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Effects of Rehearsal Time and Repertoire Speed on Extensor Carpi Radialis EMG in Conservatory Piano Students

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BACKGROUND: Repetitive actions while playing piano may overload forearm muscles and tendons, leading to playing-related musculoskeletal disorders (PRMDs), including lateral epicondylitis. **METHODS:** In this pilot study, surface electromyography (sEMG) activity of the extensor carpi radialis (ECR) 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. Statistical analysis encompassed 2-way repeated measures ANOVAs for the amplitude and frequency components of the sEMG signal (α set at 5%). The students also rated the intensity of rehearsals using a VAS. **RESULTS:** The ECR presented with a mean amplitude of 23%MVC for the slow scores, which increased significantly to 36%MVC for the fast scores. The sEMG signal presented a significant though small decrease of 1.9%MVC in amplitude between baseline and 4 hrs of rehearsal time and no shift in frequency, which may indicate that the rehearsals were held at a physiological steady-state and suggesting optimization or complementary muscle loading. **CONCLUSIONS:** These data accentuated that the loading of the ECR (as reflected in the amplitude component) was higher than that seen for computer keyboard workers. The augmented loading of the ECR and reduced blood flow to forearm muscles may be a factor in the development of PRMDs in pianists. *Med Probl Perform Art* 2020;35(2):81–88.

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PIANO PERFORMANCE involves the repetition of key-striking actions reaching thousands of times per minute with reaction forces at the fingertips around 8 N for weak sound dynamics and as high as 50 N for strong sound dynamics.[(1)] This activity cumulatively (over)loads muscles, tendons, and joints over time, which may lead to performance-related musculoskeletal disorders (PRMDs), including lateral epicondylitis (LE). In their systemic review, Bragge et al. (2006) accentuated that the epidemiology of PRMDs in pianists still needs more detailed clarification due to lack of operational definition, criteria, biases in design, and mixed instrumental cohorts.[(2)] On a sample of 195 piano conservatory students, Bruno et al (2008) found point prevalences of disabling PRMDs for the elbow and forearm of 5.5% and 24%, respectively.[(3)] In this context, only limited numbers have been reported on the presence of LE in pianists. In 200 professional pianists or piano students who had hand and forearm pain solely attributed to overuse while playing the piano, 27 (13.5%) were diagnosed with LE.[(4)] In an analysis of medical records of 183 professional pianists at a performing arts clinic, 3.9% of the professional pianists and 6.2% of the piano students presented with LE.[(5)] Although these data do not represent the prevalence of LE in the population of pianists, they identify the existence of LE in pianists.

A significant relationship has been found between the occurrence of PRMD and the number of practice hours and a negative relationship to the habit of taking breaks during practice as revealed by Ling et al. (2018) in a multivariate logistic regression.[(6)] In the context of LE, even under low amplitude of extensor carpi radialis (ECR) activation, long-term decreased intramuscular blood flow has been associated with the symptoms of LE.[(7,8)] For the ECR, a significant reduction in muscle oxygenation during isometric contractions as low as 10%MVC has been demon-

TABLE 1. Demographic and Playing Characteristics of Participants

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

L/R, left/right handedness. Musculoskeletal discomfort measured on a 5-point severity scale.

strated.[9] These findings suggest questions such as the muscle activity of the ECR while playing the piano.

This pilot study examined by means of surface electromyography (sEMG) the amplitude and frequency components of ECR muscle activity of the dominant arm, measured in conservatory piano students while playing a fast and slow music score taken from the individual's repertoire, combined with the effect of long rehearsals of piano *études* on these performances. The output is discussed in comparison with critical data being evidenced from other kinds of working situations involving long-term low-amplitude muscle activity of the ECR, such as work on computer keyboards.

METHODS

This study was approved by the Ethical Commission of the Vrije Universiteit Brussel (BUN 143201732690). All participants provided written informed consent.

