Morenko A.G., Korzhik O.V.

**BRAIN PROCESSES IN WOMEN WITH DIFFERENT MODAL ALPHA-FREQUENCY THROUGH THE EXECUTION OF MANUAL MOVEMENTS WITH APPLYING OF FORCE**

Lesia Ukrainka Eastern European National University
43000, Ukraine, Lutsk, av. Voli 13

Email: alevmore@gmail.com, olga.korgik@gmail.com

The study involved 136 females of 19-21 years with high and low individual α-modal EEG frequency. We evaluated a simple sensomotor reaction and the choice stepping time, speed capabilities of neural processes during Finger-Tapping Test, as well as performance capacity and coherence of EEG frequency components. These parameters were specified individually, at rest, during doubling and unclenching the fist with power load. Women with high frequency of the α-rhythm were characterized by higher level of selective attention and local changes in the electrical activity of the cerebral cortex. Females with low α-frequency have less differentiated features of cortex activation, which can be caused by lower ductility of brain processes under power load and setting pace. Women with high α-frequency had better speed performance in terms of sense-motor response.

**Keywords:** modal individual frequency alpha rhythm, power manual movements, EEG, power, coherence, psychodynamic properties.

Моренко А.Г., Коржик О.В.

**МОЗКОВІ ПРОЦЕСИ ЖІНОК ІЗ РІЗНОЮ МОДАЛЬНОЮ АЛЬФА-ЧАСТОТОЮ ПІД ЧАС ВИКОНАННЯ СИЛОВИХ МАНУАЛЬНИХ РУХІВ**

Східноєвропейський національний університет імені Лесі Українки
43000, Україна, Луцьк, пр. Волі 13

Email: alevmore@gmail.com, olga.korgik@gmail.com

Обстежено 136 жінок віком 19–21 року з високою і низькою фоновою індивідуальною модальною α-частотою електроенцефалограми. Оцінювали час простої сенсомоторної реакції та реакції вибору, швидкісні можливості нервових процесів під час теппінг-тестування, показники потужності та когерентності частотних компонентів електроенцефалограми, визначених у кожної обстежуваної індивідуально, у стані спокою, під час стискання і розтискання пальців кисті із силовим навантаженням. Жінок із вихідною високою частотою α-ритму відзначає вищий рівень вибірковості у вагі й локальніші зміни електричної активності кори головного мозку. Для осіб із низькою α-частотою притаманні дещо менш диференційовані особливості активації кори, що можуть відзначатися меншою пластичністю мозкових процесів за умови застосування силового навантаження і досягненні встановленого темпу. Жінки з високою α-частотою мали кращі швидкісні показники сенсо-моторного реагування.

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Обследованы 136 женщин в возрасте 19-21 года с высокой и низкой фоновой индивидуальной модальной α-частотой ЭЭГ. Оценивали время простой сенсомоторной реакции и реакции выбора, скоростные возможности нервных процессов при теппинг-тестировании, показатели мощности и когерентности частотных компонентов ЭЭГ, определенных у каждого обследуемого индивидуально, в состоянии покоя, во время сжимания и разжимания пальцев кисти с силовой нагрузкой. Женщины с исходной высокой частотой α-ритма отличает высший уровень избирательности внимания и более локальные изменения электрической активности коры головного мозга. Для лиц с низкой α-частотой присущи несколько менее дифференцированные особенности активации коры, которые могут характеризоваться меньшей пластичностью мозговых процессов в условиях применения силовой нагрузки и соблюдения установленного темпа. Женщины с высокой α-частотой имели лучшие скоростные показатели сенсомоторного реагирования.
indicators of the brain activities being correlated with manual locomotion using the power load are existed.

