

A Novel Method for Individual Age Group Determination Based on the Hand Muscle Synergy

Abstract

Background: As people get older, muscles become more synchronized and cooperate to accomplish an activity, so the main purpose of this research is to determine the relationship between changes in age and the amount of muscle synergy. The presence of muscle synergies has been long considered in the movement control as a mechanism for reducing the degree of freedom of the motor system. **Methods:** By combining these synergies, a wide range of complex movements can be produced. Muscle synergies are often extracted from the electromyogram (EMG) signal. One of the most common methods for extracting synergies is the nonnegative matrix factorization. In this research, the EMG signal is obtained from individuals from different age groups (namely 15–20 years, 25–30 years, and 35–40 years), and after preprocessing, the muscular synergies are extracted. By processing and studying these synergies. **Results:** It was observed that there is a significant difference between the muscular synergy of different age groups. Furthermore, there was a significant difference in the mean value of synergy coefficients in each group, especially in motions that were accompanied by force. **Conclusion:** This result candidates this parameter as a biomarker to differentiate and recognize the effects of age on the individual's muscular signal. In the best case, using the synergy tool, classification of the age of persons can be done by 77%.

Keywords: Age groups, electromyogram, nonnegative matrix decomposition, synergy

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Introduction

In recent years, the study on muscle synergy has been considered by many researchers and physicians, and due to the high potential, it provides for treatment of complications. However, it is not completely known how the central nervous system coordinates all the muscles involved in a particular movement. It has been suggested that muscle synergy provides the nervous system with a strategy for control of the motor system. In this regard, several different models have been presented to describe various human movements, such as standing, walking, running, and pedaling.^[1] For most scholars in the field of motor studies, the synergy term is associated with Bernstein and its famous problem of “motion redundancy.”^[2,3] Cheung *et al.* have compared the muscle synergies of a person with stroke and a healthy person while performing movements and claimed that,

since synergies are related to the spinal cord, brain damage does not change the individual's inability to perform different tasks.^[4,5] Azari Pasand *et al.* suggested that individual's inability to perform movements is related to the inappropriate stimulation factor of synergies.^[6] They postulated the electromyogram (EMG) signal as a linear combination of a number of basic vector models. The activity of the muscles is measured as the rate of ignition of the motor neurons and is limited to nonnegative values. There are, in general, different methods for testing but generally matrix-decomposition algorithms are used such as principal component analysis, independent component analysis, and nonnegative matrix factorization (NMF).^[7]

Eskandari *et al.* studied the reliability and coordination of muscle synergy during isometric trunk insertion in sagittal and transverse synergies of healthy individuals.^[8] In their study, the lumbar spine model was used in conjunction with 18 muscles. One of the limitations of this

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study is that only the equilibrium conditions have been taken into account.

The lifestyle of individuals and their physical and recreational activities may affect muscle strength. Low-antigravity muscle weakness plays an important role in losing the balance and hence injuries to people.^[9] In a study, muscle neuromuscular adaptation has been studied with age. The results indicate that the muscular nervous system in older people is influenced by the choice of fast entropy fibers and the difference in firing motor unit.^[10] Ahamed *et al.*^[11] recorded EMG from the biceps muscle to identify the age group and they concluded that, in larger time windows, the resolution of the root-mean-square (RMS) signal is increased. Of course, no synergy has been used in their study. Khayat *et al.* characterized prolonged standing and its effect on postural control in old and adult individuals and showed that the signal of the center of pressure can be studied in the chaotic domain and characteristic features can be extracted from the signal in the frequency domain and chaotic domain too.^[12]

In this study, considering the importance of balance and power in the health of the elderly, the effect of age on muscle strength on women aged 21–80 years was determined. As it was expected, the results concurred that muscle strength decreases significantly with age. According to the results, it can be predicted that as age increases and muscle strength decreases, the standing and standing balance of individuals decreases. Furthermore, a biomarker for classifying age group based on the EMG synergy is proposed.

In the following, first, data acquisition is described, and then, the proposed algorithm including signal preprocessing, synergy calculation, time segmentation, RMS extraction from time segments, and statistical analysis of the difference between the RMSs of different age groups are described.

Methods

Figure 1 shows the flowchart of the proposed method. According to this chart, first, data were acquired and preprocessed. Then, synergy was extracted and the similarity test was done. Furthermore, after time segmentation of synergies, RMS was calculated and compared in different age groups.

Data

Data used in this research were acquired from 18 women in three age groups (six people aged 15–20 years, six people aged 25–30 years, and six people aged 35–40 years). To minimize the effect of ECG interference in the records, all right-handed people were selected and the trials were done with the right hand.