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 ECR 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 Gohm; CMRR 100 dB). Wires from the electrodes to the device were fixed with tape to the subject in order not to hinder natural movement during piano playing. Surface electrodes (Ambur bluesensor N surface ECG electrodes) were placed following the recommendations of Barbero, Merletti, and Rainoldi (2012).[10] For the maximal voluntary contraction reference (MVC), the guidelines of Barbero et al. (2012)[10] were followed also.

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 repetitions (4 hrs of rehearsal time, time point t3), together with sEMG capturing of the MVC. The excerpts were performed in the same order at every time point.

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 2nd-order Savitzky Golay filter (frame length 15). To analyze the frequency component on the non-stationary sEMG signal while playing a music score, Fourier analysis is not the most efficient method. Wavelet transform is well suited to non-stationary signals like sEMG.[11] Within this study, a real-time procedure based on a non-orthogonal wavelet scalogram was used encompassing 10 frequency bands following von Tscharner (Table 2, Fig. 1).[11] These procedures were programmed in a GUI Matlab interface (Matlab version 2019a; MatLab, Natick, MA, USA).

Amplitude Component: As checked with Q-Q plotting and formal testing using Shapiro-Wilk, the smoothed amplitude data were normally distributed for all subjects. The distribution of the smoothed amplitude data was analyzed with the following output variables: mean (Mean), percentile 10 (P10), percentile 20 (P20), percentile 80 (P80), percentile 90 (P90), and cut-off score for the cumulative percentage under 20%MVC (Cutoff20) and under 10%MVC (Cutoff10). Cutoff10 and Cutoff20 refer to the percentage of

TABLE 2. Characteristics of the Frequency Bands of the von Tscharner Wavelets Scalogram[11]

	Frequency Band Number									
(Hz)	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 during the fast and slow repertoire performances spent below 10% and 20% MVC thresholds, respectively. P10, P20, and Cutoff10 and Cutoff20 were chosen for comparison of the amplitude data with the critical percentiles and cut-off scores as presented in the literature related to other kinds of working situations involving long-term low-amplitude muscle activity of the ECR, such as computer keyboard work.

Frequency Component: The distribution of the amplitude over the 10 frequency bands throughout the 3 minutes of piano playing were expressed in a normalized signal (in %): i.e., for each of the frequency bands, the total amount of %MVC was summed up over the 3 minutes and expressed as a percent of the global amount of %MVC. This percentage is termed as the *frequency band power* (FBP), and the global amount of %MVC is called the *sEMGpower*.

Statistical Analysis

For statistical analysis, these output variables were organized with two factors: a factor "Type" with two levels (fast and slow dividing the measurements from the fast and slow scores) and a factor "Reps" for repetitions with three levels (level 1 for the initial measurements, level 2 for the measurement after 2 hrs of rehearsal of *études,* and level 3 for the measurements after 4 hrs of rehearsal).

For the statistical analysis of the amplitude data, SPSS (ver. 25, IBM SPSS, Armonk, NY, USA) was used. Normal distribution of the data sets was checked by means of Shapiro Wilk testing and Q-Q plotting. All data sets presented were normally distributed. For statistical analysis, a two-way repeated measures ANOVA (2-way RM-ANOVA) was used with a factor Type (with levels fast and