Records of the electroencephalography (EEG) are specifically valuable when the relevant issues are studied. Many scientists (Boldyreva et al., 2009; Sorokin et al., 2006; Bazanova, Stark, 2007; Bazanova, Aftanas, 2007; Anokhin et al., 2006; Christian et al., 1996: Clark et al., 2004; Hooper, 2005) have found that a significant informative importance in determining the state of the human main physiological functions was evidenced by individual values of the amplitude- frequency characteristics of α-rhythm, including its modal frequency. According to Bazanova and Stark (2007), Kristeva et al. (2005) optimal coordination processes of movements and the capacity for the self-control are positively correlated with an individual capacity of α-EEG range and negatively with tensions of facial muscles (forehead) being not involved while exercising voluntary MMs. Men with a high background mode of α-frequency have greater selectivity of their attention and more local changes in the electrical activity of the cerebral cortex during the performance of manual movements correlating with higher rates of speed and accuracy of their sensorimotor responses. The predominance of relatively low or high α-rhythm of the background EEG (Bazanova, Aftanas, 2007; Bazanova, Stark, 2007; Umryuhin et al. 2007; Klimesch et al., 2009, Angelakis et al., 2004; Kaplan et al. 2003; Rusalova, 2003) is explained by a prognostic criterion of the various types of the effectiveness of the professional and intellectual abilities. Such statements are based on the fact that modal α-frequency of the EEG is considered as strictly deterministic genetic basis as it reflects the important innate characteristics of the structural organization of thalamic and cortical neurons, particularly features of ionic processes in these cells (Page et al., 2006; Sperge, 2007; Bellone & Bellone, 2007; Ng, Raveendran, 2007; Zhavoronkova, 2009).

Defining the critical importance of results obtained by different scientists it should be noted that information of such a kind is clearly insufficient for a comprehensive understanding of the individual neurophysiological characteristics of aimed arm movements performed by the testees. There are critically limited data on how such congenital aspect of mental functioning as the modal frequency of the EEG α-rhythm is related to the activities controlling the distal hand muscles when performing MMs with applying force.

The goal of research is to explore those possibilities of brain processes being underlain in the regulation of manual movements performed with applying force and as the reaction on sensory signals in women with some high and low modal frequencies of the EEG α-rhythm; and to consider the prognostic value of some relevant information concerning the possibilities of velocity as to nervous processes.
MATERIALS AND METHODS

The object of the study. The participants in our study were 136 female volunteers from the ages of 19 to 21, each of whom has given written consent. Biomedical ethics rules in accordance with the Helsinki Declaration of the World Medical Association on the Ethical Principles of Scientific and Medical Research involving Human Subjects were adhered to during the experiment. All the females were healthy and had normal hearing with regard to the judgment and advisory conclusions of their medical professionals. A survey of women was conducted during the secretory phase of the menstrual cycle.

Psychophysiological examination. As part of the psychophysiological testing for each subject was determined profile of manual and auditory asymmetry. It determined by the nature of responses in the survey, execution of the motor and psychoacoustic tests and counting the individual ratio of the manual and auditory asymmetries, K skew (Zhavoronkova, 2009).

\[
K_{skew} = \frac{\sum_{\text{right}} - \sum_{\text{left}}}{\sum_{\text{right}} + \sum_{\text{left}}} \times 100\%
\]

where \( \sum_{\text{right}} \) – the amount of tasks where a right hand (right ear) is dominating during their execution, \( \sum_{\text{left}} \) – the amount of tasks under which the left hand (left ear) is dominant.

Further studies involved dextral testees whose coefficients of manual and auditory asymmetries were positive and were above 50%. The total number of women was of 113 people.

The level of speed properties of testees’ nervous processes were surveyed with a simple sensorimotor reaction taking into consideration time period and sensorimotor responses in the choice of one of three objects as signals (triangles, circles, squares). See the program "Diagnostician -1", Ukraine. All testees had to respond to the certain stimuli as quickly as possible with pressing the button by the right hand.

All examinations were performed in the morning. The profile of the asymmetry and time of simple and complicated sensory-motor reactions was evaluated 30 minutes before the EEG recording registration. It made impossible to influence on the experiment, particularly, on EEG results.

