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Fatigue-induced changes in tremor caused by physical efforts of different volume and intensity

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The aim of the study was to compare the changes in tremor after two exercises. Twelve male kayakers and seventeen male PE students participated in the study. The kayakers performed a specific kayak ergometer test. The students performed bilateral elbow flexion/extension with a barbell. Tremor was measured accelerometrically pre-exercise and then 10 and 30 min after the last bout. The tremor spectra were computed for each subject. Fatigue evoked in both tests brought about dramatic increases in tremor amplitude. The changes observed after strength training were greater but recovered faster than those after ergometer test.

1. Introduction

In several studies, fatigue has been recognised as a factor influencing characteristics of physiological tremor (Arblaster et al. [1], Viitasalo and Gajewski [14], Gandevia [5], Hunter et al. [6], Morrison et al. [10]). A temporary decrease in tremor amplitude just after strong brief effort is followed by its gradual increase above a pre-fatigue level (Arblaster et al. [1]). The maximal tremor amplitude is observed between the 10th and the 15th minutes of recovery after strength exercise (Gajewski et al. [4]). The enhanced amplitude can then last even for several hours after physical effort performed (Lippold [8]). The above mentioned increase especially concerns tremor spectral components occupying the range of 10–20 Hz (Viitasalo and Gajewski [14]). An increase in tremor amplitude during fatigue occurs only in the muscle groups involved in the effort performed (Furness et al. [2]). The central nervous system (CNS) is suggested to play the main role in this phenomenon. Fatigue of muscle does not simply reside in muscle itself (Gandevia [5]). However, delayed and prolonged increase in tremor log-amplitude can also be attributed to acute changes in potassium concentration in muscle cells (Sejersted et al.

[11], Lakie et al. [9]) acting on force generation mechanism. Furness et al. [2] concluded that the magnitude of the tremor increase seems to depend on the amount of the "effort" exerted by subject rather than his actual performance in lifting the weight. Biochemical responses to physical efforts depend much on the volume and intensity of the exercise performed. The aim of the study was to compare the changes in tremor spectrum after two exercises differing in volume, intensity and biochemical response. The exercises compared were paddling of increasing intensity on kayak ergometer and strength training of elbow flexors.

2. Methods

Twelve male kayakers, members of the Polish National Team (group A), and seventeen male physical education students (group B) participated in the study. Their age, body mass and height are given in the table.

Table. Characteristics of the tested groups: A ($n = 12$) and B ($n = 17$)

	Body mass [kg]	Body height [cm]	Age [years]
Mean±SD	89.0± 7.0 (A) 77.2± 8.2 (B)	184.7±4.4 (A) 186.3±8.6 (B)	23.4±3.3 (A) 21.8±4.8 (B)
Range	82–105 (A) 64–89 (B)	178–191 (A) 164–195 (B)	19–29 (A) 21–42 (B)

The kayakers, members of the group A, performed a specific test on the kayak ergometer (Larsson et al. 1988). The test consisted of three four-minute submaximal trials and trials of increasing intensity (45, 55 and 65% of averaged maximal intensity estimated during previous test) performed with one-minute break in between. After next four minutes athletes performed the four-minute maximal trial.

The students (group B) took part in two measurement sessions with one week in between. They performed bilateral, dynamic elbow flexions using free-moving barbell. The exercise was performed in a sitting position on a special training device which supported the subject's upper arms and chest. During the first measurement session individual values of 1 RM were estimated. At the time of the second measurement session a subject performed a standardized warm-up followed by four sets of the exercise (with two-minute recovery in between). During each set a subject performed as many repetitions as possible. A training load of 85% of the individually obtained 1 RM was used.

In both groups, capillary blood samples were taken four minutes after the last effort. Lactate accumulation was estimated using the Boehringer–Mannheim measurement set. Tremor was measured accelerometrically before the exercise session and then 10 and 30 minutes after the last effort performed. Tremor measurements were carried out in a sitting position using a piezoelectric accelerometer (RFT – group A, Brüel & Kjær – group B) fixed to the cuff placed on the subject's wrist. The vertical component of forearm acceleration was measured and digitized during 30.7 s at the sampling frequency of 64 Hz and 200 Hz for group A and B, respectively. A subject flexed his left forearm against a spring and tried to keep his forearm horizontally. The spring was fixed, via a rigid chain and a force transducer, between the floor and the cuff, so that when the subject reached the desired force level (30 N) his forearm was horizontally aligned. Power spectrum density (*PSD*) function was estimated for each acceleration signal using Fast Fourier Transform procedure. Since values of the *PSD* function were found as log-normally distributed along the frequency domain (Gajewski et al. [3]), the ln*PSD*(f) functions were analysed. The analysis concerned the increases in log-power (comparing to pre-exercise values) as a function of frequency. The significance of tremor log-power increases in each group was evaluated by Student's t-functions computed along the frequency domain:

