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ORIGINAL ARTICLE

The Most Effective VAF Threshold for Extracting the Optimum Number of Synergies for Reaching Movement in a Two-Link Arm Model with Two DoF

Fereidoun Nowshiravan Rahatabad, Elham Farzaneh Bahalgerdy *

Department of Biomedical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

*Corresponding Author: Elham Farzaneh Bahalgerdy
Email: ef135145@yahoo.com

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Abstract

Purpose: Muscle synergy is a motor feature composed of synergy patterns and activation coefficients. This study aimed to combine the two-link arm model with synergy patterns and muscle activation coefficients, which in turn leads to selecting the optimum number of synergies by changing the best Variability Account For (VAF) criterion.

Materials and Methods: In this paper, signals were recorded from six arm muscles involved in arm-reaching movement while carrying a certain weight (w=700 g) by 20 subjects. The synergy pattern and activation coefficient matrices were calculated by using the Non-negative Matrix Factorization method (NNMF) and VAF criterion. Subsequently, to find the best VAF threshold, the output of signal preprocessing and NNMF's output were done on Hill's model.

Results: Average VAF% for 20 subjects in the mentioned movement was 97.34±2.0%, and four numbers of synergies were determined.

Conclusion: The results of the study suggest that the output of the W*H matrix (W and H are equal to the synergy pattern matrix and the activation coefficient matrix, in turn) had harmony with the output of the signal matrix recorded from all 20 subjects (output means the endpoint position and theta 1 and theta 2 angles) when they were performed as input on the two-link arm model. This harmony can be seen when choosing the best VAF critical threshold (value≥96%) via the aforementioned procedure. This harmony in turn contributes to exerting a positive influence on optimal extracting synergy patterns and describing the arm-reaching space more clearly.

Keywords: Reaching Movement; Two-Link Arm Model; Synergy Pattern; Muscle Activation; Non-Negative Matrix Factorization; Variability Account For; Electromyography.

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1. Introduction

Kinematic and kinetic analysis of reaching movement has shown that the Central Nervous System (CNS) uses a limited number of basic training signals called "muscle synergy patterns" to command diverse activities instead of separate commands to each muscle [1, 2]. To extract the muscular synergies, a method called "Non-negative matrix factorization" (NNMF) which is more consistent than the other methods such as Principal Component Analysis (PCA) or Independent Component Analysis (ICA) [3, 4] is utilized in the present study. As can be seen in Figure 1, the output of the NNMF method includes two matrices: W (muscle synergy patterns matrix) and H (activation coefficient matrix).

In addition, the activation coefficient matrix is positive and varies between 0 and 1 (Figure 1). Each muscle can be activated in more than one synergy. Like the synergy approach and the NNMF method is excluded this method can be considered an approach for reducing the dimensionality of the extraction muscle synergy [5-7]. In other words, the NNMF method in turn leads to projecting data into lower-dimensional spaces which can reduce the number of features while keeping the basic information required to reconstruct the original data.

Variability Account For (VAF) is the criterion for selecting the appropriate number of synergies. The VAF threshold should be chosen in the best way, and thus, it can describe the arm-reaching movement space more clearly with fewer calculations needed. According to Kai Gui *et al.* [3], the VAF threshold value is generally chosen empirically, and the lowest number of synergies extracted by this criterion.

1.1. Related Research Work

Sabzevari *et al.* [5] extracted muscle synergy from six upper limbs and shoulder muscles (eight muscles) using the NNMF method. Three numbers of synergies were extracted and the VAF threshold was set at 99%. All subjects did arm-reaching movements at three different speeds (slow, moderate, and fast). In the paper by Steele *et al.* [6], such criteria were set at 90%. Signals were recorded from five muscles on each leg (signals were recorded from rectus femoris, medial hamstrings, lateral hamstrings, medial gastrocnemius, and anterior tibialis) and through the NNMF method, three numbers of synergies were extracted. In a further study by Ioannis Delis *et al.* [7], the electromyogram of nine arm and shoulder muscles was recorded when the subjects did arm-reaching movement and the VAF criterion was chosen 75%. Four numbers of synergies were extracted. Thus, many studies chose the value of the threshold VAF empirically.

Is it true that higher values of the VAF threshold offer a better result? A question that is raised here is related to the extent of the VAF threshold required to extract the optimum number of synergies. Can the value of the VAF criterion threshold which impacts

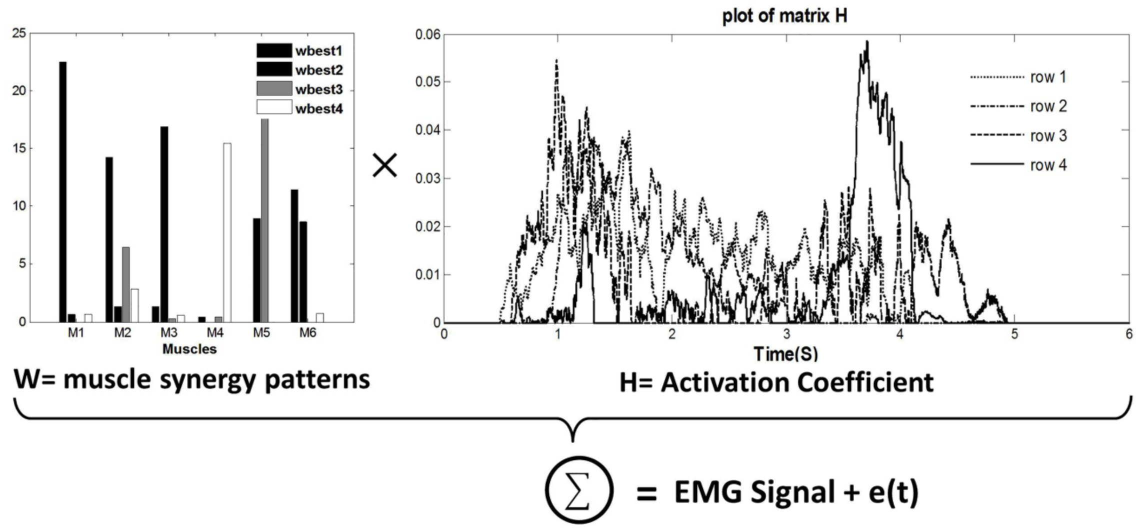

Figure 1. The process by which the NNMF method functions to extract muscle synergy patterns matrix (W) and activation coefficient (H) from the EMG signals