EEG testing procedures. The testees were in a quiescent state with their eyes closed and in a reclining position with their limbs relaxed and not crossed during the EEG testing. The experiment was carried out in a room which was sound-proof and light-proof. The whole experimental procedure consistently included the following steps for each testee:

Step 1. The EEG recording in the functional balance (background)
Step 2. The EEG recording while performing the power movements by fingers of the right hand.

Each step lasted 40 s. To exclude the edge effects, the EEG recording registration was started at 15 s after the beginning and had been stopped at 5 s by its completion. During the clamping and unclamping fingers testees keep by halfbent fingers loading 10 N (1 kg).

Each finger flexion or extension was performed by the testees in response to the sound. The electronic version of the drum battle (the software of Finale 2006) was used for this purpose. Binaural stimuli were produced by four speakers placed in different corners of the room at the distance of 1.2 m from the testee’s right or left ear (Каменская, 1995).

The stimulus duration was 120 ms; the playback sound volume did not exceed 55-60 dB at outlet from the speakers under the measurements carried out by the sound level meter of the ‘DE-3301’ type (certificate of attestation # 025-2009, valid until 21.12.2014). Additionally, the sound loudness was individually regulated for each testee to achieve the necessary level.

The rate of the sound stimuli delivery was 2 c⁻¹. The choice of the relatively low acoustic stimulation is caused by the fact that such frequency corresponds to the frequency range of the MM execution. Such a range is essentially determined by biomechanical movements implemented by the distal parts of the hand.

*Registration and primary analysis of EEG data.* Active electrodes were placed in accordance with the international system 10/20 in nineteen points on the scalp of the head during the electroencephalogram (EEG “Neurocom”, and the Certificate of State registration # 6038/2007, valid until 18.04.2014) recording.

The performance of the EEG recording was monopolar, with the use of ear electrodes as a reference. The Fourier analysis era was 4 s with a 50% overlap. Duration of sample was 40 s. ICA-procedure analysis was used for the rejection of EEG anomalies.

Both the power (μV²) and the coherence of the brain electrical activity in the θ-, α-, β- and γ-frequency intervals were also evaluated. Taking into consideration the functional heterogeneity of different sub-bands of the EEG α- and β-rhythms, the changes in the power and coherence of each of them were considered, and coefficients of coherence above 0.5 were analyzed as well.

The mode of the EEG α-rhythm spectral power was determined for each testee at each EEG lead and when they (testees) were motionless and had their eyes closed. Its value was averaged for all the leads; value obtained was considered as an individual α-frequency for each testee (fαF, Hz) (Klimesch et al., 2007; Angelakis et al., 2004).

Any average value of the index was calculated for all the men and women.
Conditional distribution of the sample was taken into account. The testees, having the value of IαF less than average, belonged to the group of testees with a low IαF. The testees, having value of IαF higher than average, joined to the group of testees with a high IαF, and additionally, the level of the value sustainability of the EEG individual α-frequency was identified for ten testees in quiescent intervals and according to the indicators of human memory registered in different days.

The EEG frequency interval limits were determined individually, relying on the value of the testee’s IAF. The following algorithm (Klimesch et al., 2007; Angelakis et al., 2004) was used and the truth of which was that the upper limit of α3-subband was set to the right side of the IAF in increments of 2 Hz.

It corresponded to the lower limit of the β1-band. The upper limit of the β1-sub-band was defined according to the standard concepts as 25 Hz. The lower limit of the α2-band was determined in steps of 2 Hz to the left of the peak, and the α1-band in 4-Hz steps, as well as θ-frequencies – in 6 Hz. Limits of β2- and γ-bands were recognized as standard, properly, 26 – 35 Hz and 36-45 Hz.

Statistical analyses. A statistical data analysis was performed by using the package ‘STATISTICA 6.0’ (Stat-Soft, 2001). Any normalcy of the data distribution in testees’ subgroups was evaluated by means of the Shapiro-Wilks test (indicator SW). Based on test results, it was found that all of our studied samples had a normal data distribution.