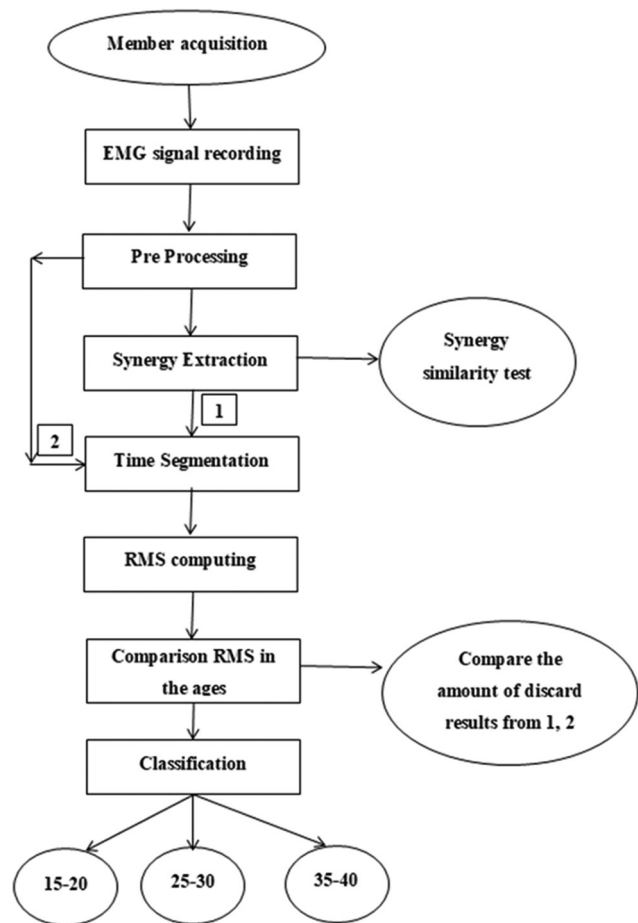


Figure 1: A flowchart of the proposed method

The Biopac-MP100 and surface electrodes were used to record surface electromyogram (SEMG) data. Bipolar SEMG electrodes were placed on the surface of the skin (with 2-cm inter-electrode distance) over the brachioradialis muscle, flexor carpi, triceps, and biceps. A ninth electrode was mounted to the opposite (nonpreferred) acromion process in the function of an “electrical common” for data recording. An elastic bandage was wrapped around the EMG electrodes to secure the devices from extraneous movement; it did not impeding muscular function or movement about the shoulder and elbow joints. An amplifier with 60 dB gain was used.^[13] Sampling frequency was set at 1000 Hz.^[14]

For each individual, the EMG signal is recorded during six activities:

1. Hand in rest
2. Biceps flexion with a weight of 2 kg
3. Biceps muscle at a maximum force
4. Triceps muscle at a maximum force
5. The flexor carpi muscle at a maximum force
6. Brachioradialis muscle at a maximum force.

Preprocessing

The initial 5 s of the signals were saved and the remaining was deleted. A fourth Butterworth bandpass filter with a cutoff frequency of 50–150 Hz was used to eliminate artifacts and noise.

Synergy extraction

Given that a four-channel EMG was recorded, a maximum of four synergies were extracted from each instance of the signal.^[1,4] A nonnegative matrix factorization (NNMF) analysis method was used to extract synergies. Given that the matrix in this method should be nonnegative, the magnitude of the signal was first calculated and then fed to the matrix analysis algorithm. Figure 2 shows the error value in terms of the number of synergies to determine the appropriate number of synergies. As can be seen, in the case of three synergies, the error has dropped to a satisfactory level, and therefore, this number of synergy was the most appropriate choice.

Then, the variance accounted for VAF is calculated using the following equation:

$$VAF_i = \left(1 - \frac{\text{var}(y_i - \hat{y}_i)}{\text{var}(y_i)} \right) \cdot 100\% \quad (1)$$

Where y is the main data, \hat{y} is extracted data of NNMF. Figure 3 shows the amount of VAF in terms of synergy to determine the appropriate number of synergies. For each data, the results of this chart were averaged over 18 subjects and 4 reconstructed outputs. As it can be seen, in the case of three synergies, the VAF has reached about 98%, and therefore, three synergies were considered.

Synergy similarity verification

To compare the synergies of various subjects, their synergies were clustered in three different categories, so that in each activity, in each cluster, only one synergy of three synergies of each subject was considered. To do this, three synergies from a random subject were selected

as the center of three clusters. Then, the synergies of the subsequent random subject were assigned to each cluster based on the distance from the cluster's center, and the center of each cluster was updated at the end of each epoch. This process was continued to the last subject.

After clustering of synergies, the similarity between the synergies of each cluster was calculated using the cosine similarity criterion, which was calculated for the two vectors X and Y as following:

$$CS = \cos(\theta) = \frac{X \cdot Y}{\|X\| \cdot \|Y\|} \quad (2)$$

Comparison of root-mean-square rates at different age ranges

The 5-s signal of each subject was divided into ten windows, and energies of each of these windows were calculated. To determine the intensity of the signal in each window, the RMS of signal is used as:

$$RMS_j = \sqrt{\frac{1}{N} \sum_{i=1}^N x_i^2} \quad (3)$$

Where j is the window number and N is the number of samples in each window. It should be noted that for comparing the performance of synergies in classification, the RMS value was calculated for both synergies and different channels.

Results

Synergy clustering results

Synergies of different individuals were clustered into three clusters, as it was described in the previous section. Figure 4 shows the average values of these similarities for different activities. As can be seen, intracluster similarity for synergy 1 and 2 was always more than 0.7, indicating that there was a high similarity between the synergies placed in these clusters.^[15]

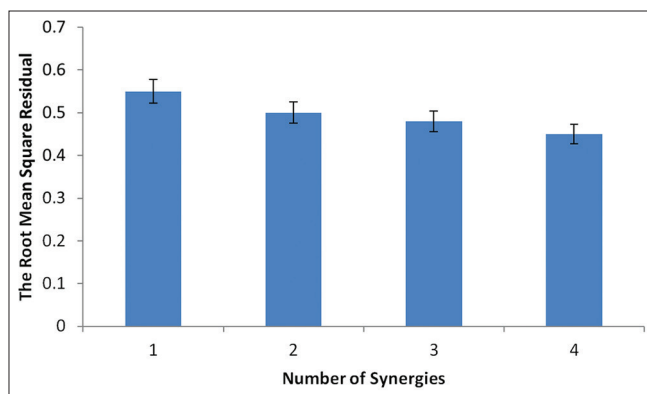


Figure 2: The variation of the error value in terms of the number of synergies

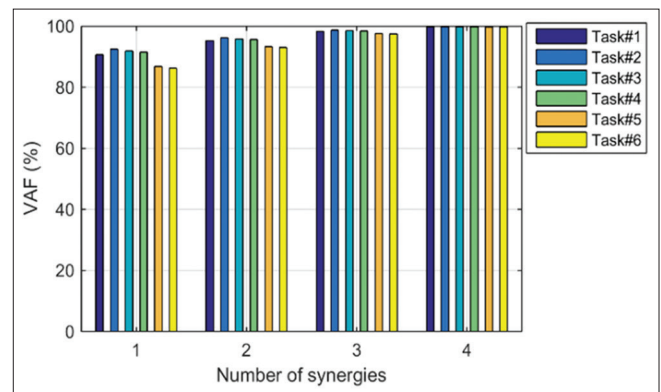


Figure 3: Changes in the amount of variance accounted for in terms of the number of synergies in different activities

Comparison of mean root-mean-squares in synergies

Using the method described in the previous section, it was observed that seventh window yielded the maximum discrepancy between the age groups. Figures 5-10 compare the dispersion values of RMSs in activities one through six in the seventh window between different age ranges. In these figures, the three upper plots represent the RMSs dispersion, and the three lower plots represent *P* values from *t*-test. As it can be seen, in the figures relating to the second, third, and sixth activities, some differences are found in the mean value of RMSs, which indicate that these activities are more appropriate than

other activities (3, 1, and 5) to distinguish between the age groups.

