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Determination of the best recovery based on muscles synergy patterns and lactic acid

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ABSTRACT

The determination of the best recovery after an anaerobic exercise is an important challenge for professional athletes. This study compared and analyzed three methods that are often used in professional teams included: 1. Cold water pool 2. Use the massager 3. Running with 40 to 50 percent of heart rate. Methods: In this work recovery the 15 minutes recovery is done immediately after doing exercise. The impact of a particular method of recovery is quantified via lactic acid in the blood after the recovery and the synergy patterns of muscle activity. In each method, Biceps femoris, rectus femoris, tibialis anterior, lateral gastrocnemius muscles were analyzed. Results showed that there were synergy patterns in two running and ice methods, because maximum errors between basis vectors in all of the subjects were 0.13 and 0.18 respectively and Standard deviation of maximum MSE errors for all subjects is 6 (MSE index), whereas in massage recovery synergy has not been recognized because minimum error between basis vectors in all of the subjects was 4.29 and Standard deviation of maximum MSE error for all subjects is 4. Running has the best result in evacuating lactic acid. However, result in the ice method is similar to running. **Key words:** RECOVERY, SYNERGIES, MONARK CYCLE ERGOMETER, THE HALS ALGORITHM, LACTIC ACID, ELECTROMYOGRAM SIGNAL

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INTRODUCTION

The recovery after exercise at the level of professional sport is very essential and has a great importance (Elena S et al., 2014). Muscles fatigue can decrease the ability of athletes during the competition (Manuel R. et al., 2016). Good recovery is one of the secrets of professional athletes, for this reason they can put their bodies under heavy training week to week and develop their abilities without dropping performance (Bishop A et al., 2008; Ingram J et al., 2009). However, determination of the best recovery after an anaerobic exercise is a challenge for professional athletes (Elena S et al., 2014). Athlete's ability to perform daily exercises depends on how the muscles have returned to normal mood after exercise. The main index to quantify the impact of a particular method of recovery is the level of lactic acid in the blood after the recovery (Draper n et al., 2006; Mori h et al., 2004). Nowadays, different methods of recovery are done by coaches, including: contrast bath and ice bath (Higgins TR et al., 2011), running with 50 % percent of heart rate (Lattier G et al.,2004), immersion methods (Ingram J et al., 2009) and massage (Mori h et al., 2004; Robertson A et al., 2004).

On the other hand, there are 2 aspects in recovery issue in previous studies namely: active recovery which 4 methods of it mentioned above and some dietary supplements are used to speed up muscles recovery such as: L-carnitinenutrient (Huang, A. and K. Owen. 2012).

These days, how body of human can organize its muscles to perform certain task like gait, which it is in turns one of major issue for researchers (Tresch MC, Jarc A 2009).

Muscles synergy patterns were extracted from EMG by using Non-Negative Matrix Factorization (Tresch MC J et al.,2006; Fre` re J, Hug F 2012) and HALS algorithm (Kaboodvand N et al.,2013; Koohestani, A et al.,2014; Cichocki A et al., 2007; Cichocki A et al., 2009) during daily activities.

MATERIALS AND METHODS

Participants

Ten active males volunteered to participate in this study. Six of them were member of professional teams (football, basketball and volleyball), four participated in individual sports (swimming, tennis, wrestling and sprint athletics) in premier league of Iran with average age 20±2. All the Participants were healthy without any sport's injury. These athletes were selected due to muscle mass after body composition test with BMI index of body (BMI was between 21.58 and 24) (Kyle UG et al., 2004).