To estimate the significance of differences existing in testees’ subgroups, the Student's t-test (indicator t) was used between steps of testing both for independent equal samples and for dependent samples. Significant differences between testees’ subgroups and among steps of testing were statistically considered at p ≤ 0.05 and p ≤ 0.01.

Statistical calculations and plotting or diagramming were made by means of the computer whose type – IBM PC Pentium and software package M. Excel Windows Vista.

RESULTS AND DISCUSSION

The individual modal frequency evaluation of the α-EEG activity and individual limits of the frequency content of the EEG sub-rang in female testees findings. The average value of the modal frequency of any α-activity in samples of female testees was 10.25 ± 0.03 Hz. Considering the leveled nature of the individual α-frequency value histogram (Fig.1) in the female testees, it was made the conditional distribution of samples under the average mean of the modal frequency of α-activity.

Two groups were formed, in particular, groups having the high value of IαF (n=59, IαF ≥ 10.25 Hz) and groups with the low value of IαF (n=54, IαF < 10.25 Hz).

Under the results of the five background EEG registrations, the average error (± m) for IαF values was ranged from 0.003 to 0.024 in testees in different days. These results certified some sustainability of relatively high values of IαF in the testees.
Features of the Output Speed Characteristics of the Nervous Processes in Women with Some High and Low $\alpha F$. Women with a high $\alpha F$ had a less time of simple and complex reactions (Table 1).

Table 1. Results of Psycho-Physiological Tests Characterizing Time of Simple and Complex Sensor and Motor Reactions in Women

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with high $\alpha F$</td>
</tr>
<tr>
<td>Simple Reaction Time, ms</td>
<td>253,40 ± 6,54</td>
</tr>
<tr>
<td>Selection Reaction Time, ms</td>
<td>378,33 ± 8,77</td>
</tr>
<tr>
<td>Tapping-movements number for 30 s</td>
<td>31,43 ± 1,54</td>
</tr>
</tbody>
</table>

*, ** – indicators of significant differences between the groups of the testees with a high and low $\alpha F$, $p \leq 0.01$.

It proves that testees had got higher speed capabilities of their nervous processes. Moreover, values of the maximum rate of movements exercised by the human hand during the hand-tapping testing had not significantly varied among groups.

The cerebral cortex electrical activity during the performance of MMs with some power load in response to the sensory signals in women having some high and low individual $\alpha$-frequency. Some increase in the $\theta$- and $\gamma$-capacity has been found in women throughout the whole neocortex ($p \leq 0.05$), Fig. 2 and may be an indicator of motivational, emotional and energetic requests increased in women. The expression of $\gamma$-waves was more significantly represented in women with some low $\alpha F$, probably, reflected greater needs of the integration related to sensory, cognitive and executive processes within this framework.
Fig. 2. Topographic maps of changes in the spectral power and coherence of the EEG frequency components in groups of women with different frequency α-rhythm during clenching and unclenching fingers of the right hand with the power load compared to the quiescent state.

Note: △▲(▼▼▼) – increase (decrease) of power, the white triangle: \( p \leq 0.05 \), a black triangle: \( p \leq 0.01 \); —(⋯⋯) – the increase (decrease) coherence, a thin line: \( p \leq 0.05 \), and a thick line: \( p \leq 0.01 \).