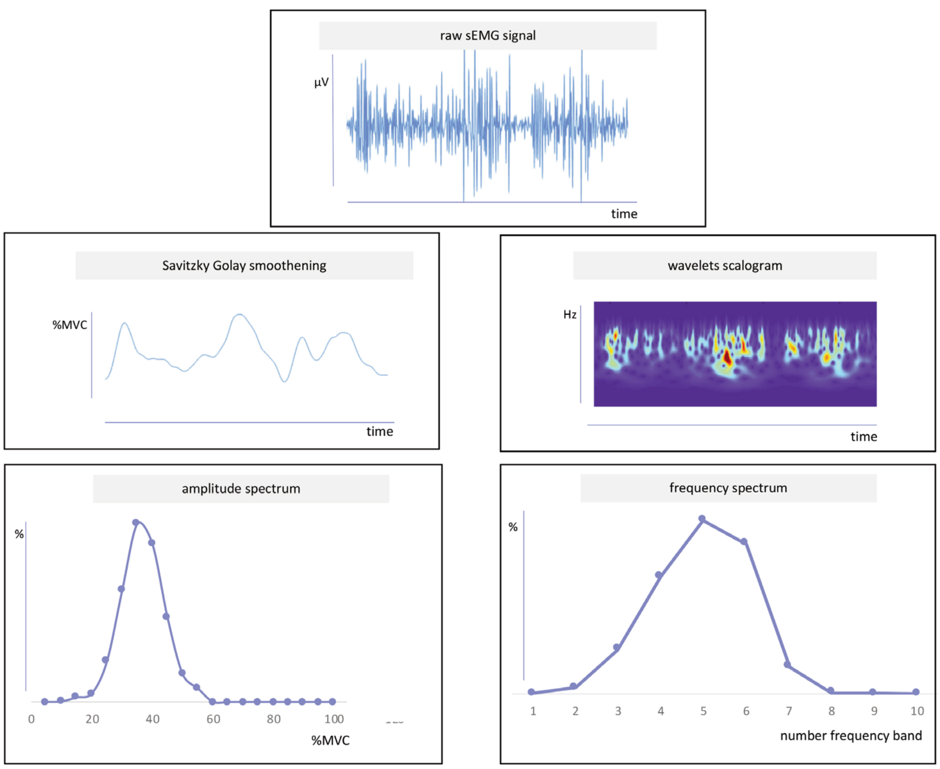

FIGURE 1. Visual representation of the processing procedure of the sEMG signal. The left side represents the processing of the amplitude component of the sEMG signal: a Savitzky Golay smoothing was followed by analysis of the amplitude distribution. The right side represents the processing of the frequency component of the sEMG signal: a wavelets scalogram was used to analyze the frequency band powers (FBP) (the colors within the wavelet scalogram represent the level of activity, increasing from blue to red). For clear visualization, the figures for "raw sEMG signal" and the related "Savitzky Golay smoothing" and "wavelets scalogram" represent but a few seconds from the total time of 3 minutes of a piano score played. The graphs for the amplitude spectrum and FBP distribution over the frequency bands are an example from a 3-minutes piano play.

TABLE 3. Mean and 95% Confidence Intervals (95%CI) of the Relative Amplitude Variables (in %MVC) for the Different Music Score Performances

		t1_F	t1_S	t2_F	t2_S	t3_F	t3_S
Mean (%MVC)	Mean	37.04	23.43	34.75	21.69	35.68	21.00
	95%CI	32.19, 41.88	19.48, 27.37	29.75, 39.75	17.17, 26.21	30.77, 40.59	17.00, 25.00
P10 (%MVC)	Mean	18.06	9.61	18.53	8.81	19.34	8.16
	95%CI	13.04, 23.08	7.54, 11.67	13.42, 23.63	6.17, 11.46	14.01, 24.67	5.78, 10.55
P20 (%MVC)	Mean	23.67	14.74	23.10	14.09	24.04	12.05
	95%CI	19.11, 28.23	12.56, 16.92	18.24, 27.96	11.02, 17.16	19.00, 29.97	9.04, 15.06
P80 (%MVC)	Mean	48.26	31.84	44.97	29.73	46.02	28.76
	95%CI	41.76, 54.75	25.52, 38.15	38.40, 51.54	22.78, 36.68	39.53, 52.50	22.17, 35.34
P90 (%MVC)	Mean	54.22	35.76	52.33	36.32	53.73	35.48
	95%CI	48.19, 60.25	25.32, 48.20	45.16, 59.50	27.41, 45.21	46.81, 60.65	27.37, 43.59
Cutoff 10 (%)	Mean	2.89	12.63	3.01	17.74	2.62	18.09
	95%CI	0.49, 5.29	6.83, 18.42	0.15, 5.89	8.41, 27.06	–0.16, 5.40	9.87, 26.30
Cutoff 20 (%)	Mean	12.96	47.16	15.44	52.52	14.20	54.17
	95%CI	6.33, 19.59	34.96, 60.25	7.88, 22.99	35.28, 69.75	6.23, 22.16	38.56, 69.77

t1, initial baseline measurement; t2, measurement after 2 hrs of repetition and t3, measurement after 4 hrs of repetition; F, fast music score; S, slow music score.

