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Electroencephalography Measurement to Compare Visual and Kinesthetic Motor Imagery of Squat Vertical Jump

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Abstract

Background: Motor imagery is a form of mental representation of action without any apparent movement. It can be performed in two modalities kinesthetic and visual motor imagery. Although there is ample evidence that motor imagery share many features of real action, such as the similar solicited cerebral region, it is still unknown whether visual motor imagery and kinesthetic motor imagery recruit comparable or distinct neural networks.

Objective: The purpose of this study is to compare the relationship between the two imagery modalities: visual (external) and kinesthetic imagery during a complex motor task; squat vertical jump, by means of electroencephalogram brain wave activity, and to determine if these two modalities demonstrated different topographic patterns of brain activation.

Method: The electroencephalography signals were acquired during sequences of MI squat vertical jump in kinesthetic and visual modalities and also in control condition. Twenty healthy subjects (10 males and 10 females) participated in this study. The event-related-potential approach to the electroencephalography data was applied to investigate where the movements-related potential in alpha power were localized.

Electroencephalography alpha rhythms from the occipital and sensorimotor regions of the brain were analyzed. Results: Imagery rehearsal of motor performance result in a change of brain rhythm activity especially in alpha rhythm. Moreover, the focus of activity during kinesthetic imagery was found close to the sensorimotor area (74%), whereas visual–motor imagery produce greater relative occipital, parietal-occipital activation (75%) than sensorimotor activation (24%).

Conclusion: In summary, the present findings confirm previous studies that motor imagery can be used to produce movement-specific and locally restricted patterns of the oscillatory brain activity

Keywords: Motor imagery; Kinesthetic imagery; Visual imagery; EEG; Alpha band; Squat vertical jump, ERPs.

Introduction

Motor imagery, based on mental images, is a mental rehearsal of movement [1] performed within working memory [2] without any overt movement or apparent muscle contraction [3] and it involves the whole body (e.g. walking), or it is limited to a body part (e.g. grasping) [2]. It can be virtually experienced by everyone with minimal training, in many situations of everyday life, such as preparing or intending to move, watching somebody's action with the desire to imitate it, refraining from moving, or remembering an action [4]. Motor imagery and real execution of action share many behavioral and cerebral determinant similarities [5], and also induces similar measurable changes in scalp-recorded electroencephalograph [6], and solicited a similar brain network [7]. Motor imagery can be performed in either a visual or kinesthetic and from a first- person (i.e. feeling the movement of one's body) or third-person perspective (i.e. seeing someone else move) [8]. Despite the earlier accumulated evidence which demonstrates the similarities in the recruited neural substrate between MI and real action little is known about the different neural network specific to each modalities [9]. The EEG is a non-invasive medical imaging techniques that reads scalp the electrical activity generated by brain structures [10]. Motor imagery of movement either in whole body or in part of the body induces different EEG pattern that are concentrated in different brain region depending on the part of body imaged moving [11]. EEG studies of motor imagery are mainly based on the alpha frequency band (8-13 Hz) [12]. The two modalities of MI, either visual-motor imagery or kinesthetic motor imagery [13] and also action observation of biological movement [14] provokes similar brain oscillations on mu and beta frequency bands [15]. Several studies have attempted to explore the brain activation during this two modalities using different techniques of neuroimaging such as FMRI [9,16] and electroencephalogram (EEG) [12,17] time response paradigm [18], for simples and complex tasks [12], in novel and skilled subjects [19]. Thus the aim of this study is to compare the relationship between the two imagery modalities, visual (external perspective) and kinesthetic motor imagery, for a complex motor task squat vertical jump by means of EEG brain wave activity and to determine if this two modalities demonstrated different topographic patterns of brain activation.

