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Influence of upper extremity position on EMG signal measures calculated in time, frequency and time-frequency domains

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The aim of this study was to investigate the relationship between time-frequency, time and frequency measures when considering various upper extremity positions below the level of the shoulder and in trapezius as well as deltoideus muscles. During the experiment, 15 subjects performed a task that involved screwing and unscrewing a screw cap on a board in six different locations, i.e., there were six upper extremity positions. Variables were calculated in the time, frequency and time-frequency domains on a recorded EMG signal. The results showed that parameters analyzed in the time-frequency domain were more sensitive to changes in position than parameters analyzed in the frequency domain.

Key words: *upper extremity, EMG, positions, time-frequency domain*

1. Introduction

Nowadays, work efficiency and duration of work are attracting increased attention. People experience mental and physical stress in various kinds of work [1]. Some jobs require tiny movements and low forces, e.g., those of office workers; other jobs require large movements and strong forces, e.g., those of construction workers. Both can cause the development of musculoskeletal disorders. The level of the strenuousness of work and the risk of developing musculoskeletal disorders depend on the type of work [2]. That is why it is important to properly assess work-related musculoskeletal load.

It can be expected that the heavier the work load, the higher the rate of musculoskeletal disorders. Most work does not require high force exertion, e.g., at computer work stands. However, computer operators experience neck and shoulder problems [3]. The fact that they hold their neck and shoulders in the same positions for a long time is the most important risk factor that affects them. Holding the same position influences muscle load, because the contraction of the muscles depends strongly on the body posture maintained at work [4]–[6].

Musculoskeletal load can be assessed with surface electromyography (EMG). EMG is applied in the clinical area [7], rehabilitation and in studying the biomechanics in humans and animals [8]–[10]. It is used to record and evaluate the signal from skeletal muscles. A wave of an electromyogram shows if a muscle is active, relaxed or fatigued. EMG is commonly used in assessing muscle load [11], [12]. EMG can also help in distinguishing the differences in various conditions of load [4].

Assessing measures of the EMG signal from one muscle in various postures in the time and frequency domains makes it possible to establish how body posture influences muscle load during individual activities. Muscle activity is usually expressed with RMS (root mean square), MF (median frequency) and

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MPF (mean power frequency). Their values increase and decrease not only in accordance with changes in external force but also in accordance with changes in posture [13], [14]. That is especially important in considering the upper extremity, whose inadvertent movements can affect the EMG signal, thus blurring changes caused by fatigue, for example.

The upper extremity is especially vulnerable in tasks that require high accuracy in one position. *m. trapezius* and *m. deltoideus* are important in sustaining upper extremity position [15]. Therefore, the load of those muscles is important in a general assessment of the upper extremity as it is related to upper extremity positions.

The influence of upper extremity positions on the measures of the time and frequency domains has been studied previously. Niu et al. [3] considered the differences in MPF and RMS in *m. trapezius* and *m. deltoideus* in different positions. The averaged results of RMS in certain postures in a Video Display Terminals (VDT) keyboard task showed an overall increase in RMS; MPF decreased steadily when the muscles had awkward postures. Kleine et al. [13] investigated the relationship between upper extremity positions and shoulder muscles in workers at visual display units. Parameters RMS and MF described that relationship. The results showed a relationship between shoulder movements and the activity of m. trapezius in RMS; MF did not change though. Roman-Liu et al. [15], too, investigated how the positions of the upper extremity influenced parameter MPF, which could reflect muscle contraction in a precise task. The results indicated that MPF of *m. trapezius* slightly decreased, i.e., upper extremity positions barely influenced it. Veiersted et al. [16] tested *m. trapezius* during static contraction during work with a packing machine by using a number of gaps.

The studies discussed here either considered *m. trapezius* or *m. deltoideus* or used parameters only in the frequency and time domains. Lately, a method using wavelet transform in the time-frequency domain has become increasingly common [3], [10], [17]. Wavelet transform is a method of evaluating a raw EMG signal recorded from muscles. It is precise because wavelet transform has changeable window dimensions: wide in low frequencies, narrow in high frequencies [11]. That mechanism can provide better resolution and results. Lauer et al. [17] used wavelet transform to process EMG data to analyze children's gait. Hussain and Mamun [18] used wavelet transform to analyze the EMG signal to detect muscle fatigue. According to Hussain et al. [19], wavelet transform effectively removed interference of the EMG signal noise.

There are two kinds of wavelet transforms: continuous (CWT) and discrete (DWT). CWT makes it possible to obtain accurate results, but calculations are time-consuming. DWT is more time efficient and, at the same time, produces good results [20].

MPF obtained with CWT with db5 wavelet (CMPFdb5) and morlet wavelet (CMPFmo) can be used as measures in the time-frequency domain [20], [21]. The energy of approximations (EA) and the energy of details (ED) can be obtained with DWT.

