SYNERGY PATTERNS OF BRAIN ACTIVITY DURING LEARNING OF THE DART THROWING SKILL WITH THE DOMINANT AND NON-DOMINANT HAND

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ABSTRACT

The mechanism and neural origin of the differences between the two hands in motor control and learning are still unknown. The aim of the present research is to examine the changes in synergy patterns in different brain regions while learning the dart throwing skill with the dominant and non-dominant hand. The sample population consisted of 10 students aged 23±2.5 divided into two groups of dominant and non-dominant hand. To record brain activities, a 32-channel wireless Electro-encephalography (EEG) system was used. Data were recorded through three stages of pre-test (pre-training), acquisition (after 4 weeks of training) and retention (after one week of non-training). EEG signals were analysed in alpha, beta and gamma bands. EEG analysis showed that the synergy patterns during acquisition and retention stages were significantly similar to each other and largely different from the pre-training stage in all three bands. Increasing activity levels of the contralateral cortical areas and formation of a different activity pattern after learning in the two groups, were other results obtained. Learning a new motor skill requires relatively lasting changes in the brain map and synergy patterns of brain activities are different for motor learning when the dominant or non-dominant hand is used.

Keywords: Brain activity; Dart throwing; Motor learning; Motor skills; Synergy patterns

INTRODUCTION

One of the most important strategies that the central nervous system (CNS) employs to control various movements easily, despite the high degree of freedom in humans, is to use the concept of muscle synergy, first introduced by Bernstein (1966). Bernstein believes that motor learning overcomes this redundancy and controls degrees of additional freedom (Bernstein, 1966) through the concept of synergies. Muscle synergies are coordinated neuromuscular structures that reduce the computational burden of controlling movement and body posture and thereby facilitate motor control and learning (Bizzi & Cheung, 2013).

Given the concept of muscle synergy, the concept of synergy for brain regions, has recently been used by researchers, who have referred to it as brain activity synergy (Yoshimura *et al*., 2017). The motor areas of the cerebral cortex have complex functional anatomy and their

multiple interactions in the execution of voluntary movements are still unknown. Neurons in these areas have unique characteristics and interact with each other at different stages of the execution of a movement from the beginning of motor planning to the execution of motion (Friston *et al.*, 2013). In a study, Yoshimura *et al.* (2017) investigated the decoding of finger movement using EEG cortical current signals. In this study, the researchers concluded that concurrent activity of the neuronal mass present in different brain regions probably reflects the formation and modifications of the motor programme to perform the tasks(Yoshimura *et al.*, 2017). In a study, Rana *et al.* (2015) concluded that there are specific cortical-motor regions in the human brain that produce different muscle synergies. The connections between brain regions and networks that can create many combinations of muscle synergies in order to produce different movements in humans, are still unknown (Rana *et al.*, 2015).

On the other hand, hand dominance is a very important concept in motor control and learning, and although the neurological control results in the hands are generally accepted, the mechanism and neural origin of the differences between the two hands in motor function are still unknown (Duthilleul *et al.*, 2015). In addition, there are theoretical models explaining hemispheric synergy and learning with both dominant and non-dominant hand motions, including the Callosal (access), proficiency (specialised) and cross-activation models. For example, according to the Callosal model, there is only one motor programme to control both hands in the dominant hemisphere. The dominant hand has direct access to this motor programme, while the non-dominant hand accesses it only through the corpus callosum.

In proficiency and cross-activation models, it is assumed that there is a separate motor programme in the contralateral hemispheres to control each hand (Panzer *et al.*, 2010; Harley, 2011). The results of this study could be helpful in examining these theoretical models. Some studies on motor learning have shown that two-way transfer from dominant hand to non-dominant hand and vice versa is possible (Boroujeni & Shahbazi, 2011), which may indicate that the dominant and non-dominant hand have the same brain map in performing a task. In recent years, although some progress has been made regarding the structure and processing of the cortical pathways, there is still little information available on the brain's mechanism for planning and controlling movement. The reason for this problem is partly due to the complex and nonlinear nature of connections between cortical neurons, and another barrier could be excessive redundancy in the nervous and musculoskeletal systems (Flash & Bizzi, 2016).

Considering all these facts, it may be concluded that a careful study of the motor learning mechanism in the cerebral cortex can add to existing knowledge of how the central nervous system functions and how the areas of the brain cortex work together while learning a motor skill. There is still little consensus regarding which areas of the brain are consistently activated during the acquisition of motor skills. The challenge remains as to what changes in activation of these areas may occur with changing task demands (Hardwick *et al.*, 2013). According to the traditional definitions of motor learning, in the early stages of learning due to the cognitive need for the task and the multitude of the degrees of freedom, there is a high degree of variability in the performance. This variability decreases with the progress in training and the stability of the performance increases at the same time (Edwards, 2010).