Synergy

Muscle synergy is a coherent local and temporal activity from a set of muscles which are in relation to each other in order to sustain a special performance variable. Synergy includes two types of synchronous (constant Synergy and variable coefficients) and Asynchronous (variable synergy and constant coefficients). Synergy pattern can be used for functional electrical stimulus (Zhuang C et al., 2015). Each muscle performance will be divided into linear vectors, every moment, the sum of these vectors with specific coefficients Reconstruct electromyogram signal.

$$M(t) = \sum_{i=0}^{k} c(t)_i w_i \qquad 1$$

M represent the time-varying muscle activation pattern of involved muscles. $w_i$is the ith dimensional basis vector.$c(t)_i$ is the scalar activation coefficient for the ith basis vector. There is different method to extract muscles synergy patterns such as: Non-Negative Matrix Factorization and HALS algorithm (Kaboodvand N et al.,2013; Koohestani, A et al.,2014).

HALS algorithm

In this algorithm, there are some local cost functions. By minimizing the cost functions consecutively, based on the optimality conditions, the stationary points of local cost function can be estimated using the gradient of local cost functions as follows:

$$\nabla c_j D_f^j (M^j || C_j W_j^T) \geq 0 \qquad 2$$

$$\nabla w_j D_f^j (M^j || C_j W_j^T) \geq 0 \qquad 3$$

Where the gradient of the local cost function can be estimated as follows:

$$\nabla c_j D_f^j (M^j || C_j W_j^T) = \frac{\partial D_f^j (M^j || C_j W_j^T)}{\partial c_j} = C_j w C_j - M^j w_j \qquad 4$$

$$\nabla\, w_j D_f^j (M^j || C_j W_j^T) = \frac{\partial\, D_f^j (M^j || C_j W_j^T)}{\partial\, w_j} = C_j^T C_j w_j - M^j C_j \qquad 5$$

If it is assumed the C_j and w_j are positive number then the stationary points can be estimated using the update laws as follows:

$$W_j \leftarrow \frac{1}{C_j^T C_j} [M^{j^T} a_j] = \frac{1}{C_j^T C_j} MAX\{\varepsilon, M^j W_j\} \qquad 6$$

$$W_j \leftarrow \frac{1}{C_j^T C_j} [M^{j^T} a_j] = \frac{1}{C_j^T C_j} MAX\{\varepsilon, M^j W_j\} \qquad 7$$

Where ε is a small positive number, above update rules are known as the HALS algorithm was proposed by Chikokiet et al (Kaboodvand N et al.,2013; Koohestani, A et al.,2014; Cichocki A et al., 2007; Cichocki A et al., 2009).

Equipment

The equipment used in this study include: inbody 720 for body composition, Monark cycle ergometer, *treadmill Technogym*, scout and lancet needle for Measurement of blood lactate, Flexcomop recording device (this device can eliminate 50Hz noise with notch filter). Data were recorded with 4 Channels, sampling rate of 2048 bits per second by biograph infinit software. sEMG was recorded in the Laboratory of Sport Sciences Ferdowsi University of Mashhad.

Procedures

EMG data were collected from 4 muscles of the right foot include: Biceps femoris, rectus femoris, tibialis anterior, lateral gastrocnemius. 12 Ag/Agcl surface electrodes of 10 diameter were used to record sEMG (skin tact). Before beginning of the experiment the foot skin was cleaned with alcohol for better connection.

Step1: having been isolated for 2 days, athletes began warming up their leg muscles, having done this for 5 minutes (cycling at 1 W/kg and 70 rpm), each participate pedaled on the Monark cycle ergometer (brake weight was 0.075 of weight per person) for 30 seconds. After that participates were relaxed on a bed and received massage for 15 minutes by a professional sports Massagers, sEMG signals were recorded at the same time. Finally, blood lactate level were measured.

Step 2: having finished step1, after 2 days each participant warmed up their leg muscles for 5 minutes. (cycling at 1 W/kg and 70 rpm) They pedaled on the Monark cycle ergometer (brake weight was 0.075 of weight per person) for 30 seconds. Then they were running for 15 minutes on a treadmill with 50 to 60 percent of their heart rate. sEMG signals were recorded at the same time. Finally, blood lactate level were measured.