According to Figures 5-10, it can be concluded that the first synergy value in the second activity, the second synergy value in the third activity, and the first synergy

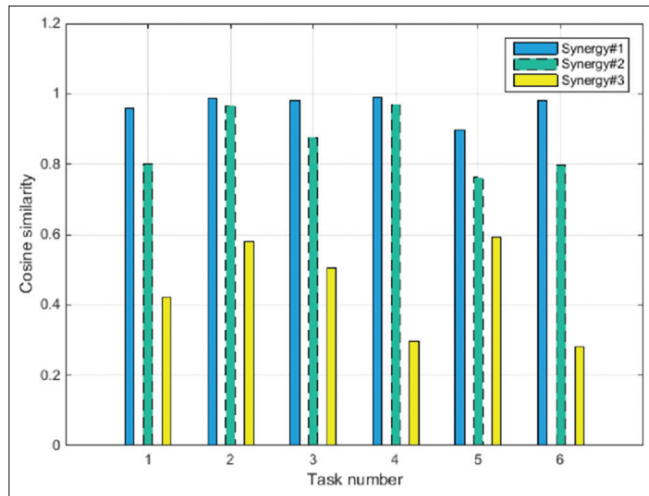


Figure 4: The average value of cosine similarity in different clusters of different activities

Table 1: Classification accuracy and precision in classifying using the rootmeansquare value of the synergy in the seventh window

Accuracy (%)	Precision (%)	<i>K</i>
77.7±1	78.8±0.5	3
77.7±0.9	79.6±1.2	4
69.4±1.7	70.5±1.8	5

Table 2: Classification accuracy in classifying using the root-mean-square value of the signal in the seventh window

Accuracy (%)	Precision (%)	<i>K</i>
44.4±1.5	46.2±1.2	3
50±1	50.0±0.9	4
37.5±1.7	40.1±1.3	5

Table 3: Classification accuracy in classifying using synergies and channel root-mean square in the seventh window

Accuracy (%)	Precision (%)	<i>K</i>
81.9±1.2	83.5±0.9	3
77.7±1.5	80.4±0.8	4
77.7±1.9	79.2±1.4	5

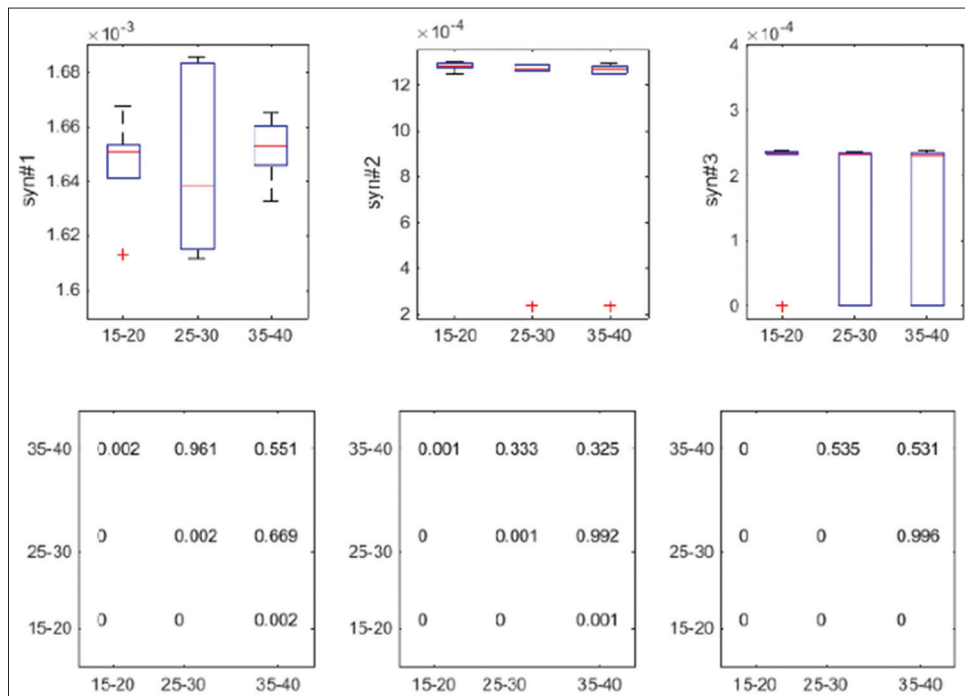


Figure 5: Dispersion of root-mean-square values of main synergies (up) and *P* values of the first activity among different age groups and in the seventh window

