Investigating the EEG Alpha Band during Kinesthetic and Visual Motor Imagery of the Spike Volleyball Movement

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Abstract— **Motor Imagery (MI) is the mental simulation of motor tasks and its execution may recover a motor planning in the central nervous system. The purpose of this study was to analyze the changes along trials of Motor Imagery (MI) in Kinesthetic (KMI) and Visual (VMI) modalities. The casuistry initially consisted of 15 right-handed male volleyball athletes (AG) and 18 non-athletes (NAG). By previously applying MIQ-R, 3 subjects from NAG were dismissed of the study due to their low questionnaire score. Both groups performed 30 trials of KMI and VMI of spike volleyball movement, intermixed with mental countdown (REF). The t-test ($\alpha = 0.05$) resulted in similar MIQ-R mean scores for both groups, although AG demonstrated greater facility to imagine the volleyball task than NAG. Each EEG free-artifact signal was subdivided in three sequences (S1, S2 and S3) with 8 epochs each. Wilcoxon paired tests ($\alpha = 0.05$) of the EEG power spectrum in the vicinity of alpha peak (ABP) suggests habituation during initial trial (S1) mainly for athletes. The comparisons between REF and KMI using the spectral F-test (SFT with $\alpha = 0.05$) indicates the left occipital (athletes) and parietal (non-athletes) sites as those in which $SFT>SFT_{crit}$. Based on such results, one can conclude that the KMI modality promotes more cortical changes than VMI, particularly for non-athletes. These findings suggest a different learning process of MI execution of repetitive sequences, related to previous knowledge of the real task.**

Keywords— **Motor Imagery, Kinesthetic and Visual, EEG, spectral F-test, spike volleyball movement.**

I. Introduction

The Motor imagery (MI) is the technique of mentally simulating a motor action, without the real execution of such movement[1]. It is already well established that mental training using MI can improve muscular force[2] and motor performance[3,4], constituting an important method to recover neuro-muscular disabilities[5]. Many techniques have been used to assess physiological changes during MI. One of them, the electroencephalogram (EEG), extensively applied in research of Brain Computer Interfaces[7], has the advantage of being a non-invasive technique which offers a good temporal resolution[6].

Usually, the cerebral activity investigation with MI paradigms in frequency domain is based on the mean power in EEG frequency bands[8-10], mainly in alpha band (8-13 Hz). The alpha activity may differ inter-individually according to inheritance[11], age[12], gender[13] and cognitive state[14]. This variation is more pronounced at the frequency where the maximum power contribution occurs, so called the alpha band peak (ABP).

There are basically two modalities do MI: the Visual Motor Imagery (VMI), which corresponds to one imagining himself executing a motor task as an spectator, and the Kinesthetic Motor Imagery (KMI), which generates sensations about the body position and joint movements[8]. Moreover, some studies have concluded that there is an association between cortical responses and different MI modalities[10,14].

Since the works concerning MI paradigm do not consider the inter-individual differences and previous knowledge of motor action, we hypothesize that athletes with previous knowledge of a complex motor action will execute the correspondent MI more easily than non-athletes. Such difference in MI performance would be reflected as changes in the frequency domain, more specifically in ABP of parietal and occipital areas, when a sequence of complex MI task is executed several times. Hence this work aims at investigating the existence of differences in alpha band power, focusing the frequencies around the alpha peak, during sequences of MI of the spike volleyball movement in athletes and non-athletes.

II. Material and mehotds

A. Casuistry

The casuistry consisted of 15 indoor-volleyball athletes (age 22.7 ± 2.3) (AG) and 18 subjects (age 27.3 ± 4.1) without experience in this sport (NAG). All volunteers signed a consent form containing the description of the purpose of the study and indicating the anonymity of the participants, answered a personal information questionnaire about athletic history, and indicated no neurological disturbs nor the use of drugs that could affect the cognitive performance. All subjects of both groups were right-handed males. This study was submitted and approved by ethical committee and the tests were carried out in the Laboratory of

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Table 1 p-values of Wilcoxon tests comparing the ABP between sequences during kinesthetic and visual motor imagery condition for all electrodes. The [*] indicate the comparisons where p < α

	KMI						VMI					
	Athletes			Non-athletes			Athletes			Non-athletes		
	S1 x S2	S1 x S3	S2 x S3	S1 x S2	S1 x S3	S2 x S3	S1 x S2	S1 x S3	S2 x S3	S1 x S2	S1 x S3	S2 x S3
O1	0.0479*	0.2293	0.4573	0.3591	0.4212	0.3894	0.3591	0.0256*	0.2293	0.0833	0.1876	0.8469
O2	0.0730	0.0833	0.1070	0.1688	0.5614	0.1876	0.1070	0.1514	0.4543	0.1070	0.5245	0.8040
P3	0.0215*	0.0256*	0.1688	0.8469	0.9341	0.1354	0.4543	0.0637	0.1876	0.5995	0.7197	0.3028
P4	0.0946	0.0479*	0.1688	0.0054*	0.8040	0.1070	0.0413*	0.0637	0.4543	0.5245	0.2524	0.5245

Cerebral Mapping and Motor Sensory Integration (Psychiatry Institute) and the Laboratory of Image and Signal Processing (Biomedical Engineering Program) both from Federal University of Rio de Janeiro.

