in a rehearsal context with re-evaluation of the performances after 2 and 4 hours of continuous repetition of études.

The global mean for amplitude of the sEMG signal of the UT in our study was 5.86 %MVC for the left trapezius and 5.83 %MVC for the right trapezius, which are half of the median values on %MVC obtained in the repetition context in Yoshie et al.'s studies.[32,33] Yoshie et al. used median values, and in our study means were calculated which can explain but a minor part of the difference. The difference may be due to a number of differences between the study designs. To capture the MVC reference values, we used shoulder shrugging with resistance, whereas Yoshie et al. used shoulder shrugging without resistance. This may have relatively reduced the sEMG activity output, hence augmenting the %MVC. In Yoshie et al.'s studies,[32,33] the pianists had to perform a musical excerpt of their choice requiring considerable playing skills, whereas in our study the pianists had to play a fast and a slow musical score, chosen from the individual's repertoire.

Degrave et al. (2020)[23] measured the EMG activity of the UT in 12 professional classical pianists during four series of performance of 40 slow-paced isolated keystrokes using the combinations of pressed and struck touch with *staccato* and *tenuto* articulation on a Bosendorfer CEUS grand piano with the middle finger of the right hand at a slow tempo (30 bpm) and at a high intensity level (*forte*). The article did not provide details concerning whether left or right UT was measured. MVC of the UT was taken before the trials from manual resistance with shoulder abduction in 90° for a 3-second period. Mean ± SD (peak ± SD) values of %MVC of the UT were 4.2 ± 2.6 (10.3 ± 5.5) for struck staccato, 4.1 ± 2.9 (9.2 ± 5.3) for struck tenuto, 4.8 ± 2.9 (12.0 ± 6.9) for pressed staccato and 4.9 ± 2.8 (10.4 ± 4.8) for pressed tenuto.

Our study presented magnitudes in %MVC which are comparable to Degrave et al.[23] However, Degrave et al.'s study was strictly experimental with isolated keystrokes using the middle finger of the right hand. Furthermore, Degrave et al.[23] used shoulder abduction at 90° for MVC, whereas we used shoulder shrug against resistance.

Effects of Type and Reps on the Amplitude Component of the EMG Data

Following the output of the ANOVA procedures and post hoc comparisons, no main effect was presented for the factor **Side**. **Reps** presented with a significant increasing effect on the EMG amplitude between t1 and t2 for P10 (50%), for Q1 (53%), for the median (47%), for Q3*Fast (61%), for Q3*Slow (40%), for P90*Fast (61%), for P90*Slow (42%). No significant differences were presented for the **Reps** between t2 and t3 on either of the amplitude variables.

Effects of Type and Reps on the Frequency Component of the EMG Data

sEMG is a non-invasive method to evaluate the myoelectric properties associated with muscle contraction. sEMG can be used for real-time fatigue monitoring task. The decrease of sEMG median frequency is considered an indicator of muscle fatigue due to its linear relationship with the conduction velocity of the active motor units, which decreases with muscle fatigue.[39] The study of Ortega-Auriol et al. (2018)[40] revealed that in the context of dynamic muscle activation, sEMG amplitude did not change systematically with fatigue, whereas EMG median frequency consistently decreased. For non-stationary sEMG signals, fast Fourier transform (FFT) is not applicable for analysis whereas wavelet transform is a very reliable to process the median frequency.[41] Even though the amplitude of upper trapezius activity presented low with the mean of the median values around 6%MVC, the significant decrease in median frequency after 2 and 4 hours of rehearsals reflected a fatiguing effect.

The reported amplitudes of upper trapezius activation during piano performance are comparable to upper trapezius activation during computer-based tasks. For instance, Januario et al. (2018)[42] presented for the upper trapezius median activation values of 6.3%MVC for the dominant and 5.9%MVC for the non-dominant side.

Long hours of repetitive upper trapezius activation at low amplitude is typical for computer workers. In computer workers, this may lead to so-called work-related musculoskeletal disorders (WRMD, similar to PRMD) and has been evidenced to be related to the so-called Cinderella hypothesis.[43,44] The Cinderella hypothesis states that the development of muscular pain and repetitive strain injury is due to an overuse of fibers belonging to low threshold motor units. In our study, piano performance presented upper trapezius fatigue after 2 and 4 hours of rehearsals. Muscle fatigue in pianists is not only a risk factor for PRMDs, but it is also detrimental for motor control and consequently performance.[30,45]

Limitations and Future Studies

This study was an exploratory pilot study with a small sample size of 10 participants. In context of being a pilot, the significance level was set at 10% with a higher chance of type I error.