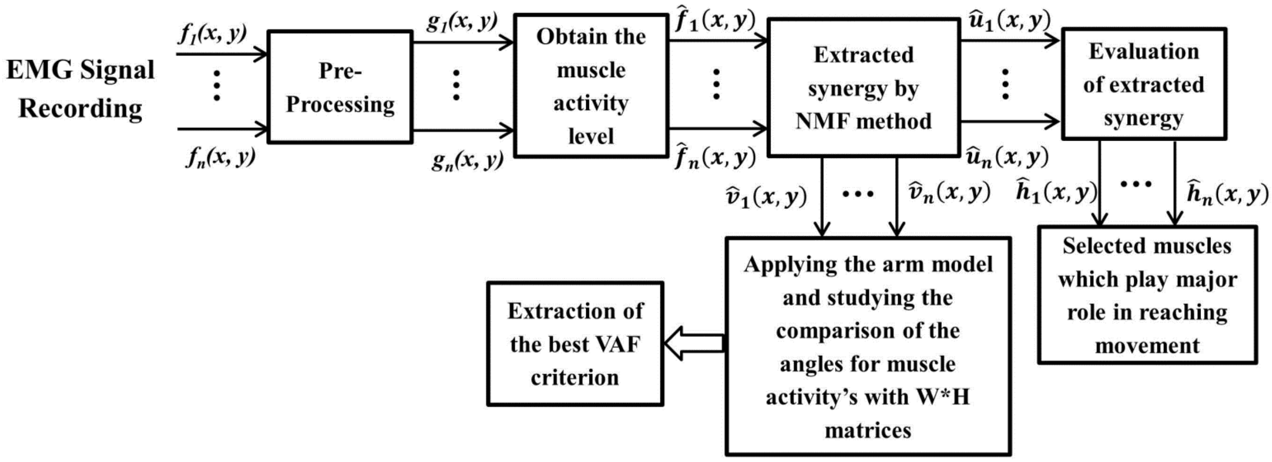

Figure 2. The process of achieving the best VAF% criterion threshold value in arm-reaching movement in the horizontal plane in the present study. Firstly, the EMG signals were recorded, and then signal preprocessing was done before extracting synergy by the NNMF method. In the next stage, numbers of synergies and muscle activation coefficients were applied to the two-link arm model. In the fifth step, the outputs were compared, and the output of the two-link arm model when applying the initial signal matrix recorded from all subjects as an input. In addition, in the sixth step, the synergies were evaluated before selecting the muscles which were played a crucial role in reaching movement

the optimum number of synergies, reduce the residual value? Overall, the present study aims to analyze this question: how much does VAF criterion threshold need to function for extracting the optimum number of synergies and surveying the advantages of the method performed in this paper. In this investigation, by combining the two-link arm model with synergy patterns, activation coefficient matrix, and choosing the best VAF threshold which in turn leads to selecting the optimum number of synergies and increasing the harmony among the output of the two-link arm model when W.H matrix and signal matrix recorded from all 20 subjects (desired value matrix) applied on the model as inputs (Figure 2).

The results of the study suggest that those muscles that play a major role in arm-reaching movement can be selected by surveying the synergy patterns, and then they can be fruitful in selecting the suit arm model. The goal of our method is:

1. To choose the best VAF threshold,
2. so the VAF threshold is not chosen empirically,
3. And therefore it would reduce the calculation.

2. Materials and Methods

2.1. The Trend of This Paper

After preprocessing, the synergy patterns were extracted. The synergies were extracted by using the NNMF and the VAF criterion methods. To calculate the optimum number of synergies, the best VAF criterion threshold is need. Thus, diverse VAF levels were done on the NNMF algorithm for extracting W*H, and subsequently, they were applied to the two-link arm model to compare its output with the output of the two-link arm model when the initial signal matrix, recorded from all 20 subjects (desired value matrix) was performed as an input. This can result in observation of the harmony or non-harmony of two matrices (that is W*H and desired value matrices). For simulating arm-reaching movement, the two-link arm model with six muscles was simulated, and the physical parameters of the model were extracted through [8] study. Thus, the protocol was:

Firstly, the average of the signal matrix recorded from all subjects was applied to the two-link arm model, and the output of the model was obtained. The output included: Theta1 and Theta2, angular velocity joints 1 and 2, and Endpoint Position (EP). Then, the W*H matrix was performed as the input, and its output was obtained. Finally, the results were compared with each other (Figures 9 and Figure 10). If the results of the control do not have harmony; the VAF value threshold should be increased.

For example, alteration of the initial value of VAF 93% instead of the value of 92% can change the harmony or non-harmony of the outputs. This process was done until all outputs had harmony (Figure 3). Modeling, simulation, and implementation of the two-link arm model were performed in MATLAB software using the SimMechanics toolbox (Figure 2).

2.2. Experimental Setup

In this study, signals were recorded from six muscles that were involved in reaching movement in the horizontal plane according to the literature [9]. These muscles were [9]: Biceps Short Head (BSH), Biceps Long Head (BLH), Pectoralis Major (PMJ), Deltoids (DEL), Triceps Long Head (TRIO), and Triceps Lateral Head (TRIA). The muscles' signals were recorded by the BIOPAC system at 1 kHz sampling and 5000 gain factor amplifiers (BIOPACEMG100A) [10]. Electrodeposition was chosen based on the SENIAM standard [11].

The signals were recorded from 20 right-handed male subjects (aged between 21 and 30 years old) who had no nervous muscle disorder. The protocol of movements was done while subjects did arm-reaching movements in the horizontal plane and carried a certain weight (w=700g) to increase the signal amplitude recorded.

All subjects were asked to sit at a desk. Regarding position, their shoulders and bodies were at an angle of 90 degrees. The subjects were asked to do the arm-reaching movement on a certain path (Figure 4). For each subject, the arm-reaching movement was performed up to 10 times.