Because wavelet analysis is finding increasingly broad applications, it is important to find out if measures of the EMG signal analyzed in the time-frequency domain are more sensitive to changes in upper extremity positions compared to the time and frequency domain measures. The aim of this study was to investigate the relationship between time-frequency, time and frequency measures when considering various upper extremity positions below the level of the shoulder and in trapezius as well as deltoideus muscles.

2. Materials and methods

2.1. Subjects

Fifteen male students of the University of Physical Education in Warsaw, Poland, took part in the experiment. They were all healthy, had no muscle pain or diseases during the past 6 months and were right-hand dominant. The Ethics Committee approved the study protocol. The subjects were informed about the nature of the experiments and signed a consent form. Table 1 presents the subjects' characteristics.

Table 1. Characteristics of subjects

No.	Subject	Age (y)	Body weight (kg)	Body height (cm)
1	MP	22	80	181
2	KT	22	79	183
3	MS	21	70	177
4	TW	22	70	183
5	TO	22	79	184
6	JP	23	85	180
7	KC	22	77	184
8	TL	20	77	182
9	GS	22	92	184
10	ML	20	73	181
11	MW	22	70	180
12	MM	21	71	182
13	KZ	22	69	176
14	PG	23	86	182
15	MD	22	80	183
Mean		21.73	77.20	181.47
Standard deviation		0.85	6.62	2.33

2.2. Experimental procedure

During the experiment, the subjects performed a task that required accuracy, in a sitting posture. It involved screwing and unscrewing a screw cap on a board in six different locations, i.e., there were six upper extremity positions (Fig. 1).

First, the subject unscrewed the cap from position 1 (P1) and screwed it on in position 2 (P2). Next, he unscrewed it from position 3 (P3) and screwed it on in position 4 (P4). Then, he unscrewed the cap from position 5 (P5) and screwed it on in position 6 (P6). Finally, he repeated the movements in reverse order.

Fig. 1. Experimental set-up

Individual positions were associated with the upper extremity positions maintained while working at a given point. Upper extremity positions were designated according to the position of the screws: P1 and P2 were closest to the subject's body, P5 and P6 most distant. Thus, the subject's upper extremity was extended more in P5 and P6 than in P1 and P2.

2.3. Measurements

Two active electrodes were stuck over the belly of each of the two muscles: *m. trapezius descendens* and *m. deltoideus anterior*. The third electrode was a reference one; it was located at a distance from the target muscle. To obtain precise results and lowest resistance, the skin was first cleaned and scrubbed to make electrode–skin resistance lower.

2.4. Equipment

The Bagnoli-16 device (Delsys, USA) was used to measure and record raw EMG signal [22], [23]. The sampling frequency of the signal was 4 kHz. The bandwidth of Bagnoli-16 ranges from 20 to 450 Hz (±10%). EMG amplification is 1000. Bandwidth roll-off was 80 dB/decade, overall noise ≤ 1.2 μV. The EMG signal was recorded with EMG Works 3.5 software and double differential surface electrodes DE-3.1 (Delsys, USA), which were used to reduce the risk of crosstalk [24]. The distance between the three electrodes was about 10 mm. The contact material of the sensor was 99.9% Ag.

2.5. Analysis of the data

On the basis of the measurements, parameters characterizing the EMG signal were calculated in the time domain (RMS), in the frequency domain (MF and MPF) and in the time-frequency domain (CMPFdb5, CMPFmo, from EA1 to EA5 and from ED1 to ED5). Parameters CMPFdb5 and CMPFmo are the MPF obtained with CWT with db5 wavelet (CMPFdb5) and morlet wavelet (CMPFmo). Each parameter was developed in Matlab (version R2009). The RMS was calculated with 1-second-long boxcar windows (4000 samples) with 50% overlap. For parameters MPF and MF, Fast Fourier transform Hanning window (4000 samples, 1 s, 50% overlap) was used. In the time-frequency domain, parameters CMPFdb5 and CMPFmo were determined by calculating the wavelet coefficient from 16 and 18 scales for db5 and morlet wavelets, respectively. Each scale represented the EMG signal in the frequency range from 19 Hz to 675 Hz (for db5) and from 20 Hz to 531 Hz (for morlet). Parameters from EA1 to EA5 were the energy of approximations in 5 levels of decomposition, obtained with DWT. Parameters from ED1 to ED5 were the energy of details in 5 levels of decomposition, also obtained with DWT. The analysis was to determine the influence of upper extremity positions on the values of those parameters. To make data comparable, the variables were normalized by dividing the values obtained at positions from P2 to P6 by the value obtained at P1. Normalized values, denoted nMPF, nMF, nRMS, etc., were analyzed statistically. Normalization reduces the influence of individual factors on the EMG signal (body fat, resistance of the skin) [23].

2.6. Statistical analysis

The statistical analysis was done with STATISTICA 9 (StatSoft). Upper extremity positions defined by P1-P6 were the independent variable. Normalized measures calculated from the EMG signal in the time, frequency and time-frequency domains were the dependent variables. The analysis of variance (ANOVA) was used to test the influence of upper extremity positions on those parameters.