Step3: having finished step 2, after 2 days each participant warmed up their leg muscles for 5 minutes (cycling at 1 W/kg and 70 rpm). They pedaled on the Monark cycle ergometer (brake weight was 0.075 of weight per person) for 30 seconds. Then participants on the bed and ice templates were put on the above mention muscles. sEMG signals were recorded meanwhile. Finally, blood lactate level were measured.

The experiment was carried out 9 days. All of participate were in same condition and diet.

In all of steps the Flexcomop recording device fixed in a place close to the subject to avoid disruptions and artifact. In addition, slightly disruptions and artifacts can be eliminated by this recording device due to auto calibration.

Figure 1 indicates placement of electrodes.

Figure 1. Placement of electrodes.

Analysis

In the first step raw sEMG signals were band pass filtered (10–500 Hz), in the second step sEMG signal were rectified. In the third step signals were normalized to be in the range between zero and one, finally the signal was filtered by the low pass filter (with cut off frequency 20 Hz). Figure 2 shows these processes.

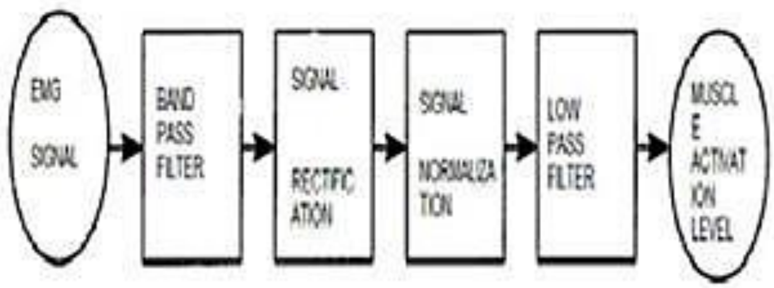

Figure 2. Analysis process

RESULTS

R^2 criteria were used to assess the synergy. R^2 represents the fraction of total variation accounted for by the synergy reconstruction. R^2 is obtained as follows:

$$R^2 = 1 - \frac{SSE}{SST} = 1 - \frac{\sum_s \sum_{k=1}^{k_j} ||m^j(t_k) - \sum_i c_i^j w_i(t_k - t_i^j)||^2}{\sum_s \sum_{k=1}^{k_j} ||m^s(t_k) - \bar{m}||^2} \qquad 8$$

Where SST is the sum of the squared residuals, and SST is the sum of the squared residual from the mean activation vector ($\bar{m}$). In this study, four Synergies were selected for leg muscles, because after four Synergies, R^2 was constant. (Kaboodvand N et al.,2013 ; Koohestani, A et al.,2014 D'Avella A et al., 2006).

Figure 3 illustrates the changes of R^2 against number of synergies.

