Age-Related Discrimination of Visual-Evoked Potentials Using Cross-Coherence Analysis

Ahmed Fadhil Almurshedi (PhD)[1]*

[1]Department of Physics, College of Science, Al-Muthanna University, Iraq

ABSTRACT

Background: Cross-coherence is used to evaluate the correlation between two sources of signals and to evaluate the power transfer between input and output of two linear sources. Visual evoked potential (VEP) is used to study the visual pathway of patients according to the ISCEV standard.

Objective: The cross-coherence analysis is used to examine the interconnections between channels across two age groups mature and young.

Material and Methods: This experimental and analysis study implements a statistical method based on coherence analysis horizontally, vertically, and diagonally across the brain hemisphere. It investigates and discriminates the VEP responses related to age in two groups, matured and young.

Results: The coherence results compared in both the time and frequency domains for the two age groups. In the young age group, there is greater coherence between the occipital lobes compared to the frontal lobes in horizontal coherence. The diagonal coherence in the young age group was less than 0.4, whereas it exceeded 0.4 and 0.5 in the mature age group for the time and frequency domains, respectively.

Conclusion: The frequency coherence shows the spectrum of an alpha wave of frequency 15 Hz in the matured group. The vertical coherence of matured age group shows an extra peak in the range of late Alpha wave at 25 Hz compared to that in the young age group. The diagonal coherence shows the frequency peak of the Alpha wave at 15 Hz in the matured age group. While the young group shows the late Alpha wave at around 25 Hz.

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Keywords

Electroencephalography; Visual Evoked Potentials (VEP); Cross Coherence Analysis; Brain Hemisphere; Occipital Lobe; Frontal Lobe; Time Domain; Frequency Domain

Introduction

The interactions between brain areas are certainly key to the computational power of the cortex. For normal individuals, the principal technique to estimate brain activity is EEG and its derivatives in the fast time domain [1].

Visual evoked potential (VEP) is an averaged response recorded from the occipital area of the brain, elicited simultaneously with the presentation of pattern-reversal checkerboard visual stimulation. VEP response consists of a small negativity at 75 milliseconds, which is called

*Corresponding author: Ahmed Fadhil Almurshedi
Department of Physics, College of Science, Al-Muthanna University, Iraq
E-mail: fhahmed2@mu.edu.iq

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(N75), followed by a positivity appearing at 100 milliseconds, which is called (P100). The latest component is considered the main peak of VEP [2].

Coherence analysis estimates the linear directions between two independent sources [3,4]. Besides, the linear dependency is inefficient for the complex or nonlinear analysis of bioelectronics signals [5]. Therefore, cortico-muscular coherence is influenced by the emphasis on the precision of behavioral presentation [6]. Additionally, coherence may either be absent or weak in some subjects [7,8]. Coherence across EEG channels is predominantly used to assess functional connectivity over different brain regions [1]. An algorithm is used based on auto cross-correlation applied across both hemispheres to examine intra hemispheric coherence of EEG to diagnose various forms of dysfunction in the brain [3].

Mutual information across brain channels may present the relationship between electroencephalogram and electromyogram or any other recorded signals using a nonlinear method [9-11].

The important studies used global coherence analysis based on the surface Laplacian scheme and spectral analysis to track the anesthetic level of brain. They also used spatiotemporal dynamics, which measures the radial current density at each electrode position. The spectral analysis results show an increase in alpha and delta wave activity on the frontal lobe and an increase and a decrease in delta activity and alpha activity, respectively, in the occipital lobe. While the coherence analysis predicts a strong alpha activity in the occipital lobe during alertness of the subject and moves later to the frontal lobe during unconscious. Coherence was weak in the delta frequency range in both unconscious and awake conditions [12]. EEG spectrum of range (0-64) Hz is used, covering delta to gamma wave. The use of coherence on the patients revealed that the particular pairs of electrodes, which are symmetrical on the cortex, are dramatically differed in specific areas of damage [3]. However, coherence is related to brain disease, such as epilepsy and Alzheimer's disease [13-16].