2.3. Signal Preprocessing

The preprocessing was performed on signals recorded from 20 subjects with the output of the preprocessing shown in Figure 5. For selecting the desired arm-reaching movement, 10 arm-reaching

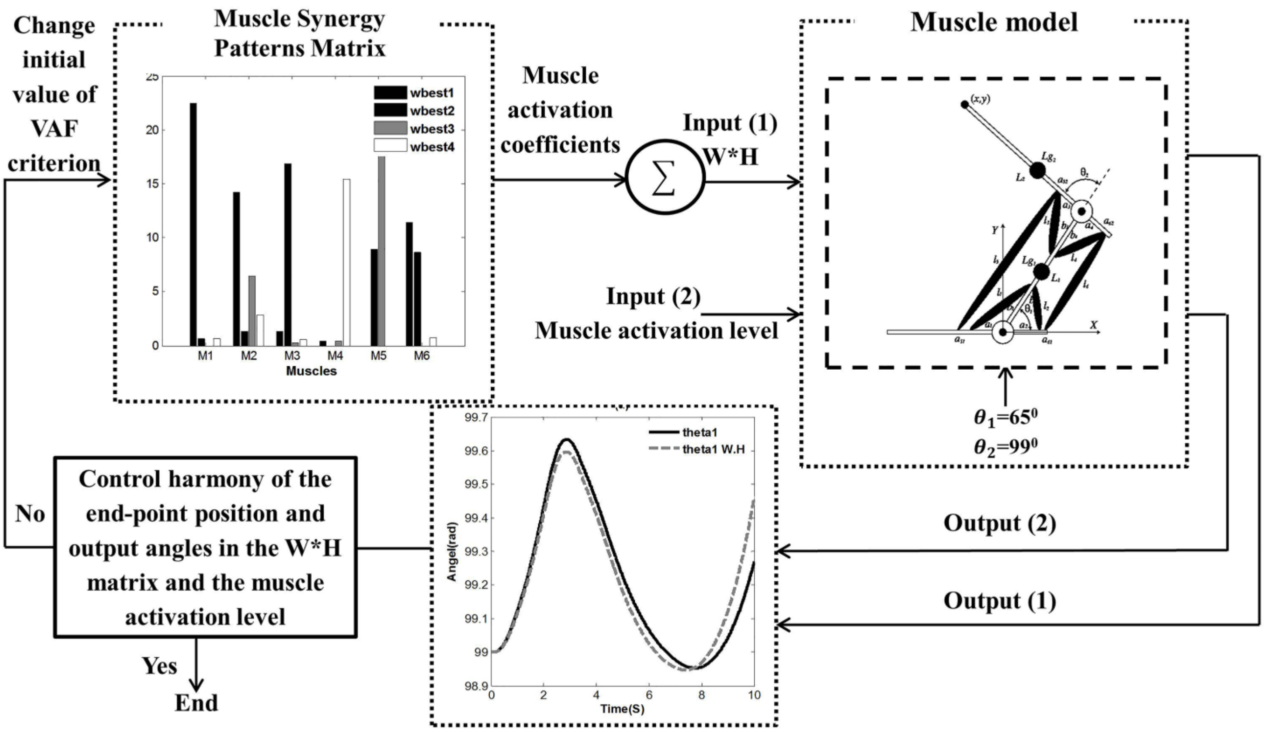

Figure 3. Schematic view of the method used in this paper. The NNMF method was performed to extract muscle synergy (W) and activation coefficient (H) from the EMG signals. Subsequently, W*H was applied to the two-link arm model, and the output of the model included Theta1 and Theta2, angular velocity joints 1 & 2, and end-point position (EP) were compared with the output of the two-link arm model when the average signal matrix recorded from all subjects was applied on the model. The initial value of the VAF % criterion has effects on the optimum number of synergies, which exerts influence on the harmony or non-harmony of the end-point position and output angles in the W*H matrix and the signal matrix recorded from all subjects

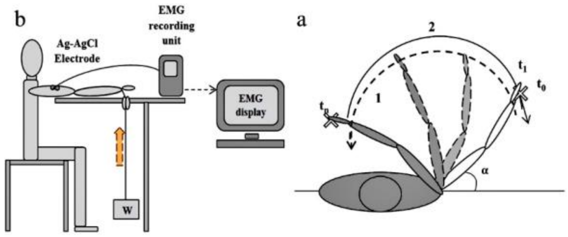

Figure 4. Information on the experimental setup. Doing arm-reaching movement while carrying a certain weight (w=700 g) by 20 subjects: a- The right image is related to the arm-reaching movement protocol. If we look at picture b, the subjects sit at the table whose shoulders and bodies were at an angle of 90 degrees. Protocol was done at a certain endpoint position

movements were recorded from each subject (10 arm-reaching movements in each person's protocol).

From among 10 repetitions recorded in each protocol from each subject, the third and/or the fourth record's arm-reaching movements were selected. The reason why this is the case is that some signal values were reduced from the fifth arm-reaching movements (it seemed that the subject's muscles became tired).

Signals recorded were passed through high pass and low pass filters which were 1 Hz and 500 Hz, respectively. Subsequently, the following signal preprocessing was done on the signals:

1. rectifying full signal,
2. correcting the baseline,
3. and normalizing signal with the maximum EMG of channels [12, 13].

2.4. Variability Account For (VAF)

According to Alessandro *et al.* [14], very similar muscular synergies are found among the subjects in many cases. This similarity was also observed in the patterns extracted in the study.

The VAF criterion calculates to what extent W*H can be reconstructed from the original EMG data [15]. According to Equation 1, in VAF calculation EMG and W*H are the actual and estimated values of the signal, respectively [6]:

$$VAF = 1 - (\|EMG - W \times H\|2 / \|EMG\|2) \quad (1)$$

Non-Negative Matrix Factorization (NNMF) method was used to extract the synergies [16, 17]. According to Equation 2, W and H are muscle synergy

