Research article/Raziskovalni prispevek

ELECTROENCEPHALOGRAPHIC (EEG) COHERENCE BETWEEN VISUAL AND MOTOR AREAS OF THE LEFT AND THE RIGHT BRAIN HEMISPHERE WHILE PERFORMING VISUOMOTOR TASK WITH THE RIGHT AND THE LEFT HAND

ELEKTROENCEFALOGRAFSKA KOHERENCA MED VIDNIMI IN MOTORIČNIMI PREDELI LEVE IN DESNE POLOBLE PRI IZVAJANJU VIDNO-MOTORIČNE NALOGE Z DESNO IN LEVO ROKO

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Abstract

Background *Unilateral limb movements are based on the activation of contralateral primary motor cortex and the bilateral activation of premotor cortices. Performance of a visuomotor task requires a visuomotor integration between motor and visual cortical areas. The functional integration (»binding«) of different brain areas, is probably mediated by the synchronous neuronal oscillatory activity, which can be determined by electroencephalographic (EEG) coherence analysis. We introduced a new method of coherence analysis and compared coherence and power spectra in the left and right hemisphere for the right vs. left hand visuomotor task, hypothesizing that the increase in coherence and decrease in power spectra while performing the task would be greater in the contralateral hemisphere.*

Methods *We analyzed 6 healthy subjects and recorded their electroencephalogram during visuomotor task with the right or the left hand. For data analysis, a special Matlab computer programme was designed. The results were statistically analysed by a two-way analysis of variance, one-way analysis of variance and post-hoc t-tests with Bonferroni correction.*

Results *We demonstrated a significant increase in coherence ($p < 0.05$) for the visuomotor task compared to control tasks in alpha (8–13 Hz) in beta 1 (13–20 Hz) frequency bands between visual and motor electrodes. There were no significant differences in coherence nor power spectra depending on the hand used. The changes of coherence and power spectra between both hemispheres were symmetrical.*

Conclusions *In previous studies, a specific increase of coherence and decrease of power spectra for the visuomotor task was found, but we found no conclusive asymmetries when performing the task with right vs. left hand. This could be explained in a way that increases in coherence and decreases of power spectra reflect symmetrical activation and cooperation between more complex visual and motor brain areas.*

Key words *cerebral cortex; electroencephalography (EEG); synchronous electrical oscillations; coherence; power spectrum; visuomotor integration; binding*

Izvleček

Izhodišča

Najnovejši pogled na delovanje možganov je, da možgani obdelujejo informacije vzporedno, tako da so funkcijsko različna in distribuirana nevronska mrežja aktivna sočasno. Funkcija sloni na sinhronizirani interakciji več (definiranih) možganskih predelov, ki niso nujno neposredno anatomsko povezani. Možgani s časovno zamejenim integriranjem delovanja teh področij omogočajo enovito notranjo reprezentacijo določenega vzorca dražljaja. Tovrstno komunikacijo med anatomsko ločenimi področji označujemo z izrazom funkcijska konektivnost ali povezovanje (angleško binding). Komunikacija med nevronskimi populacijami morda poteka preko sinhronizirane oscilirajoče aktivnosti nevronskih mrežij, ki se da določiti z merjenjem elektroencefalografske koherence. Koherenca nam pove, kako časovno usklajeno narašča in upada moč v določenih frekvenčnih spektrih med poljubnimi možganskimi področji. Pri izvajanju motoričnih nalog, vodenih z vidom, je potrebna vidno-motorična integracija, povezovanje vidnih in motoričnih predelov možganske skorje. V metodološko različnih študijah so ugotovili, da je nevronska aktivnost med hotenimi gibi prstov ene roke v primarnih motoričnih področjih bolj lateralizirana kot aktivnost v premotoričnih in suplementarnih motoričnih predelih možganske skorje, kjer je pri gibu ene roke aktivnost razporejena po obeh straneh. Premotorični (PM) in suplementarni motorični polji (SMP), ki sodelujeta predvsem pri zamisli in načrtovanju giba, se pred izvedbo giba z enim udom aktivirata v obeh možganskih poloblah razmeroma simetrično, primarno motorično polje M1, ki je hierarhično nižje in skrbi za samo izvedbo giba, pa izrazito bolj v polobli, ki je gibajočemu se udu nasprotna. Cilj naše raziskave je bil primerjava sprememb koherence in močnostnih spektrov nad levo in desno možgansko poloblo pri izvajanju vidno-motorične naloge z desno ali z levo roko. Preiskovanec je moral prilagajati moč stiska prstov, da je lahko (prek vmesnika) na računalniškem zaslonu spreminjal položaj točke in z njo sledil tarči. Predpostavili smo, da bo povečanje koherence in zmanjšanje močnostnih spektrov pri izvajanju naloge z desnico večje nad levo poloblo in obratno.