Current research further used coherence analysis horizontally, vertically, and diagonally for the discrimination and elicitation of how the coherency of VEP responses differs from the age of subjects. The study of coherence with respect to the age between multi-brain locations in different directions provides a prestep of study brain connectivity. Such research provides valuable information for the research line clinically and anatomically.

Material and Methods

Experimental and analysis implementation investigates the visual evoked potential response with respect to the age of the subject. Cross-coherence analysis techniques are employed to assess the strength of connectivity between different brain lobes, particularly those associated with VEP in the frontal and occipital regions, in various spatial directions (horizontal, vertical, and diagonal). Furthermore, cross-coherence has been examined in both the time and frequency domains.

Samples Data and Recording

The sample data is collected for the human healthy subjects, classified into two groups. The first group is called the matured group with an average age of 25±2.6 SD years old. The second group is called the young group with an average age of 10±2.6 SD years old. A written statement confirmed that the subject has neither been diagnosed with nor is currently suffering from any physiological, neurological, psychological, or ophthalmological disorders. For correcting the degree of vision of some subjects, they were wearing glasses during the data recording. The subject was trained to set stable on the experiment chair with a gap of about 100 cm from the display screen [17,18]. Full-field visual stimulation was used to activate the visual pathway. Specifically, a high-contrast pattern reversal checkerboard, composed of alternating black and white checks arranged in a tessellated pattern, was presented at a reversal frequency of 1 Hz [2].

The data were collected using a KT88-2400 EEG machine following standard protocols for recording both EEG and VEP. A head cap was securely attached to the scalp to facilitate accurate data acquisition [19,20]. The electrodes distributed in the scalp follow the 10-20 electrode system [21]. The cap consists of 19 channels covering all the brain lobes (frontal, parietal, central, temporal, and occipital) and referenced to the earlobe (Figure 1).

VEP Cross Coherence Analysis

The quantitative assessment of linear dependency across different brain regions is referred to as coherence analysis. EEG records brain activity, and coherence analysis illustrates the interactions between electrode sites [22]. In fact, the correlation between any pair of EEG signals in the frequency domain gives the coherency. However, the correlation between signals calculated the ratio using equation (1) [23]. Where the mean square value is the sum of squares of the signal divided by the corresponding degrees of freedom.

$$co = \frac{E(xy)}{\sqrt{E(x^2) \times E(y^2)}} \quad (1)$$

Where, $E(xy)$ is the mean product of two signals x and y, and $E(x^2)$ and $E(y^2)$ are the mean square values of the first and the second signal, respectively.

Alternatively, the correlation can be expressed in terms of covariance, as shown in Equation (2). Here, variance measures the extent to which each value in the signal deviates from its average, and it is commonly referred to as the power of the signal.

$$co = \frac{COV(x,y)}{\sqrt{Var(x) \times Var(y)}} \quad (2)$$

Where $COV(x,y)$ is the coberence of the signals, $Var(x)$ and $Var(y)$ are the variance of the first and second signal respectively [23].

Current research investigates the coherence across the brain hemispheres horizontally, vertically, and diagonally (Figure 1). The horizontal coherence is compared in both age groups for the frontal lobe (Fp1 - Fp2) and occipital lobe (O1 - O2). Also, the vertical coherence is compared for both groups for left and right hemispheres, between occipital and frontal lobes (Fp1 – O1) and (Fp2 – O2). In addition, the diagonal coherence is compared for both age groups between (Fp1 – O2) and (Fp2 – O1).