PURPOSE OF THE RESEARCH

The main question of the current research is, what changes will occur in the active brain areas as the skill develops and learning progresses? In other words, how does the pattern of the brain map change during learning dart throwing skills (pre-test, acquisition, and retention)? Is this

pattern different for subjects throwing with the dominant and non-dominant hands? Based on this, the research hypothesis was that the pattern of brain activity changes during the learning of the dart throwing skill, and there is no difference between the pattern of dominant and non-dominant hand activity. Therefore, given the scarcity of research in this area and the forward-looking research in motor learning at the brain level (Hardwick *et al*., 2013), the aim of this study was to investigate the patterns of brain activity map during learning dart throwing skills for dominant and non-dominant hands.

RESEARCH METHODOLOGY

Participants

This research is a fundamental study. It is a quasi-experimental interventional research. The research design is pre-test – post-test with repeated measurements. The subjects of the research consisted of Tehran University students who did not study physical education (they studied computer engineering, physics, chemistry, biology and history) and their average age was 23 ± 2.5 years. Fifty male students unfamiliar with dart throwing skills were invited to participate in the study. Eight subjects withdrew after being informed of the research conditions. Using G.Power software, the sample size was estimated as being 10. Mean effect size of 0.5, alpha value of 0.05, and test power of 0.85 was used to estimate the number of samples. Due to the number of samples, the subjects were divided into two groups: 5 with dominant hand and 5 with non-dominant hand. The criteria for inclusion in this study were a lack of familiarity with the dart throwing skill and having no formal training. All the subjects had dominant and non-dominant hands (none of them were equally dominant in both hands). In addition, subjects with a history of neuromuscular disease and visual impairments were not included in the study.

Measurement tool

In order to record the data related to muscular signals, Electromyography (EMG) device manufactured by Myon Company and to record the data related to brain signals in various cortical regions, 32-channel wireless EEG device manufactured by G.TEC Company available at the National Brain Mapping Laboratory were used (Guger, 2017). A standard dart board consisting of concentric circles was used to evaluate the subjects' performance in pre-test, acquisition and retention, which allowed for the recording of scores according to the distance from the point of the throw to the center of the circle (target). To measure the score of the throw, the middle circle had 10 points, the next circle had 9 points, and so on, and finally the last circle had 1 point. Zero points were given for throws that did not hit the board or were outside the circles. According to the rules of the World Darts Federation (WDF), the dartboard was placed at a height of 1.73 metres from the ground and a distance of 2.37 metres from the subject. To separate the signals related to the pattern of dart throwing skill from all available signals, a pushbutton device was used that was connected to an EEG and EMG device via an interface. The Edinburgh inventory was also used to identify subjects' handedness (Oldfield, 1971).

Ethical considerations

Prior to the start of the research, volunteers completed an informed consent form and ethics code no. IR.UT.SPORT.REC.1397.026 was obtained from the Ethics Committee of the Faculty of Physical Education, University of Tehran.

Research process

Prior to practising, a pre-test of dart throwing skill for both groups was performed by simultaneous recording of EMG and EEG to determine the shape of brain activity synergy patterns in 30 regions. Then dart throwing training, which had been designed from simple to complex with increasing contextual interference (Waterhouse, 2014), was performed three sessions per week. In each session, each subject performed at least 15 blocks, with a total of 45 throws, supervised by the instructor and continued for four weeks. During this period, each subject performed a total of 540 throws, because previous findings have shown that this number of training efforts affects error reduction, parametric changes and learning to throw darts (Didier *et al*., 2013; Waterhouse, 2014; Hatami *et al*., 2018). At each stage of the test, each person was required to have the least number of errors in 10 blocks of three, which made up a total of 30 throws. The accuracy of dart throwing for each subject was calculated by absolute error. The acquisition test was performed after four weeks along with re-measurement of musculoskeletal signals. Finally, the retention test was performed after a week of rest (no training). Given that a motor activity was used in this study, alpha, theta and gamma frequency bands were analysed.

Data analysis

In this study, repeated measures ANOVA was used to evaluate the acquisition of the dart throwing skill at the performance level. For this purpose, subjects' darts throwing scores during pre-test, acquisition and retention were recorded and analysed using SPSS 18 software (Kinnear & Gray, 2011). EEG data was recorded through 32 channels using 10-20 electrode positioning standard. It should be noted that the two channels po7 and po8 (shown with yellow colour in Figure 1) were excluded from the list of available channels due to their poor post-test signals, which can be considered as limitations during the investigation. Figure 1 shows the positioning of the 30 EEG channels used in this study. The sampling rate was 500Hz. While recording the EEG signal, EMG signals from three muscles were recording simultaneously. These muscles were the biceps, triceps and deltoid. The sampling rate was 2000H.