Metode

Analizirali smo 6 EEG posnetkov zdravih desničnih preiskovancev, ki so med elektroencefalografskim snemanjem izvajali vidno-motorično nalogo (VM) z levo ali desno roko (naloga je zahtevala usklajeno delovanje vidnih in motoričnih polj) in jo primerjali s kontrolnimi nalogami (zgolj opazovanje vidnega dražljaja; zgolj stiskanje prstov brez vidnega dražljaja; stiskanje prstov ob motečem vidnem dražljaju). Pri vidno-motorični nalogi (VM) je preiskovanec sledil tarčnemu signalu na zaslonu s spreminjanjem sile stiskanja. Za izračun sprememb koherence in močnostnih spektrov smo izdelali računalniški program v programskem okolju Matlab. Rezultate smo statistično obdelali z metodami dvosmerne variance, enosmerne variance ter s post-hoc testi t s korekcijo po Bonferroniju.

Rezultati

Dokazali smo statistično pomembno povečanje koherence ($p < 0,05$) pri vidno-motorični nalogi (VM) glede na kontrolne naloge v frekvenčnih pasovih alfa (8–13 Hz) in beta 1 (13–20 Hz) med ciljnimi pari elektrod (frontalne, centralne in okcipitalne). Spremembe koherence niso bile statistično pomembno odvisne od tega, s katero roko so preiskovanci izvajali nalogo, in so se v obeh primerih simetrično zvečale v obeh poloblah. Podobno velja za spremembe – zmanjšanja močnostnih spektrov.

Zaključki

V skladu s prejšnjimi raziskavami smo dokazali specifično povečanje koherence med vidnimi in motoričnimi polji pri izvajanju vidno-motorične naloge in pokazali, da ni prepričljivih asimetrij pri izvajanju le-te z desno oz. levo roko. Slednje je možno razložiti, če povečanje koherence odseva sodelovanje med sekundarnimi kompleksnejšimi vidnimi in motoričnimi področji možganske skorje. Kolikor bi se med izvajanjem vidno-motorične naloge z vidnimi polji povezalo predvsem polje M1, bi pričakovali, da bo ta povezava in s tem vrednost koherence med poloblama asimetrična. Naše rezultate, ki ne potrjujejo tovrstne hipoteze, pa bi bilo mogoče razložiti s povezovanjem vidnih polj predvsem s polji PM in SMP. Informacije o položaju tarče in o položaju točke, s katero ji s prilagajanjem moči stiskanja prstov poskušamo slediti, verjetno služijo za izdelavo motoričnega programa in ne za samo izvedbo giba. V prid taki interpretaciji so tudi podatki o anatomskih povezavah (okcipitoparietalno-frontalne zanke) ter rezultati – visoke vrednosti koherenc tudi med frontalnimi (premotoričnimi) in posteriornimi pari elektrod. Simetrična povečanja koherence med različnimi frontalnimi, centroparietalnimi in okcipitalnimi odvodi EEG pa morda ne odražajo zgolj specifičnega povezovanja motoričnih in vidnih polj pri vidno-motorični integraciji, ampak so lahko tudi odraz drugih motoričnih, kognitivnih ali moti-

vacijskih procesov. Če povzamemo, metoda elektroencefalografske koherence se je izkazala uporabno za namen raziskovanja integrativne funkcije možganov, z izborom različnih nalog oz. paradigem pa bi lahko preučevali fiziološke in patofiziološke vidike motoričnih, senzoričnih in kognitivnih funkcij centralnega živčnega sistema.