slow dividing the measurements from the fast and slow scores), and a factor Reps for repetitions with three levels (level 1, 2, and 3 as above). 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 pairwise comparisons, the Bonferroni correction was used.

Effect size was calculated by means of partial eta squared (η_p^2). For the statistical analysis of the power distribution over the frequency bands, a two-way RM-ANOVA with factors Type and Reps was with one-dimensional statistical parametric mapping (SPM) (Pataky, 2012).[12] SPM calculates F-statistics for the main effects of Type and Reps and the Type*Reps interaction at each frequency band just as classical zero-dimensional statistics, but the inference is performed not at each band separately but for the complete spectrum at once, which implicitly takes the correlation between different bands into account. The significance level for the inferential statistical analysis was set at 5%.

TABLE 4. 2-Way RM-ANOVA Output for the Factors Repetitions and Type of the Amplitude Variables (in %MVC) of the Music Score Performances

	Factor	Mauchley *p*	*F*	*p*	Partial Eta²	Observed Power
Mean	Reps	0.264	3.795	0.042	0.297	0.744
	Type		47.486	0.000	0.841	1.000
	Reps*Type	0.777	2.455	0.114	0.214	0.571
Cutoff 10%MVC	Reps	0.743	3.661	0.046	0.289	0.730
	Type		17.337	0.002	0.658	0.985
	Reps*Type	0.389	2.584	0.103	0.223	0.591
Cutoff 20%MVC	Reps	0.255	3.144	0.067	0.259	0.668
	Type		34.537	0.000	0.793	1.000
	Reps*Type	0.769	2.796	0.088	0.237	0.681
Percentile10	Reps	0.002	0.015	0.929	0.002	0.102
	Type		25.890	0.001	0.742	0.999
	Reps*Type	0.025	2.290	0.152	0.203	0.459
Percentile20	Reps	0.080	0.608	0.555	0.063	0.226
	Type		38.214	0.000	0.809	1.000
	Reps*Type	0.073	3.990	0.053	0.307	0.763
Percentile80	Reps	0.270	4.709	0.023	0.343	0.825
	Type		50.480	0.000	0.849	1.000
	Reps*Type	0.542	2.926	0.079	0.245	0.640
Percentile90	Reps	0.107	0.073	0.930	0.008	0.115
	Type		40.356	0.000	0.818	1.000
	Reps*Type	0.006	0.535	0.602	0.055	0.208

Reps, repetitions; Type, fast or slow type of music score; Reps*Type, interaction between Reps and Type. Degrees of freedom for Reps = 2, Type = 1, Reps*Type = 2. Reps level 1 = first measurement, 2 =second and 3 = third; for Type level 1 = fast and level 2 = slow.

TABLE 5. Mean (SD) of the Frequency Band Power (FBP) of the Frequency Bands (in %) for the Different Music Score Performances