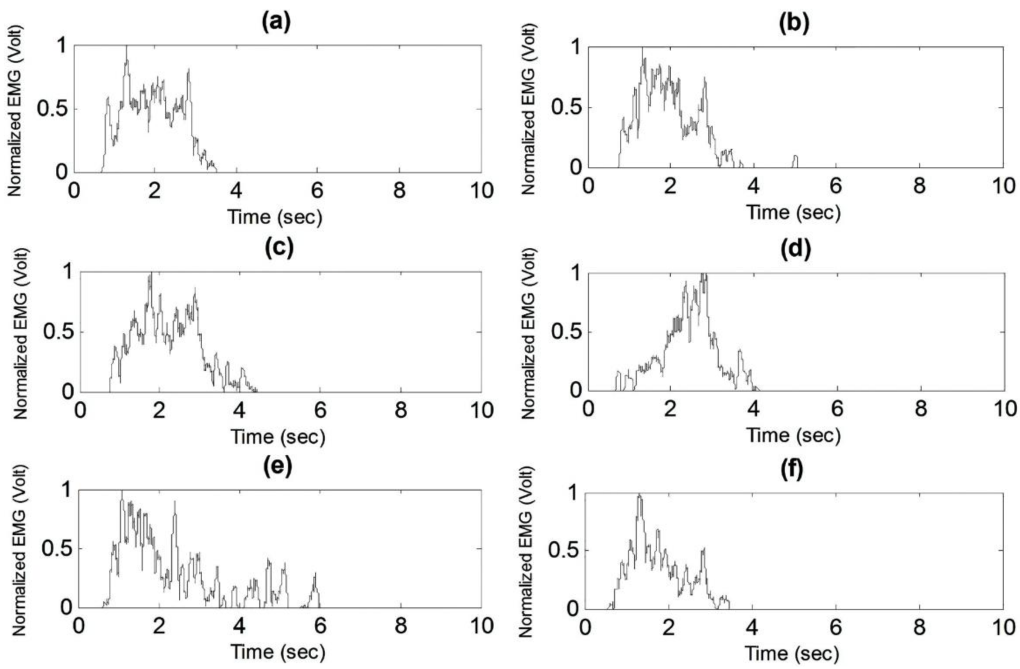

Figure 5. The entire preprocessing trend on a subject and output signal in the protocol. The horizontal and vertical axis illustrates time (sec) and normalized EMG (Volt), respectively. The graph shows the extracting muscle activity level. a- (Biceps Long Head (BLH)), b- (Biceps Short Head (BSH)), c- (Triceps Lateral Head (TRIA)), d- (Pectoralis major (PMJ)), e- (Deltoids (DEL)), f- (Triceps Long Head (TRIO)

and activation coefficients matrices, while e is the residual error matrices:

$$M n \times m \approx W n \times r \, H r \times m + e \quad (2)$$

2.5. Muscle Modeling Structure in the Horizontal Plane

In order to model the two-link arm in the horizontal plane the following equation was used. The Degrees Of Freedom of this model is two (2-DOF) and it is a Two-D model. The following equation is based on the Lagrange equation [8]:

$$Mq+\vec{v}(q,\dot{q})+\vec{G}(q)=\tau \quad (3)$$

Where matrix M contains mass expressions of the arm; vector V comprises centrifugal and Coriolis expressions and G is the vector of gravity. τ is a vector of joint torque [18].

Consequently, muscle output is shown by the following equation in the present model [8]:

$$F=\bar{\alpha}-\bar{\alpha}bi-\bar{\alpha}k\Delta l \quad (4)$$

$$\bar{\alpha}=\alpha.f_0\,,\ b=b'/f_0\,,\ k=k/f_0\,,\ \Delta l=l-l_0 \quad (5)$$

Where F and $\bar{\alpha}$ are the output force of muscles and muscle contractile force, respectively. Where f_0 is the maximum output force, $\bar{\alpha}$ $(0\leq\alpha\leq1)$ is the muscle activity level, b′ is the positive coefficient of intrinsic damping, k is the muscle stiffness coefficient, and finally $(l\text{-}l_0)$ is the difference in muscle length from the rest mode. The following geometric relationships and

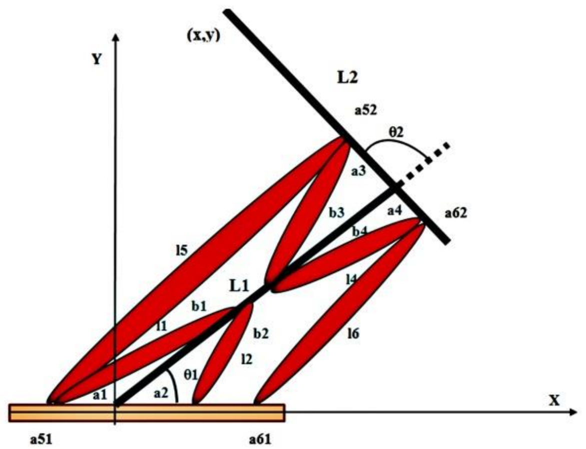

Figure 6. Two-link arm model with six muscles

Figure 6 shows the length of the muscles on their attachment points and the angles of joints:

$$\begin{aligned}
&l_1=(a_1^2+b_1^2+2a_1b_1\cos\theta_1)^{1/2}\\
&l_2=(a_2^2+b_2^2+2a_2b_2\cos\theta_1)^{1/2}\\
&l_3=(a_3^2+b_3^2+2a_3b_3\cos\theta_2)^{1/2}\\
&l_4=(a_4^2+b_4^2+2a_4b_4\cos\theta_2)^{1/2}\\
&l_5=(a_{51}^2+a_{52}^2+L_1^2+2a_{51}L_1\cos\theta_1+2a_{52}L_1\cos\theta_2\\
&+2a_{51}a_{52}\cos(\theta_1+\theta_2))^{1/2}\\
&l_6=(a_{61}^2+a_{62}^2+L_1^2+2a_{61}L_1\cos\theta_1+2a_{62}L_1\cos\theta_2\\
&+2a_{61}a_{62}\cos(\theta_1+\theta_2))^{1/2}
\end{aligned} \quad (6)$$

Where l_i is the length of each muscle, θ_1, and θ_2 are the angles of each joint, a_i and b_i are the places where muscles and links join, and finally, L_i are links.