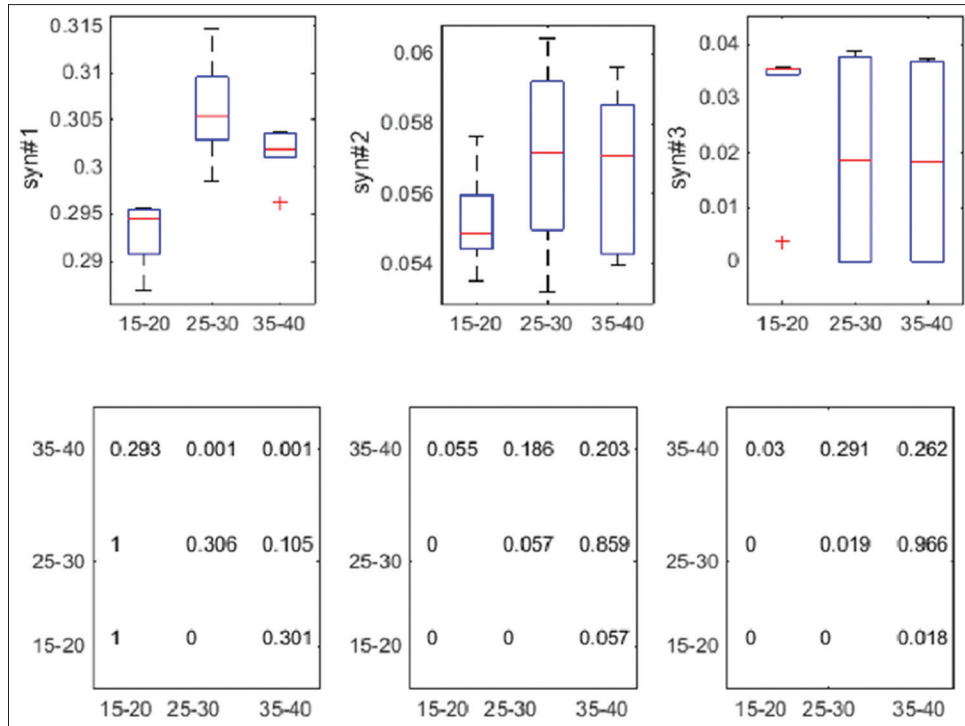


Figure 6: Dispersion of root-mean-square values of the main synergies of the second task among different age groups and in the seventh window

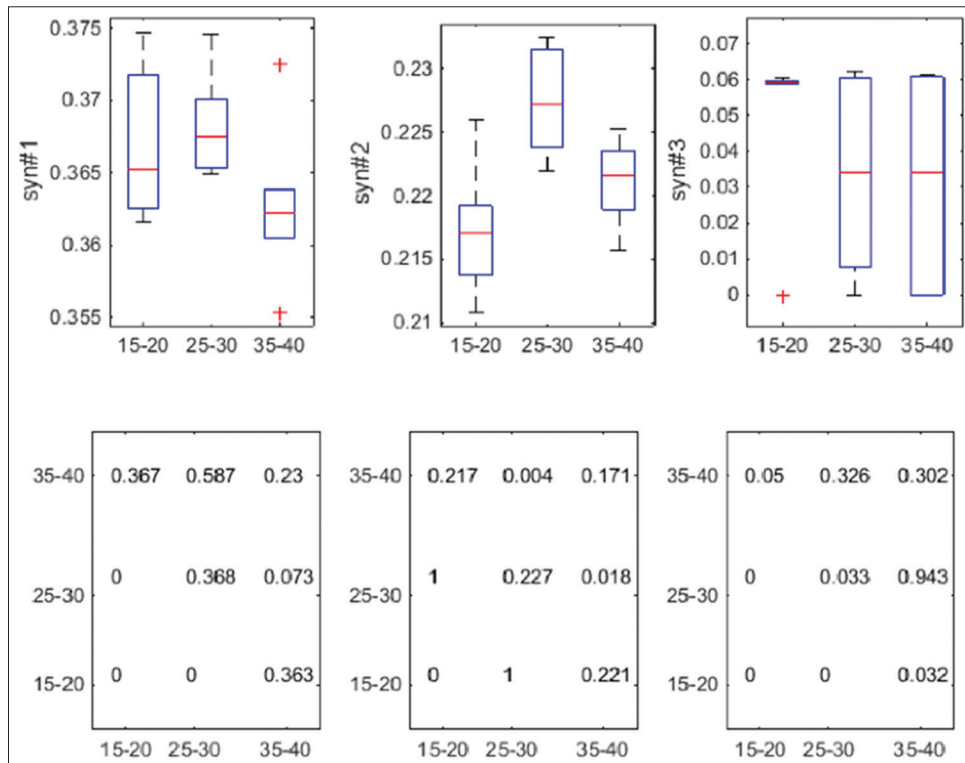


Figure 7: Dispersion of root-mean-square values of main synergies of the third task among different age groups and in the seventh window

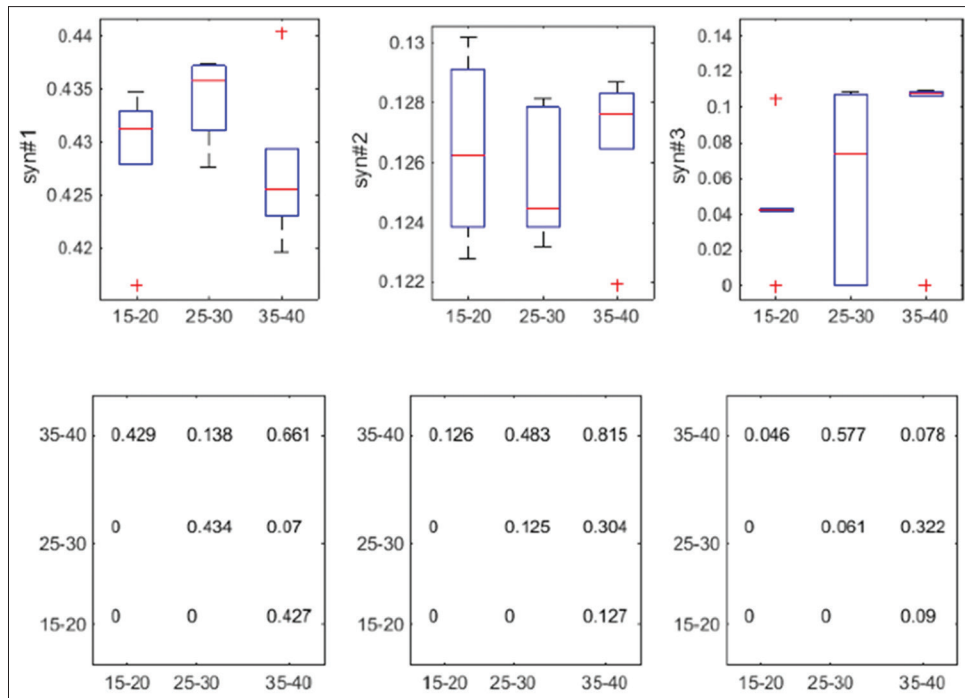


Figure 8: Dispersion of root-mean-square values of the main synergies of the fourth task among different age groups and in the seventh window