	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	271.50	330.63
Frequency band	9.77	15.63	21.48	27.34	35.16	41.02	46.88	52.73	58.59	66.41
F1	0.03 (0.01)	1.22 (0.31)	9.49 (1.68)	23.67 (2.41)	33.53 (0.91)	26.82 (2.93)	5.10 (1.00)	0.14 (0.04)	0.00 (0.00)	0.00 (0.00)
F2	0.03 (0.01)	1.25 (0.34)	9.77 (1.67)	23.89 (2.18)	33.21 (0.97)	26.75 (2.78)	4.96 (0.81)	0.14 (0.03)	0.00 (0.00)	0.00 (0.00)
F3	0.04 (0.01)	1.29 (0.32)	9.70 (1.63)	24.01 (2.58)	33.79 (1.32)	26.21 (2.97)	4.81 (0.06)	0.14 (0.04)	0.00 (0.00)	0.00 (0.00)
S1	0.03 (0.01)	1.25 (0.23)	9.55 (1.31)	23.00 (2.30)	33.22 (0.96)	27.36 (2.59)	5.42 (0.83)	0.17 (0.04)	0.00 (0.00)	0.00 (0.00)
S2	0.04 (0.01)	1.36 (0.30)	10.16 (1.62)	23.92 (2.36)	33.37 (0.99)	25.95 (3.34)	5.05 (1.17)	0.15 (0.05)	0.00 (0.00)	0.00 (0.00)
S3	0.04 (0.01)	1.40 (0.31)	10.36 (1.55)	23.98 (2.40)	32.86 (0.88)	26.08 (3.05)	5.12 (1.05)	0.16 (0.05)	0.00 (0.00)	0.00 (0.00)

F, fast score of piano play; S, slow score of piano play; 1, baseline measurement; 2, measurement after 2 hrs of rehearsal time; and 3, measurement after 4 hrs of rehearsal time.

RESULTS

EMG Amplitude

The descriptive statistics on the Mean, percentiles (P) and cut-off scores (Cutoff) of the normalized amplitude data (in %MVC) for the different levels of piano playing within the factors Type and Reps are presented in Table 3. No significant interaction between Type and Reps was observed for the Mean (p=0.114), P10 (p=0.152), P20 (p=0.053), P80 (p=0.079), and P90 (p=0.602), and Cutoff10 (p=0.103) and Cutoff20 (p=0.088).

The Mean, percentiles (P), and cut-off scores (Cutoff) of the relative amplitudes (in %MVC) for the different levels of piano playing within the factors Type and Reps are presented in Table 3. The two-way RM-ANOVA Output for the factor repetitions and type of amplitude variables (in %MVC) of the music score performances are presented in Table 4.

Fast vs Slow Repertoire

Mean presented a significant main effect of Type (p<0.001) with an increase of 13.780 %MVC (95% confidence intervals [95%CI] 9.256, 18.303) from a marginal mean of 22.041 %MVC (95%CI 18.026, 26.056) for the slow scores to 35.820 %MVC (95%CI 31.063, 40.578) for the fast scores. A significant effect was presented for Reps (p=0.042).

Post hoc pairwise comparisons indicated a significant (p=0.032) but small decrease of 1.891%MVC between the initial and third measurement (95%CI 0.207, 3.575).

Cutoff10 presented a significant (p=0.002) decrease of 13.310% (95%CI 6.079, 20.541) from the marginal mean of 16.150% for the slow scores (95%CI 8.853, 23.448) to 2.841% for the fast scores (95%CI 0.388, 5.293).

For Cutoff20, a significant (p<0.001) decrease of 37.083% was observed (95%CI 22.809, 51.357) from a marginal mean of 51.282% for the slow scores (95%CI 36.296, 66.278) to 14.199% for the fast scores (95%CI 7.091, 21.306).

P10 differed significantly (p<0.001) with 9.781%MVC (95%CI 6.257, 13.305) between fast (marginal mean 18.647%MVC; 95%CI 14.777, 22.517) and slow scores (marginal mean 8.866%MVC; 95%CI 7.048, 10.683).

For P20, a significant (p<0.001) difference of 9.973% MVC (95%CI 7.016, 12.931) was found between fast (marginal mean 23.602%MVC; 95%CI 19.975, 27.229) and slow scores (marginal mean 13.629%MVC; 95%CI 711.668, 15.591).

P80 showed a significant (p=0.023) difference of 16.307%MVC (95%CI 12.100, 20.514) between fast (marginal mean 46.420%MVC; 95%CI 41.259, 51.581) and slow scores (marginal mean 30.113%MVC; 95%CI 24.880, 35.345).