$$t(f) = \frac{\overline{\Delta \ln PSD(f)}}{s_{\Delta}(f)}\sqrt{n}\,,$$

where: $\overline{\Delta \ln PSD(f)}$ – the mean increases in log-power spectrum as a function of frequency f, s_{Δ} – the standard deviations of ln*PSD*(f) increases, n – the number of subjects.

In order to study in more detail the changes in tremor amplitude at the higher frequencies, the logarithmic index of amplitude λ was used (Gajewski et al. [4]). The logarithmic index of amplitude was calculated for each acceleration course registered. The index λ was defined as mean value of ln*PSD*(f) in the range from 10 to 20 Hz. Thus λ reflects the "log-amplitude" of the tremor components which are most sensitive to fatigue (Viitasalo and Gajewski [14]). A difference between λ measured after the exercise session and under pre-fatigue conditions ($\Delta\lambda$) was utilised as quantitative measure of the system reaction related to the local fatigue caused by the exercise performed. As a relative measure the $\Delta\lambda$ did not depend on sampling frequency. The way of the $\Delta\lambda$ processing is presented in figure 1. Variables' distributions were assessed using Shapiro–Wilk's test. The comparison of mean values of $\Delta\lambda$ in both groups in the 10th and the 30th minutes of recovery was done using ANOVA for repeated measures. Other comparisons were done using nonparametric Mann–Whitney's U-test or Friedman's ANOVA.