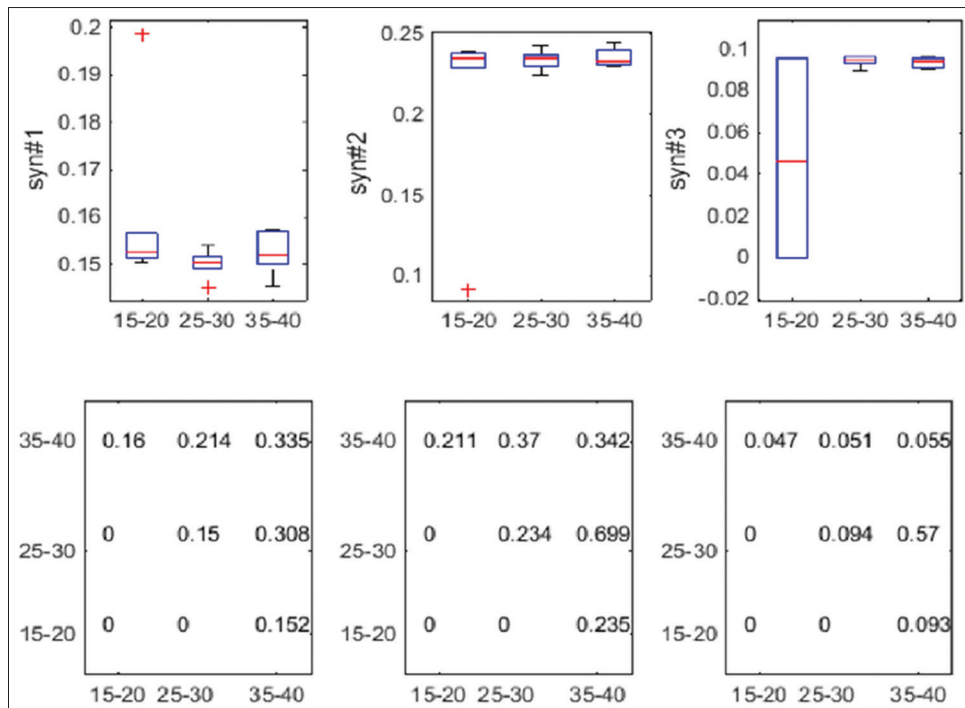


Figure 9: Dispersion of root-mean-square values of main synergies of the fifth task among different age groups and in the seventh window

value in the sixth activity can be used to identify the age ranges.

Comparison of mean channel root-mean square

RMS of each channel also was calculated to be compared with the results attained from the previous

section. Given that in the previous section it has been determined that activities 2, 3, and 6 can differentiate between different age categories, RMS calculation was performed only for these three activities. Figures 11-13 show the dispersion of the RMS values of the main

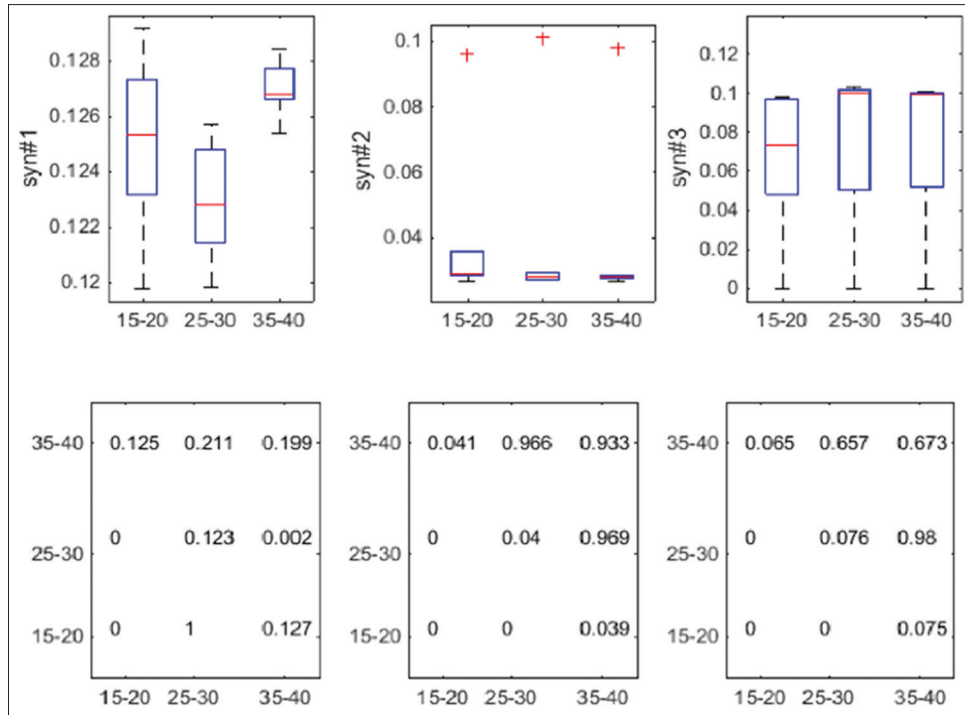


Figure 10: Dispersion of the root-mean-square values of main synergies of the sixth task among different age groups and in the seventh window