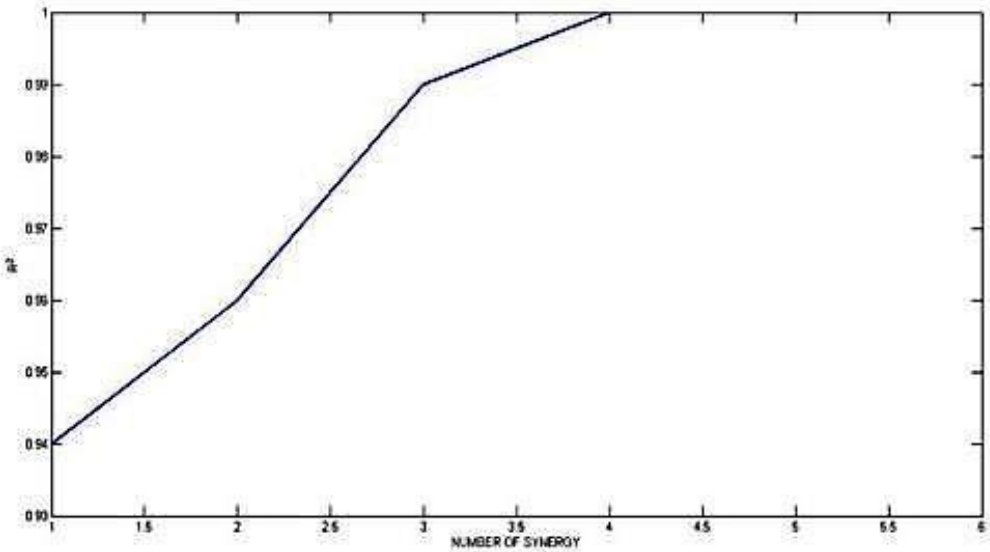

Figure 3. Changes of R2 against number of synergies

Table 1 illustrates MSE maximum errors between reconstructed signals and the original signals in 3 recoveries in all the 90 intervals. Maximum error in the all of subjects is 7.9×10^{-10}.

Table 1: MSE maximum errors between reconstructed signals and the original signals in 3 recoveries

Subject	massage recovery $\times 10^{-10}$	ice recovery $\times 10^{-10}$	running recovery $\times 10^{-10}$
1	6.2	7.9	3.19
2	5.79	6.8	6.9
3	5.9	4.9	6.13
4	1.9	7.3	2.67
5	2.8	4.71	5.75
6	1.69	3.41	3.43
7	6.4	4.01	5.09
8	6.3	3.08	6.91
9	6.7	3.18	4.09
10	4.19	5.17	5.29

Table 2 shows the results of the changes in lactic acid after 3 recoveries. According to the table, running recovery has the best results, although results in the ice method is very close to running recovery. The worst results have been shown in use of massage for recovery.

Table 2: results of the changes lactic acid after of 3 recoveries

subject	Before massage recovery	After massage recovery	Before ice recovery	After ice recovery	Before running recovery	After running recovery
1	12.6	10.5	12	6.9	12.9	5.4
2	10.5	8	11.5	6.4	13.8	6
3	13.7	11	13.5	8.1	13.9	6.5
4	9.7	7.6	10.5	6.6	10	4.1
5	13.4	11	11.2	6.5	13.4	5.6
6	14	11.7	11.9	6.7	13.3	5.5
7	13.4	11.2	11.4	6	12.7	4.8
8	12.2	10.1	11.1	6.1	13	5.1
9	14.8	12	12.6	6.4	15	7.3
10	13.7	11.3	12.7	6.7	12.6	4.7

In the next step, 10 second intervals in the sEMG signal were selected. In each interval the basis vectors and activation coefficients were estimated using HALS algorithm. The basis vectors in each interval were compared element to element with other intervals and errors were calculated. Subsequently in the massage recovery (due to high error) least errors, and in the ice and running recoveries (due to low error), maximum errors were listed in Table 3 (Standard deviation of maximum MSE error for all subjects are 4 for massage recovery and 6 for ice and running recoveries).

Table 3: MSE error in 3 recoveries

Subject	Least error in massage recovery	Maximum in ice recovery	Maximum in running recovery
1	17.8	0.07	0.02
2	16.71	0.09	0.03
3	14.78	0.01	0.08
4	21.79	0.05	0.07
5	114	0.04	0.11
6	12.69	0.06	0.06
7	4.24	0.09	0.13
8	16.49	0.18	0.03
9	15.4	0.08	0.04
10	12.77	0.17	0.09

As the results showed in the table, errors in ice and running recoveries were low, so the basis vectors of these recoveries in each interval were compared element to element and errors was calculated. The maximum error for each person listed in Table 4 (Standard deviation of maximum MSE error for all subjects is 6).

Table 4: MSE maximum error between running and ice recoveries

Subject	maximum MSE error
1	0.98
2	0.71
3	1.18
4	1.01
5	1.05
6	0.84
7	0.71
8	1.08
9	1.12
10	0.94

Basis vectors in each interval were compared element to element to measure the similarity between the basis vectors of each recovery in different subjects, then errors were calculated. Tables 5 and 6 demonstrate the maximum errors of different subjects in ice and running recoveries respectively.