P90 presented a significant (p<0.001) difference of 17.576% MVC (95%CI 11.318, 23.835) between fast (marginal mean 53.429%MVC; 95%CI 46.926, 59.931) and slow scores (marginal mean 35.852%MVC; 95%CI 27.411, 44.293).

Changes After 2 and 4 Hours of Rehearsal Time

Mean presented a significant main effect for Reps (p=0.042). Post hoc pairwise comparisons indicated a significant (p=0.032) but small decrease of 1.891%MVC (95%CI 0.207, 3.575) between baseline (30.23%MVC, 95%CI 26.40, 34.046) and after 4 hrs of rehearsal time (marginal mean 28.34%MVC, 95%CI, 24.65, 32.04).

P80 presented a significant (p<0.001) main effect of Reps. Pairwise comparisons demonstrated a small significant (p=0.011) decrease of 2.699%MVC (95%CI 0.416, 4.981) between baseline (40.05%MVC, 95%CI 34.17, 45.93) and after 2 hrs of rehearsal time (37.35%MVC, 95%CI 31.09, 43.62).

For Cutoff10, Reps presented a significant main effect (p=0.046). Pairwise comparisons demonstrated a small significant (p=0.043) increase of 2.617% (95%CI 0.579, 4.656) between baseline (7.76%, 95%CI 4.39, 11.13) and after 2 hrs of rehearsal time (marginal mean 10.38, 95%CI 5.43, 15.33). No significant main Reps effects could be demonstrated for Cutoff20 (p=0.067), P10 (p=0.929), P20 (p=0.555), and P90 (p=0.930)

Frequency Analysis

The mean and standard deviations (SD) of the FBPs for the different music score performances are presented in Table 5. For all repeated measures and for both scores, the highest FBP was observed in wavelet 4 (central frequency 92.36 Hz) (Table 5). Wavelets 3–5 (62.09–128.48 Hz) contained more than 83.6±0.4 % of sEMG power in all subjects and on all occasions, 98.5±0.07% between wavelets 2–6 (Table 5).