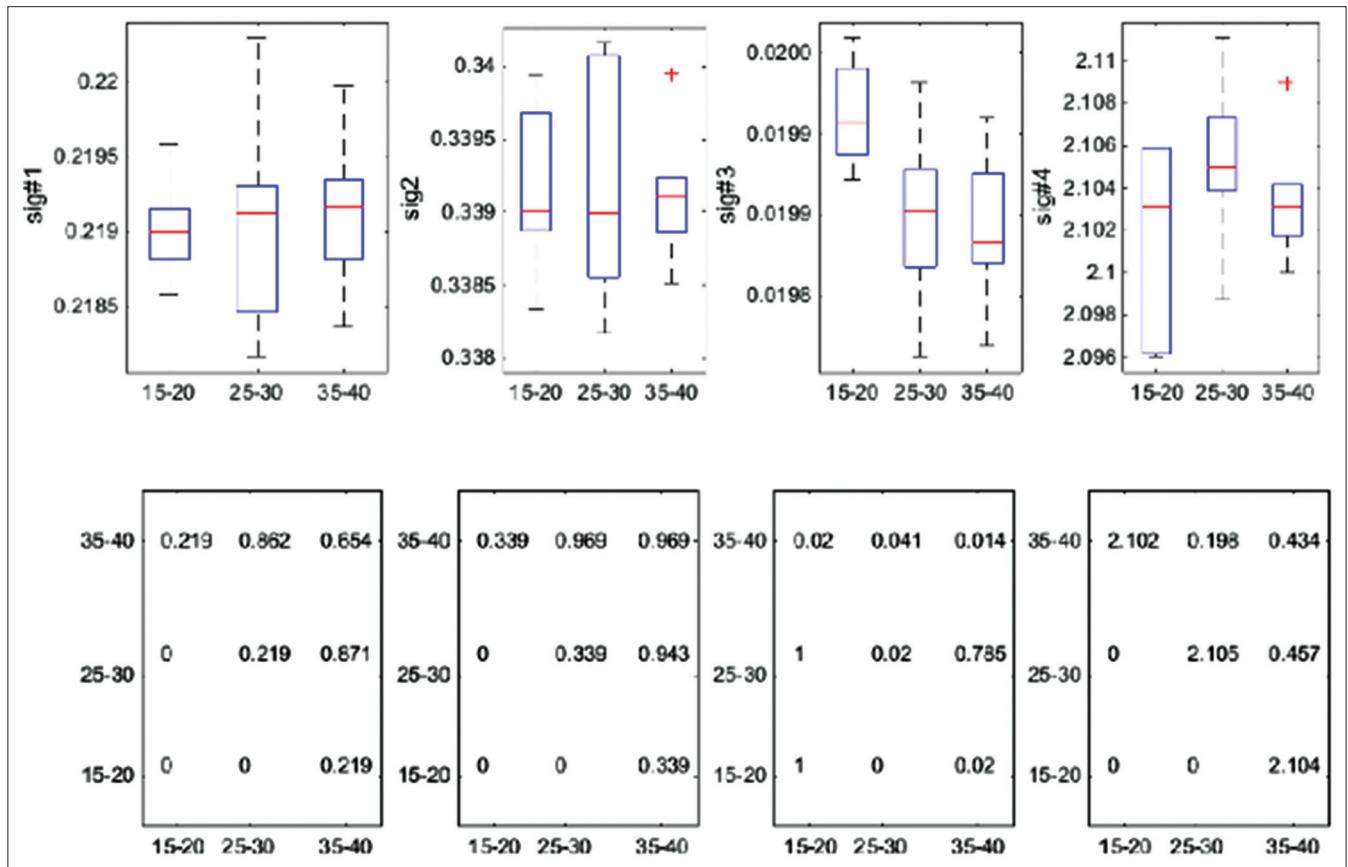


Figure 11: Dispersion of root-mean-square values of the main signals of the second activity among different age groups and in the seventh window