Participants could choose slow and fast excerpts from their individual repertoire because this reflects the individual's performance context. Although this may have generated a variability in technical difficulty and loudness within the study, the 90% CIs on the median variable of the %MVC presented acceptably small (see Figure 2 and Appendix Table A1). The intensity of the performance during the rehearsals was evaluated by the students as moderate. It may be interesting for future research to investigate training sessions which are technically more difficult and stressful.

It has been demonstrated that performance patterns associated with less 'rest' in the trapezius muscle, i.e., less periods at very low activity (referred to as "gaps") have a higher risk of developing trapezius myalgia.[46–49] Breaks have a protective role in the development of PRMDs. A higher frequency of breaks but not their duration was demonstrated to have a preventive effect.[9,49] Bruno et al. (2008)[2] found that periods of at least 60 min of continuous piano practice without breaks resulted in a higher risk of PRMD. Future experimental designs of piano performance should encompass this factor, e.g., by means of exposure variation analysis.[50]

We used shoulder shrugging for MVC of the trapezius following the SENIAM consensus guidelines. Boettcher et al. (2008)[51] validated reliable shoulder MVCs which are preferable in future designs.

In this study, the effect of fast and slow type of piano performance was evaluated. Differences in %MVC of upper trapezius activation were presented between the individuals which might be related to their specific repertoire. Linked to the factor 'Type,' it's advisable for future research to incorporate the specific repertoire as an independent factor in the study design, besides other factors such as performance anxiety or technical difficulty level. It should be accentuated that type of performance is but a single factor to be included in future research designs besides biomechanical factors such as posture and psychological factors such as performance anxiety.

Conclusion

The amplitude of the upper trapezius activity during the piano sessions in this study was relatively small with a global 6%MVC, but similar to computer workers who present WRMDs similar to PRMDs. The activity of the upper trapezius was equivalent on the left and right. Rehearsals of moderate intensity increased the amplitude of %MVC of the upper trapezius by 40 to 50% and decreased the median frequency which is a sign of muscle fatigue. Playing faster presented higher magnitude of activity of the upper trapezius.

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APPENDIX TABLE A1. Mean and 90% Confidence Intervals of the Relative Amplitude Variables (in %MVC) of the Left and Right Upper Trapezius for the Different Music Score Performances

	F_t1	S_t1	F_t2	S_t2	F_t3	S_t3
Left upper trapezius						
P10	1.81	1.53	2.85	2.52	2.67	2.78
	1.50, 2.13	1.08, 1.98	2.13, 3.60	1.62, 3.56	2.11, 3.18	1.36, 4.43
Q1 (%MVC)	2.81	2.19	4.62	4.07	4.44	3.64
	2.30, 3.37	1.59, 2.79	3.26, 6.12	1.17, 5.57	3.42, 5.39	1.06, 4.76
Me (%MVC)	4.76	3.63	8.09	5.39	7.87	5.45
	4.02, 5.55	2.79, 4.40	5.83, 10.65	3.80, 7.00	6.45, 9.33	3.56, 7.65
Q3 (%MVC)	7.48	5.42	12.66	7.62	12.36	7.80
	6.35, 8.60	4.19, 6.62	9.78, 16.01	5.73, 9.52	10.35, 14.74	5.65, 10.27
P90	10.75	7.12	17.36	10.09	17.09	10.33
	9.16, 1.31	5.51, 8.67	13.86, 21.45	8.17, 12.14	14.53, 20.26	7.75, 13.23
Right upper trapezius						
Q1 (%MVC)	3.40	2.60	3.70	4.13	4.20	3.69
	2.65, 4.21	1.78, 3.52	2.44, 5.01	2.28, 6.45	3.35, 5.14	1.02, 4.81
Me (%MVC)	5.69	4.01	7.27	5.76	6.78	5.48
	4.28, 7.09	3.02, 5.04	5.83, 8.97	3.57, 8.40	5.32, 8.41	3.45, 7.86
Q3 (%MVC)	8.58	5.64	11.39	7.79	10.16	7.66
	6.51, 10.65	4.34, 6.94	9.23, 13.97	5.26, 10.77	8.11, 12.62	5.34, 10.37
P10	2.20	1.92	2.70	3.11	2.75	2.84
	176, 2.66	1.31, 2.63	2.15, 3.35	1.58, 5.10	2.26, 3.34	1.38, 4.63
P90	11.80	7.29	15.78	10.10	13.72	9.88
	9.31, 14.36	5.72, 8.85	13.02, 19.18	7.34, 13.44	11.23, 16.65	7.35, 12.88

Data presented as mean and 90% CI: F, fast music score; S, slow music score; t1, initial baseline measurement; t2, measurement after 2 hrs of repetition; t3, measurement after 4 hrs of repetition.