Ključne besede *možganska skorja; elektroencefalografija (EEG); sinhrone električne oscilacije; koherenca; močnostni spekter; vidno-motorična integracija; funkcijsko povezovanje*

Introduction

The central problem for integrative neuroscience is to describe complex higher brain processes. The modern view of brain function is based on reverberations of reentrant electrical activity in complex neural networks, producing oscillations, and mainly parallel (but also serial) information processing so that functionally distinct and distributed neuronal networks are activated simultaneously.[1] Therefore, the function is probably mediated by synchronized interaction of many (defined) brain regions, which are not necessarily directly anatomically connected.[2] The exact mechanisms of dynamic interactions of many involved but anatomically separated brain regions are not yet well known. The functional integration (»binding«) of different brain areas, responsible for specific functions, is one of the key problems in understanding brain function – a question not yet resolved.[3] Synchronization is how the brain probably achieves large-scale integration of its many parallel, distributed processing activities, allowing coherent complex brain function, cognition and behaviour. Recent evidence shows that synchronous neural electrical oscillations and computations performed by functionally connected neurons reveal much about the nature of processes such as perception, complex motor behaviour, visuomotor integration, memory, attention and consciousness.[1, 4] Many studies have found that synchronous oscillations correlate with specific behavioural contexts and cognitive tasks (e. g. working memory, selective attention etc.).[5–9] Anyway, the binding phenomena were first investigated in mammalian visual systems, where synchronized oscillations among different areas of visual cortex were noted during perception.[10–13] The same needs for connecting different components of information also exist in the motor systems, where execution of complex action depends on harmonized function of multiple motor and non-motor cortical areas.[14–19] Most likely, synchronized oscillations between neuronal networks also mediate this function. Such oscillations were found during spontaneous movements and during bimanual motor learning.[5, 20, 21]

EEG is a method, suitable for the study of oscillations, as it measures repeated, periodic electrical activity of cortical (pyramid) neurons. Summed activity (mainly postsynaptic potentials: excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs) with resulting extracellular ionic currents) of many neurons results in field potentials, many of them constituting macropotential (EEG signal).[22] It is influenced by intrinsic qualities of neurons and by dynamic interactions between communicating neuronal networks. The macropotential is a result of changing pattern of synchronization and desynchronization of regional brain cells, which results in amplitude changes of specific frequency bands.[23] EEG has great time resolution and shows distinct patterns of activity (brain rhythms, oscillations). Brain rhythms can be divided into many frequency bands (delta: 0.5–4 Hz, theta: 4–7 Hz, alpha: 8–13 Hz, beta: 13–30 Hz, gamma: more than 30 Hz) with their specific functional and behavioral correlates and activating contexts and spatial scales. Mainly alpha and beta rhythms are involved in motor processes.[19, 24] Generally, the proposed role of brain oscillations is switching neural networks between different functional states with activating or inhibiting proper neural systems.[23, 25, 26] The neurophysiological theory of higher brain functions predicts that multiple superimposed synchronized (coherent) oscillations in different frequency bands with different spatial patterns and functional correlates govern specific mental functions.[27–29] Synchronized oscillatory activity of EEG signals can be measured and calculated by different correlation methods, but mostly electroencephalographic (EEG) coherence analysis is used.[30, 31] EEG coherence and power spectra analysis are newer methods for analyzing the complex, information-rich EEG signal. Power spectra are the measure for degree of representation of specific frequency band in the signal. The power spectra changes reflect different levels of regional cortical activity or different level of their synchronization – synchronization usually reflecting cortical inactivity (e. g. event-related synchronization – ERS; resulting in power spectrum increase) and desynchronization (event-related desynchronization – ERD; resulting in power spectrum decrease) reflecting cortical activity.[32–34] Coherence between two EEG signals (x, y), on the other hand, equals the squared cross-correlation power spectrum in the frequency domain. It reflects the degree of amplitude- and phase-locking (coupling) – the similarity and inter-dependence between two distant signals. Coherence values can span the interval between 0 and 1, where value 0 means total absence of synchronous coupling and value 1 means full matching of two signals.[30, 31] Task-related coherence (TR-CoH) refers to a value of coherence in specific frequency band during the interval of stationary conditions during the task (e. g. finger movement performance).[19, 33, 35] To summarize, activity of neuronal networks can be regulated at least in two ways. Firstly, by regional synchronization and desynchronization (resulting in power spectra changes) and secondly, by increasing or decreasing inter-areal functional connectivity of different neuronal networks by phase-locking/synchronization (resulting in coherence changes). Power spectra and coherence changes therefore reflect two different operational systems of the brain.[7, 8, 31, 35]