B. Data Acquisition

Before carrying out the protocol, the Revised version of Movement Imagery Questionnaire[15] (MIQ-R), concerning body movements and their respective motor imagery in kinesthetic and visual modalities, was applied (version in Portuguese) to ensure that all subjects could see or feel mental images with a minimum of clearness. As exclusion criterion, the sum of scores in each imagery subscales below 15 yielded the exclusion of 3 subjects from NAG.

A 5-min video was played on a monitor for all subjects before the acquisition, showing the scene of an expert volleyball athlete during execution of several trials of spike volleyball movement task in different points of view, in order to demonstrate the attack movement.

The EEG signals were acquired according to the 10-20 international system[16] with BNT-36 electroencephalograph (EMSA – Rio de Janeiro), previously filtered with an anti-aliasing of 100 Hz and high-pass of 0.1 Hz, and sampled at 240 Hz (using digital 60 Hz notch filter), in three different conditions: reference condition (RC), kinesthetic motor imagery (KMI) and visual motor imagery (VMI). RC was composed of free mental countdown started at number 1000 during 90 s and was registered preceding MI conditions and in the final of experiment. KMI and VMI conditions have 30 target MI trials of volleyball spike randomly intermixed with 20 trials of hand clapping in kinesthetic and visual motor imagery respectively. The start of each trial was triggered by a beep with one of two tonalities to indicate the task to be imagined (volleyball spike or hand-clapping), preceded by a preparation beep presented 2 s before. This procedure was applied to avoid the subjects to anticipate the MI executions before the trigger sounds. After the end of KC and VC all subjects indicated the imagery clearness of each condition block using the respective MIQ-R subscales.

The acquired signals were segmented into 5-s epochs synchronized with the start trigger of KMI and VMI. The artifacts were removed by means of an adapted algorithm[17], resulting in 24 artifact-free epochs. In order to assign changes in ABP along epochs, the set of 24 epochs was sequentially divided into three segments (S1, S2 and S3) with 8 epochs each one and the periodogram technique was implemented with epochs equally subdivided in five windows of 1 s (spectral resolution of 1 Hz). Aiming at minimizing the inter-individual alpha peak variability (frequency of maximal contribution of band power), the power was calculated within a narrow band of 2 Hz (ABP) centered in alpha peak. The results of multiple Wilcoxon (paired, non-parametric) tests ($\alpha = 0.05$) are shown in the Table 1 and indicates changes in ABP during initial epochs. Hence, the 8 first epochs of each experimental block for all electrodes were eliminated from subsequent signal analysis.

To check differences between MI modalities and groups of the signals, the spectral F-test (SFT) has been implemented. The $SFT(f)$ is a statistical test that compares the PSD of two distinct signals, specifically their power contribution in each frequency. Considering two Gaussian and independent signals $x[t]$ and $y[t]$, and their respective PSD $P_{xx}(f)$ and $P_{yy}(f)$, where M_x and M_y are the numbers of epochs, the $SFT(f)$ is expressed as[18]:

$$SFT(f) = \frac{\hat{P}_{xx}(f)}{\hat{P}_{yy}(f)} = \frac{\frac{1}{M_x}\sum_{m=1}^{M_x}\left|\tilde{X}_m(f)\right|^2}{\frac{1}{M_y}\sum_{m=1}^{M_y}\left|\tilde{Y}_m(f)\right|^2} \quad (1)$$

where $\tilde{X}_m(f)$ and $\tilde{Y}_m(f)$ correspond to PSD of the m-th epoch. From equation 1, the $SFT(f)$ has $2M_x$, $2M_y$ degrees of freedom. Hence, the null hypothesis (H_0) of equality of the power in some frequency can be assessed with the critical value of $SFT(f)$, described in other study[17] and defined as:

$$SFT_{Crit} = F_{2M,2M,\alpha} \quad (2)$$

where $M = M_x = M_y$ and α is the level of significance. Applying this on the 16 epochs (5 windows each) of EEG, then

$M = 80$, and considering $\alpha = 0.05$ $SFT_{Crit} = 1.3045$ ($SFT_{Crit} = 1.4018$ after the *Bonferroni* correction). MIQ-R scores and vividness during experiment were analyzed with simple (inter-groups) and paired (intra-groups) Student t-test ($\alpha = 0.05$). The differences in ABP between S1, S2 and S3 were assessed using the Wilcoxon (paired, non-parametric) test ($\alpha = 0.05$).