Methods

Participants

Twenty healthy volunteers (10 males, 10 females, age range 20-40 years old) recruited from AZM center for research in biotechnology at the Lebanese University participated in this study. All participants are healthy, have a normal or corrected vision and have a good score (>38) of MIQ-Rs test and all have the same physical state (non-athlete). They received written experimental instructions, and signed an informed consent before starting the experiment. Participants are also naïve to the purpose of the experiment, and they don't have any previous experience in motor imagery Subjects with any neurological or psychiatric disorder are excluded from the study.

Experimental tasks and procedure

Subjects were required to mentally rehearse the task of Squat Vertical Jump (SVJ). The jump consisted in classical maximal SVJ, i.e..parallel feet, heels on the ground, separated as wide as the shoulders, knees bent at 90°, hands on hips during the whole jump executed without any noticeable countermovement [20].

During the experiment, the participants were sitting comfortably with closed eyes in a silent room. To minimize participant's movements during imaging exercises, they were asked to keep their arms on the armrest and to stay as relaxed and motionless as possible. Before the EEG acquisition, a video that shows a subject during execution of several trials of squat vertical jump in different points of view displayed on a monitor for all subjects in order to demonstrate the correct execution of task. Subjects are required to minimize distractions as much as possible. They were asked to maintain a stable body position, teeth bites and head movements during the experiment. Possible sources of distraction or noise, such as sound or light, are minimized. Before each task condition, participants have taken all the verbal instructions about the experiment, and they have practice a number of trials until they felt confident enough that they could perform the respective task. The experimental procedure is composed of the control condition, two imagery tasks, and rest condition. The control condition (CON) was composed of unitary mental countdown that starts at number 1000 during 90s and were registered preceding MI conditions. This counting task aimed to maintain a standard mental engagement for all volunteers, which would be difficult to achieve if the subjects were requested not to think in anything. KMI of vertical jump: subjects were instructed to imagine themselves jump. They were asked to imagine the kinesthetic experience of movement while their arm rested relaxed on the armrest. and avoiding muscle tension. VMI of vertical jump: subjects were asked to create a mental video of the movements of the vertical jump watched previously. In the rest phase subjects were asked to stay motionless and relax. The three conditions were performed in separate blocks; with the presentation order is counterbalanced across subjects. The experimental protocol was divided into two sequences that differ by the order of modalities. Then the subject chooses randomly the sequence to perform firstly. Experience begins with a preparation phase for 2 seconds, and then the subject is asked to start the control condition when he hears the GO signal and stops when he hears the STOP signal. Then 2s after, another GO signal is given to inform the subject the start of the imagery exercise for 10s and he stops when he hears the signal STOP, trial is repeated 20 times. Then subject starts with the other modality of imagery 20 trials for 10s each and begins when he hears the GO and stops when he heard the STOP signal. The two types of motor imagery are separated by a rest phase for 20 s. In each condition the EEG recording starts 4s after the subject hears the GO signal. Subjects have controlled by themselves the length of the inter-trial rest period i.e., they started the next trial when they feel comfortable and completely rested. The inter-trial period varied randomly between 0.5 and 2.5s (Figure 1).

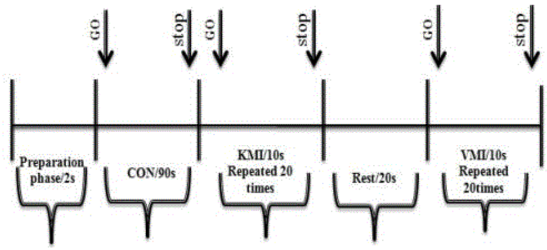

Figure 1: Experimental paradigm.