The first step consisted in Levene's test to check homogeneity of variance of the parameters from *m. trapezius* and *m. deltoideus*. Levene's test is a precondition for ANOVA. Homogeneity of variance was checked to select an appropriate statistical test. If the results in Levene's test were statistically significant at $p \leq 0.05$, the Kruskal–Wallis test was used; if not, ANOVA.

3. Results

Figures 2–5 present trends of changes in parameters influenced by the position of upper extremity.

In Fig. 2, variables nRMS and nMF were more sensitive to changes in *m. deltoideus* than in *m. trapezius*. It is clear that the trends in the parameters increased steadily as the upper extremity extended from the closest P1 and P2 to the most distant P5 and P6. Conversely, parameter nMPF did not change when position changed. In *m. trapezius*, the three parameters were clearly almost flat when position changed. Data fluctuated only in P2 in *m. trapezius*.

Figure 3 shows significant differences in measures nCMPFdb5 and nCMPFmo in *m. deltoideus* in the time-frequency domain (Tables 3 and 4). The trends went down gradually when position changed from P1 to P2. For *m. trapezius* in the same situation, the two measures almost overlapped, no differences were related to upper extremity positions. Figure 4 shows the

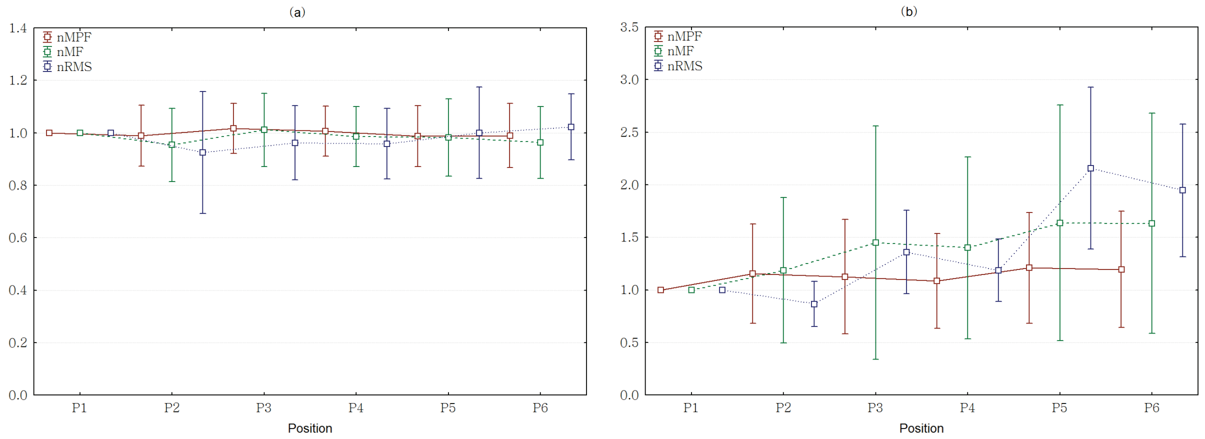

Fig. 2. Mean values and standard deviations of parameters nMPF, nMF and nRMS calculated on the basis of the EMG signal registered from (a) TR, (b) DE in six upper limb postures (P1-P6)

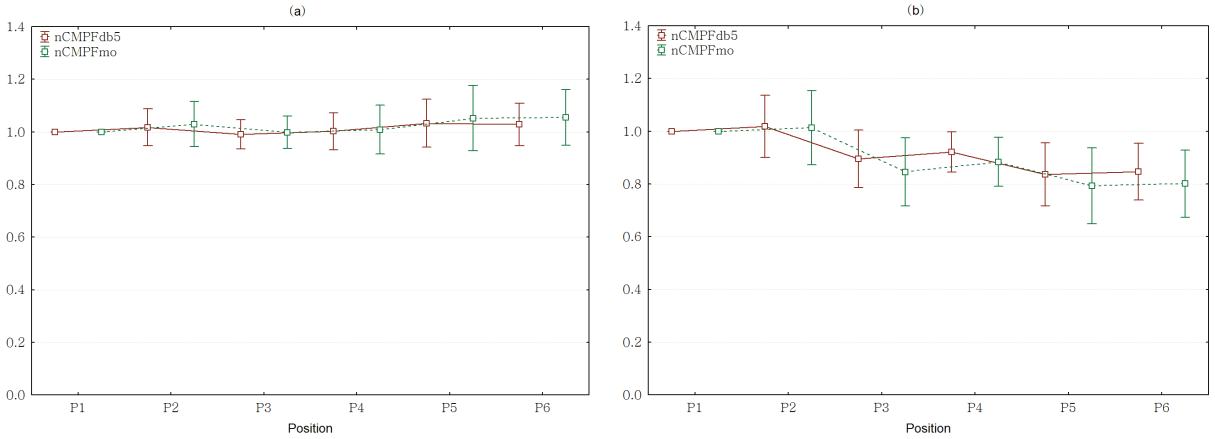

Fig. 3. Mean values and standard deviations of parameters nCMPFdb5 and nCMPFmo calculated on the basis of the EMG signal registered from (a) TR, (b) DE in six upper limb postures (P1-P6)