III. Results

While the t-test indicated no statistical differences in MIQ-R mean scores between groups or MI modalities, the comparison of volleyball MI cleareness indicated that athletes imagine themselves more clearly than non-athletes during the MI of volleyball attack (*p groups*) as appointed in the Table 2. The intra-group comparison (*p modalities*) indicated no significant differences in clearness between MI modalities for both groups.

Observing the Figure 1, one can notice the differences in the frequency of alpha peak between the power spectrum of non-athlete #9 (11 Hz) and the athlete #1 (10 Hz). Changes in ABP occurred between RC, KMI and VMI. These alterations are presented in gray areas of (a) and (c), whilst statistically significant differences ($\alpha = 0.05$) based on the results of the respective *SFT*(*f*) are shown in (b) and (d).

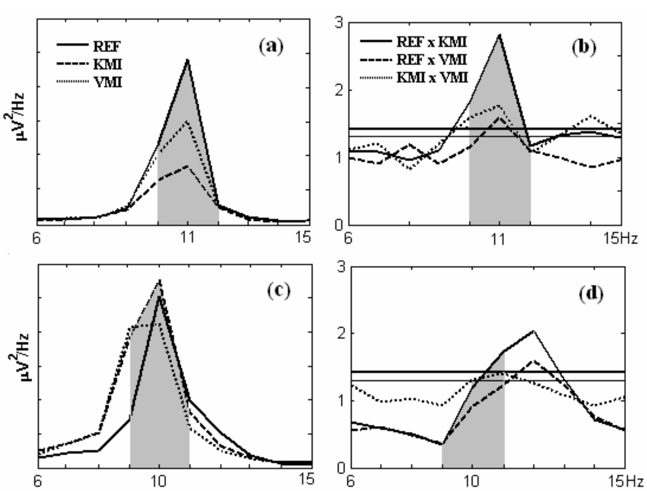

Fig. 1 Power Spectral Density (in arbitrary scale of power) and *SFT*(*f*) from non-athlete #9 [a,b] and athlete #1 [c,d] both in O1 site. The horizontal thin line is the *SFTcrit* and the thick one is the *SFTcrit* with *Bonferroni* correction to ABP (grey areas)

The percentage of subjects where $SFT > SFT_{crit}$ in the comparison between the three experimental conditions for AG and NAG is summarized on the Table 3. It is possible to observe a great number of subjects with significant differences in O1 of athletes. In parietal sites of non-athletes the comparison between RC and KMI and between KMI and VMI also demonstrates a high number of subjects with power differences.

Table 2 Mean scores, statistical analysis inter groups and inter modalities of MIQ-R and MI clereness of Spike Volleyball

	MIQ-R			MI Clereness		
	KMI	VMI	*p modalities*	KMI	VMI	*p modalities*
AG	21.73	23.67	0.22	6.00	5.60	0.25
NAG	20.79	21.14	0.84	4.20	4.47	0.63
p groups	0.53	0.10		<0.01	0.04	

Table 3 Percentage of subjects where $SFT>SFT_{crit}$ in ABP, comparing the three experimental conditions to both groups

	Athletes			Non-athletes		
	REFxKMI	REFxVMI	KMIxVMI	REFxKMI	REFxVMI	KMIxVMI
O1	80,0	66,7	46,7	73,3	66,7	66,7
O2	73,3	60,0	60,0	66,7	53,3	73,3
P3	73,3	66,7	66,7	86,7	73,3	86,7
P4	73,3	53,3	60,0	80,0	53,3	80,0

IV. Discussion

The MIQ-R is composed of real execution and mental simulation in kinesthetic and visual MI of motor tasks such as bending and extending the knee in stand position and complex movement like jumping with both hands up, which is similar to some part of volleyball spike movement. Considering that MIQ-R have unfamiliar movements for both groups, there is no significant difference in MIQ-R scores between them. Nevertheless, the AG scores were slightly higher than those for NAG. Since a high level of motor skill is demanded from athletes when executing the volleyball movements during the real training sessions and matches, when compared with unexperient subjects (who declared to perform no complex task in their quotidian life), an increase in the number of subjects may statistically confirm that athletes tend to be better imaginers than non-athletes. During the experimental MI blocks, significant differences were found in clearness score of MI modalities of spike volleyball movement, statistically stronger in KMI, with athletes imagining more easily than non-athletes. This response is presumably because volleyball athletes execute this specific movement exhaustingly, which implies in a solid planning of the motor action.