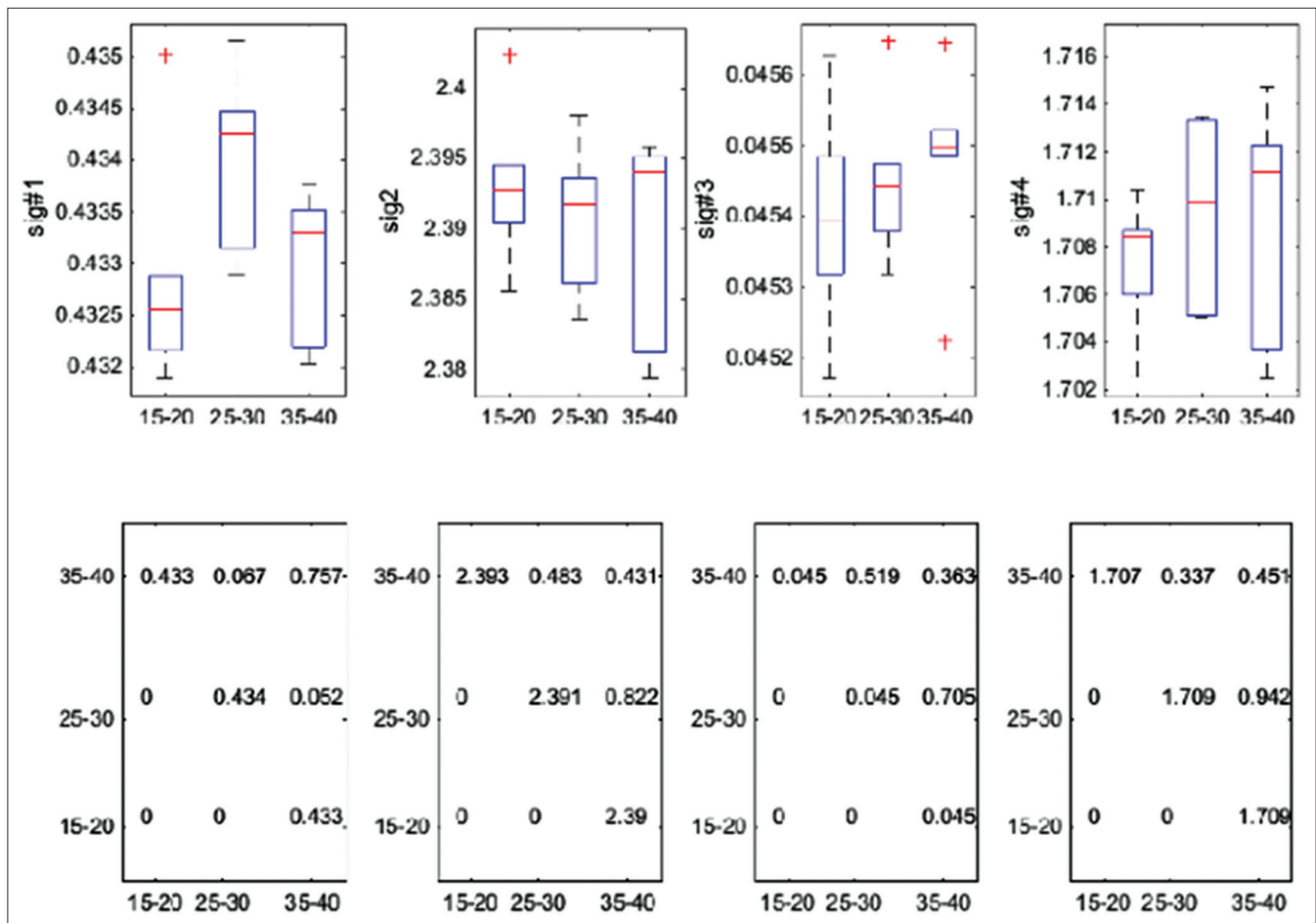


Figure 12: Dispersion of root-mean-square values of the main signals of the third activity among different age groups and in the seventh window

signals in these three activities and in the seventh window. As expected, the classification of the 3 age groups can be achieved in some of the channels. For instance, in the second activity, the third channel could partially divide the first age from the second and third ones.

Classification using synergies

The RMS of the three most significant synergies (Section 3–2) was used for classifying using the k-nearest neighbor method. K-fold cross-validation with $K = 10$ has been used.

Table 1 shows the results of this classification using the most significant synergies. $K = 3$ was set on training data, and as it can be seen, using that K , the best accuracy was about 77%. Figure 14 shows the related confusion matrix.

Classification using the channels

Table 2 shows the classification results using the channels. $K = 4$ was set on training data and as it can be seen, using that K , the best accuracy is about 50%. Figure 15 shows the related confusion matrix.

Comparison of this value with the value obtained by synergies shows that synergy extraction has been able to provide better characteristics for the classification of age ranges.

Classification using a combination of synergy and channel

Table 3 shows the results of the classification using both synergy and channel features. Figure 16 shows the related confusion matrix. As it is seen, a slight improvement was obtained in contrast to using only synergies or channel information.

Discussion and Conclusion

In this study, it was demonstrated that using the EMG signal, the age group can be determined. Considering that in only three of the six activities, the classification of age groups was possible, and it can be postulated that activities which assert force and time on muscle and thus leading to fatigue can be used for the classification of age groups. Furthermore, the accuracy

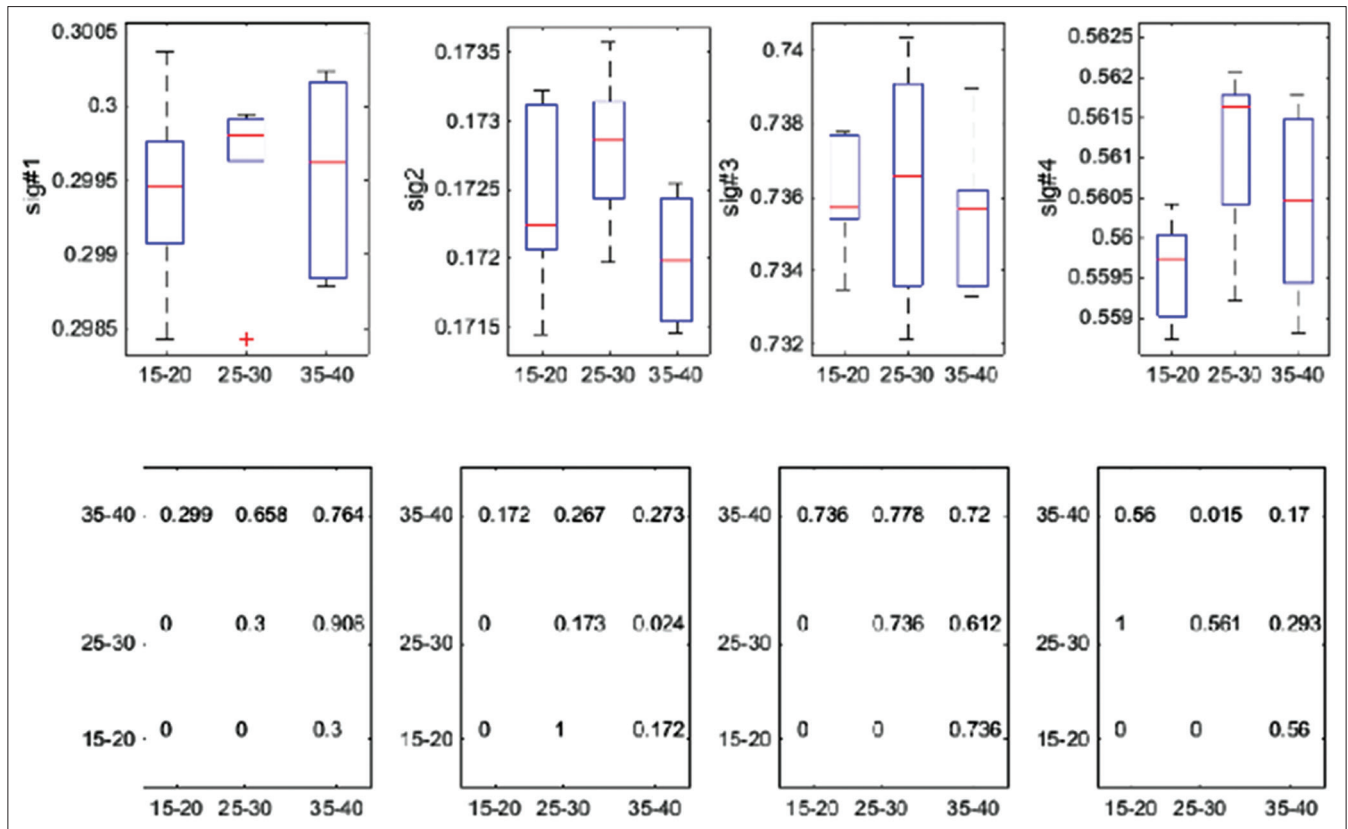


Figure 13: Dispersion of root-mean-square values of the main signals of the sixth activity among different age groups and in the seventh window