APPENDIX TABLE A2. Three-way RM ANOVA on the Amplitude Data (in %MVC) of the Upper Trapezius (Side*Type*Repetitions)

Upper Trapezius	Factor	F-value	*p*	Partial η^2	Observed Power
P10	Side	0.573	0.468	0.060	0.182
	Reps	3.375	0.081	0.273	0.697
	Type	0.005	0.944	0.171	0.101
	Side*Reps	0.327	0.726	0.001	0.167
	Side*Type	0.462	0.514	0.035	0.166
	Reps*Type	0.550	0.586	0.049	0.214
	Side*Type*Reps	19.949	0.058	0178	0.487
Q1	Side	0.082	0.781	0.009	0.112
	Reps	4.076	0.035	0.312	0.669
	Type	0.578	0.467	0.060	0.183
	Side*Reps	0.594	0.563	0.062	0.223
	Side*Type	0.561	0.473	0.059	0.180
	Reps*Type	0.214	0.810	0.023	0.144
	Side*Type*Reps	1.670	0.216	0.152	0.437
Median	Side	0.002	0.969	0.000	1.000
	Reps	3.571	0.076	0.284	0.604
	Type	4.098	0.074	0.313	0.589
	Side*Reps	0.935	0.411	0.094	0.294
	Side*Type	0.714	0.420	0.074	0.202
	Reps*Type	1.184	0.329	0.116	0.344
	Side*Type*Reps	1.866	0.183	0.172	0.473
Q3	Side	0.106	0.752	0.012	0.115
	Reps	3.809	0.042	0.297	0.745
	Type	12.122	0.007	0.574	0.941
	Side*Reps	1.086	0.359	0.108	0.324
	Side*Type	1.076	0.327	0.107	0.251
	Reps*Type	2.879	0.082	0.242	0.633
	Side*Type*Reps	2.404	0.119	0.211	0.563

(*continued on next page*)

APPENDIX TABLE A2. Three-way RM ANOVA on the Amplitude Data (in %MVC) of the Upper Trapezius (Side*Type*Repetitions) (*continued*)

Upper Trapezius	Factor	F-value	*p*	Partial η^2	Observed Power
P90	Side	0.249	0.630	0.027	0.136
	Reps	4.431	0.049	0.330	0.803
	Type	26.532	<0.001	0.747	0.999
	Side*Reps	1.235	0.314	0.121	0.354
	Side*Type	1.596	0.238	0.151	0.319
	Reps*Type	2.951	0.078	0.247	0.643
	Side*Type*Reps	2.266	0.133	0.201	0.541

APPENDIX TABLE A3. Marginal Means and Post Hoc Pair-Wise Comparisons for P10, Q1 and Median Between the Levels of the Factors Presenting a Significant Main Effect

Upper Trapezius	Marginal Means	Marginal Means CI90%	Pair Wise Comparison	*p*	Adjusted *p*	Δ%MVC Mean	Δ%MVC Mean CI90%	Cohen's *d*
P10	t1 1.863	1.472, 2.254	t2-t1	0.084	0.11	0.935	0.053, 1.816	0.615
	t2 2.798	1.799, 3.797	t3-t1	0.093	0.14	0.899	0.022, 1.775	0.595
	t3 2.762	1.698, 3.826	t3-t2	0.859			–0.398, 0.326	
Q1	t1 2.751	2.199, 3.303	t2-t1	0.060	0.06	1.407	0.205, 2.609	0.678
	t2 4.158	2.841, 5.475	t3-t1	0.070	0.07	1.318	0.142, 2.494	0.650
	t3 4.059	2.666, 5.472	t3-t2					
Median	t1 4.521	3.776, 5.266	t2-t1	0.079	0.09	2.107	0.155, 4.060	0.626
	t2 6.628	4.850, 8.406	t3-t1	0.087	0.12	1.878	0.085, 3.671	0.607
	t3 6.399	4.625, 8.172	t3-t2	0.392		–0.229	–0.949, 0.490	
	F 6.743	5.526, 7.960	F-S	0.074	0.08	1.787	0.169, 3.406	0.640
	S 4.956	3.305, 6.606						

t1, initial baseline measurement; t2, measurement after 2 hrs of repetition; t3, measurement after 4 hrs of repetition; F, fast music score; S, slow music score. Based on Benjamini-Hochberg procedure, *p*-values ≤ 0.093 were accepted as significant.