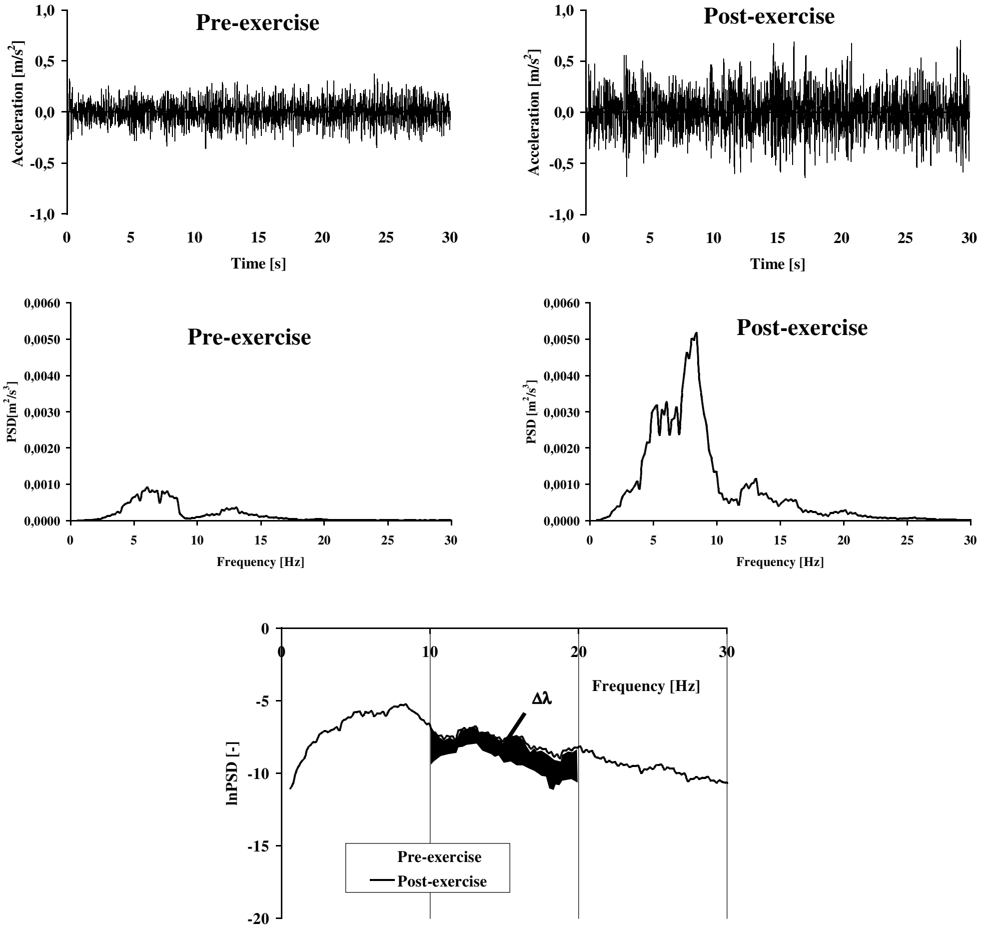

Fig. 1. The way of the $\Delta\lambda$ processing: the tremor spectra are processed using FFT procedure based on pre- and post-exercise acceleration series; the $\Delta\lambda$ is defined as an averaged difference of the log-spectra in the frequency range from 10 to 20 Hz (the square between curves)

3. Results

The kayakers (group A) when paddling on kayak ergometer developed an average power of 3.35±0.25 W/kg of body mass during their maximal bout. Their heart rate reached 191.2±6.5 bps. The students (group B) exercising with load of 85% 1 RM performed 9.5±3.9, 7.4±2.6, 6.5±2.6 and 5.4±2.8 repetitions in subsequent sets, respectively. A gradual decrease in the number of repetition was confirmed by Friedman's ANOVA ($\chi^2 = 37.9$, $p < 0.001$) indicating a growing fatigue.

The exercises evoked completely different biochemical response: lactate density in kayakers amounted to 13.32±2.41 mmol/dm^3, while its value in students was 4.61±1.15 mmol/dm^3. The difference was highly significant (*U*-Mann–Whitney's test, $p < 0.001$). In both groups, the tremor amplitude considerably increased. An average increase in the tremor log-power along the frequency domain is shown in figure 2. The values $\Delta\lambda$ for kayakers were 0.94±0.94 10 min post-exercise and 1.17±0.61 30 min post-exercise. The same for students were 1.49±0.39 10 min post-exercise and 1.20±0.59 30 min post-exercise. The analysis of variance carried out on $\Delta\lambda$ values showed neither effect of a group (or exercise) factor ($F_{1,27} = 1.79$, p n.s.), nor a significant effect of repeated factor ($F_{1,27} = 0.06$, p n.s.). Nevertheless, a significant interaction between group and repeated factor was found ($F_{1,27} = 4.96$, $p < 0.05$) as the evidence of different tremor recovery pattern in both groups. Distributions of $\Delta\lambda$ were proved normal in both groups (Shapiro–Wilk's test, $p > 0.20$). In order to point out the frequency ranges of the most pronounced tremor changes, the *t*-functions for ln*PSD* increases was calculated along the frequency domain. The curves representing *t*-functions computed for both groups in the 10th and the 30th minutes after effort are shown in figure 3.

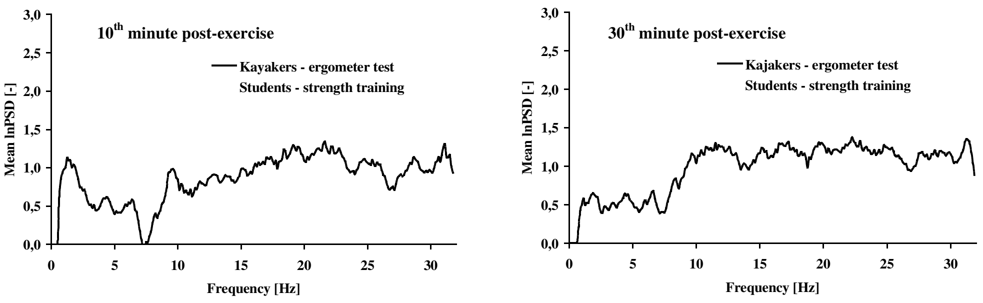

Fig. 2. Average increases in the tremor log-power along the frequency domain for both groups in the 10th and the 30th minutes after exertion