EEG recordings and preprocessing

Continuous EEG signals were recorded from 32 scalp sites (water based electrodes, extended 10–20 system) using an electrode cap fitted to the subject's head. The EEG signal collected from the scalp is guided to the PC via an optic fiber system to minimize the impact of noise and motion. Then the signals are saved on the PC using Open-Vibe software. The EEG recordings were band-pass filtered from 8 to13 Hz using a finite impulse response (FIR) filter. The data were processed in Mat lab 7 (Math Works, Natick, MA) using scripts based on EEGLAB 4.51 (EEGLAB toolbox for single trial data analysis, Swartz Center for Computational Neurosciences, La Jolla, CA; http://www.sccn.ucsd.edu/eeglab), as well as a dedicated home-made code are created for this study. Signal processing

In a first step of analysis, the EEG data were subjected to ERP time–frequency analysis for purpose of convenient data inspection. For this goal two electrodes were selected from each lobe, from sensorimotor area the central electrodes (C3-C4) were chosen, from occipital (O1-O2), from parieto occipital (PO3-PO4), from temporal (T7-T8), then we calculate the time frequency analysis for each channel in the two imagery modes (KMI and VMI).Then the visual inspection of the individual topographic maps in two conditions (KMI and VMI) is done. Visual inspection of the individual topographic map is done to show the changes in cerebral activity for each subject in the alpha ranges in sensorimotor area (frontocentral, central,Centro- parietal), occipital area (O1 O2), and parieto occipital area (PO3-PO4) and maps for all the subjects were computed. The MIQ-Rs scores before experiment were analyzed with paired- samples (intra-groups) student t-test.

Results

No statistical differences were found in MIQ-R mean scores between MI modalities as indicated in t-test scores of Table 1. The box plot (Figure 2) confirms this result and shows that the values of MIQ-Rs are in the same range. Table 2 shows the percentage of activation in sensor motor and occipital areas during the 2 imaging modalities. The

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data collected over the two ERP signals for KMI and KMI in a time period of 10s cut into 9 intervals of 1 s each, in each interval 15 maps chosen at different times and we registered the lobes in which the activity is localized according to the active electrode .For this purpose we employed from all the pairs of electrodes, 8 electrodes from sensotimotor area FC5, FC1, C3, CP1 (from left hemisphere), FC2, FC6, C4 and CP2 (from right hemisphere) and 4 electrodes from occipitals and parieto-occipital area O1, PO3 (from left hemisphere), O2, PO4 (from right hemisphere).The results shows that the signal in the ERPs KMI have greater percentage of activation in sensorimotor lobes (74.1%) than that attained in the occipital and parieto-occipitales lobes (25.8%).And vice versa for the ERP signal in the VMI, there is a greater activity in the occipital lobes (75.1%) than those found the central lobes (24.8%). Visual inspection of the individual ERP time-frequency maps revealed event-related EEG changes in alpha frequency bands, which differed dependent on the experimental task.

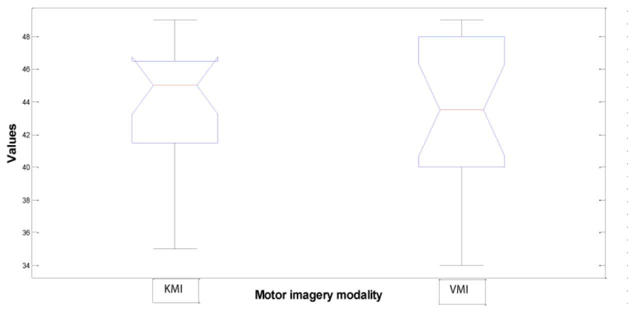

Figure 2: Box plot for the values distribution of average of MIQ-Rs test in kinesthetic motor imagery (left) and visual motor imagery (right).

	Kinesthetic	Visual	P-value
Mean	43.85	43.5	0.5796
SD	4.25	4.76	

Table 1: MIQ-RS mean score.