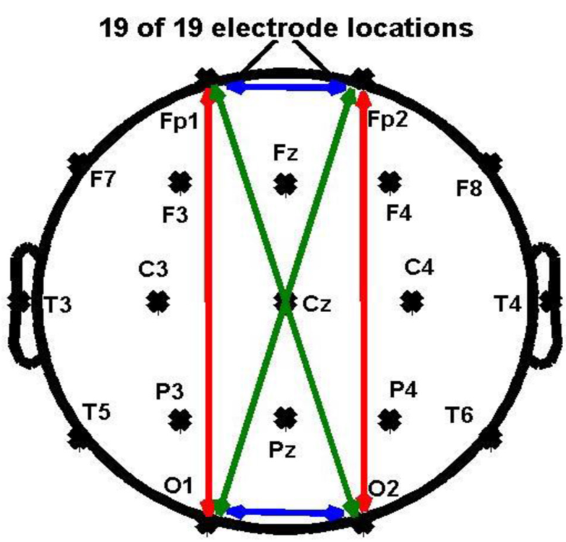
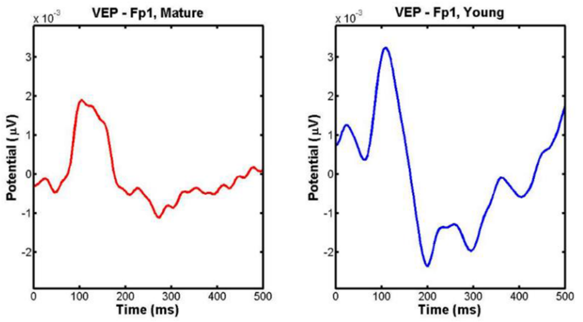


Figure 1: Horizontal (blue), vertical (red), and diagonal (green) coherence across the brain hemisphere for the frontal and occipital lobe

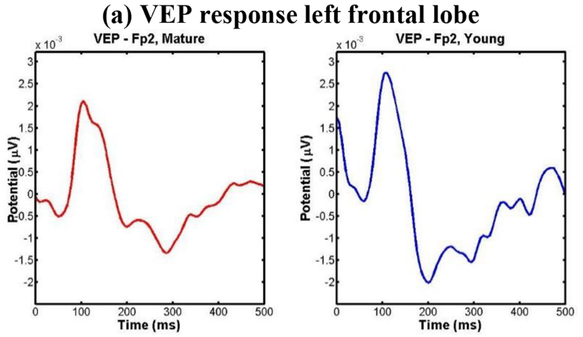
Results

VEP Response Result

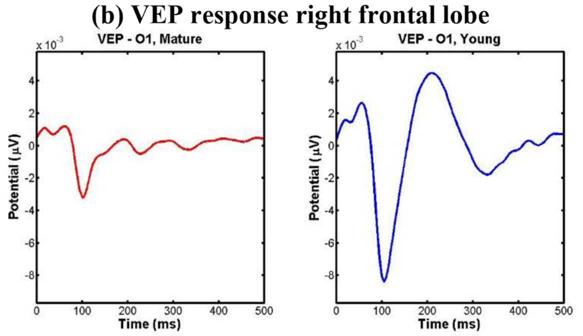
Visual evoked potentials are recorded for 19 electrodes attached to the brain for both groups. The group analysis of averaged VEP recorded from 19 channels and 20 subjects was studied for each age group. However, a prominent response was clearly observed in the frontal and occipital regions of the brain, as shown in Figures 2 (a, b, c and d). This result is consistent with previously reported



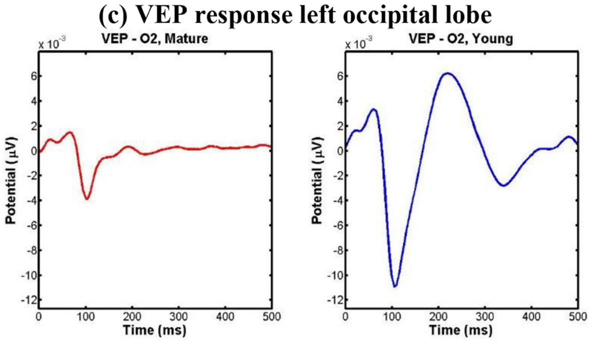
(a) VEP response left frontal lobe



(b) VEP response right frontal lobe



(c) VEP response left occipital lobe



(d) VEP response right occipital lobe

Figure 2: The visual evoked potentials response using pattern reversal checkerboard stimulation for young and matured groups (**a**) and (**b**) in the frontal lobe and (**c**) and (**d**) for the occipital lobe. The amplitude of the prominent peak of Visual evoked potential (VEP) at 100 ms is much higher in the young group than in matured in the electrode site of the frontal and occipital lobes.

findings [2].