The capacity strengthening some α1-activity in the frontal and anterior temporal leads of the cortex, especially in women with some high IαF is obviously a consequence of the inverse front-cortical-thalamic influence development (Klimesh et al., 2007) resulting in the increase of some voluntary attention, actualization of running memory traces and permission to keep the focus on the information and sensory stimuli and ongoing movements. Rising power capacity of the α2- and α3-oscillations \( (p \leq 0.05) \), as well as reducing power of β-waves in the frontal, central and parietal areas of the cortex \( (p \leq 0.05) \) in women with some high IαF may have been the results of the additional inhibitory back reactions developing in terms of the increase of muscular efforts and some difficulties in implementing movements. This feature can display the additional suppression of the sensory input mechanisms (Angelakis et al., 2004; Pulvermuller et al., 1997) and can be the EEG correlator of the process comparing the afferent information flows with the top-down effects of the frontal cortex against the previous motor program. Such descending inhibitory influences can certify some lower flexibility (Pulvermuller et al., 1997) in this female
group relative to the motor task complication and need to respect the established rate of movement.

Women with low IαF have been characterized by the capacity reduction of the cognitive α2- and α3-activity in the frontal and anterior temporal areas. This phenomenon is likely to point to the involvement of cognitive information processing elements. We assume that this group of women implementing tasks has been primarily associated with the motor programming processes and their complication in the cerebral cortex. Simultaneously, any execution of movements was very difficult, as evidenced by some capacity increase of the α2- and α3-EEG activities in the posterior temporal, parietal and occipital cortical areas. Being observed under these conditions, the generalized expression of the β- and γ-activity can be the criterion strengthening the global non-specific cortical activation.

The changes in the spectral power of all the women are combined with increasing values of the coherence of the EEG frequency components ($p \leq 0.05 - \leq 0.01$), probably indicating the increasing role of activation patterns in the cortex (Boldyrev et al., 2013; Zhavoronkova et al., 2009). Women with some low IαF are characterized by greater significance of these changes, especially in the left hemisphere and could be indicative of some less differentiation in the cortical processes. The phenomenon of the bilateral high-coherence (β2- and γ-) activity increasing in the frontal and central areas and its simultaneous decreasing in the posterior temporal, parietal and occipital areas of the cortex, especially its right hemisphere attracts our attention and taking into account in both groups of testees. Subject to the data obtained by Pfurtscheller et al. (1999) during the execution of certain cognitive tasks (the perception of double images), it can hypothetically associated with the inhibition of the sensory afferent activity needed in a situation of reciprocal refocusing from the processing of sensory stimuli to programming movements in frontal and central areas.

Thus, in conditions of our experiment, women with different IαF were characterized, to some extent, by hallmarks of information processing to achieve a successful outcome. However, we believe that changes found in both of the groups may have some compensatory significance against the background obviously insufficient level of selective processes in the thalamic and cortical interactions.

**Intergroup Differences**

Movements with applying force performed by fingers of the right hand of women with a low IαF are associated with some higher capacity of θ-, α1-, α2- and β-oscillations ($p \leq 0.05 - \leq 0.01$) in the cortex, α3- and γ-activity ($p \leq 0.05$) – in its posterior areas than by people with a high IαF. Such conformity may indicate a nonspecific cortical tone being higher in women with some low IαF under such conditions. Instead of it, relatively low power of θ-, α3-, β2- and γ-activity ($p \leq 0.05 - \leq 0.01$) EEG was recorded in frontal leads of women with a high α-frequency and it
seems probable that the evidence of greater selectivity of afferent processes is herein. Such intergroup differences in power of the cortical electrical activity were completed by relatively high levels of their coherence, particularly in the frontal, temporal and central areas in women with low IαF (Fig. 3).

Fig. 3. Topographic images of the intergroup differences in spectral power and coherence of the EEG frequency components at finger movement with applying force.

1) Δ ▲ ( ▼) – Higher (lower) power in women with low IαF, a white triangle: $p \leq 0.05$, a black triangle: $p \leq 0.01$;

2) △(●●) – Higher (lower) coherence in women with some low IαF, a thin line: $p \leq 0.05$, a thick line: $p \leq 0.01$

Corresponding coherence changes may indicate the facilitation in the spread of excitement between some "nodes of the structural and functional systems of perception" in case of less differentiation processes of the cortical activation (Yakovenko et al., 2013). The functional content of such a type of spatial synchronization in the cortex is associated with higher levels of "intensity" of brain processes (Knipst et al., 1982) modulating by strengthening tonic effects of brain structures such as the limbic system (in a low frequency range) and reticular formation (in the band of the EEG high frequency range). However, relatively low coherence was recorded in women with low IαF in their posterior parts of the cortex in θ-, α1- and β2-, γ-bands ($p \leq 0.05$), which may indicate relatively high levels of spatial attention in women with high IαF under these conditions.