Table 5: the maximum error of different subject in ice recovery

Subject	1	2	3	4	5	6	7	8	9	10
1	0	1.52	1.33	1.12	1.41	1.03	1.06	1.38	1.12	0.95
2	1.52	0	0.94	0.81	1.39	1.14	1.66	1.17	0.95	1.38
3	1.33	0.94	0	1.16	1.45	1.05	0.51	1.47	1.01	0.71
4	1.12	0.81	1.16	0	1.49	1.03	1.32	1.65	1.4	1.75
5	1.41	1.39	1.45	1.49	0	0.96	1.38	1.48	1.53	1.76
6	1.03	1.14	1.05	1.03	0.96	0	1.65	1.11	1.14	1.07
7	1.06	1.66	0.51	1.32	1.38	1.65	0	0.75	0.38	0.82
8	1.38	1.17	1.47	1.65	1.48	1.11	0.75	0	0.62	0.52
9	1.12	0.95	1.01	1.4	1.53	1.14	0.38	0.62	0	1.04
10	0.95	1.38	0.71	1.75	1.76	1.07	0.82	0.52	1.04	0

Table 6: the maximum error of different subject in running recovery

Subject	1	2	3	4	5	6	7	8	9	10
1	0	1.53	1.14	0.98	1.66	1.32	1.87	1.41	1.29	1.86
2	1.53	0	1.71	1.78	1.09	1.79	1.78	1.49	1.09	1.98
3	1.14	1.71	0	1.54	1.83	1.45	1.51	1.75	1.78	0.93
4	0.98	1.78	1.54	0	0.95	1.57	1.7	1.57	1.91	1.92
5	1.66	1.09	1.83	0.95	0	0.88	1.61	1.49	1.18	1.11
6	1.32	1.79	1.45	1.57	0.88	0	1.08	1.91	1.05	1.56
7	1.87	1.78	1.51	1.7	1.61	1.08	0	1.73	0.25	0.49
8	1.41	1.49	1.75	1.57	1.49	1.91	1.73	0	1.61	1.91
9	1.29	1.09	1.78	1.91	1.18	1.05	0.25	1.61	0	0.84
10	1.86	1.98	0.93	1.92	1.11	1.56	0.49	1.91	0.84	0

Table 7 shows the level of activity of 4 involved muscles in ice and running recoveries corresponding to each synergy pattern.

Table 7: the level of activity 4 involved muscles in ice recovery and running recovery

Synergy	lateral gastrocnemius in ice recovery	tibialis anterior in ice recovery	rectus femoris in ice recover	Biceps femoris in ice recovery	lateral gastrocnemius in running	tibialis anterior in running	rectus femorisin running	Biceps femoris in running
W1	0.03	1.82	0.02	1.82	0.05	3.6	0.03	3.6
w2	0.01	0.02	6	0.02	0.02	0.01	6	0.01
w3	3.54	0.01	0.01	0.01	0.76	0.99	0.01	0.99
w4	0.01	0.01	1.28	0.01	1.72	0.01	0.02	0.01

sEMG threshold (0.1 of the maximum amplitude of sEMG) was used to estimate percentage of activity of each muscle.

DISCUSSION

The main purpose of this study was to determine the best recovery among three types of them based on lactic acid (Draper n et al., 2006; Mori h et al., 2004), then achieve the proper muscle synergy patterns in each recovery and compare them. Firstly, the basis vectors and activation coefficients were extracted by using HALS algorithm. The reconstructed signals were compared with the respective original signals to ensure the accuracy of the analysis. Slight differences proved the accuracy of the analysis based on MSE. The basis vectors from each subject for each method of recovery in different intervals were compared and the results showed that in both ice and running recoveries, synergy patterns were existed because of low error between basis vectors, whereas there were not any synergy patterns in massage recovery due to high error between basis vectors. It is probably because there were no regular hand movement of the massager on the athlete's foot muscles. Mori et al showed massage enhancement of blood flow only in local regions (Mori h et al., 2004).

Matrices of synergy in ice recovery and running recovery in each subject were compared; maximum error was 1.2 and standard deviation was 6, so it can be claimed that two synergy patterns in an athlete is almost similar.