In Figure 2, the prominent peak of VEPs is recorded in the frontal and occipital areas of the brain. Therefore, these areas are logically used to study the coherence across the brain for comparison purposes between age groups.

Cross Coherence Analysis Result

The coherence is compared between cross-hemisphere frontal and occipital electrode sites (Fp1, Fp2, O1, and O2). Coherence has been investigated in two age groups for the time and frequency domains. The cross coherence represents horizontal coherence versus the time domain of the frontal and occipital lobes between electrode positions Fp1, Fp2, O1, and O2 for matured and young age groups, Figures 3 (a, b, c, and d).

It is observed that coherence varies with time, exceeding 0.5 in the occipital lobe in both mature and young age groups (Figures 3c and 3d). In contrast, the coherence value is approximately 0.2 in the frontal lobe for both age groups (Figures 3a and b).

In the mature group (Figures 3a and c), the fluctuation in coherence was clearly proportional to the epochs of the recorded (VEPs). Specifically, within each time window, an increase in coherence was observed to correspond with the prominent VEP peak. However, this pattern was not discernible in the younger age group, where fluctuations in coherence exhibited no clear association with the time windows of the VEP response (Figures 3b and d).

The variation of horizontal coherence versus frequency bands of VEP is shown in Figure 3 (e, f, g, and h). The coherence between the left and right frontal lobes shows a frequency response at 15 Hz, representing Alpha wave is seen in both matured and young age groups (Figures 3e and f). While this response is only seen in the matured gropes in the coherency of the occipital lobe (Figure 3g and h). The alpha wave disappears in the occipital lobe from the young age group.

The vertical coherency in the time domain, for the left side of the brain between Fp1-O1 and the right side of the brain between Fp2-O2 are mostly similar in both mature and young age groups (Figures 4a, b, c, and d). Since there is no significant difference or indicator to differentiate between these groups.

The vertical coherence with frequency bands is shown in Figure 4 (e, f, g, and h). The frequency vertical coherence in the matured age group between Fp1-O1 shows an extra peak in the range of late Alpha wave at 25 Hz compared to that in the young age group. All other frequency peaks are almost the same for all coherence and groups as in Figure 4 (e, f, g, and h).

Similar to vertical coherence in the time domain, diagonal coherence across brain hemispheres displays a similar pattern, as demonstrated in Figures 5 (a, b, c, and d). Notably, coherence values in the young age group were slightly lower than those in the mature age group. In the mature group, the coherence exceeded 0.5, while in the young group, it was approximately 0.4. This slight difference may serve as an indicator of neural maturity.

The diagonal coherence in the frequency domain shows the frequency peak of the Alpha wave at 15 Hz in the matured age group. While the young group shows the late Alpha wave at around 25 Hz, as shown in