To find the signs of growing expertise in participants, the conventional EEG brain map was used. This map shows the energy of EEG signals in different channels and in a specified time period. An energy map of recorded EEG in each electrode position is constructed for each of three mentioned sessions. This is due to capability of comparing pre-learning, learning and retention sessions and designate different patterns in these areas
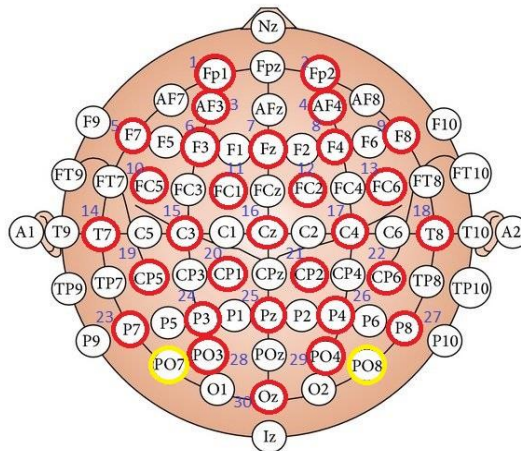
***Figure1*. 30 RECORDING EEG CHANNELS MARKED WITH RED CIRCLES**

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a) First step: EEG signals were filtered in the specified frequency band (alpha or beta). The filter was an 8th order bandpass Butterworth filter (Zhongshen, 2007).

b) Second step: The EEG signal was decomposed to several trials. Each subject in each session had thrown 30 darts. Each of those throws was considered as a trial, therefore there were 30 trials per subject and per session. The time index of throws was indicated by a supervisor who had a pushbutton. In addition, there were three accelerometers installed on each subject, which gave a very accurate time index for start and finish of throws. Each trial consisted of three phases:

Phase 1: Planning phase, which is from 0.3 second before the throw up to the start of the throw.

Phase 2: Performance phase, which is from start of the throw to specified time length of the throws (this specified time length is calculated as the average of 30 throws time lengths for each subject in each session).

Phase 3: Feedback phase, which is from the end of throw to 0.3 second after the end.

c) Third Step: Spatial filtering and calculating energies.

During experiments, EEG signals were very noisy and contaminated with several types of noises, including heart beat noise (ECG), power line noise, noise of eye blinking and EMG noise, which is due to movements from throwing darts. To have a valid analysis on EEG signals, a noise reduction step is necessary. Several methods of spatial filtering (including PCA, ICA, CSP and laplacian filter) were performed and the best results were obtained by large laplacian filter (McFarland *et al.*, 1997). To implement laplacian filter each channel was

subtracted from a weighted sum of its surrounding electrodes. The surrounding electrodes were chosen as their distance to be from 50mm to 70mm from the central electrode (Note that the distance was calculated in Euclidean metric) (Carvalhaes & Suppes, 2011). The weight coefficient was calculated as the ratio of the average of absolute value of the central electrode signal to the average of absolute value of sum of the surrounding electrodes signals under the analysing time window.

After spatial filtering, for each trial the logarithm of energies for all electrodes and in three mentioned phases were calculated. Energy values were normalised, such that the energy of the electrode with highest value was set to 1. This is due to eliminate the effect of noisy trials and to prevent tending results toward bad data. After calculating energies for all trials, the average energy was calculated as the final result. Therefore, there is the average energy of all trials in each electrode, which results in an energy map of the brain. This map was constructed for three phases and for each subject in each session.

RESULTS

Performance level

Table 1 shows the mean and standard deviation of the absolute error of both groups in pre-test, acquisition and retention. It is noteworthy that although the dominant group in the pre-test had lower mean absolute error than the non-dominant group, the independent t-test showed no significant difference in the absolute error rate between the two groups (p=0.235).

Table 1. **MEAN AND STANDARD DEVIATION OF ABSOLUTE ERROR OF BOTH GROUPS FOR PRE-TEST, ACQUISITION AND RETENTION**

Time	Group	Mean±SD absolute error (cm)	n
Pre-test	Dominant	5.38±0.89	5
	Non-Dominant	6.02±0.66	5
Acquisition	Dominant	3.82±0.57	5
	Non-Dominant	3.62±0.34	5
Retention	Dominant	3.44±0.33	5
	Non-Dominant	3.56±0.48	5

The results of Mixed ANOVA (2*3) with repeated measures and considering the non-sphericity assumption according to the Mauchly's test (Kinnear & Gray, 2011) (p=0.004) and using the Greenhouse-Geisser correction show the main effect of the test (f(1/11)=37.53, p<0.001, $\eta^2 P = 0.824$) was statistically significant but test-group interaction (f1/11)=1.14, p=0.320, $\eta^2 P = 0.126$) was not significant.

Bonferroni test results (Kinnear & Gray, 2011) for paired comparisons of the main effect of the test showed a significant difference between the mean absolute error of pre-test and acquisition (p=0.002) and pre-test and retention (p<0.001), but this difference between acquisition and retention was not significant (p=0.185), (Table 2). These results indicate that the absolute error in acquisition and retention is significantly reduced and forgetfulness has not occurred after a week of no-training.