$i=Q(\theta).\dot{\theta}$, where $i\in R^{6\times1}$ is the vector of the contractile velocity of muscles, $\dot{\theta}\in R^{2\times1}$ the velocity matrix for each joint angle, and $Q(\theta)\in R^{6\times2}$ is the Jacobian matrix from space muscles to the joints. This matrix can be shown as follows [16]:

$$Q^T(\theta)=\begin{pmatrix} r_{11} & r_{12} & 0 & 0 & r_{15} & r_{16}\\ 0 & 0 & r_{23} & r_{24} & r_{25} & r_{26}\end{pmatrix} \quad (7)$$

Where r_{ij} s- as Equation 8- are:

$$\begin{aligned}
&r_{11}=-(a_1b_1\sin\theta_1)/l_1\\
&r_{12}=-(a_2b_2\sin\theta_1)/l_2\\
&r_{23}=-(a_3b_3\sin\theta_2)/l_3\\
&r_{24}=-(a_4b_4\sin\theta_2)/l_4\\
&r_{15}=(-a_{51}L_1\sin\theta_1-a_{51}a_{52}\sin(\theta_1+\theta_2))/l_5\\
&r_{25}=(-a_{52}L_1\sin\theta_2-a_{51}a_{52}\sin(\theta_1+\theta_2))/l_5\\
&r_{16}=(-a_{61}L_1\sin\theta_1-a_{61}a_{62}\sin(\theta_1+\theta_2))/l_6\\
&r_{26}=(-a_{62}L_1\sin\theta_2-a_{61}a_{62}\sin(\theta_1+\theta_2))/l_6
\end{aligned} \quad (8)$$

By using virtual work, the relation between muscle forces and joint torques τ is expressed as: $\tau=w.f$. Where $F\in R^{2\times1}$ and $\tau\in R^{2\times1}$ are force vectors for six muscles and joints' torque vectors, respectively.

3. Results

3.1. Performing NNMF Method

Based on section 2.1, the synergy pattern and the numbers of synergies were extracted by using NNMF and VAF methods.

3.1.1. Synergy Extraction

Figure 7 presents information about the average number of synergies extracted from 20 subjects from

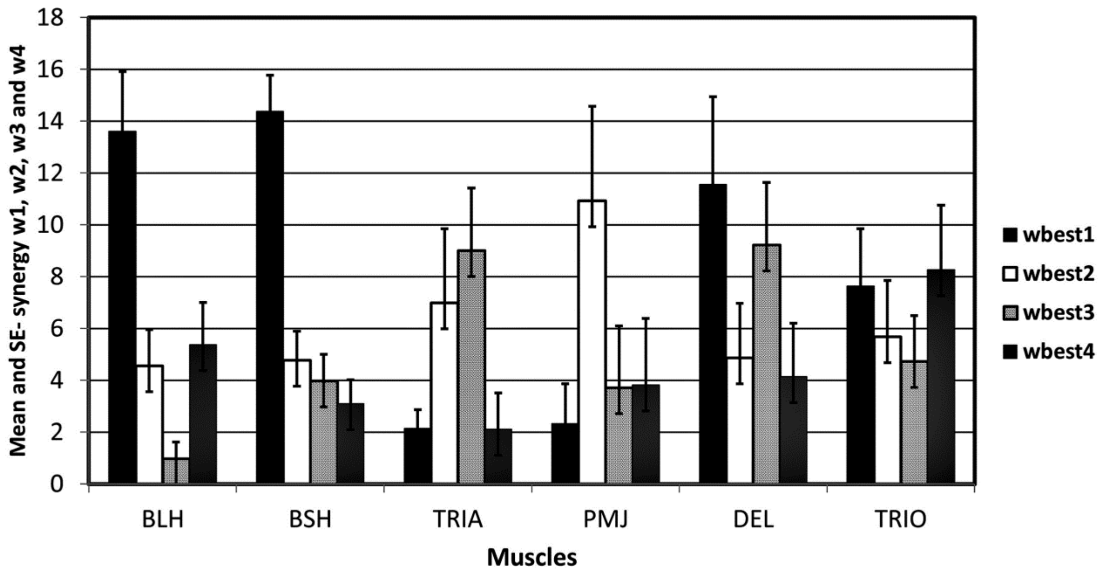

Figure 7. Information on the average number of synergies extracted from 20 subjects. The horizontal axis depicts the number of muscles and the vertical axis shows the value role of each muscle in reaching movement. Biceps Long Head (BLH), Biceps Short Head (BSH), Triceps Lateral Head (TRIA), Pectoralis Major (PMJ), Deltoids (DEL), Triceps Long Head (TRIO)

the six major muscles. Overall, it can be clearly seen that the Biceps, Triceps, Pectoralis major, and Deltoids muscles involved the largest average number of synergy. With regard to the average number of synergies in W1, the figures for BLH and BSH were the largest (just under and just over 14, respectively). The figure for DEL was also large (just under 12) as opposed to the figure for TRIA and PMG which were the lowest. As for the average number of synergies in W2, the figure for PMJ was the highest (approximately 11).

On the other hand, the average number of synergies in W3 and W4 were under 9, suggesting that these muscles are used less than others in the arm-reaching movement.

3.1.2. Evaluating the Extracted Synergy

As mentioned earlier, to evaluate the optimum number of synergies, the VAF% value graph was generated. According to Figure 8, the line graph depicts information about the average proportion of the VAF criterion. The horizontal axis illustrates the number of extracted synergies while the vertical axis represents the VAF% value.

The average percentage of VAF criterion extracted in all the subjects was 97.34±2.0%.

3.2. Applying the Two-Link Arm Model and Studying the Comparison of the Angles for the Initial Signal Matrix Recorded from All Subjects with the W*H Matrix

According to the graphs' survey, the angles for the initial signal matrix recorded from all subjects (desired value matrix) were convergent with the W*H matrix (when the VAF threshold was 96%).

For example, the similarity between the two matrices (in the VAF) has been 96%. Therefore, if Theta1 and Theta2, joints (1 and 2), the angular velocity, and EP for two matrices have harmony, this similarity means that the number of synergies is optimum. Theta1 and Theta2 had initial values, and they were applied at 65 and 99 rad on the two-link arm model, respectively. The initial angles at the start of the movement for all experiments were set at these values. Figures 9 and Figure 10 illustrate the outputs of the matrices.

The results of the W*H matrix (with VAF criterion≥ 96%) and desired value matrix performed on the two-link arm model are shown in Figure 9.