Regarding the time evolution of the study, no significant differences have been found between segments S2 and S3 in any derivation neither in any group. Although there were cases (derivations or groups, in both MI modalities) where no difference in ABP could be inferred throughout the whole experiment, whenever a difference has been achieved it occurred between S1 and S2 or between S1 and S3. This finding, although is not confirmative, at least suggests some level of habituation in the beginning of the experiment, more pronouncedly in athletes. It could be interpreted as a learning process along the sequences of MI, which become easier to execute, specifically in the subjects, who have long experience in real practice of the imagined task.

The spectral F-test ($\alpha = 0.05$) of subsequent trials appointed a great number of subjects who showed $SFT > SFT_{Crit}$ in left occipital site for athletes and left parietal sites for non-athletes in the comparisons between REF and KMI. This modality of MI promotes more cortical changes than VMI specifically for non-athletes as appointed in similar study[8], since the non-athletes have not yet retrieved the planning of the volleyball spike movement.

V. CONCLUSIONS

According to these results, the sequential execution of motor imagery of complex tasks, such as the volleyball spike movement, promotes changes in occipital and parietal areas differentially in kinesthetic and visual modalities, exhibiting a temporal adaption of the responses, which may indicate a habituation caused by the learning process of motor imagery. Such process occurs more quickly with athletes than with non-athletes, and is reflected by the mean alpha power (within the vicinity of alpha peak), which is associated to the knowledge of real task execution and the modality of motor imagery executed. Further studies using different statistical techniques and protocols to analyze the behavior of alpha power during motor imagery must be conducted in order to support these results.

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REFERENCES

1. Gentilli R, Papaxanthis C, Pozzo T (2006) Improvement and generalization of arm motor performance through motor imagery practice. Neuroscience 137:761-772
2. Ranganathan VK, Sieminow V, Liu JZ et al. (2004) From mental power to muscle power – gaining strength by using the mind Neuropsychologia 42:944-956
3. Hall JC (2002) Imagery practice and the development of surgical skills Am J Surg 184:465-470
4. Roure R, Collet C, Deschaumes-Molinaro C et al. (1999) Imagery quality estimated by autonomic response is correlated to sporting performance enhancement Physiol Behav 66:63-72
5. Dickstein R, Dunsky A, Marcovitz E (2004) Gait performance may be enhanced by use of motor imagery in mental practice of motor tasks in people with hemiparesis following a stroke Phys Ther 84:1167-1177
6. Cochin S, Barthelemy C, Roux S et al (1999) Observation and execution of movement: similarities demonstrated by quantified electroencephalography Eur J Neurosci 11:1839-1842
7. Neuper C, Shcherer R, Reiner M et al (2005) Imagery of motor actions: Differential effects of kinesthetic and visual-motor mode of imagery in single trial EEG Cogn Brain Res 25:668-677
8. Cremades JG (2002) The effects of imagery perspective as a function of skill level on alpha activity Int J Psychophysiol 43:261-271
9. Marks DF, Isaac AR (1995) Topographical distribution of EEG activity accompanying visual and motor imagery in vivid and non-vivid imagers. (electroencephalographic activity) (Imagery and Motor Processes). Brit J Psychol 86:271-282
10. Stecklow MV, Infantosi AFC, Cagy M (2007) Alterações da banda alfa do eletrencefalograma durante imagética motora visual e cinestésica Arq Neuropsiquiatr 65:1084-1088
11. Smit CM, Wright MJ, Hansell NK et al (2006) Genetic variation of individual alpha frequency (IAF) and alpha power in a large adolescent twin sample Int J Psychophysiol 61:235-243
12. Böttger D, Herrmann CS, Cramon DY (2002) Amplitude differences of evoked alpha and gamma oscillations in two different age groups Int J Psychophysiol 45:245-251
13. Clark CR, Veltmeyer MD, Hamilton RJ et al (2004) Spontaneous alpha peak frequency predicts working memory performance across the age span Int J Psychophysiol 53:1-9
14. Sirigu A, Duhamel JR. (2001) Motor and visual imagery as two complementary and neurally dissociable mental processes J Cognitive Neurosci 13:910-919
15. Hall CR, Martin KA (1997) Measuring movement imagery abilities: A revision of movement imagery questionnaire J Ment Imagery 21:143-154
16. Jasper HH (1958) The ten twenty electrode system of International Federation. Electroen Clin Neuro 10:917-975
17. Tierra-Criollo CJ, Infantosi AFC (2006) Low-frequency oscillations in human tibial somatosensory evoked potentials Arq Neuropsiquiatr 64:402-406
18. Tierra-Criollo CJ, Simpson DM, Infantosi AFC (1998) Detección objetiva de las respuestas evocadas en el EEG con la prueba espectral F ponderada Memorias del 1er Congresso Latinoamericano de Ingenieria Biomédica, Matzalán, Mexico, 1998, pp 151-154

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