Table 2. **PAIR COMPARISONS ABSOLUTE ERROR RATE IN PRE-TEST, ACQUISITION AND RETENTION**

Time	Stage	Mean Diff.	Std. Error	Sign.
Pre-test	Acquisition	1.980*	0.354	0.002
	Retention	2.200*	0.315	0.000
Acquisition	Pre-test	-1.980*	0.354	0.002
	Retention	0.220	0.101	0.185
Retention	Pre-test	-2.200*	0.315	0.000
	Acquisition	-0.220	0.101	0.185

Also, the results of intergroup test showed that there was no statistically significant difference between the dominant and non-dominant groups (p=0.329). Examining the results of both groups, these results show that acquisition has occurred in both dominant hand and non-dominant hand groups (Figure 2), although there is not a significant difference between the two groups in the amount of acquisition (p>0.05). However, the dominant hand group had less mean absolute error in retention than the non-dominant hand group.
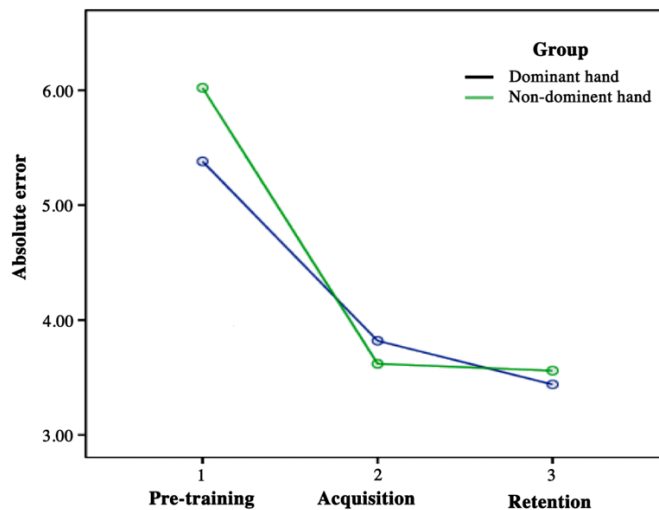

Figure 2. **ABSOLUTE ERROR RATE OF DOMINANT AND NON-DOMINANT HAND GROUPS AT PRE-TEST, ACQUISITION, AND RETENTION**

Cortical level

Alpha band

In the alpha band, the dominant and non-dominant hand groups had opposite results in the central cortex map. In the dominant hand group (throwing with the right hand) after training, at the performance stage, the activity of the left central cortex, including fc5, fc1 and c3 regions, increased. Also, during the planning and feedback stages, the activity of the fc5 region increased significantly after training.

In the non-dominant hand group (throwing with the left hand), after training and during performance, the activity of the right central cortex, including cp2, fc2, and cz regions, increased. Also, the activity of the fc5 region decreased in all three stages of planning, performance and feedback in contrast to the dominant-hand group. In general, the results obtained in the central cortex (sensory-motor regions) in the alpha band show that the cortical map pattern change in the centre occurred in both groups after training and this pattern change was not the same in the two groups (Figure 3).

Figure 4 illustrates the activity pattern of the 30 channels recorded in the alpha band in the dominant hand group. The activity results of these areas show that after training and in the planning stage, the activity of the frontal areas, especially on the left (fp1, fp2, af3, f7, f3), is increased. These results are somewhat different in the non-dominant hand group and the activity of the frontal areas, especially on the right (fp1, fp2, af4, f4, f8), increased. At the
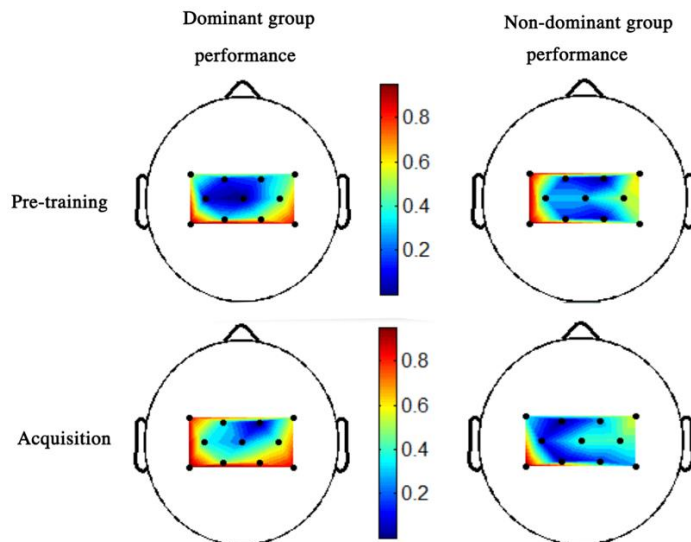