Subjects	KMI		VMI	
	Sensorimoto Activation	Occipital + parietoccipital Activation	Sensorimoto Activation	Occipital+ parietoccipital Activation
S1	98	37	28	107
S2	99	36	29	106
S3	104	31	39	96
S4	99	36	29	106
S5	104	31	34	101
S6	95	40	33	102
S7	91	44	32	103
S8	100	35	40	95
S9	100	35	37	98
S10	96	39	34	101
S11	99	36	36	99
S12	102	33	36	99
S13	102	34	39	96
S14	99	36	34	101
S15	104	31	39	96
S16	98	37	27	108
S17	103	32	37	98
S18	105	30	32	103
S19	100	35	27	108
S20	104	31	30	105
Mean	100.05	34.95	33.6	101.4
Percentage	74.1%	25.88%	24.88%	75.1%

Table 2: Percentage of topographic activity in central area (FC5-FC1-C3-C4-CP-CP) vs. occipital and parietooccipital area (O1-O2-PO3-PO4) in KMI and VMI.

Table 3 illustrates the energy peak in frequency spectrum reached in twenty subjects during the kinesthetic and visual imaging. No statistical difference (p>0.63) was demonstrated in the energy peak between these two types of imagery modalities for the same subject. This is proved by the box plot (Figure 3) which shows the distribution of the 20 average peak of energy of frequency signal is in the same marge.

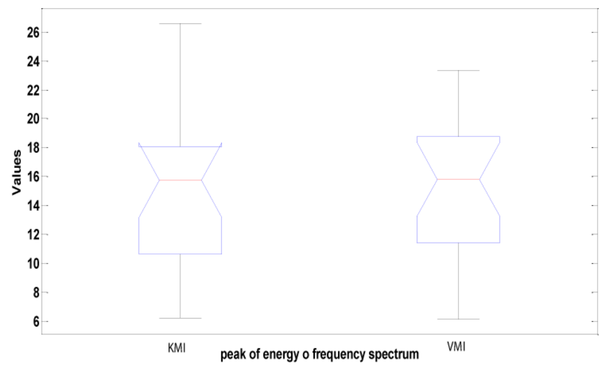

Figure 3: Box plot for the values distribution of average of peak of energy of frequency spectrum in kinesthetic motor imagery (left) and visual motor imagery (right).

Figure 4 illustrated the averaged time frequency maps. That shown clear differences between kinesthetic (KMI) and visual–motor imagery (VMI): The analysis of time-frequency domain showed that KMI has energy on channel C3 across the spectrum with a power that reaches 2dB. The same for channel C4 where there is energy in the spectrum (1s to 9s) but reached power is slightly inferior to that seen on C3. The energy on the two channels O1-O2 is very inferior to those found on

C3-C4 and it reached max 1dB. Whereas in VMI we see a great energy on channel O1 O2 reaching a max of 2dB. This energy is more prevalent at the beginning (1s-3s) and end time (7s -9s) comparing to that detected on channel C3 C4 with max power is 1 dB. For the energy on channel PO3 PO4 in both imaging modalities we found energies that are close but not in all the spectrum and reaching a maximum power of 2.5 dB to 3 dB for KMI and VMI. These energies localized in the middle and the end of time. For Channel T7 T8 we noticed an energy but inferior to those of C3 and C4 for KMI and to O1 O2 for VMI localized mainly at the beginning of time with max power of 2.5 dB. All energies are taken in the alpha band between 8 and 13 Hz.

The maps (Figure 5) show the topography of activation over all subjects, which have been plotted at the corresponding electrode positions. Red areas indicate most relevant electrode positions for the recognition of the respective task, whereas recording locations coded in blue did not provide essential information. The results show that electrodes overlying approximately in the sensorimotor area (close to position C3-C4) provided the most activity during the recognition of the kinesthetic motor imagery (KMI) task. For the visual motor imagery highest activity is reached for electrodes overlying the occipital cortical areas (channels O1 and O2), parieto-occipital areas (PO3- PO4), and temporal area (T7-T8).