APPENDIX TABLE A4. Mean and 90% Confidence Interval of Q3 and P90 (in %MVC) of the Upper Trapezius (Combined Data of Left and Right) for the Different Music Score Performances

	F_t1	S_t1	F_t2	S_t2	F_t3	S_t3
Q3 (%MVC)	8.04 6.89, 9.25	5.54 4.66, 6.47	12.03 10.10, 14.03	7.71 5.90, 9.28	11.26 9.69, 13.00	7.74 6.11, 9.58
P90	11.27 9.84, 12.79	7.216 0.07, 8.32	16.571 4.26, 18.98	10.09 8.34, 12.10	15.41 13.38, 17.64	10.11 8.23, 12.21

Data presented as mean and CI 90%.

APPENDIX TABLE A5. One-Way RM ANOVAs with Factor Reps on the Q3 and P10 Output Variables after a sSplit File Procedure for Type

	Factor	F-value	*p*	Partial η^2	Observed Power
Q3 Fast	Reps	6.647	0.005	0.259	0.918
Q3 Slow	Reps	4.152	0.038	0.179	0.717
P90 Fast	Reps	6.824	0.005	0.264	0.926
P90 Slow	Reps	5.570	0.014	0.227	0.845

APPENDIX TABLE A6. Post Hoc Pair-Wise Comparisons for Q3 and P90 Between the Levels of Reps After Split File for Type

Upper Trapezius	Pair-Wise Comparison	Δ% MVC Mean	*p**	Δ% MVC CI 90%	Cohen's *d*
Q3 Fast	t2-t1	3.993	0.006*	1.737, 6.249	0.684
	t3-t1	3.226	0.022*	0.990, 5.462	0.558
	t3-t2	–0.767	0.363	–2.191, 0.656	
Q3 Slow	t2-t1	2.170	0.055*	0.335, 1.004	0.457
	t3-t1	2.200	0.033*	0.544, 3.856	0.514
	t3-t2	0.031	0.952	–0.847, 0.908	
P90 Fast	t2-t1	5.295	0.005*	1.197, 7.064	0.712
	t3-t1	4.130	0.025*	2.422, 8.169	0.544
	t3-t2	–1.165	0.295	–3.034, 0.704	
P90 Slow	t2-t1	2.887	0.022*	0.844, 4.894	0.556
	t3-t1	2.898	0.018*	0.954, 4.842	0.576
	t3-t2	0.011	0.986	–1.073, 1.095	

t1, initial baseline measurement; t2, measurement after 2 hrs of repetition; t3, measurement after 4 hrs of repetition.
*Significant *p*-values, based on the Benjamini-Hochberg procedure.

APPENDIX TABLE A7. Paired Comparisons Between Fast and Slow Type of Piano Performance for the Q3 and P90 Variable over the Different Levels of Reps

Upper Trapezius	LevelsReps\Type	Fast	Slow	Δ% MVC	*p*	Cohen's *d*
Q3	t1	8.04 6.89, 9.25	5.54 4.66, 6.47	2.501 1.267, 3.734	0.002	0.784
Q3	t2	12.031 0.10, 14.03	7.71 5.90, 9.28	4.324 2.69 4, 5.955	<0.001	1.025
Q3	t3	11.26 9.69, 13.00	7.74 6.11, 9.58	3.527 1.925, 5.128	0.001	0.851
P90	t1	11.27 9.84, 12.79	7.216 0.07, 8.32	4.067 2.807, 5.337	<0.001	1.238
P90	t2	16.571 4.26, 18.98	10.09 8.34, 12.10	6.476 4.680, 8.272	<0.001	1.394
P90	t3	15.411 3.38, 17.64	10.11 8.23, 12.21	5,299 3.400, 7.204	<0.001	1.076

Data presented as mean and CI 90%.

APPENDIX TABLE A8. Relative Frequency Band Power (rFBP, in %) in Left and Right Upper Trapezius for the Different Music Score Performances