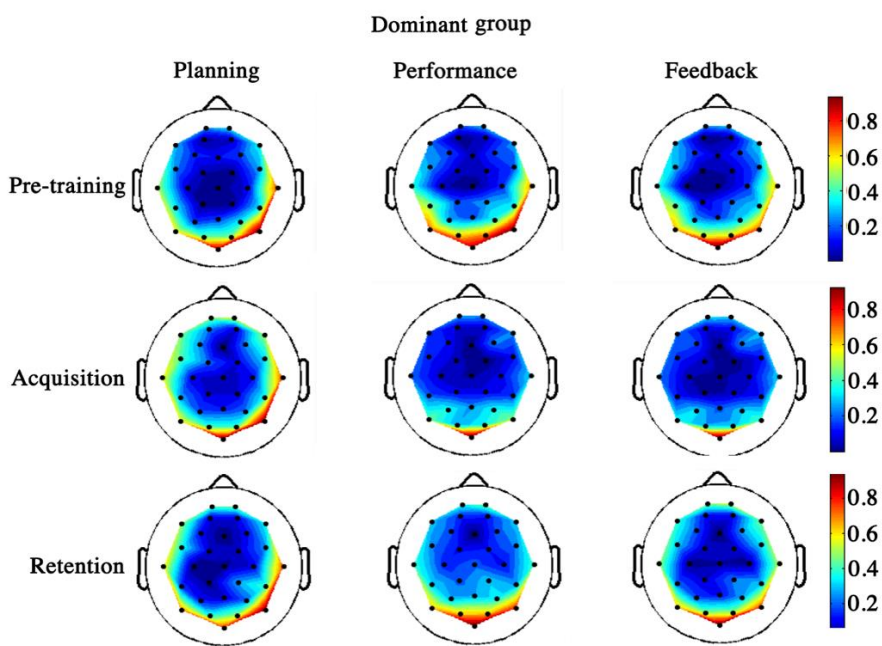**Figure 3. ACTIVITY OF CENTRAL CORTEX DURING DART THROWING IN ALPHA BAND**

Figure 4. **DOMINANT HAND GROUP: CORTICAL REGION ACTIVITY IN ALPHA BAND DURING ACQUISITION**

performance stage, a very important result, especially in the dominant hand group, is that the number and intensity of active areas has decreased after acquiring the skill and the patterns of acquisition and retention are similar.

The results of this study also show that, in the performance stage and after acquisition, the central zone (cz) is more active in the non-dominant hand group than the dominant hand group. In the feedback stage, in addition to increased frontal region activity in both groups after training, the focus of cortical activity is on the centre of the occipital zone (oz), and in this stage, acquisition and retention patterns are also similar. Finally, it can be said that the change in brain map pattern and the co-activity of different brain regions occurred in both groups after acquiring the skill, and this pattern change was not the same in both groups.

Figure 5 shows the parieto-occipital regions in the alpha band, which, like the other regions mentioned above, despite the change in cortical pattern and active regions, the parieto-occipital activity was not similar in the two groups. This means that in the dominant hand group after training the central and left parietal regions including pz and p3 and in the non-dominant hand group, the central and right parietal regions including pz and p4, had been highly active.
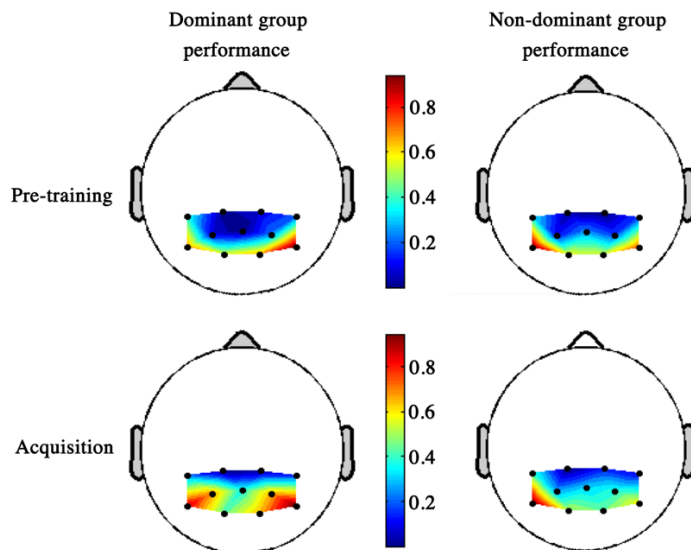
Figure 5. **ACTIVITY OF OCCIPITAL REGIONS IN ALPHA BAND BEFORE AND AFTER TRAINING**