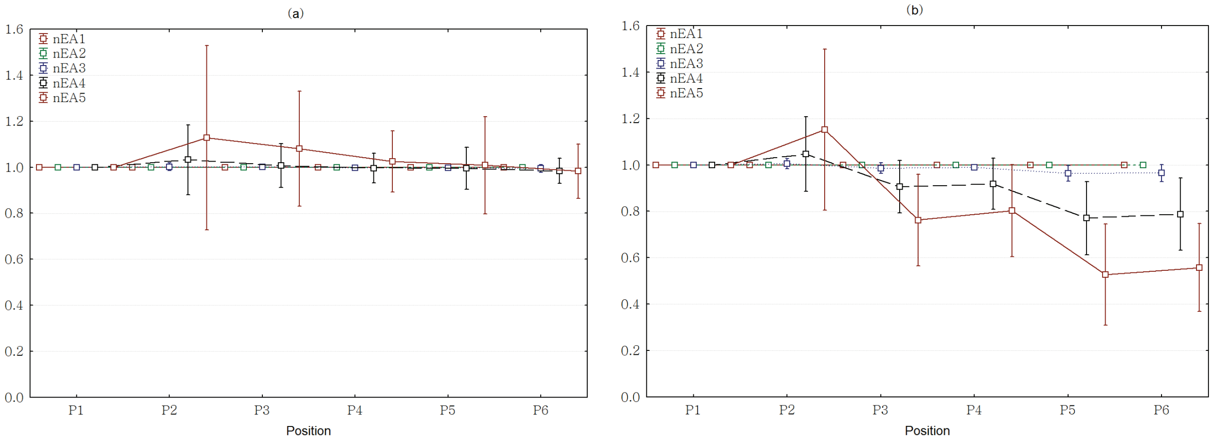

Fig. 4. Mean values and standard deviations of parameters nEA1-EA5
calculated on the basis of the EMG signal registered from (a) TR, (b) DE in six upper limb postures (P1-P6)

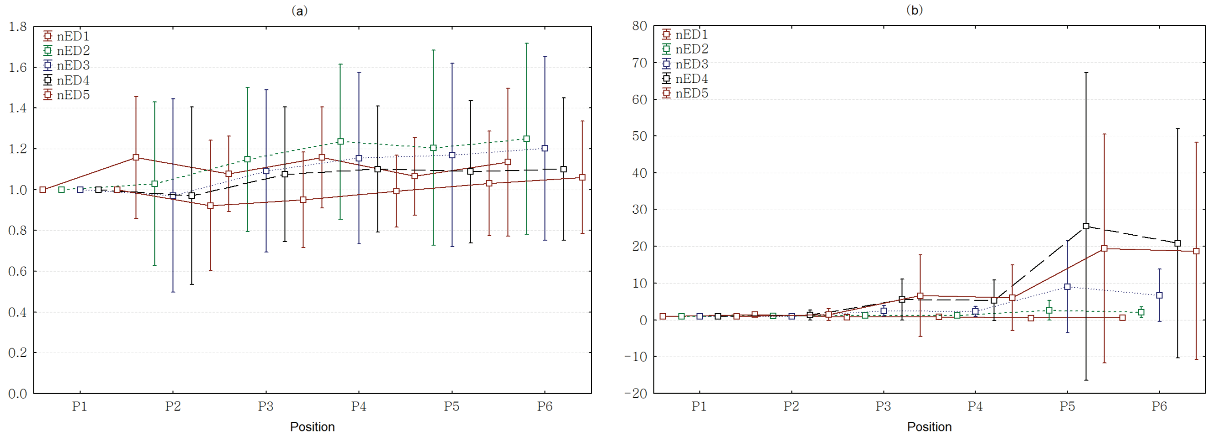

Fig. 5. Mean values and standard deviations of parameters nED1-nED5
calculated on the basis of the EMG signal registered from (a) TR, (b) DE in six upper limb postures (P1-P6)

mean values and standard deviations of parameters nEA1 and nEA2 calculated on the basis of the EMG signal recorded from *m. deltoideus* and *m. trapezius* in six upper extremity positions (P1–P6).

In the case of parameters from EA1 to EA5 calculated from *m. deltoideus*, only nEA4 and nEA5 showed a difference between upper extremity positions, while the rest of the discrete parameters had almost no visible differences (Fig. 4). In *m. trapezius*, only nEA5 fluctuated at P2 and was stable again, whereas the other measures were not sensitive to changes in upper extremity positions.