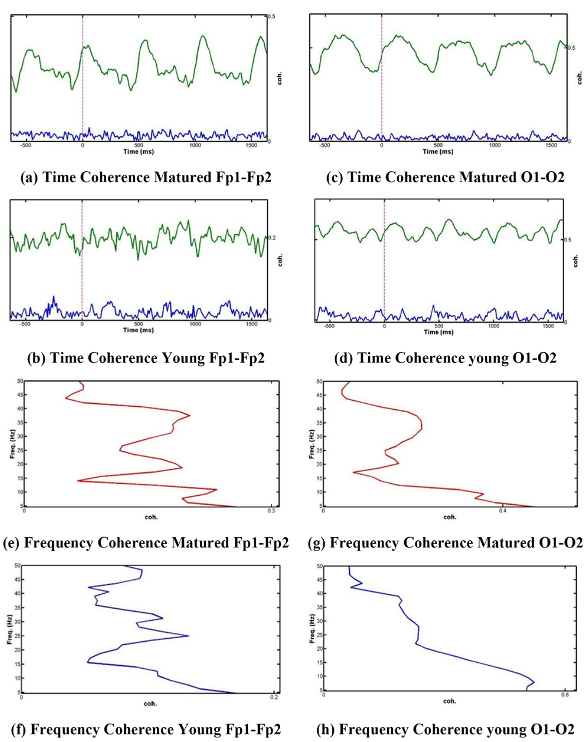


Figure 3: Horizontal coherence of the frontal and occipital lobes between electrodes positions in time domain (**a**) Fp1 and Fp2 for matured, (**b**) Fp1 and Fp2 young age groups, (**c**) O1 and O2 for matured and (**d**) O1 and O2 young age groups and in the frequency domain (**e**) Fp1 and Fp2 for matured, (**f**) Fp1 and Fp2 young age groups, (**g**) O1 and O2 for matured and (**h**) O1 and O2 young age groups

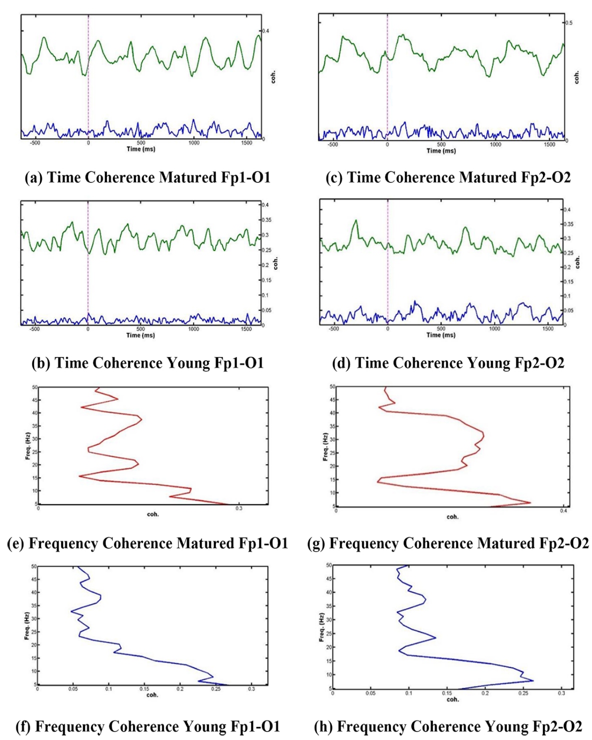


Figure 4: Left and right vertical coherence between electrodes positions in time domain (**a**) Fp1 and O1 for matured, (**b**) Fp1 and O1 for young age groups, (**c**) Fp2 and O2 for matured and (**d**) Fp2 and O2 young age group and in the frequency domain (**e**) Fp1 and O1 for matured, (**f**) Fp1 and O1 for young age groups, (**g**) Fp2 and O2 for matured and (**h**) Fp2 and O2 young age group