Considering visuomotor integration, it is well known that the function of nervous system and its motor reflection is dependent on the input of sensory information in any moment and at any hierarchical level. For any goal-directed, purposeful movement or action, the brain has to develop a strategy, a motor program. For this purpose, premotor and supplementary motor areas (SMA) cooperate with posterior parietal lobus and with primary motor area.[36] Research shows that neuronal activity before and during volitional movements of fingers of one hand or arm is more lateralized in hierarchically lower contralateral primary motor areas M1 (motor execution) than in premotor and supplementary motor cortex (motor conception and planning/programming), where activity is bilateral and symmetrical in both brain hemispheres.[37–40] Sensory information of different modalities (e. g. visual, auditory, proprioceptive), which are important for movement, are being processed in parallel operation systems. For visuomotor control, parietofrontal networks of parallel loops are especially important.[41] The movements with visual guidance activate predominantly superior parietal lobus (SPL) and dorsal premotor areas. SPL plays a bridging role in the loops between visual and motor cortex, which are not directly anatomically connected. Therefore, the information from the primary and secondary visual cortex, parietooccipital cortex and SPL about the location, size and form of the target are being stored and integrated in premotor cortex, for developing of motor programmes.[17, 41–43] Interestingly, Classen et al. (1998)[5] and Brežan et al. (2005)[35] already showed that EEG-coherence increases between visual and motor areas in tasks, which require visuomotor integration. There were increases of coherence between visual and motor areas at visuomotor task compared to control tasks, which is in accordance with the concept of synchronization as a neuronal correlate of increased functional connectivity.[28, 30, 31] Example of such task is visuomotor tracking, whereby the subject has to adjust movement to the visual stimulus. Increase of TRCoH was specific for such task, but in contrast, was not found in the control tasks.[5, 35] Presently, we wanted to examine potentially asymmetrical changes of coherence and power spectra at performance of the visuomotor task with the left vs. the right hand, comparing the relevant values in both brain hemispheres. We hypothesized that coherence increases and power spectra decreases would be greater in contralateral motor areas of left hemisphere when performing the task with the right hand and vice versa, based on the knowledge of mainly asymmetrical contralateral (relative to the hand used in the task) activation of motor areas for unilateral movements.

Methods

In our study we included 6 healthy right-handed volunteers (5 men, 1 woman), aged between 26 and 32 years (average age 28 years). Their handedness was determined by Edinburgh Handedness Questionnaire. The necessary condition to participate was absence of any known neurological/psychiatric diseases and the condition to exclude participant's data post hoc was the presence of too many artefacts in their EEG recordings (1 EEG recording was excluded). All the participants gave their informed consent. The study was approved by the Slovenian Commission for Medical Ethics at the Ministry of Health of the Republic of Slovenia in 2003.

The participants carried out 4 different tasks during EEG recordings. Each task was made of 20 repeated segments and each segment was composed of 25-second period of activity and 25-second period of rest. During rest, the participants had to observe only the fixation cross in the centre of the computer screen. All the tasks have been described in the previous publication (to Brežan et al., 2005)[35] and are not the focus of this article. All tasks were programmed in Matlab software (The Mathworks Inc., Natick, USA).

The tasks performed by participants included 3 control tasks and experimental visuomotor task (VM), which required the subjects to adjust the force of finger gripping, so that they were able to change the position of the moving point presented on the computer screen to track the target (sinusoid, 0.1 Hz) signal according to the visual feedback. The force of finger gripping (cca. 20 N) was acquisited in real-time by force sensor.[44] This task was performed either with the right (RVM) or with the left hand (LVM) half of the total time, and half of participants started to perform with the left hand and the other half with the right hand so that the hypothetical effect of learning was eliminated.