In the case of DWT of *m. deltoideus*, the last three levels of decomposition illustrate that P5 and P6 were very significant during extremity extension. Parameters of DWT in *m. trapezius* showed some differences in each position as the upper extremity moved from one position to another. However, the differences were not as significant as in *m. deltoideus* (Tables 3 and 4).

Table 2. The results of Levene's test of variance homogeneity.
Bold = results statistically significant at $p \leq 0.05$;
italics = results calculated with the Kruskal–Wallis test

Parameter	*m. deltoideus*		*m. trapezius*	
	F	*p*	*F*	*p*
nCMPFdb5	**5.95**	**<0.001**	**9.14**	**<0.001**
nCMPFmo	**5.70**	**<0.001**	**8.76**	**<0.001**
nMPF	*2.13*	*0.069*	**5.37**	**<0.001**
nMF	**2.36**	**0.046**	**5.05**	**<0.001**
nRMS	**6.30**	**<0.001**	**4.76**	**<0.001**
nEA1	**2.94**	**0.017**	**3.98**	**0.003**
nEA2	**6.20**	**<0.001**	*1.70*	*0.144*
nEA3	**6.34**	**<0.001**	*2.31*	*0.051*
nEA4	**4.22**	**0.002**	**2.56**	**0.032**
nEA5	**8.20**	**<0.001**	*2.25*	*0.057*
nED1	**11.21**	**<0.001**	**4.34**	**0.001**
nED2	**7.29**	**<0.001**	**4.28**	**0.002**
nED3	**7.82**	**<0.001**	**5.19**	**<0.001**
nED4	**7.58**	**<0.001**	**4.44**	**0.001**
nED5	**9.25**	**<0.001**	**4.11**	**0.002**

Table 2 shows the results of Levene's test; almost all parameters were statistically significant except nEA2, nEA3 and nEA5 in *m. trapezius* and nMPF in *m. deltoideus*.

Table 3. The influence of upper limb posture (P1–P6) on the values of parameters from *m. deltoideus* and *m. Trapezius* obtained with ANOVA and the Kruskal–Wallis test. Bold = results statistically significant at $p \leq 0.05$; italics = results calculated with the Kruskal–Wallis test

Parameter	Posture			
	m. deltoideus		*m. trapezius*	
	F	*p*	*F*	*p*
nCMPFdb5	**9.07**	**<0.001**	0.92	0.469
nCMPFmo	**10.19**	**<0.001**	1.25	0.292
nMPF	*1.87*	*0.867*	0.21	0.959
nMF	1.19	0.322	0.45	0.808
nRMS	**19.18**	**<0.001**	0.84	0.524
nEA1	**4.26**	**0.002**	0.55	0.739
nEA2	**3.00**	**0.008**	*5.10*	*0.404*
nEA3	**7.60**	**<0.001**	*3.18*	*0.671*
nEA4	**10.98**	**<0.001**	0.52	0.760
nEA5	**19.04**	**<0.001**	*3.67*	*0.597*
nED1	**11.34**	**<0.001**	0.99	0.427
nED2	**4.08**	**0.002**	1.17	0.328
nED3	**4.70**	**<0.001**	0.84	0.524
nED4	**3.58**	**0.005**	0.45	0.815
nED5	**2.99**	**0.015**	0.70	0.626

Table 3 shows that position had a great influence on the values of almost all parameters in *m. deltoideus* but not in *m. trapezius*.

As there were no significant differences in Table 3, it was not necessary to investigate the relationship between positions of *m. trapezius*. Meanwhile, Tables 2–4 show that there were significant differences for almost all parameters in the following positions: P1–P5, P1–P6, P2–P5 and P2–P6. This means there were significant differences in the values of those parameters between cases when the subjects performed the task in P1 or P2 and P5 or P6. The distance between those positions was longest. The results show that m. deltoideus was influenced by positions from the closest to the most distant.

The results in Table 4 also show that parameters nCMPFdb5 and nCMPFmo were the most sensitive to changes in upper extremity positions. They show differences between all upper extremity positions except P1–P2, P3–P4, P3–P5, P3–P6 and P5–P6. There were no statistically significant differences in parameters nMF and nMPF between upper extremity positions. Parameters nEA1-nEA5 and nED1-nED5 were all sensitive in P1–P5, P1–P6, P2–P5 and P2–P6. Parameters that are affected by changes in position can be useful in assessing the difference in the EMG signal in various upper extremity positions.

Table 4. Results of a post-hoc analysis of *m. deltoideus*: statistically significant changes between postures (P1, P2, etc.)