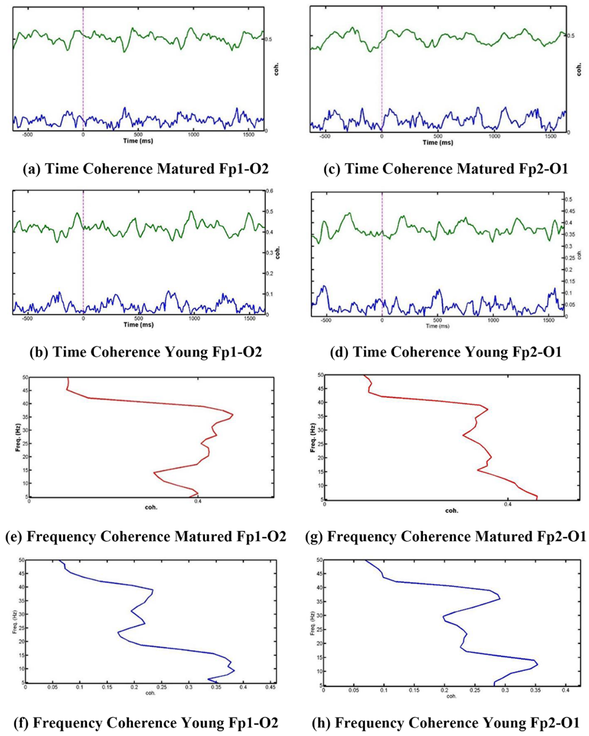


Figure 5: Diagonal coherence between electrodes positions in time domain (**a**) Fp1 and O2 for matured, (**b**) Fp1 and O2 for young age groups, (**c**) Fp2 and O1 for matured and (**d**) Fp2 and O1 for young age groups and in frequency domain (**e**) Fp1 and O2 for matured, (**f**) Fp1 and O2 for young age groups, (**g**) Fp2 and O1 for matured and (**h**) Fp2 and O1 for young age groups

Figures 5 (e, f, g, and h). The two frequencies, early and late alpha waves, are clearly indicated in both cross coherence between left and right brain hemispheres and frontal and occipital brain lobes.

Discussion

In the result section, an important finding is highlighted through the investigation of VEP responses and cross-coherence analysis. As shown in Figure 2, the VEP response was noticed clearly in the frontal and occipital lobes of the brain across the brain hemispheres. As a comparison between age groups, the pattern reversal VEP showed no differences in latency; the main P100 peak consistently appeared at 100 ms after the onset of visual stimulation for both groups. In contrast, significant differences were observed in the amplitude of the VEP responses. In the frontal regions, specifically at electrodes Fp1 and Fp2, the amplitude in the young age group exceeded 3×10^{-3} µV, whereas it was less than 2×10^{-3} µV in the mature group. Similarly, in the occipital regions (O1 and O2), which are critical for visual processing, the amplitude of the P100 component in the young subjects was approximately twice as high as that in the mature subjects.

On the other hand, as discussed in Figure 3, horizontal coherence illustrates the relationship between the left and right brain hemispheres by comparing connectivity within the same lobe. As expected, the horizontal coherence results in normal subjects should be symmetric within the same lobes, given that the VEP response serves as a test of the visual pathway [24]. In contrast, diagonal coherence successfully revealed age-related variations (Figure 5), with coherence values in the mature group surpassing those in the young group. This finding suggests stronger interconnections between different brain lobes and hemispheres in the mature group, indicating a more advanced level of neural development.

Furthermore, coherence in the frequency domain demonstrated a marked distinction between the age groups: the mature group exhibited a dominant coherence peak at approximately 15 Hz, while the younger group showed a peak around 25 Hz. This observation suggests that a decrease in frequency is indicative of increased neural maturity. This may correlate with more advanced levels of thinking, decision-making, and perception. These results are consistent with previous EEG age-related studies [25] that reported decreased coherence in the theta and alpha bands in younger individuals. Our findings also revealed two prominent peaks in the early and late alpha frequency ranges, with strong coherence in some brain regions related to the VEP response and diminished coherence in others. Examining coherence across various brain lobes and directions will enhance our understanding of brain connectivity, particularly as the number of electrodes, components, and nodes increases.

Conclusion

Cross-coherence is a statistical approach used to quantify the relationship between two signal sources. This study aimed to compare horizontal, vertical, and diagonal coherence across brain hemispheres, as well as between the frontal and occipital lobes, in both mature and young age groups. In the time domain, horizontal coherence was observed to be higher between the occipital lobes than between the frontal lobes. Diagonal coherence in the younger age group was below 0.4, whereas it exceeded 0.4 in the time domain and 0.5 in the frequency domain for the mature group. These findings suggest that diagonal coherence effectively distinguishes between age groups, unlike vertical coherence, which did not show significant differences. In the frequency domain, horizontal coherence between the left and right occipital lobes in the mature group displayed an alpha wave peak at 15 Hz, a feature absents in the younger group. Furthermore, vertical coherence between Fp1 and O1 in the mature group exhibited an additional peak in the late alpha range at 25 Hz, while diagonal coherence revealed a 15 Hz peak for the mature group compared to a 25 Hz peak for the younger group.

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Ethical Approval

Ethical Approval is obtained before data recording. Data management follows ethical guidelines. The personal information of all participants is protected and secured.