EEG recording was done in a darkened quiet room. Participants were lying on the bed with their upper body raised to relax their head and neck musculature and were observing the screen at a distance 2.5 m, where the tasks were projected. The gripping movements were performed with relaxed extended right or left arm on specially designed gripping force measuring device.[31]

Elastic EEG caps (E1-S Electro-Cap) were placed on participants' heads, according to international 10–20 system of EEG standard electrode placement with 5 extra electrodes above motor cortical areas (Fz, FCz, Cz, CPz, Pz) (altogether 27 electrodes on the scalp). We used linked ear- reference electrodes, the ground electrode was put on the forehead. EEG was recorded with EEG apparatus Medelec (Profile Multimedia EEG System, version 2.0, Oxford Instruments Medical Systems Division, Surrey, England). The impedances were held under 10 kΩ. The gripping force and EEG signal were recorded on 2 separated computers, with synchronization signal connecting them, which enabled us to synchronize the recorded data. The muscular activity was recorded with electromyogram (EMG) with superficial electrodes placed on the hand.

By measuring EMG, we wanted to make sure that during rest (control) periods the participants were not carrying out any movements. The eye movements and blinking was observed by occulogram (EOG), with 2 electrodes placed above and under the eye The gripping force was measured with a special device, which was being pressed by the participants with their first two fingers. The device was connected to computer via 12-bit measuring card PCI-DAS1002 (Measurement Computing Corp., Middleboro, USA). The sampling of force was done with 100 Hz and resolution of 0.05 N. The data was filtered with the Butterworth filter of II. order and border frequency of 12 Hz.[31, 45] For storing, processing data and coherence calculation a special software was designed in Matlab. EEG data was initially stored in standard *.edf (European Data Format) files and then transferred to Matlab via a special subprogramme which enables processing and read out of *.edf files. For analysis only 2-second segments of artefact-free EEG data were selected and were classified as periods of experimental task (activity, movement) or rest period. Such segments were transferred to Matlab and discrete Fourier transformation (DFT) was performed on the data, the power spectra of the segments were averaged and then the function of coherence for each pair of electrodes was calculated. Mathematically, coherence is calculated by using the below formula:[9, 33, 45]:

$$C_{xy}(\omega): \quad \frac{|\ \Phi_{xy}\ (\omega)^2|}{C_{xy}(\omega) = \Phi_{xx}\ (\omega)\ .\ \Phi_{yy}\ (\omega)}$$

$C_{xy}(\omega)$: coherence value between signals x and y

$\Phi_{xy}(\omega)$ – value of cross-correlation power spectrum of signals x, y (Fourier transformation of cross-correlation function)

$\Phi_{xx}(\omega)$ – value of auto-correlation power spectrum of signal x (Fourier transformation of auto-correlation function)

$\Phi_{yy}(\omega)$ – value of auto-correlation power spectrum of signal y (Fourier transformation of auto-correlation function)

In the final results, we always considered the difference between coherence values between activity periods and rest periods for each pair of electrodes to subtract the coherence present both in activity and rest periods: $(\Delta C_{xy}) = (C_{activity}) - (C_{rest})$. This coherence differences are shown in the result figures as straight lines connecting pairs of electrodes. The colors of these lines reflect the change/difference in coherence values either as increases or decreases according to the colour scale. Similarly, the power spectra are calculated (as intermediary step) for each electrode and the difference of spectra between activity and rest periods are expressed in %, relatively to the rest period. The results are then cartographically presented on the head model as a 3-dimensional graph, where each peak value is dependent on power spectra magnitude.

For each participant, average values of power spectra were calculated for control and experimental task in alpha, beta 1, beta 2 and gamma frequency bands in following regions of interest: left frontocentral area (average of FC3 and C3 electrodes), right frontocentral area (average of FC4 and C4) and left and right occipital areas (O1 and O2 electrodes). Similarly, coherence was also calculated between frontocentral-occipital electrodes (averages between electrodes FC3-O1, FC3-O2, C3-O1, C3-O2; FC4-O1, FC4-O2, C4-O1, C4-O2). To determine the differences in visuomotor task with the right vs. the left hand, we then compared the average values of power spectra on the left side (FC3, C3) vs. the right side (FC4, C4) and occipitally O1 vs. O2. Coherence was compared for all the right vs. left combinations of connections between frontocentral and occipital electrodes (e. g., FC4-O1 vs. FC3-O1 etc.).