Parameter	
nCMPFdb5:	P1*P3, P1*P4, P1*P5, P1*P6, P2*P3, P2*P4, P2*P5, P2*P6, P4*P5, P4*P6
nCMPFmo:	P1*P3, P1*P4, P1*P5, P1*P6, P2*P3, P2*P4, P2*P5, P2*P6, P4*P5
nMPF:	None
nMF:	None
nRMS:	P1*P3, P1*P5, P1*P6, P2*P3, P2*P5, P2*P6, P3*P5, P3*P6
nEA1:	P1*P5, P1*P6, P2*P3, P2*P4, P2*P5, P2*P6
nEA2:	P1*P5, P1*P6, P2*P5, P2*P6, P3*P5, P3*P6, P4*P5, P4*P6
nEA3:	P1*P5, P1*P6, P2*P3, P2*P5, P2*P6, P3*P5, P3*P6, P4*P5, P4*P6
nEA4:	P1*P3, P1*P5, P1*P6, P2*P3, P2*P4, P2*P5, P2*P6, P3*P5, P3*P6, P4*P5, P4*P6
nEA5:	P1*P3, P1*P4, P1*P5, P1*P6, P2*P3, P2*P4, P2*P5, P2*P6, P3*P5, P3*P6, P4*P5, P4*P6
nED1:	P1*P2, P1*P5, P1*P6, P2*P3, P2*P4, P2*P5, P2*P6, P4*P5, P4*P6
nED2:	P1*P5, P1*P6, P2*P5, P2*P6, P3*P5, P4*P6
nED3:	P1*P5, P1*P6, P2*P5, P2*P6, P3*P5, P4*P5, P4*P6
nED4:	P1*P5, P1*P6,P2*P5, P2*P6, P3*P5, P4*P5
nED5:	P1*P5, P1*P6, P2*P5, P2*P6, P4*P5

4. Discussion

The analysis of the results demonstrates that the differences in the parameters of the EMG signal related to upper extremity positions are significant in *m. deltoideus*, but not in *m. trapezius*. There is no obvious change in the results for m. trapezius, which means that upper extremity positions do not affect the parameters of the EMG signal from *m. trapezius* when the positions of upper extremities change from ones close to the body to distant ones. The results for *m. trapezius* are important for office work. Rempel et al. [25] documented that when people did office work, muscle activity increased. However, Rempel et al. [25] assessed positions both below and above shoulder level. Other studies, too, showed there were no posture-related differences in the EMG parameters of *m. trapezius*. Christensen [26] found MPF of *m. trapezius* stayed at the same level during drilling holes in a task involving small metal components requiring upper extremity positions below shoulder level. Similarly, Larsson et al. [27] reported no change in MPF in patients with chronic trapezius myalgia during low load shoulder elevation tasks, which required the upper extremity lifted higher than shoulder level. Wærsted [28] reported that EMG activity of m. trapezius did not change during pencil and paper work and work with visual display equipment. Roman-Liu et al. [15], too, reported only slight changes in MPF for *m. trapezius*, but the distance between the hands and the body was not considered. However, Milerad and Ericson [29] showed that a precision task involving a hand held dental instrument below the shoulder level influenced the contraction of *m. trapezius*, which was reflected by a normalized mean EMG amplitude. All those results suggest that although m. trapezius is commonly considered to be an indicator of upper extremity load, its EMG signal is not sensitive to changes in upper extremity positions when that extremity is below shoulder level.

Changes in the EMG signal recorded from *m. deltoideus* are related to upper extremity positions. Results clearly show that the shorter the distance between the subject and the hand (at work stands, where operations are performed), the smaller the changes in the EMG signal. And, conversely, the farther the subjects extend their upper extremities, the more obvious the influence of upper extremity positions on the changes in EMG variables. Gopura et al. [30], too, found that when people raised the upper extremity, parameter RMS in *m. deltoideus* increased. That is in step with the results of the present study.

There was a decreasing tendency for nCMPFmo and nCMPFdb5 in *m. deltoideus* in the current study. The farther the upper extremity from the body, the lower the values of nCMPFmo and nCMPFdb5 in *m. deltoideus*. Kumar and Kumar's [31] task was similar to the one in the current experiment; the load of six different positions using mean %MVC (maximal voluntary contraction) was recorded to test the differences in using two types of computer mice.

Mamaghani et al. [32] used RMS and MPF to evaluate the four shoulder muscles, i.e., upper *m. trapezius*, *m. anterior deltoideus*, *m. biceps brachii* and *m. brachioradialis*, through elbow movement. They found that RMS increased in the four muscles at 20% MVC as the shoulder angle increased below shoulder level; whereas MPF did change significantly *in trapezius*, *deltoideus* or *m. brachioradialis*. However, in *m. biceps brachii* the differences were highly significant. In Potvin's [33] research, parameter MPF recorded on *m. biceps brachii* increased as the joint angle increased. This proves that MPF is sensitive in the activation of muscles.

Lately, wavelet transform has been widely used in analyzing the EMG signal. For example, in his study of the muscles on the back, Pope et al. [34] showed that wavelet transform improved the analysis of the EMG signal when determining muscle activity. In Hussain and Mamun's [18] study that used a treadmill, wavelet transform could express better walking activities and basic wavelet db45 was more efficient. Canal [35] used Fourier transform and wavelet transform in the same experiment and showed that the latter provided better resolution. Azzerboni et al. [36] also obtained the same results; they showed that DWT characterized arm movements with great precision. In Karlsson and Gerdle's [37] research, CWT was used to test *m. vastus lateralis* during knee extension; they found that using parameters MF based on CWT produced better statistically significant results than RMS in the time domain.