Beta band
As shown in Figure 6, the changes in the pattern of activity of the cortical regions also occurred in the beta band. In this band, similar to the alpha band, brain map changes in the dominant hand group occurred in the left area of the central cortex and in the non-dominant group in the right area of the central cortex, except that the regions with increased activity in the alpha band showed a decreased post-training activity in the beta band after training had decreased. In other words, the activity of cp5 in the left area of the central cortex that had increased in the alpha band, decreased in the beta band in both acquisition and retention stages. Also, in the non-dominant hand group, the activity of the fc6, c4, and cp6 electrodes in the right area of the central cortex decreased in both acquisition and retention stages. Given that activity in one band increases as activity in the other band decreases, this result was not unexpected.
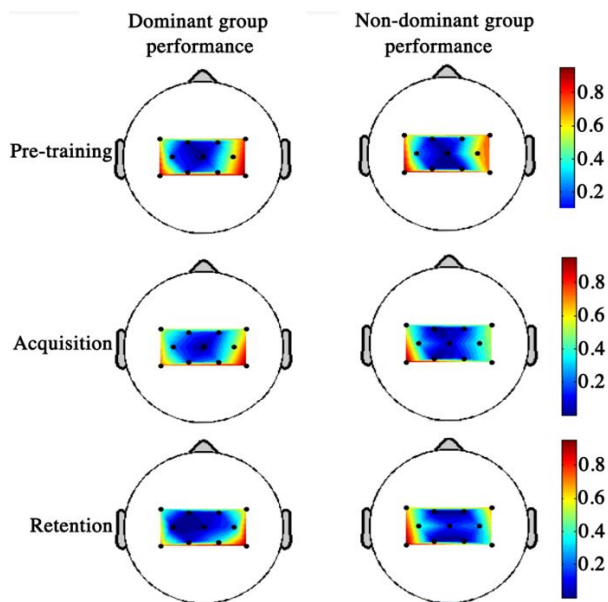
Figure 6. **ACTIVITY OF CENTRAL CORTICAL REGIONS IN BETA BAND DURING ACQUISITION AND RETENTION STAGES**

Examining all the channels (30 channels) in the beta band shows that after training and in the planning stage, the frontal area activity in both groups is increased, except that in the dominant hand group, the left areas, and in the non-dominant hand group, the right areas are more active. However, the topographic patterns of the cortical map in the acquisition and retention stages are similar in both groups. Besides, in the performance and feedback stages, in addition to active frontal areas, the potential of energetic regions is reduced, and the cortical patterns of acquisition and retention are still very similar. Another important result in this band is that in all three stages of acquisition, including planning, performance and feedback, the extent of active cortical regions is increased compared to the pre-training stage.

Gama band
In this study, the results obtained in the gamma band during the acquisition stages are very similar to those of the beta band. In other words, the regions that had increased activity in the alpha band, exhibited decreased activity in this band. Similar to the alpha and beta bands, the researchers also observed an increase in the frontal area activity, a change in the cortical map, a decrease in the intensity of the activity of the occipital area, and similar cortical patterns during the acquisition and retention stages.

Overall, the results of this study indicate that the cooperation of the frontal, central and occipital regions in both the dominant hand and non-dominant hand groups increases after a training period, which can be considered as brain activity synergy. Also, changes in the cortical map pattern after learning the skill and their similarity in the acquisition and retention stages may indicate coding and learning in the cerebral cortex. On the other hand, the results of this study show that after acquisition, especially in the beta and gamma bands, there is an increase

in the number of active cortical regions. However, in the alpha band, it was noted that after acquisition, the number of high activity regions decreases and these regions are limited to the visual cortex.

DISCUSSION

In general, this study sought to investigate the mechanism of motor learning in the cerebral cortex and how synergistic changes occur in the activity of the cortical regions during acquisition of dart throwing skill, using dominant and non-dominant hands. For this purpose, a 32-channel EEG was used to investigate how the brain regions of the subjects function in the alpha, beta and gamma bands in the three pre-training, acquisition, and retention stages. The results of this study can be evaluated in several parts and in several areas. The first result of this study was that the cortex map pattern at the acquisition and retention stages changed in the alpha, beta, and gamma bands in the prefrontal, central and occipital regions, compared to the pre-training stage. Thus, it can be said that the brain activity synergy pattern has changed during the acquisition of the skill, which may be due to changes in neuronal communication during the acquisition of dart throwing skill. Acquiring motor skills occurs by modifying and organising muscle synergies to function effectively and efficiently. The learning process is a neuro-physiological mechanism that is constantly triggered by the reorganisation of motor representations in the motor cortex, and it is believed that each specific motor map is a motor change (Monfils *et al*., 2005).

Some research on animals has shown that motor experience changes the pattern of communication between the cortical regions, which in turn changes the patterns of muscle synergies that control a particular task. Also, as training progresses, skill patterns emerge that are coded in the motor cortex (Hess, 2002). Research evidence supports the idea that brain motor maps represent a level of synaptic communications within the motor cortex that is needed to create a skilled motor pattern (Monfils *et al*., 2005). Yokoyama *et al*. (2019) confirmed the role of cortical area communications in the creation of walking muscle synergies. By decoding the brain signals during walking, they concluded that there was a relationship between the patterns of muscle synergy extracted from decoding the signals of the brain and the muscles involved in walking (Yokoyama *et al*., 2019).

In a review article, Dahms *et al*. (2020) concluded that motor learning after stroke activates different areas including the primary motor cortex, premotor area, supplementary motor area, prefrontal cortex and posterior parietal cortex. The engagement of these areas changes with ongoing practice. This change over time has a strong implication for the understanding of the mechanism underlying motor sequence learning and, furthermore, has implications for practical rehabilitation (Dahms *et al*., 2020). Another study on monkeys has shown that if they do not have to develop a new movement, there will be no change in their cortical map, even if the movement is performed very frequently (Plautz *et al*., 2000). Therefore, in light of the above, it seems that the present study suggests that changes in the cortical map during acquisition of the skill that emerged from the change in the pattern of neuronal communications led to the development of a new skilled muscle synergy pattern by the cortex.