For statistical analysis of task and frequency band effect on power spectra and coherence values, two-way ANOVA was used. For more detailed task effect in specific frequency band one-way ANOVA was used and post-hoc *t*-tests with Bonferroni correction for pairs of tasks. For statistical significance, the value of $p < 0.05$ was chosen. All the statistics were performed in SPSS for Windows, version 10.0.

Results

The effect of performing the visuomotor task (VM) with the left (LVM) vs. right hand (RVM) on values of power spectra and coherence

We analyzed the influence of performing the VM task with the left vs. right hand on the values of power spectra and coherences at occipital and left and right frontocentral brain areas (Figures 1, 2 and 3).

Figure 1 shows changes of power spectra and Figure 2 shows changes of coherence for RVM and LVM tasks. Neither at power spectra nor at coherence values, we observed no convincing asymmetries between right and left brain hemisphere considering the performance of the task with the right vs. the left hand. Values of coherence changes for VM task are greatest

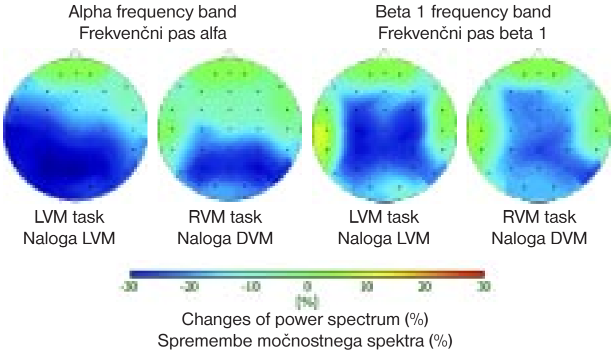

Figure 1. *Task-related changes of power spectrum in alpha and beta 1 frequency bands for left and right hand (colour scale shows changes of power spectrum in %).*

Sl. 1. *Z nalogo povezane spremembe močnostnega spektra v frekvenčnih pasovih alfa in beta 1 za levo in desno roko (barvna skala prikazuje spremembe močnostnega spektra, izražene v odstotkih).*

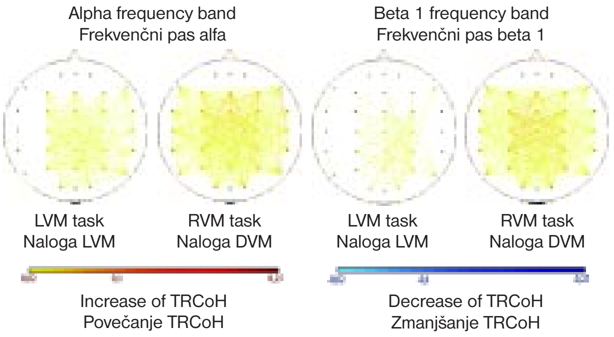

Figure 2. *Task-related coherence changes in alpha and beta 1 frequency bands for left and right hand (colour scale shows task-related coherence changes; LVM – left hand VM task; RVM – right hand VM task; TRCoH – task-related coherence).*

Sl. 2. *Z nalogo povezane spremembe koherence v frekvenčnih pasovih alfa in beta za levo in desno roko (barvna skala prikazuje spremembe z nalogo povezane koherence; LVM – z levo roko izvajana vidno-motorična naloga; DVM – z desno roko izvajana vidno-motorična naloga; TRCoH – z nalogo povezana koherenca).*

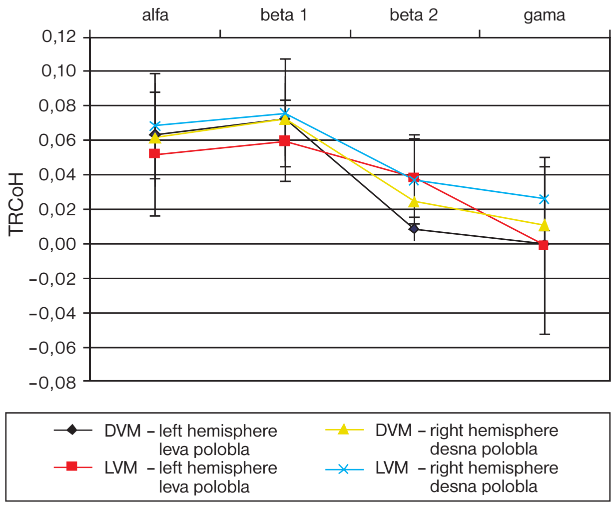

Figure 3. *Comparison of task-related coherence changes in specific frequency bands for left and right hemisphere at performing the VM task with left vs. right hand (LVM – left hand VM task; DVM – right hand VM task; TRCoH – task-related coherence; black vertical lines show standard deviations).*