Figure 9 (a and b), presents the joint angle for Theta1 and its angular velocity from left to right. Theta 1 W*H joint angle and W*H matrix's angular velocity had harmony with the desired value matrix. Figure 9

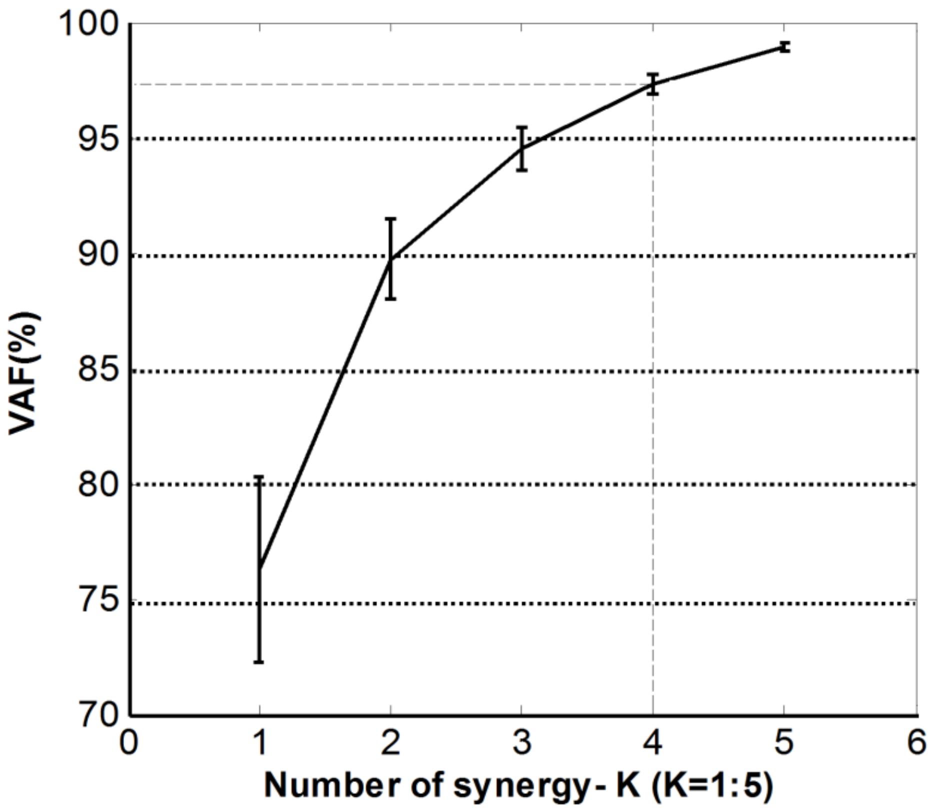

Figure 8. The average VAF % criterion extracted from all 20 subjects was 97.34±2.0%. The horizontal axis shows the number of extracted synergies and the vertical axis represents the VAF% value. Four number of synergies were chosen as the appropriate number of synergies to describe the movement. According to this figure, variation in k=NS=5 decreased in comparison with NS=4's variation, but it made a distance between the number of synergies and the main goal increase (this means dimension reduction) which was not appropriate

(c and d) displays the Theta2 joint angle and its angular velocity from left to right. Theta2 joint angle and angular velocity for the W*H matrix had harmony with the desired value matrix.

Figure 9 (e and f) depicts the endpoint position in X and Y. As shown in Figure 9, the endpoint position for the W*H matrix had harmony with the desired value.

To verify the harmony accuracy of the two matrices, the VAF criterion was set at a value≥92% and the trend (in VAF≥ 96%) was done again. As can be seen in Figure 10, the W*H matrix had no harmony with the desired value.

4. Discussion

This research examined the effect of the VAF% threshold on synergy patterns at the end-point position during arm-reaching movements in the two-link arm model. The results revealed that combining the two-link arm model with synergy patterns and muscle activation coefficients as well as choosing the best VAF threshold would contribute to selecting the optimum number of synergies. In addition, the results of the study suggest that those muscles extracted as major roles by the NNMF method can be useful for selecting the suit arm model.

As depicted in Figure 7, the important point in W1 is that the Biceps, Triceps, Pectoralis major, and Deltoids have been the major involved muscles in all the subjects. In the second synergy (W2), the Pectoralis major muscle has been actively involved in all 20 subjects, and thus, these results indicate that the two-link arm model with six muscles has been suitable.

Selecting the optimum number of synergies not only has positive effects on reducing calculations but also tries to describe the arm-reaching space well. Therefore, the first number of synergies (VAF 96%) is chosen as the appropriate number of synergies to describe the movement.

As stated, each NS (NS is the number of synergies in this study) can vary from 1 to 5, and the best number