Subjects/ modalities	KMI	VMI	
S1	14.9	16.22	
S2	6.201	6.114	
S3	10.51	8.13	
S4	17.91	17.55	
S5	19.51	18.69	
S6	18.21	19.74	
S7	15.79	16.08	
S8	10.49	10.69	
S9	10.24	10	
S10	12.73	15.67	
S11	10.76	12.89	
S12	19.92	18.83	
S13	15.68	15.13	
S14	10.34	9.32	
S15	10.34	9.32	
S16	12.39	12.16	
S17	23.59	21.31	
S18	16.96	19.22	
S19	17.41	14.7	
S20	17.87	15.92	P=0.63

Table 3: Peak of energy of frequency spectrum in KMI and VMI.

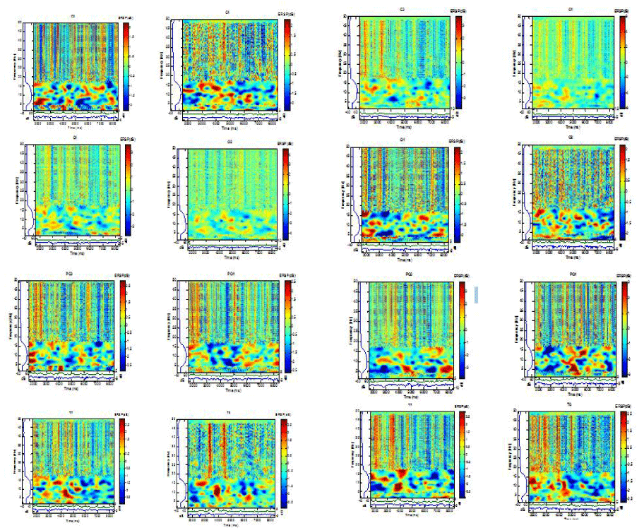

Figure 4: Averag ed time -frequency domain registered on electrodes C3-C4 ,O1-O2, PO3-PO4,T7-T8, for 20 trials of kinesthetic imagery and 20 trials for visual imagery of squat vertical jump. The display of the set point movement takes place from 1 to 9 seconds, Energy density distributions in μ (8-13HZ). EEG bands. Horizontal scale: time in seconds, vertical scale frequency in Hz.

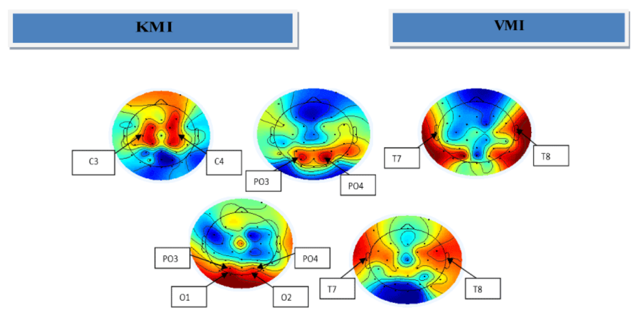

Figure 5: Topographic maps showing the cerebral activation. Grand average maps of ERP in alpha bands during motor imagery. Above: KMI modality-below: VMI modality.