Maximum error between different subjects in ice recovery, running recovery and standard deviation were 1.77, 1.98 and 6 respectively, therefore athlete's foot muscle during a specific time almost used the same synergy patterns to return to the initial state.

In ice recovery, percentage of activity of lateral gastrocnemius, tibialis anterior, rectus femoris, Biceps femoris muscles were 95%, 89%, 95% and 97% respectively and coaction was 83%.

In running recovery percentage of activity of Lateral gastrocnemius, Tibialis anterior, Rectus femoris, Biceps femoris muscles were 54%, 54%, 80% and 50% respectively and coaction was 24 percentage.

As a result, percentage of muscle activity in ice recovery was more than running recovery, this can be due to fact that running recovery is an aerobic exercise by consuming oxygen, so it affects the blood circulation and evacuates lactic acid but ice recovery is an anaerobic exercise without consuming oxygen, therefore more percentage of muscle activity is expected to evacuate lactic acid in this method. According to this hypothesis

Robertson et al showed active mode of recovery is helped the football recovery faster in terms of systolic blood pressure as compared to the passive and massage recoveries. (Robertson et al., 2004)

The difference in the percentage of muscle activity were influenced coefficients matrix and did not have much impact on synergy matrix, this can justify the difference in signal level.

The main advantage of this work is combination between sport science and engineering owing to using synergy patterns to compare similarity between methods of recoveries. Up to now nobody has used synergy patterns to compare one task from different method.

In previous works similarity between methods of recoveries never has investigated. In former researches, recoveries were compared separately in other factors. For further explanation, Effect of massage on blood flow and muscle fatigue was investigated with factors include: Skin blood flow (SBF), muscle blood volume (MBV), skin temperature (ST), and subjects' subjective feelings of fatigue. This work indicated Lumbar massage administration appeared to have some effect on increasing skin temperature and enhancement of blood flow only in local regions. (Mori h et al., 2004). Muscle soreness ratings was main factor to assess effect of water immersion methods on post-exercise recovery from simulated team sport exercise. This work demonstrated that cold following exhaustive simulated team sports exercise offers greater recovery benefits than contrast water immersion.(Ingram J et al., 2009). In additional, some research illustrated Effectiveness of dietary supplements (Huang, A. and K. Owen. 2012) it should be investigated impact of active recovery and dietary supplements at the same time in future studies.

Previous studies have demonstrated that the central nervous system (CNS) makes use of muscle synergies as a neural strategy to simplify the control of a variety of movements by using a single pattern of neural command signal. So extracted synergy patterns of this study can be used in rehabilitation (C. Zhuang et al., 2015). That is to say, stimulation with specific patterns can be used instead of mentioned recovery because in some situation athletic cannot use these recovery, for example, in locker room between two half time of competition. As well as, stimulation in people with spinal cord injury in order to help to move, produce acid lactic so stimulation with these specific patterns can be used to evacuate acid lactic of muscles in these people.

CONCLUSION

Results showed that athlete's foot muscles in ice recovery and running recovery used the same patterns to refreshment.

The best method of recovery by lactic acid index was running but results of ice method were close to running which can be justified by little difference between the synergy matrices. In the future, researchers can use little pool (in this study only one leg has been in contact with the ice) and then measure difference between amount of lactic acid and synergy matrices in two methods of recovery.