The results of the present study show that both DWT and CWT are more sensitive to upper extremity positions than nRMS, nMF and nMPF of *m. deltoideus*. That suggests that when looking for parameters documenting changes in positions, wavelet analysis can be more effective than time or frequency.

Limitations of the study are mostly related to the number of subjects. Even though all of them were male and attention had been paid to make the group homogenous, 15 may seem to be too few. However, it should also be considered that laboratory studies based on EMG measurements usually have few subjects [18], [33], [38], [39]. Therefore, it is also important to verify results by performing similar studies on different groups of people.

5. Conclusion

The results of this study indicate lack of changes in EMG parameters in *m. trapezius* when changes in upper extremity positions below shoulder level are considered. Such changes of EMG parameters can be observed in the time and time-frequency domains in *m. deltoideus anterior*. The results also show that parameters analyzed in the time-frequency domain are more sensitive to changes in positions than parameters analyzed in the frequency domain.

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References

[1] Visser B., Jaap H., Dieën V., *Pathophysiology of upper extremity muscle disorders*, J. Electromyogr. Kinesiol., 2006, Vol. 16(1), 1–16.

[2] Buckle P.W., Devereux J.J., *The nature of work-related neck and upper limb musculoskeletal disorders*, Appl. Ergon., 2002, Vol. 33(3), 207–217.

[3] Niu H., Li R., Liu G., Pu F., Li, D. Fan Y., *Using EMG to evaluate muscular fatigue induced during video display terminal keyboard use task*, 7th Asian-Pacific Conference on Medical and Biological Engineering, IFMBE Proceedings, 2008, 19, 329–332.

[4] Hostens I., Ramon H., *Assessment of muscle fatigue in low level monotonous task performance during car driving*, J. Electromyogr. Kinesiol., 2005, Vol. 15(3), 266–274.

[5] Gnitecki J.E., Kler G.P.S., Moussavi Z., *EMG signs of fatigue in anterior and posterior deltoid muscles: questioning the role of RMS during fatigue*. 2002, Retrieved from www.ee.umanitoba.ca/~moussavi/papers/CMBES02_Jan.pdf

[6] Hostens I., Seghers J., Spaepen A., Ramon H., *Validation of the wavelet spectral estimation technique in biceps brachii and brachioradialis fatigue assessment during prolonged low-level static and dynamic contractions*, J. Electromyogr. Kinesiol., 2004, Vol. 14(2), 205–215.

[7] PullmanS. L., Goodin D. S., Marquinez A. I., Tabbal S., Rubin M., *Clinical utility of surface EMG. Report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology*, Neurology, 2000, Vol. 55, 171–177.

[8] Mulas M., Folgheraiter M., Gini G., *An EMG-controlled exoskeleton for hand rehabilitation*, International Conference on Rehabilitation Robotics, 2005, 371–374.

[9] Whelan P.J., *Electromyogram recordings from freely moving animals*, Methods, 2003, Vol. 30(2), 127–141.

[10] Neto O.P., Marzullo A.C., *Wavelet transform analysis of electromyography Kung Fu strikes data*, J. Electromyogr. Kinesiol., 2008, Vol. 18(6), 1047–1052.

[11] Vannozzi G., Conforto S., D’Alessio T., *Automatic detection of surface EMG activation timing using a wavelet transform based method*, J. Electromyogr. Kinesiol., 2010, Vol. 20(4), 767–772.

[12] Jost W.H., Ecker K.W., Schimrigk K., *Surface versus needle electrodes in determination of motor conduction time to the external anal sphincter*, Int. J. Colorectal Dis., 1994, Vol. 9(4), 197–199.

[13] Kleine B.U., Schumann N.P., Bradl I., Grieshaber R., Scholle H.C., *Surface EMG of shoulder and back muscles and posture analysis in secretaries typing at visual display units*, Int. Arch. Occup. Environ. Health., 1999, Vol. 72(6), 387–394.

[14] Jiang C.F., Kuo S.L., *Comparative study of wavelet denoising of surface electromyographic signals*, Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2007, 1868–1871.

[15] Roman-Liu D., Tokarski T., Kamińska J., *Assessment of the musculoskeletal load of the trapezius and deltoid muscles during hand activity*, Int. J. Occup. Saf. Ergon., 2001, Vol. 7(2), 179–193.

[16] Veiersted K.B., Westgaard R.H., Andersen P., *Pattern of muscle activity during stereotyped work and its relation to muscle pain*, Int. Arch. Occ. Env. Hea., 1990, Vol. 62, 31–41.

[17] Lauer R.T., Stackhouse C., Shewokis P.A., Smith B.T., Orlin M., McCarthy J.J., *Assessment of wavelet analysis of gait in children with typical development and cerebral palsy*, J. Biomech., 2005, Vol. 38(6), 1351–1357.