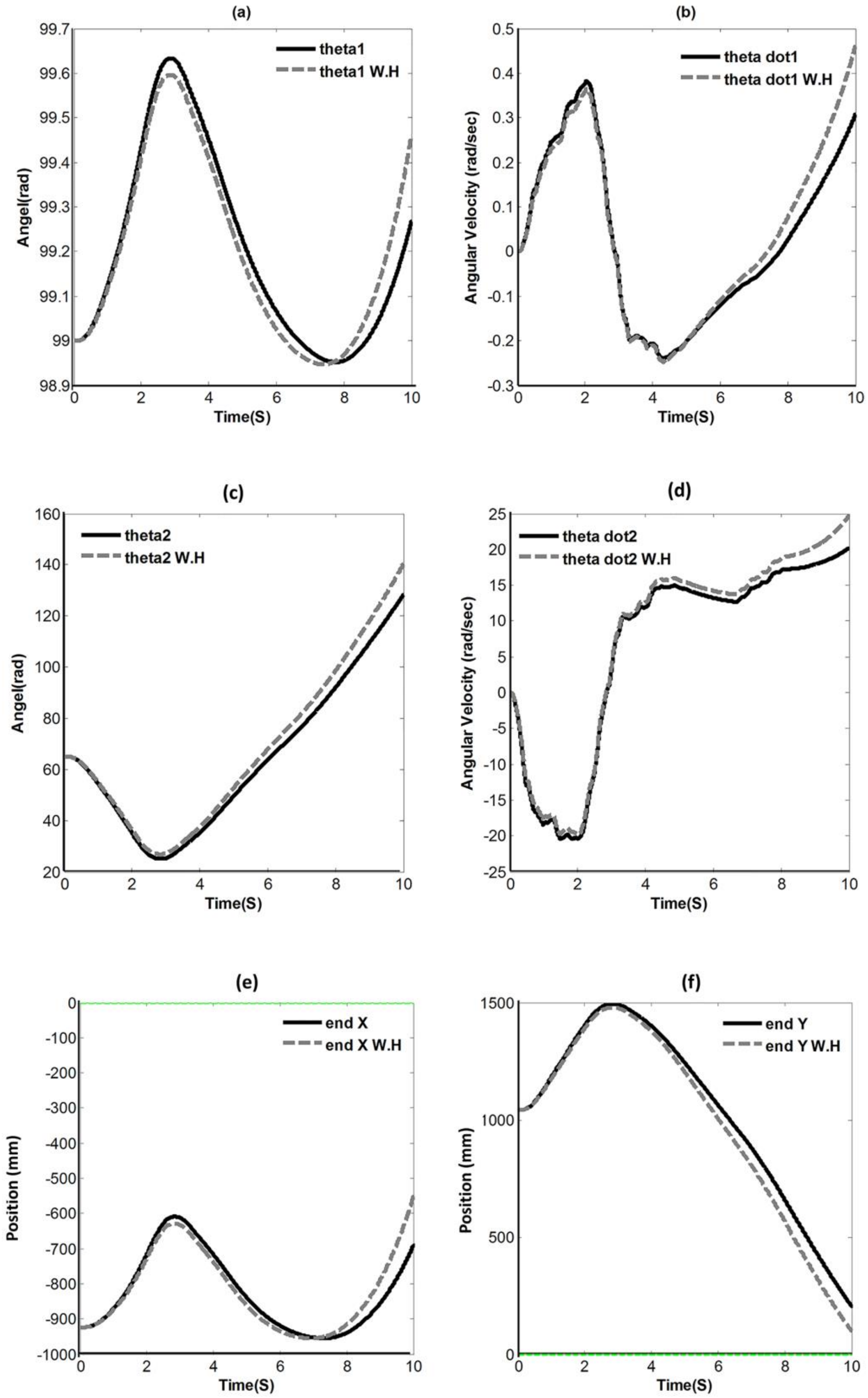

Figure 9. The joint angle for a) Theta1 and b) its angular velocity (W*H matrix and muscle activity matrix (VAF criterion≥ 96%)). Theta 1 W*H joint angle and W*H matrix's angular velocity were convergent to the muscle activity matrix. The joint angle for c) Theta2 and d) its angular velocity (W*H matrix and muscle activity matrix (VAF criterion≥ 96%)). Theta 2 W*H joint angle and W*H matrix's angular velocity were convergent to the muscle activity matrix. The task space end-point position: that indicates the endpoint position in e) X and f) Y (W*H matrix and muscle activity matrix (VAF criterion≥ 96%)). The endpoint position in X & Y W*H matrices was convergent to the muscle activity matrix