	Frequency Band Number									
Left Trapezius	0	1	2	3	4	5	6	7	8	9
Center frequency %	6.90	19.29	37.71	62.09	92.36	128.48	170.39	218.08	271.50	330.63
Frequency band %	9.77	15.63	21.48	27.34	35.16	41.02	46.88	52.73	58.59	66.41
Relative Frequency Band Power (rFBP, in %)										
F_t1	0.16	5.21	25.52	37.39	24.31	6.80	0.60	0.01	0.00	0.00
	0.14, 0.19	4.71, 5.69	23.12, 29.24	36.34, 39.49	22.16, 26.36	5.35, 8.20	0.40, 0.78			
F_t2	0.15	5.13	26.03	38.38	23.54	6.23	0.52	0.01	0.00	0.00
	0.13, 0.17	4.64, 5.63	24.08, 28.08	37.65, 39.10	21.85, 25.17	5.16, 7.33	0.38, 0.65			
F_t3	0.16	5.35	27.13	38.72	22.59	5.57	0.47	0.01	0.00	0.00
	0.14, 0.18	4.92, 5.82	26.06, 29.28	37.93, 39.66	20.86, 24.28	4.65, 6.51	0.35, 0.59			
S_t1	0.26	6.29	26.80	36.01	22.89	25.08	8.29	0.02	0.00	0.00
	0.14, 0.46	4.78, 8.31	24.72, 28.85	33.73, 37.94	20.98, 7.02	5.85, 0.72	0.55, 0.91			
S_t2	0.21	5.80	27.73	37.49	21.92	36.24	0.61	0.01	0.00	0.00
	0.14, 0.30	5.06, 6.76	25.96, 29.53	36.17, 38.88	20.18, 23.7	5.09, 7.37	0.47, 0.75			
S_t3	0.20	5.81	28.07	37.60	21.55	6.15	0.62	0.01	0.00	0.00
	0.15, 0.26	5.07, 6.60	26.09, 29.92	36.11, 39.09	19.92, 23.42	4.107, 0.66	0.46, 0.78			
	Frequency Band Number									
Right Trapezius	0	1	2	3	4	5	6	7	8	9
Center frequency %	6.90	19.29	37.71	62.09	92.36	128.48	170.39	218.08	271.50	330.63
Frequency band %	9.77	15.63	21.48	27.34	35.16	41.02	46.88	52.73	58.59	66.41
Relative Frequency Band Power (rFBP, in %)										
F_t1	0.17	5.40	27.60	36.93	22.17	6.97	0.74	0.01	0.00	0.00
	0.13, 0.20	4.27, 6.44	23.25, 31.45	34.45, 38.32	18.85, 25.83	4.80, 9.54	0.47, 1.06			
F_t2	0.16	5.47	27.78	37.86	21.67	6.38	0.65	0.01	0.00	0.00
	0.13, 0.19	4.50, 6.45	23.63, 31.64	36.53, 39.03	18.20, 25.19	4.44, 8.56	0.42, 0.93			
F_t3	0.17	5.84	29.32	37.47	20.67	5.91	0.61	0.01	0.00	0.00
	0.14, 0.20	4.86, 6.80	25.56, 32.83	36.28, 38.64	17.54, 23.95	4.16, 7.90	0.39, 0.87			
S_t1	0.19	5.39	27.21	35.95	22.25	7.99	0.98	0.02	0.00	0.00
	0.14, 0.23	4.15, 6.48	22.77, 31.31	34.15, 37.46	18.59, 26.15	5.54, 10.84	0.65, 1.41			
S_t2	0.17	5.68	29.00	36.30	21.05	6.94	0.81	0.02	0.00	0.00
	0.14, 0.21	4.51, 6.85	24.65, 32.99	34.89, 37.48	17.44, 24.79	4.90, 9.55	0.54, 1.18			
S_t3	0.18	5.78	29.48	36.46	20.43	6.66	0.78	0.02	0.00	0.00
	0.14, 0.21	4.65, 6.79	24.96, 33.51	35.08, 38.02	16.67, 24.58	4.43, 9.25	0.50, 1.12			

Center frequency and frequency band presented as %; Relative frequency band power presented as mean and CI 90%.
F, fast music score; S, slow music score. t1, initial baseline measurement; t2, measurement after 2 hrs of repetition; t3, measurement after 4 hrs of repetition. Relevant %s >20% are highlighted.

APPENDIX TABLE A9. Three-Way RM ANOVA of the Median Frequency of the Upper Trapezius Activity During Piano Performance

Factor	F-value	*p*	Partial η^2	Observed Power	Pairwise Comparison	ΔMedian Frequency (in Hz)	*p*	ΔMedian Frequency (in Hz) CI 90%
Reps	0.164	0.850						
Side	0.052	0.824	0.006	0.108	L-R	0.528	0.824	−3.706, 4.763
Reps	6.144	0.012	0.406	0.908	t2-t1	−0.984	0.048	−1.774, −0.194
Type	0.135	0.722	0.015	0.200	t3-t1	−1.754	0.020	−2.893, −0.616
Side*Reps	0.695	0.512	0.072	0.244	t3-t2	−0.771	0.106	−1.557, 0.016
Side*Type	2.558	0.144	0.221	0.268	F-S	0.421	0.722	−1.680, 2.522
Reps*Type	1.000	0.386	0.100	0.308				
Side*Type*Reps	3.292	0.103	0.435	0.513				