Another noteworthy result of this study is that the patterns of brain map in acquisition and retention stages are similar and seem to correlate. Given the concept of motor learning, which refers to relatively lasting changes in motor function that are related to practice and experience (Wolpert *et al*., 2001), the present study demonstrates that these relatively lasting

neurophysiological changes at the cerebral cortex can be observed after acquiring the skill. Given that the capacity to produce skilful movements is maintained even in the absence of training, it is hypothesised that motor skills are coded and stored during neuro-physiological changes in the motor cortex of the central nervous system (Ito, 2002).

Some studies on rats show that if an exercise such as access accuracy is eliminated at an early stage, even if access accuracy is significantly improved, no changes in the cortical map will occur. These results suggest that reorganisation of the cortical map can indicate motor skill consolidation so that in the absence of continued training, motor skills are still maintained without degradation (Monfils *et al*., 2005). Since in this study, after one week of non-training, the retention test was performed and the results of brain activity synergy patterns in the acquisition and retention stages were very similar, the concept of motor learning at the cerebral cortex can also be deduced, which may be referred to as brain activity synergy learning. Yoshimura *et al*. (2017) indicated in a study on decoding finger motions using cortical current signals, that the concurrent activity of neuronal mass present in different brain regions likely reflects coordinated interactions of neuronal networks in different brain regions that can indicate the formation of the motor planning and performance of the motor plan (Yoshimura *et al*., 2017). In this study, the relative consistency of the brain map pattern in all three stages of motion planning, motion performance, motion feedback after a week of non-training could be a reflection of motor plan learning and skilful performance.

Another result of this study was that after acquisition of the skill in the central and occipital regions in the alpha band, in the dominant hand (right hand) group, areas of the left cortex and in the non-dominant hand (left hand) group, areas of the right cortex became more active. The increased activity of the contralateral cortex in this study is consistent with the results of neural control of the hands in the opposite cortex (Duthilleul *et al*., 2015).

In the central part of the head, the somatosensory cortex (S1) is closely related to the primary motor cortex (M1) both anatomically (Veinante & Deschênes, 2003) and functionally (Witham *et al*., 2007). Therefore, the sensory inputs of the somatosensory cortex that are related to senses and body motions, constantly affect the outputs of the motor cortex in humans (Roy & Gorassini, 2008; Schabrun *et al*., 2012). Yokoyama *et al*. (2019), in a study on muscle synergy patterns of gait, argued that the sensory cortex is not only constantly associated with body posture but also indirectly influences gait control. In their view, altering sensory cortex inputs modifies and facilitates the use of muscle synergy patterns of gait by motor cortex (Yokoyama *et al*., 2019).

In the present study, it seems that due to repeated stimulation of this area of the brain during dart throwing exercises and the crucial role that visual feedback has on improving the performance of the subjects, the increased activity of the central cortex (S1-M1) and occipital zone (OZ) can be justified. On the other hand, some studies have shown that the primary motor cortex (M1) is an area for the acquisition and storage of muscle synergies in fast and accurate movements (Krakauer & Mazzoni, 2011; Penhune & Steele, 2012). Thus, in this study, increased activity of central areas after the acquisition of the skill in both dominant hand and non-dominant hand groups could probably be due to increased sensory cortex activity and storage of new muscle synergy patterns in the motor cortex and ultimately increased communication between these two areas.

It is worth noting that in the present study, although alpha wave activity increased in the central and occipital regions after skill acquisition, beta and gamma waves activity in the same areas decreased, which is consistent with recent studies showing that alpha and beta waves oscillate during learning tasks that require low activity and high concentration. Makada *et al*.

(2016) found that increasing the alpha wave and simultaneously decreasing the beta wave in the brain will improve memory retention. Aumann and Prut (2015) demonstrated that beta wave oscillations in the brain help maintain precision and different representations of muscle synergy in M1.

Recently, some studies have shown that alpha and beta waves oscillations in the human brain play a critical role in scheduling and performing tasks that require attention and spatial orientation (Klimesch, 2012; Brinkman *et al*., 2014; Hatami *et al*., 2018). Thus, in the current study it may be argued that the increase in alpha wave and the decrease in beta wave in the central and occipital regions are due to the nature of the dart throwing task, which requires low activity, high concentration and accurate spatial orientation.