Informed Consent

This study was approved by the Al-Muthanna University, College of Science in the scientific plan and Informed consent was also obtained.

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This research is self-funded.

Conflict of Interest

None

References

1. Snyder AC, Issar D, Smith MA. What does scalp electroencephalogram coherence tell us about long-range cortical networks? *Eur J Neurosci.* 2018;**48**(7):2466-81. doi: 10.1111/ejn.13840. PubMed PMID: 29363843. PubMed PMCID: PMC6497452.
2. Brenner R. Investigations in Multiple Sclerosis. In: Schapira AHV, Byrne E, DiMauro S, Frackowiak RSJ, Johnson RT, Mizuno Y, et al., editors. Neurology and Clinical Neuroscience. Philadelphia: Mosby; 2007. p. 1031-44.
3. Poulos M, Papavlasopoulos S, Alexandris N, Vlachos E. Comparison between auto-cross-correlation coefficients and coherence methods applied to the EEG for diagnostic purposes. *Med Sci Monit.* 2004;**10**(10):MT99-108. PubMed PMID: 15448608.
4. Meng F, Tong KY, Chan ST, Wong WW, Lui KH, Tang KW, et al. Study on connectivity between coherent central rhythm and electromyographic activities. *J Neural Eng.* 2008;**5**(3):324-32. doi: 10.1088/1741-2560/5/3/005. PubMed PMID: 18756033.
5. Popivanov D, Dushanova J. Non-linear EEG dynamic changes and their probable relation to voluntary movement organization. *Neuroreport.* 1999;**10**(7):1397-401. doi: 10.1097/00001756-199905140-00003. PubMed PMID: 10380953.
6. Kristeva R, Patino L, Omlor W. Beta-range cortical motor spectral power and corticomuscular coherence as a mechanism for effective corticospinal interaction during steady-state motor output. *Neuroimage*. 2007;**36**(3):785-92. doi: 10.1016/j.neuroimage.2007.03.025. PubMed PMID: 17493837.
7. Hashimoto Y, Ushiba J, Kimura A, Liu M, Tomita Y. Correlation between EEG-EMG coherence during isometric contraction and its imaginary execu-

tion. *Acta Neurobiol Exp (Wars)*. 2010;**70**(1):76-85. doi: 10.55782/ane-2010-1776. PubMed PMID: 20407489.