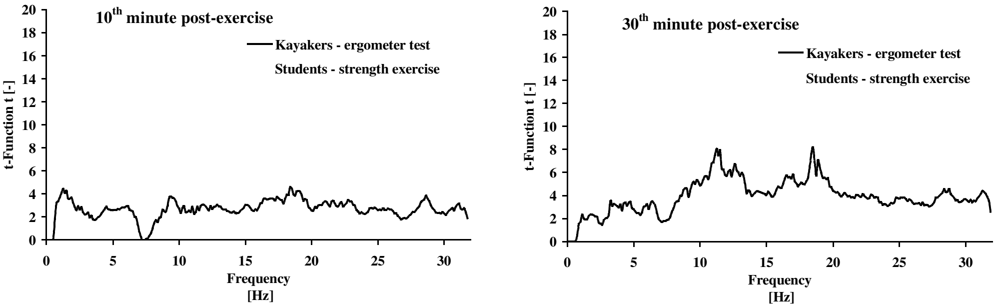

Fig. 3. *t*-Functions describing significance of the tremor log-power increases along the frequency domain for both groups in the 10th and the 30th minutes after exertion

The values *t* above 2.16 and 2.12 indicate a significant increase in the tremor log-power for kayakers and students, respectively. As is clearly seen in figure 3, 10 minutes after exertion the most pronounced post-exercise increase in log-power approaches 12 Hz for students performing strength exercise. Half an hour later tremor power is still increased (figure 2), however individual reactions are different – the *t*-function shows no distinguished maxima. For kayakers the most significant increases concern the range above 15 Hz. The maximum for ca. 18 Hz stays highly significant even half an hour after exertion.

4. Discussion

The results of the experiment showed that physical effort such as strength training or paddling with growing intensty on kayak ergometer can significantly influence tremor amplitude. This was in line with an available literature (Furness et al. [2], Jessop and Lippold [7], Lippold [8], Arblaster et al. [1], Lakie et al. [9]). The increases in tremor log-power were not equally distributed along the frequency domain, contrary to the conclusions by Furness et al. [2] and Lippold [8]. The greatest increases were found for rather low frequencies (from 2 to 4 Hz) and high frequencies (from 10 to 20 Hz). Since the first of the above-mentioned ranges could reflect the changes concerning voluntary movements, particular attention was paid to the second one. Jessop and Lippold [7] pointed to a synchronization of motor units firing as one of the possible mechanisms, which could produce fatigue-induced changes in tremor amplitude. According to Windhorst and Schwestka [15] the frequency range in which synchronization contributes to tremor is about 8–12 Hz. The range proposed, i.e. from 10 to 20 Hz, thus contains the components generated due to synchronization and this phenomenon seems to play the main role in the variability of λ observed.

The current results suggest that tremor log-amplitude is normally distributed amongst general population, which is in line with previous findings (GAJEWSKI et al. [3], VAN HILTEN et al. [13]). The logarithmic transform should be applied to the tremor amplitude or power before their statistical analysis not only for comparisons between subjects (VAN HILTEN et al. [13]), but also for intra-individual comparisons. It can be stated that for different subjects, the same (or similar) degree of fatigue induces a similar increase in tremor log-amplitude. This means an exponential increase in absolute values, which is dependent on the pre-fatigue level of amplitude.

The fatigue-induced changes in tremor amplitude are most significant at the frequency between 10 and 20 Hz. The difference between the log-powers in this frequency range ($\Delta\lambda$) is proposed as a normally distributed indicator of fatigue-induced increases in the tremor amplitude. The amplitude of tremor increases during a single strength training unit, exceeding maximum between the tenth and fifteenth minutes of recovery which was reported previously (GAJEWSKI et al. [4]). Probably the difference in biochemical response (LA concentration) between groups was responsible for the different patterns of recovery in both groups. As was suggested by LAKIE et al. [9], a delayed increase in tremor post-exercise amplitude might be caused by the shift of potassium in plasma changing its concentration in the interstitial fluid in the muscle. The present results suggest that the greater biochemical response to exercise, the longer delay in tremor increase and recovery. No signs of the tremor recovery were observed in kayakers' tremor even half an hour after ergometer test. Maximal exertion evokes not only biochemical response, dependent on energetic sources engaged, but also neural response both on the central and peripheral levels (GANDEVIA [5]). However, it seems that the effect of a central fatigue on tremor is limited by the magnitude of biochemical response to exertion. The exercises applied demanded maximal engagement of the subject. The different frequencies dominating in the tremor log-power increase can be attributed to different types of motor units utilized in both exercises.

In conclusions, it can be stated that maximal exercises of different types cause significant increase in tremor amplitude. This can be explained by both peripheral and central neural fatigues which affect postural control, changing the properties of motoneurons and neural drive. The so-called "paradox of fatigue" (TAKANOKURA et al. [12]), i.e., delayed and prolonged increase in the post-exercise tremor, can be attributed to the effect of interaction between metabolic and neural components of fatigue.

Acknowledgements

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