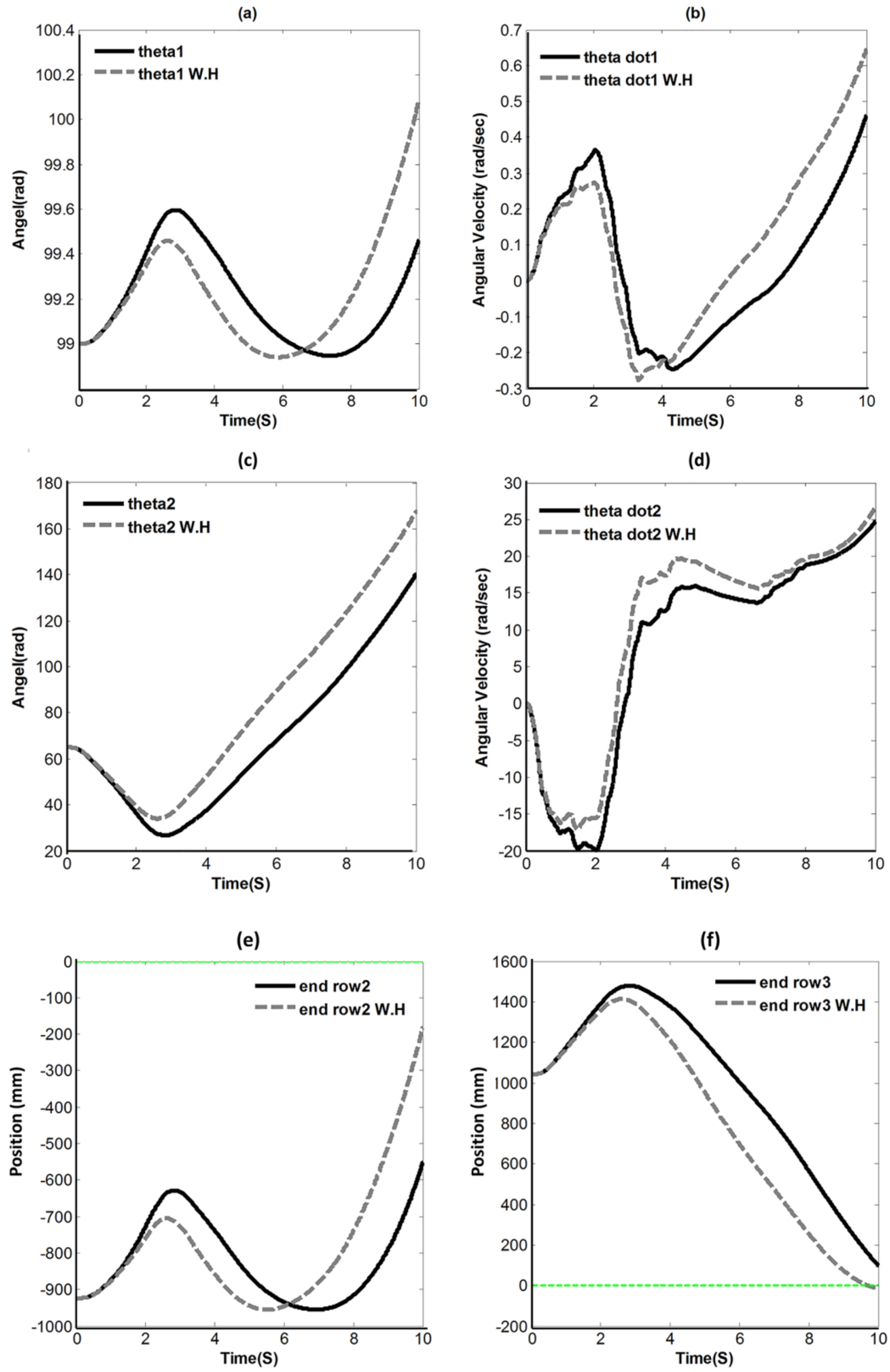

Figure 10. The joint angle for a) Theta1 and b) its angular velocity (W*H matrix and muscle activity matrix (VAF criterion≥ 92%)). The non-harmony of the W*H matrix to the desired value. b and c: The joint angle for c) Theta2 and d) its angular velocity (W*H matrix and desired value matrix (VAF criterion≥ 92%)). The non-harmony of the W*H matrix to the desired value is shown. e and f: The task space end-point position: that indicates the endpoint position in a) X and b) Y (W*H matrix and desired value matrix (VAF criterion≥ 92%)). The non-harmony of the W*H matrix to the desired value matrix

of synergies can be calculated by the VAF method (Figure 8). To evaluate the synergy extracted, the VAF% value graph was produced.

For any NS-value from 1 to 5, the VAF% value is shown in Figure 8. The average VAF % criterion extracted in all 20 subjects was 97.34±2.0% and four synergies were obtained for all 20 subjects. To choose the number of synergies, the first number of synergies (that suggest 96% changes in the input signal space) was regarded as a suitable number of synergies to describe the movement. Given such an approach, as shown in Figure 8, NS>4 enjoyed this feature. On the other hand, variation (representation matrix is more similar to the desired value matrix) in NS=5 decreased as compared to NS=4's variation but it can result in increasing the distance between the number of synergies and the main goal (that is dimension reduction).

To measure the optimum level of the VAF % criterion, a test was done to verify the results of the desired value and W*H matrices which were performed on the two-link arm model with six muscles.

In Figure 9, the convergence of the W*H matrix to the desired value reveals that the optimum synergies can be extracted using such a procedure by choosing the VAF criterion at 96%.

Inspecting Figure 10, the output of the two-link arm model in the W*H matrix and the desired value matrix have lack-harmony. It shows that the initial value of the VAF criterion (that is VAF criterion value ≥92% instead of value ≥96%) affects the optimum number of synergies, which exerts a negative influence on the harmony of the endpoint position and output angles in the W*H matrix as well as the desired value matrix in the two-link arm model.

According to [3] choosing the VAF threshold value criterion is generally empirical. As seen the initial value of VAF criterion value ≥96% instead of VAF criterion value ≥92% affected the harmony of the outputs in the W*H matrix and the desired value matrix while the optimum number of synergies is four for both trends.

Although a higher value of the VAF critical threshold seems to have a better result, this is not correct. This is owing to the fact that, when the VAF threshold value is 98%, although the outputs of the W*H matrix and the desired value matrix were completely in harmony, the number of synergies has increased (that is five numbers of synergy were extracted) and the optimum number of synergies cannot be achieved.

In other words, as mentioned earlier, the output of the NNMF method is W and H which W is the muscle synergy patterns matrix and H is the activation coefficient matrix. The outputs of the W.H matrices in W [6*5] × H [5*6] are different from the W [6*4] × H [4*6]. If the VAF threshold is chosen to be 99%, although the result (the outputs of the two-link arm model) is so similar to the desired value, it can lead to increasing calculation.

Therefore, the results of the present study suggested that residual value (being e in Equation 2) can be reduced, with the initial value of the VAF criterion (being VAF critical threshold) which influences the optimum number of synergies.

On the other hand, in other studies, as stated earlier the VAF threshold is selected empirically [3]. Selecting the VAF threshold in this way, in turn, results in increasing reconstruction error and the number of synergies, and, therefore, the W*H matrix has no harmony with the desired value matrix. For instance, Sabzevari *et al.* [5] extracted muscle synergy from eight muscles by using the NNMF method, where the VAF threshold was 99% with three synergies extracted at three different speeds (slow, moderate, and fast). In [19], the number of synergies extracted was four, setting the VAF criterion at 95% with diverse speeds (slow, self, and fast). In Steele *et al.* [6], such a criterion was set at 90% and the number of synergies was three from five muscles on each leg. Delis *et al.* [20] set the VAF criterion at 75% and the number of synergies was four. Elsewhere, Sedigheh Dehghani *et al.* [21] set the VAF criterion at 75% for extracting synergies for three different types of point-to-point reaching (simple straight, reversal, and via-point). Finally, in [7], the VAF criterion was chosen at 75% and four synergies were extracted.

Thus, by using the NNMF method by choosing the best VAF critical threshold and applying its output on the two-link arm model, one can achieve the optimum number of synergies which results in the convergence of the two matrices, the desired value matrix recorded from 20 subjects, and W*H matrix. The aforementioned procedure can be used to control arm-reaching movement which can lead to movement more realistically reflecting actual real human movement. The reason for propounding this point is related to a future study arising from the current study. Our group has seen the benefits of results by utilizing the protocol (in this lecture) and combining it with Reinforcement Learning (RL) to produce the arm-reaching movement.

If we use five synergies instead of the optimum number of synergies, which was four, and the best VAF threshold that was 96% (by utilizing the protocol in this lecture), therefore, the calculation will be increased. If the VAF threshold is choosen empirically, for controlling the two-link arm model, the RL controller ought to calculate more. This in turn leads to reducing the speed of the algorithm and increasing its steps.

5. Conclusion

In the present study, the main targets were extracting the optimum number of synergies by combining the two-link arm model with synergy patterns and muscle activation coefficients which in turn contributed to extracting the optimized number of synergies.

Furthermore, the results of the study depicted that the initial value of the VAF criterion (that is VAF criterion value ≥96% instead of value ≥92%) had effects on the optimum number of synergies, which could be affected the harmony of the endpoint position and output angles in the W*H matrix and the desired value matrix in two-link arm model.

In some cases, in which more muscles are involved in task performance to extract the number of synergies, performing the protocol of this study might be more complex, as the points mentioned before in this study their results have more advantages.

By using the NNMF method when the VAF criterion threshold is set at 96%, not only the optimum number of synergy can be achieved which results in reducing calculations, but also it can be described the arm-reaching space more clearly by the method mentioned in the present study.

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