Thus, theoretical generalization of obtained research results allows defining features of brain processes observed in the performance of MMs in case of power load which have been initiated by sensory signals in women with different α-rhythm characteristics (including different modal frequency of the given rhythm). Some specific growth of a nonspecific cortical tone was recorded in both testees’ groups. Some increased activity has been observed in cortical structures responsible
for a sensory perception, motor programming and commands and a perceptual motor coordination. However, women with different IαF within our experimental conditions have been characterized by different distinctive features of information processing to achieve a successful outcome. Women with the original high α-frequency are characterized by enhance descending inhibitory frontal thalamic and cortical influences, and according to our reckoning, they could refocus testees’ attention from processing of the afferent information to programming and starting any motor activity. Testees with some low α-frequency have been characterized by less differentiated features of the cortex activation, with the use of additional cognitive strategies during the motorial programming. It is believed that the changes found in both groups may have some compensatory significance against the background of obviously insufficient selective processes in the thalamic-cortical interactions.

Naturally there are different levels of activation capacity installed to achieve concrete results in subjects of testing who have different essential IαFs. Women with high IαF had the best characteristics of nervous processes.

Results obtained in studies indicate that the value of a human α-frequency mode having been identified at rest may have the predictive value regarding to the course of brain processes during the execution of manual movements with applying power load, and determining the speed of nervous processes.

CONCLUSIONS

1. Both female groups are characterized by the generalized increase capacity of the EEG θ- and γ-activity, and α1-oscillations in the frontal and anterior temporal areas. Women with some high IαF has the capacity of α2- and α3-activity registered in the anterior cortical areas as increased and the capacity in the β-range of the frontal, central and parietal leads – as decreased in comparison with women with low IαF having the capacity of α2- and α3-activity registered in the anterior cortical areas as decreased and the capacity in the β-range of the frontal, central and parietal leads as increased.

2. Increase coherence values of all the frequency components of the EEG in the cortex have been found in women from both groups. Simultaneously, the coherence decrease in the β2- and γ-oscillations was seen in the posterior temporal, parietal and occipital areas of cortex.

3. Women with low IαF performing movements with the application of force by fingers of her right hand has higher capacity of the θ-, α1-, α2- and β-oscillations in the cortex, as well as α3- and γ-activity – in posterior cortical areas than women with high IαF. Instead of it, relatively low power of the θ-, α3-, β2- and γ-activity was recorded in the frontal leads of women with a high α-frequency. Coherence electrical activity of the cortex was higher, especially in the frontal, temporal and central areas of women with low IαF.
4. Women with high IαF showed both less simple reaction and response selection
time. Indicators of the maximum rate of movements by hand during the hand-
tapping test had no significant intergroup differences.

**CONFORMITY WITH THE STANDARDS**

The Commission on Bioethics of Lesia Ukrainka Eastern European National
University confirmed (Minutes #1 from 18.10.2012) all of the examinations were
conducted according to the basic relating to life regulatory requirements of the
World Medical Association Declaration of Helsinki on Ethical Principles for
Scientific and Medical Research Involving Human Subjects (1964-2000), the
Declaration of Principles Dealing with Tolerance (1995) Universal Declaration on
Bioethics and Human Rights (1997), the Council of Europe Convention on Human
Rights and Biomedicine (1997), the Order of the Ministry of Health of Ukraine No.:66 from 13 February 2006. All the testees gave their written consent for participation
in the experiment. All the necessary measures to ensure the confidentiality for
testees were taken too.

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