8. Pohja M, Salenius S, Hari R. Reproducibility of cortex-muscle coherence. *Neuroimage*. 2005;**26**(3):764-70. doi: 10.1016/j.neuroimage.2005.02.031. PubMed PMID: 15955485.
9. Chen CC, Hsieh JC, Wu YZ, Lee PL, Chen SS, Niddam DM, et al. Mutual-information-based approach for neural connectivity during self-paced finger lifting task. *Hum Brain Mapp.* 2008;**29**(3):265-80. doi: 10.1002/hbm.20386. PubMed PMID: 17394211. PubMed PMCID: PMC6871222.
10. Ioannides AA, Mitsis GD. Do we need to consider non-linear information flow in corticomuscular interaction? *Clin Neurophysiol*. 2010;**121**(3):272-3. doi: 10.1016/j.clinph.2009.11.005. PubMed PMID: 20005772.
11. Kim B, Kim L, Kim YH, Yoo SK. Cross-association analysis of EEG and EMG signals according to movement intention state. *Cognitive Systems Research.* 2017;**44**:1-9. doi: 10.1016/j.cogsys.2017.02.001.
12. Cimenser A, Purdon PL, Pierce ET, Walsh JL, Salazar-Gomez AF, Harrell PG, et al. Tracking brain states under general anesthesia by using global coherence analysis. *Proc Natl Acad Sci U S A*. 2011;**108**(21):8832-7. doi: 10.1073/pnas.1017041108. PubMed PMID: 21555565. PubMed PMCID: PMC3102391.
13. Yindeedej V, Uda T, Nishijima S, Inoue T, Kuki I, Fukuoka M, et al. Changes in interhemispheric coherence after total corpus callosotomy: a scalp EEG study in children with non-lesional generalized epilepsy. *Childs Nerv Syst.* 2024;**40**(8):2483-9. doi: 10.1007/s00381-024-06435-3. PubMed PMID: 38687362.
14. Yindeedej V, Uda T, Nishijima S, Inoue T, Kuki I, Fukuoka M, et al. Preoperative interhemispheric coherence as a potential predictive marker for seizure outcome after total corpus callosotomy in nonlesional generalized epilepsy: a scalp EEG study. *J Neurosurg Pediatr.* 2024;**35**(2):174-80. doi: 10.3171/2024.7.PEDS24246. PubMed PMID: 39454219.
15. Criscuolo S, Cataldo A, De Benedetto E, Masciullo A, Pesola M, Schiavoni R. Entropy and Coherence Features in EEG-Based Classification for Alzheimer's Disease Detection. In IEEE International Instrumentation and Measurement Technology Conference (I2MTC); Glasgow, United Kingdom: IEEE, 2024. p. 1-6.
16. Hwang S, Shin Y, Sunwoo JS, Son H, Lee SB, Chu K, et al. Increased coherence predicts medical refractoriness in patients with temporal lobe epilepsy on monotherapy. *Sci Rep.* 2024;**14**(1):20530. doi: 10.1038/s41598-024-71583-0. PubMed PMID: 39227730. PubMed PMCID: PMC11372158.
17. Almurshedi AF, Ismail AK, Sulaiman N. Feature extraction of visual evoked potentials using wavelet transform and singular value decomposition. *Iran J Med Phys.* 2018;**15**:206-14. doi: 10.22038/ijmp.2018.28583.1311.
18. Almurshedi AF. Measure projection analysis of VEP localization neuron generator. International Conference on BioSignal Analysis, Processing and Systems (ICBAPS); Kuala Lumpur, Malaysia: IEEE; 2015. p. 108-11.
19. Odom JV, Bach M, Brigell M, Holder GE, McCulloch DL, Mizota A, Tormene AP. ISCEV standard for clinical visual evoked potentials: (2016 update). *Doc Ophthalmol.* 2016;**133**(1):1-9. doi: 10.1007/s10633-016-9553-y. PubMed PMID: 27443562.
20. Thompson DA, Mikó-Baráth E, Hardy SE, Jandó G, Shaw M, Hamilton R. ISCEV standard pattern reversal VEP development: paediatric reference limits from 649 healthy subjects. *Doc Ophthalmol.* 2023;**147**(3):147-64. doi: 10.1007/s10633-023-09952-9. PubMed PMID: 37938426. PubMed PMCID: PMC10638119.
21. Almurshedi AF, Ismail AK. Cross coherence independent component analysis in resting and action states EEG discrimination. *Journal of Physics: Conference Series* 2014;**546**(1):012019. doi: 10.1088/1742-6596/546/1/012019.
22. Weiss S, Mueller HM. The contribution of EEG coherence to the investigation of language. *Brain Lang.* 2003;**85**(2):325-43. doi: 10.1016/s0093-934x(03)00067-1. PubMed PMID: 12735948.
23. Shaw JC. An introduction to the coherence function and its use in EEG signal analysis. *J Med Eng Technol.* 1981;**5**(6):279-88. doi: 10.3109/03091908109009362. PubMed PMID: 7328624.
24. Hamilton R, Bach M, Heinrich SP, Hoffmann MB, Odom JV, McCulloch DL, Thompson DA. VEP estimation of visual acuity: a systematic review. *Doc Ophthalmol*. 2021;**142**(1):25-74. doi: 10.1007/s10633-020-09770-3. PubMed PMID: 32488810. PubMed PMCID: PMC7907051.
25. Vysata O, Kukal J, Prochazka A, Pazdera L, Simko J, Valis M. Age-related changes in EEG coherence. *Neurol Neurochir Pol.* 2014;**48**(1):35-8. doi: 10.1016/j.pjnns.2013.09.001. PubMed PMID: 24636768.