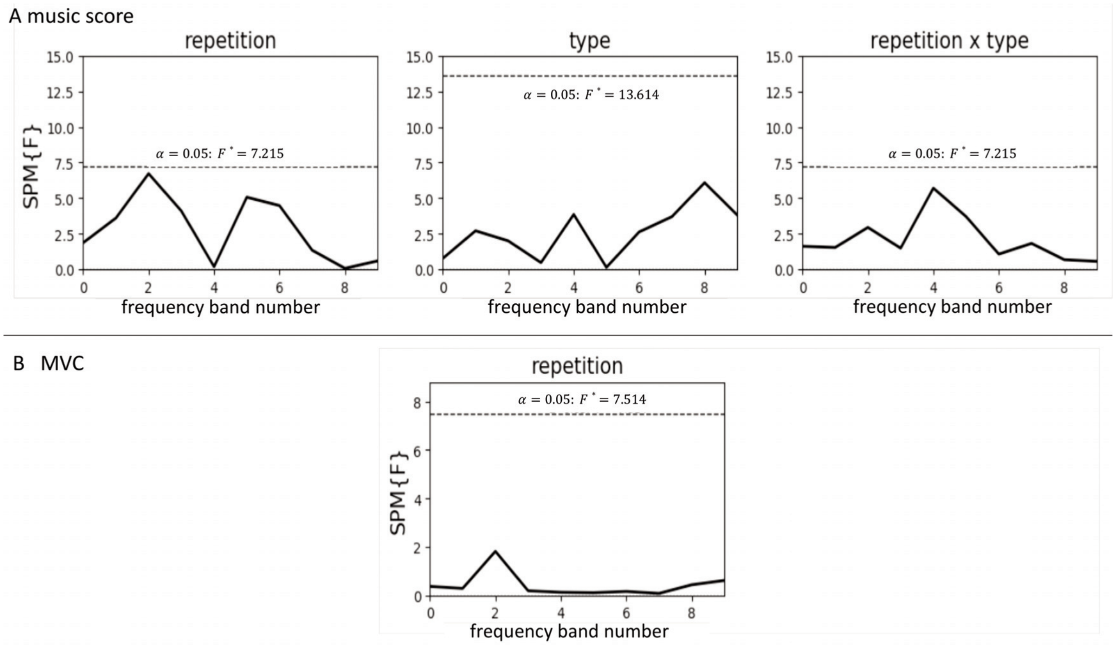

FIGURE 2. SPM analysis of the power spectrum of the frequency bands: **A**, The top panels depict the output of the SPM 2-way repeated measures ANOVA for the FBPs between fast and slow type of piano play at baseline and after 2 and 4 hrs of rehearsal. (Left and middle panels show main effects of repetition and type, and right panel shows repetition x type interaction effect.) **B**, In the bottom panel, SPM one-way repeated measures ANOVA for the MVC FBPs at baseline and after 2 and 4 hrs of rehearsal time. (SPM, statistical parametric mapping; SPM(F), F-score within the ANOVA analyses; F*, critical F-value; FBP, frequency band power; MVC, maximal voluntary contraction.)

SPM evaluation of the frequency bands did not present a significant interaction between the two factors Reps and Type (Fig. 2A, Rep × Type). SPM evaluation of the frequency bands could not reveal a significant main effect of Reps (Fig. 2A: Reps), nor a main effect for the factor Type. No significant change could be demonstrated by means of SPM within the dispersion of the frequencies of the MVC data at baseline, after the first 2 hrs of rehearsal time, and again after 4 hrs of rehearsal time (Fig. 2B).

DISCUSSION

In this study, the level of activity of the ECR as measured by sEMG presented with a mean amplitude of 23%MVC for the slow scores which increased to 36%MVC for the fast scores. Oikawa et al. (2011)[13] examined the ECR in pianists playing an octave 10 times with *staccato* touches of the right thumb and little finger at 60 beats/min (bpm), conducted in nine random sequences of playing that combined three wrist positions and three levels of loudness. The muscle activity of the ECR was the smallest in the neutral wrist position and increased from 38.0±19.8 to 45.6±23.8 %MVC with augmentation in loudness from *pianissimo* to *fortissimo*. In this study, the level of activity of the ECR of fast piano play was similar to the *pianissimo* data in the study of Oikawa et al. Playing louder requires additional muscle output (Oikawa et al.) as does playing faster (the present study).

Critical thresholds for local muscle fatigue vary with training and disease status but typically occur at 15%MVC for sustained isometric contractions and 30-40% for intermittent isometric contraction protocol.[14] In this study, fatigue could not be demonstrated following 2 and/or 4 hrs of rehearsals in terms of shift to the lower bands in the frequency domain or increase of amplitude in sEMG signal. The students evaluated the intensity of rehearsals daily, with a moderate VAS score of 5 or 6. Though small, a significant decrease in amplitude could be demonstrated for the factor Reps between the baseline Mean and after 4 hrs of rehearsal time, which may suggest concurrent optimization of function or complementary muscle loading. These findings may indicate that activity of the ECR during the rehearsals were held at a physiological steady state.

Sakai (2002)[4] reported an association between time spent playing and PRMDs of the wrist and elbow. Pianists can be compared with computer keyboard workers with long hours of rehearsals and performances on low-level muscle activity of the ECR. LE is also a known burden in computer workers.[15] Szeto (2000)[16] presented for standard keyboard activity a mean of 8.1 4±5.7%MVC. Hansson et al. (2009[17] demonstrated for repetitive office work the muscular rest time (defined as <5%MVC) below 5%, a P90 of below 20%MVC. As compared to these data on computer workers, the EMG data for the ECR's amplitude in this study presented values which were higher. In the present study, P10 presented a marginal mean value of 19%MVC for the fast type and 9%MVC for the slow type of piano playing. P20 was 24%MVC for the fast type and 14%MVC for the slow type, and as mentioned above, a Mean amplitude of 23%MVC for the slow scores and 36%MVC for the fast scores.