[18] Hussain M.S., Mamun M., *Effectiveness of the wavelet transform on the surface EMG to understand the muscle fatigue during walk*, Measurement Science Review, 2012, Vol. 12(1), 28–33.

[19] Hussain M.S., Reaz M.B.I., Ibrahimy M.I., *SEMG signal processing and analysis using wavelet transform and higher order statistics to characterize muscle force*, 12th WSEAS International Conference on Systems, 2008, 22–24.

[20] Vincent J.S., Bopardikar A., Rao R., *Wavelet analysis of neuroelectric waveforms: a conceptual tutorial*, Brain Lang, 1999, Vol. 66(1), 7–60.

[21] Sobahi N.M., *Denoising of EMG signals based on wavelet transform*, Asian Transactions on Engineering, 2011, Vol. 1(5), 17–23.

[22] Roman-Liu D., Bartuzi P., *The influence of wrist posture on the time and frequency EMG signal measures of forearm muscles*, Gait Posture, 2013, Vol. 37, 340–344.

[23] Bartuzi P., Tokarski T., Roman-Liu D., *The effect of the fatty tissue on EMG signal in young women*, Acta Bioeng. Biomech., 2010, Vol. 12(2), 87–92.

[24] de Luca C.J., *The use of surface electromyography in biomechanics*, J. Appl. Biomech., 1997, Vol. 13, 135–163.

[25] Rempel P., Janowitz I., Alexandre M., Lee D.L., Rempel D., *The effect of two alternative arm supports on shoulder and upper back muscle loading during pipetting*, Work, 2011, Vol. 39, 195–200.

[26] Christensen H., *Muscle activity and fatigue in the shoulder muscles during repetitive work. An electromyographic study*, Eur. J. Appl. Physiol. Occup. Phys., 1986, Vol. 54(6), 596–601.

[27] Larsson R., *Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia*, Pain, 1999, Vol. 79(1), 45–50.

[28] Wærsted M., Westgaard R.H., *An experimental study of shoulder muscle activity and posture in a paper version versus a VDU version of a monotonous work task*, Int. J. Ind. Ergonom., 1997, Vol. 19, 175–185.

[29] Milerad E., Ericson M., *Effects of precision and force demands, grip diameter, and arm support during manual work: an electromyographic study*, Ergonomics, 1994, Vol. 37(2), 255–264.

[30] Gopura R.A.R.C., Kiguchi K., Horikawa E., *A study on human upper-limb muscles activities during daily upper-limb motions*, Int. J. Bioelectromagnetism, 2010, Vol. 12(2), 54–61.

[31] Kumar R., Kumar S., *A comparison of muscular activity involved in the use of two different types of computer mouse*, Int. J. Occup. Saf. Ergon., 2008, Vol. 14(3), 305–311.

[32] Mamaghani N.K., Shimomura Y., Iwanaga K., Tetsuo K., *Mechanomyogram and electromyogram responses of upper limb during sustained isometric fatigue with varying shoulder and elbow postures*, J. Physiol. Anthropol. Appl. Human. Sci., 2002, Vol. 21(1), 29–43.

[33] Potvin J.R., Bent L.R., *A validation of techniques using surface EMG signals from dynamic contractions to quantify*

muscle fatigue during repetitive tasks, J. Electromyogr. Kinesiol., 1997, Vol. 7(2), 131–139.

[34] POPE M.H., ALEKSIEV A., PANAGIOTACOPULOS N.D., LEE J.S., WILDER D.G., FRIESEN K., STIELAU W., GOEL V.K., *Evaluation of low back muscle surface EMG signals using wavelets*, Clin. Biomech., 2000, Vol. 15, 567–573.

[35] CANAL M.R., *Comparison of wavelet and short time Fourier transform methods in the analysis of EMG signals*, J. Med. Syst., 2010, Vol. 34(1), 91–94.

[36] AZZERBONI B., FINOCCHIO G., IPSALE M., LAFORESTA F., CARLO MORABITO F., *A new approach to detection of muscle activation by independent component analysis and wavelet transform*, Neural Nets Lecture Notes in Computer Science, 2002, Vol. 2486, 109–116.

[37] KARLSSON S., GERDLE B., *Mean frequency and signal amplitude of the surface EMG of the quadriceps muscles increase with increasing torque – a study using the continuous wavelet transform*, J. Electromyogr. Kinesiol., 2001, Vol. 11(2), 131–140.

[38] ESQUENAZI A., TALATY M., SELIKTA R., HIRAI B., *Dynamic EMG during walking as an objective measurement of lower limb orthotic alignment*, Basic Appl. Myol., 1997, Vol. 7(2), 103–110.

[39] AMARANTINI D., RAO G., BERTON E., *A two-step EMG-and-optimization process to estimate muscle force during dynamic movement*, J. Biomech., 2010, Vol. 43, 1827–1830.