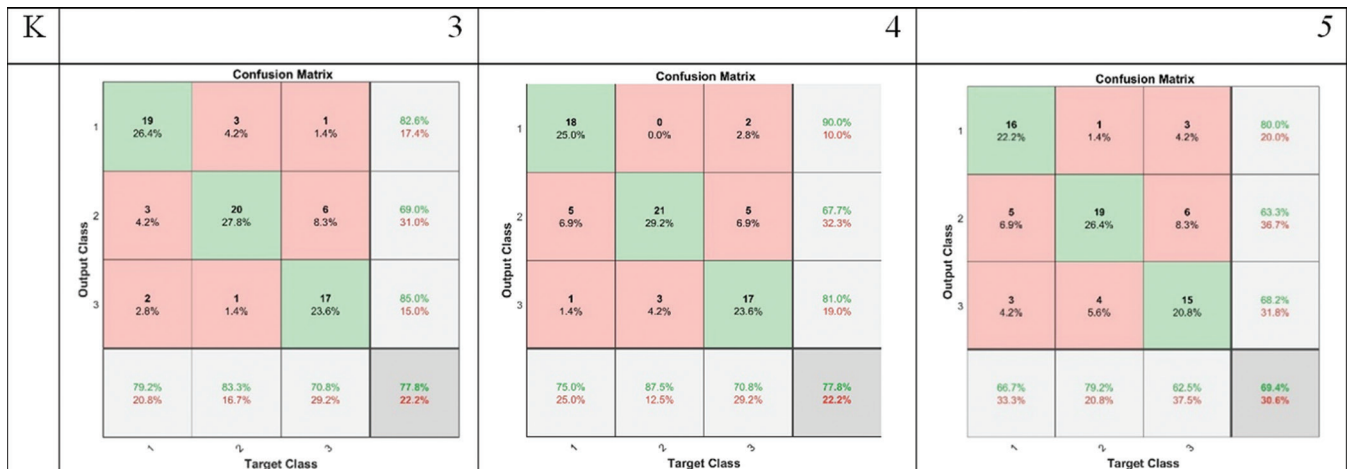


Figure 14: Confusion matrix for classifying using the root-mean-square value of the synergy in the seventh window

obtained in this work is 75% (for male samples and for the detection of a specific range of 23–29 years^[11]) which is higher compared to similar works. For precision of 74%, the research was conducted for female samples and only for the detection of a specific

range of 23–29 years.^[9] In the present study, the testing and recording of signals from female samples have been taken, but three age groups have been investigated, and ultimately, the obtained accuracy is much better than previous works.



Figure 15: Confusion matrix for classifying using the root-mean-square value of the signal in the seventh window

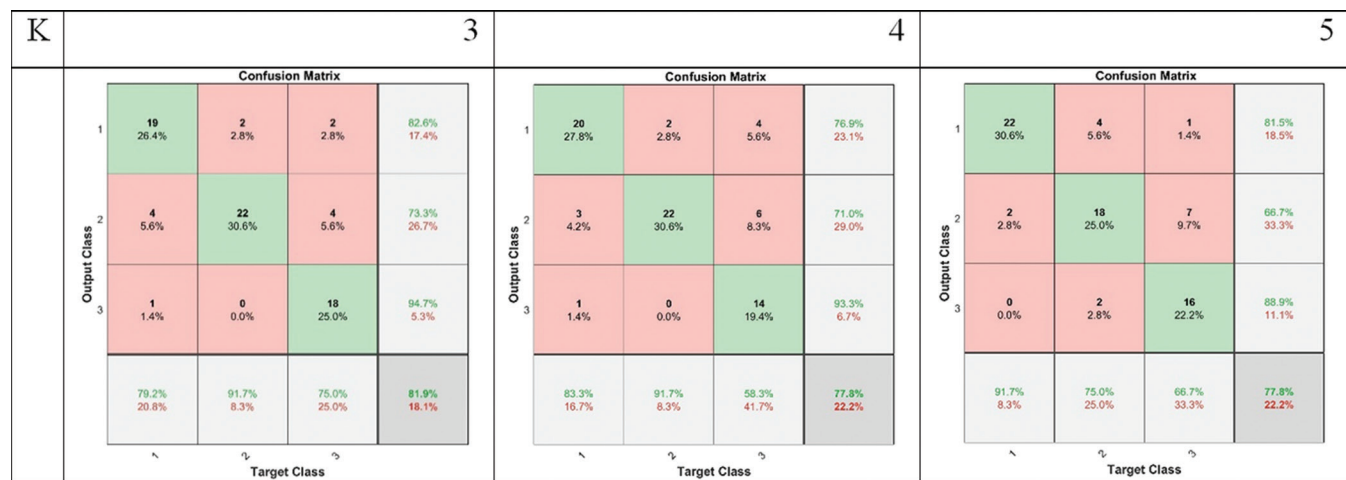


Figure 16: Confusion matrix for classifying using synergies and channel root-mean squares in the seventh window

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Conflicts of interest

There are no conflicts of interest.

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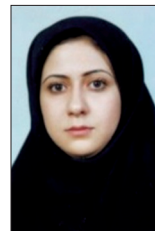
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