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REFERENCES

1. Bishop, A., Jones, E., Woods, A. (2008). Recovery from Training: A Brief Review. *J Strength Cond Res.; 22*(3), 1015-24.
2. Cichocki, A., Zdunek, R., Amari, S.I. (2007). Hierarchical ALS Algorithms for Nonnegative Matrixand 3D Tensor Factorization. in ICA07, London, UK, September 9-12, Lecture Notes in *Computer Science, 4666*,169-176.
3. Cichocki, A., Zdunek, R., Phan, A.H., Amari, S. (2009). Nonnegative Matrix and Tensor Factorizations. John Wiley & Sons Ltd: Chichester, UK.
4. D'Avella, A., Portone, A., Fernandez, L., Lacquaniti, F. (2006). Control of fast-reaching Movements by Muscle synergy combinations. *J Neurosci., 26*(30), 7791-810.
5. Draper, N.L., Bird, E., Coleman, I., Hodgson, C. (2006). Effects of active recovery on lactate concentration, heart rate and RPE in climbing. *Sports Science and Medicine, 5*(1), 97–105.
6. Elena, S., Georgeta, N., Cecilia, G. (2014). Traditional and Modern Means of Recovery in Sports: Survey on a Sample of Athletes. *Social and Behavioral Sciences, 117*, 498-504.
7. Fre` re, J., Hug, F. (2012). Between-subject variability of muscle synergies during a complex motor skill. *Front. Comput. Neurosci., 6*:99.
8. Higgins, T.R., Heazlewood, I.T., Climstein, M. (2011). A Random Control Trial of Contrast Baths and Ice Baths for Recovery during Competition in U/20 Rugby Union. *Journal of Strength and Conditioning Research, 25*(4), 1046-51.
9. Huang, A. & Owen, K. (2012). Role of supplementary L-carnitine in exercise and exercise recovery. *Med Sport Sci., 59*, 135-42.
10. Hurst, P., Foad, A., Coleman, D., Beedie, C. (2016). Development and validation of the sports supplements beliefs scale. *Performance enhancement & health*. dx.doi.org/10.1016/j.peh.2016.10.001
11. Ingram, J., Dawson, B., Goodman, C., Wallman, K., Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise, *J. Sci. Med. Sport., 12*(3), 417-21.
12. Kaboodvand, N., Towhidkhah, F., Gharibzadeh, S. (2013). Extracting and study of synchronous muscle synergies during fast arm reaching movements. Biomedical Engineering (ICBME), 20th Iranian Conference on.
13. Koohestani, A., Kobravi, H., Koohestani, M. (2014). Identifying the muscle synergy pattern during human grasping. *Journal of Biomedical Engineering and Medical Imaging*, 33-39.
14. Kyle, U.G., Bosaeus, I., De Lorenzo, A.D., Deurenberg, P., Elia, M., Gómez, J.M. (2004). Bioelectrical impedance analysis part I: review of principles and methods. *Clin Nutr., 23*(5), 1226-43.
15. Lattier, G., Millet, G.Y., Martin, A., Martin, V. et al. (2004). Fatigue and recovery after high-intensity exercise. Part II: Recovery interventions. *Int. J. Sports. Med., 25*(7), 509-15.
16. Manuel, R., Tillaar, R., Pereira, A., Marquesa, M. (2016). The effect of fatigue and duration knowledge of exercise on kicking performance in soccer players. *Journal of Sport and Health Science*, 1–7.
17. Mori, H., Ohsawa, H., Tanaka, T.H., Taniwaki, E., Leisman, G., Nishijo, K. (2004). Effect of massage on blood flow and muscle fatigue following isometric lumbar exercise. *Med. Sci. Monit., 10*(5), CR173-8.
18. Robertson, A., Watt, J.M., Galloway, S.D. (2004). Effects of leg massage on recovery from high intensity cycling exercise. *Br. J. Sports. Med., 38*, 173-176.

19. Tresch, M.C., Cheung, V.C.K., d'Avella, A. (2006). Matrix factorization algorithms for the identification of synergies: evaluation on simulated and experimental data sets. *J. Neurophysiol., 95*, 2199 –212.
20. Tresch, M.C., Jarc, A. (2009). The case for and against muscle synergies. *Curr. Opin. Neurobiol., 19*, 601.
21. Zhuang, C., Marquez, J.C., Qu, H.E., x.He, N.Ln (2015). A neuromuscular electrical stimulation strategy based on muscle synergy for stroke rehabilitation Neural Engineering (NER), 7th International IEEE/EMBS Conference on, 10.1109/NER.2015.7146748.