Discussion

The aim of our study was to compare the brain activation in both imaging modalities of a vertical squat jump in a complex task with multiple components via EEG using 32 water based electrodes on subjects (male and female), adults (20-40) and novel with no previous experience of motor imagery. The MIQ-Rs contains the mental simulation of action in both models preceded by real execution of this action, which includes 7 tasks that can be simple and complex. Subjects considered as good imagers have a score between 42 and 50 or those who are considered as poor imagers have a score between 27 and 46 [21]. The recruited subjects are considered moderate to good imagers with MIQ-RS score between 38.6 to 45.7. Thus the subjects have the same vividness for both methods when no significant difference is obtained between the two modalities (p>0.5796). The same for the peak of energy for this two modalities for the same subjects no significant difference was shown (p>0.6). Our study shows that each type of MI strategy either kinesthetic or visual induced distinct and specific patterns of EEG cortical activation, with respect of the variation in the same frequency band. The results shows for the KMI modality, that the activation percentage in sensorimotor zones (78.5%) is greater than in the occipital lobes (24%) and this is confirmed by the time-frequency domains analysis where one finds a remarkably activity higher than the detected activity over the parietal and temporal channels and minimal activity in the occipitals channels is noticed. This leads to say that during the KMI of vertical squat jump a bilateral activation (right and left) provoked in sensorimotor lobes and parietal lobes that are related to the representation of space and body scheme and visuo-spatial aspects, of movements, visuo-motor mapping [22]. In addition to temporal lobes activations that are included in memory [23]. For VMI modality the results show that the percentage of activation in occipital lobes is higher than that in sensorimotor lobes and the time- frequency analysis confirm the results which show activations in occipitals and parieto-occipital lobes larger than the activity in sensorimotor one .So the visual imagery activates bilaterally the occipital lobes parietal and temporal lobes. Our study confirmed other studies that have been achieved to compare the cerebral activation during imaging exercise in both modalities for simple and complex tasks, in novices or killed subjects with good or poor imagery abilities [19], in athletes, hemiplegic [5] and medullary injured [16,24], using several techniques of brain imaging such as FMRI, BCI based on EEG [24]. Most research and FMRI studies shows that the KMI modality recruit the similar sensory and motor areas to those activated during actual execution of the action [25]. Neuper et al. demonstrates. in his study on imagery of hand grip, when KMI is involved the sensorimotor area are primordially activated [19] or the VMI modality and visual stimulation share similar cortical activated regions that are concerned in the visual processing [17], on another EEG study, Neuper et al. demonstrates that it is difficult to decide whether the visual-motor imagery rather involved somatomotor or visual representations [20]. Lacourse et al demonstrates that during imagination of finger movement, upper alpha or mu frequency component (8-13 Hz) have higher significance compared to the beta range [19], another study on complex motor task (spike volleyball movement) shown that both modalities VMI and KMI promotes cortical changes reflected in mean alpha power [12]. These result suggest that each of its two imagery modalities have its own solicited neural system, which contributes to the distinct use of each of its modalities in field of motor learning and neurorehabilitation. Literature shows that the effectiveness of each of its two modalities different depending on the task to practice, where studies have demonstrate that the kinesthetic motor imagery may be more effective for tasks requiring more motor control, motor or visual imagery gives more results necessitate tasks in a reproduction of a form [17]. Research on the effect of imagery on performance has found that the use of kinesthetic imagery may positively impact on athletic learning and performance. Further, kinesthetic imagery is considered particularly important when form of movement is the desired performance outcome [26]. In addition, a study shows that KI modulates the body sway, or visual imagery does not show a significant effect on the body sway [27]. Another study shown that the kinesthetic Motor Imagery (KMI) of phasic thumb movement task provoke a muscle specific and temporally modulated facilitation of the cortico-spinal pathway but visual strategy does not [28]. A critical issue of this study, where the experimental methodology is only based on instructions given for the subjects, which cannot ensure the compliance of the subjects, in addition this compliance may varies between individuals, since it depends on the own individuals characteristics, and this can cause confusion between the two perspectives (internal external) in the subject. Another potential limitation is the absence of EMG control during the imagery task that can provide the excluding of any parasite muscle contraction caused by the subjects and can affect the EEG recording.

Conclusion

Our study demonstrated that during the motor imagery of a squat vertical jump, the KMI led mainly to a sensorimotor activation versus a greater activation in occipital area obtained during VMI. In summary, the present findings confirm previous studies that motor imagery can be used to produce movement-specific and locally restricted patterns of the oscillatory brain activity, and shows that the KMI and VMI activate a different neural substrate that contributes to the use each of this modalities in different purpose of neurorehabilitation, learning, improving performance in athletes but this study is limited to a healthy and not athlete population, the need for more studies in the future working on athletes or patients to confirm this hypothesis.

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