Differing patterns of cortical map in the dominant hand and non-dominant hand groups was another result of this study, which suggests that the neural mechanism and the motor execution programme are probably different in the two hands. This result supports (specialised) proficiency model which assumes that there is a separate motor programme for each brain hemisphere, but is not consistent with callosal (access) model, which assumes that there is only one motor programme for controlling both hands that is located in the dominant hemisphere (Panzer *et al*., 2010; Harley, 2011). Previous studies have shown the dissimilarity related to the two hands in the motor cortex (Pool *et al*., 2015; Nicolini *et al*., 2019) and spinal pathways (De Gennar *et al*., 2004). Also, some studies on animals have shown that the cortical map are different in dominant and non-dominant hand (Sherwood *et al*., 2007).

In this study, the activated regions of the dominant hand were not necessarily larger or smaller than those of the non-dominant hand, but their cortical map pattern differed, which corresponds to some of the results of the aforementioned studies regarding dissimilarity of the two hands in terms of cortical map in performing a similar task. The study of subcortical activity during skill learning showed that although frontal, central, and occipital regions in the contralateral area of the dominant and non-dominant hand became more active after learning the skill, while performing the task, in all subjects the other brain hemisphere was also involved in the activities, which can have different causes. Studying right foot muscle synergies while walking, Yokoyama *et al*. (2019) found that in addition to the left hemisphere of the brain, the right hemisphere was also active and this activity is not limited to one specific electrode or region. They believed that in order for a brain signal to be recorded, it had to pass through tissues, cerebrospinal fluid, cranial bone and skin. The skull bone is a very weak conductor, so the signal becomes very weak when it reaches the EEG cap and may also affect the lateral areas, which can be a reason for the spread of the signal on both sides of the cerebral hemisphere (Yokoyama *et al*., 2019).

In a meta-analysis and review of human brain motor learning using fMRI, Hardwick *et al*. (2013) concluded that doing some motor tasks using the right hand not only affects different areas of the left cortex, but also some areas of the right cortex. Overall, their results show that performing the movement using right or left hand, activates both sides of the cortex, although the active areas of the contralateral cortex are greater (Hardwick *et al*., 2013). Rana *et al*. (2015) demonstrated that cortical areas of one hemisphere that encode pelvic and leg muscle synergies, have very broad correlations with the other hemisphere (Rana *et al*., 2015). In addition to the aforementioned, the researchers found that maintaining proper balance and posture prior to dart throwing, as well as unknown communication of the two hemispheres during performance of the skill could be another reason for the involvement of both brain hemispheres in unilateral body movement.

Finally, in this study, the investigation of brain activity synergy pattern in three stages of motion planning, motion execution and visual feedback showed that in the motion planning stage, the cortical prefrontal areas had the most activity. In the motion execution stage, most activity was in the central and occipital cortex and in the feedback stage, the most activity was in the occipital (visual) cortex. Given the crucial role of the prefrontal brain region in motor planning (Koechlin *et al.*, 2000), activation of this region to select and plan the appropriate response before motion begins seems logical. The increased activity of the central cortical band (M1 and S1) during dart throwing is due to the prominent role of this region in the execution of motor tasks (Schabrun *et al.*, 2012).

Among various brain regions, the primary visual cortex (V1) had the most activity, which is consistent with the function of the visual cortex due to the prominent role of the visual cortex in visual interpretation and feedback (Petro *et al.*, 2014). Since in dart throwing, vision plays an essential role in the motion planning, execution, and feedback stages, the activity of the visual cortex at all stages is undeniable. Lastly, the results of this study showed that brain activity synergy between the prefrontal cortex, central band and primary visual cortex is essential for learning and performing dart throwing skill using the dominant and non-dominant hands. Since the results of this study could be the beginning of a study of motor learning at the brain level, it is recommended that simultaneous changes in performance and EEG activity pattern be performed in other sports, such as basketball shooting. Also, it is recommended that the similarity or dissimilarity of the activity of EEG patterns in the dominant and non-dominant hands be examined in other cortical channels.

CONCLUSION

The results of this study suggest that learning a new motor skill requires relatively lasting changes in the brain map pattern and the cerebral cortex employs new and different synergy patterns to improve the skill. Thus, brain activity synergy patterns during learning of a motor skill change until a smooth and skilled motor pattern is formed, which may indicate cortical encoding and memory consolidation. Given that the main purpose of this study was to investigate changes in brain activity during learning of a motor skill, the results of this study showed that the concept of motor learning that refers to relatively stable changes in behaviour as a result of exercise and experimentation, can also be observed at the level of brain map. In fact, these relatively stable changes are also visible at the level of the cortex. So, it can be said that while learning a motor skill, the brain map is constantly evolving until it reaches a relatively stable pattern. The results of this study showed that the neural mechanisms underlying a motor task when performed by the dominant or non-dominant hand were different when learning and performing the same task. This result supports the proficiency (specialised) model, where it is assumed that there is a separate motor programme in the contralateral hemispheres to control each hand.

RESEARCH LIMITATIONS

In this study, despite the three stages of the test, fatigue or lack of motivation at the end of the exercise and tests may have affected the recorded data. Also, because the EEG cap was placed on the head at each stage of the test, the location of the electrodes may not be exactly in place compared to the previous stage.

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