Decreased intramuscular blood flow has been proven to be associated with the symptoms of epicondylitis.[8] Together with the relationship between the occurrence of PRMD and practice hours and the negative relationship between the presence of PRMD and the habit of taking breaks during practice,[6] the relative high loading of the ECR while playing the piano emphasizes the importance of the muscle oxygenation.

For the ECR, a significant reduction in muscle oxygenation during isometric contractions as low as 10%MVC has been demonstrated.[18] An increase in contraction intensity from 20 to 50%MVC has been presented to decrease the forearm blood flow with 35.0±1.1% in male and 11.3±0.4% in female.[19] The Cutoff10 in this study presented a marginal mean of 3% for the fast type and 16% for the slow type. For the fast type of performance, 85% of the EMG data were above the Cutoff 20%MVC, and for the slow type 49%. It should be accentuated that piano performance is dynamic and therefore difficult to compare with the findings of Murthy et al.[18] and Thompson et al.[19] However, with sEMG activity of the ECR being larger than that in computer workers, further research on blood flow and oxygenation of the forearm muscles during piano performance may be of value.

The students evaluated the intensity of rehearsals daily, with a moderate VAS score of 5 or 6. Despite the relatively high activation of the ECR, the data in this study presented no increase in amplitude nor a shift in the frequency distribution of the EMG signal towards lower frequency bands as a response to the long rehearsal of 4 hrs, indicative that no local fatigue was apparent. A similar finding has been demonstrated by Bandeira et al. (2009)[20] by which an induced ischemia caused a significant reduction in the strength of the wrist extensors without significant changes in the RMS amplitude parameter or median frequency.

The pianists could choose a fast and slow music score out of their repertoire. The characteristics of the individual's repertoire may partially explain the differences in amplitude between the individuals (cfr. 95%CI for global mean scores between 18.79 and 25.29 %MVC for the slow scores and between 31.965 and 39.675 %MVC for the fast scores). Privacy reasons did not allow us to proceed into a discussion on this topic. Future research should include the individual's repertoire as an independent factor.

Together with the relationship between the occurrence of PRMDs and practice hours and the negative relationship between the presence of PRMDs and the habit of taking breaks during practice,[6] the relative high loading of the ECR while playing the piano as compared to computer workers suggests the importance of muscle oxygenation. Future research should examine the effect of posture and performance anxiety on loading of the ECR and its oxygenation. For instance, thoracic inlet reduction due to forward displacement of the head and shoulder girdle in combination with scapular protraction may result in compression of the brachial plexus, resulting in distal influence of edema, fibrosis, and temperature changes.[21] Furthermore, in pianists, music performance anxiety (MPA) has an estimated immediate increasing impact between 15 to 20% on the tension of pianists' muscles.[22,23]

Conclusion

The type of piano playing presented an effect on the activation of the ECR with a mean of 23%MVC for the slow scores and 36%MVC for the fast scores. These data accentuated that the loading of the ECR (as reflected in the amplitude component) was higher than that for computer workers (Visual Display Unit VDU) for which mean activation of the ECR has been demonstrated to be around 10%MVC. Consequently, as compared to the development of PRMDs in context of computer work, the augmented loading of the ECR may be a factor in the development of PRMDs in pianists.

The *études* were evaluated as moderate on the pianists' daily routine. The sEMG measurements at baseline and after 4 hrs of *études* revealed a significant though small decrease in amplitude and no shift in frequency, which may indicate that the rehearsals were held at a physiological steady-state and suggesting optimization or complementary muscle loading. The analysis presented differences in amplitude between the individuals which may be related to their specific repertoire. Therefore, future research should examine the specific repertoire as an independent factor besides other factors which may influence the muscle activity such as performance anxiety or technical difficulty level. Future research should also concentrate on the impact of this relatively high loading of the ECR in context of blood flow to tendon and muscle as related to LE.

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