Sl. 3. *Primerjava z nalogo povezanih sprememb koherence v posameznih frekvenčnih pasovih nad levo in desno poloblo pri izvajanju vidno-motorične naloge z levo in desno roko (LVM – z levo roko izvajana vidno-motorična naloga; DVM – z desno roko izvajana vidno-motorična naloga; TRCoH – z nalogo povezana koherenca; navpične črte predstavljajo standardne deviacije).*

for alpha and beta 1 frequency bands (Figure 3). Figure 3 shows the values of TRCoH for the left and right hemisphere considering the performance with the right or left hand. The coherences between hemispheres and between hands were not importantly different. In alpha and beta 1 the average coherence values were greater above contralateral hemisphere (relative to the hand used) compared to ipsilateral hemisphere and this was true for the right and for the left hand. But those coherence differences were not statistically significant.

With two-way analysis of variance, it was calculated that neither values of power spectra nor values of coherence were statistically significantly dependent on the fact, with which hand the task was performed, and there was also no significance dependent on the hemisphere observed.

Discussion

We demonstrated that changes of power spectra and coherence during the performance of visuomotor task with the right compared to the left hand were similar and relatively symmetrical in both brain hemispheres. Therefore, we did not confirm our hypothesis predicting asymmetric activation of contralateral hemisphere and asymmetric functional connectivity between visual and motor cortical areas at performing the VM task with either the left or right hand. Primary motor areas (M1), which mediate the very execution of movements, are activated dominantly in the hemisphere, which is contralateral to the moving limb, but hierarchically higher premotor and supplementary motor areas (SMA) are activated bilaterally. Numerous and methodologically diverse research on humans and animals supports this view (intracellular action potential detection, fMR, PET, EEG).[36, 46–52] Therefore, in case during the VM task predominantly M1 area would cooperate with visual cortex, we could expect that synchronization (coherence), comparing both hemispheres, would be asymmetrical. Since this was not the case, our results might be interpreted in a different way, i.e. by functional connectivity of visual areas with premotor/SMA cortex. This interpretation seems even more logical in a way. Information about target location and location of the moving point, with which the participants had to track the target by applying gripping movements of fingers, probably serves as input for motor programmes design and not for the very last step in a motor behaviour execution of the movement.[14, 36, 53] Also the known anatomical connection patterns between posterior occipitoparietal areas and frontal cortex (other then M1 areas) stand in support of this argument (parallel parieto-frontal loops).[41–43, 50, 53] Additionally, our descriptive results show high mainly bilateral coherence values between parietooccipital and anterior frontal (possibly premotor) pairs of electrodes, although one has to hold in mind that spatial resolution of EEG is relatively low and that only specific electrodes were statistically analyzed. Other areas of interest remain to be analyzed in future research. Interestingly, in our results, also interhemispheric increases of coherence can be seen. Such functional coupling of hemispheres is in accordance with well-known informational flow in the brain during visuomotor integration, where information from primary and secondary visual areas are first transfered via superior parietal lobus (SPL) to premotor areas, which also get activated bilaterally.[41] This means that complex sensory-motor tasks, e. g. unilateral movements with fine precision gripping require functional integrity of both hemispheres, which is also in accordance with other studies.[42] As already mentioned, we can critically argue that the absence of significant increases of EEG coherence or decreases of power spectra (representing cortical activation) mainly or exclusively between visual areas and contralateral motor areas relative to the moving hand, might also be due to a purely »technical« cause. Namely, the spatial resolution of EEG is relatively low, mainly because of volume conduction effect in the area of cortex, from which the specific electrode records from the underlying signal, is approximately 10 cm^2 wide.[8, 23, 24] From this we can infer, that it could be possible for electrode in one hemisphere to detect EEG activity also from the other, opposite hemisphere in the nearby area, which would nullify the potential differences between them. But nevertheless, this explanation does not seem very likely, because asymmetrical activation of primary motor cortex by unilateral movements alone was demonstrated in a variety of experiments using similar methodology (e. g. by measuring the »readiness potential« or premotor potential, which, interestingly, appears even before the movement itself).[54] Still another interpretation for our results could be based on the fact, that it is very hard if not impossible to exclude other (e. g. non-visuomotor) types of brain activity during specific task or paradigm, which produces difficulties in isolating the required mental process under investigation. Considering this problem, which is relevant also in any other study of brain function generally, we can argue that symmetrical (and also interhemispheric) increases of coherence between different frontal, central and parietooccipital electrodes might also reflect different mental processes going on during the task performance in participants' minds and do not solely specifically result from visuomotor integration.[55–57] These mental processes could include other motor, cognitive (e. g. working memory) and motivational processes, which in many studies were also shown to involve similar (though not equal) patterns of posterior-(pre)frontal brain functional connectivity and brain activation.[1, 6, 8, 9, 27, 58–60] Taken together, the value of EEG coherence for brain research is greatest when combined with other brain research approaches, which show different aspects of brain function. By choosing appropriate tasks/paradigms and neuropsychological tests it is possible to study physiological and pathophysiological aspects of the motor, cognitive, and sensory brain function.[61] Recently, some studies showed important differences in coherence values when comparing neurological or psychiatric patients (Alzheimer disease, Parkinson disease, schizophrenia) to healthy controls at different tasks used to study variety of brain processes.[62, 63] This opens new future perspectives for possible search of pathophysiological mechanisms and etiological factors contributing to many different brain diseases, with a chance of uncovering those diseases in the early stages, when there might be only functional deficits present.

Conclusions

In our previous research work we have already proven that EEG coherence is statistically significantly increased between the visual and motor areas of the brain during the visuomotor task requiring an important aspect of brain function-visuomotor integration (Brežan et al., 2005). Since that is in accordance with other studies, we believe that coherence truly represents a valid measure of functional connectivity/integration between the communicating brain regions. Thereby we have also shown that our research approach and methodology is appropriate to study the complex brain function, introducing newer methods (coherence, power spectra) of the complex EEG data analysis into our Institute research work. In this article, we rejected our working hypothesis when studying the visuomotor task being performed with either the right or left hand. The values of differences of coherence and power spectra between the left and right hemisphere during performance with the right vs. left hand were not statistically significant. This could be explained by arguing that bilateral symmetrical decreases of power spectra in specific frequency bands reflect the activation of the involved secondary areas of the cerebral cortex, while the relatively symmetrical increases of coherence reflect the cooperation between those same secondary complex visual and motor areas.

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DFT – discrete Fourier transformation, EEG – electroencephalography, electroencephalogram, EMG – electromyogram, EOG – electroocculogram, EPSP – excitatory postsynaptic potential, ERCoH – event-related coherence, ERD – event-related desynchronization, ERS – event-related synchronization, fMRI – functional magnetic resonance imaging, IPSP – inhibitory postsynaptic potential, M – motor task, SMA – supplementary motor area, SPL – superior parietal lobus, TRCoH – task-related coherence, V – visual task, VM – visuomotor task, V+M – visual and motor task

DFT – diskretna Fourierova transformacija, EEG – elektroencefalografija, elektroencefalogram, EMG – elektromiogram, EOG – elektrookulogram, EPSP – ekscitacijski postsinaptični potencial, ERCoH – z dogodkom povezane spremembe koherence, ERD – z dogodkom povezana desinhronizacija, ERS – z dogodkom povezana sinhronizacija, fMR – funkcijsko magnetno resonančno slikanje, IPSP – inhibicijski postsinaptični potencial, M – motorična naloga, SMP – suplementarno motorično področje, SPL – superiorni parietalni lobus, TRCoH – z nalogo povezane spremembe koherence, V – vidna naloga, VM – vidno-motorična naloga, V+M – vidna in motorična naloga

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