

# Dual-Tasking as Diagnostic and Rehabilitation Tool in Traumatic Brain Injury Patients

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## Abstract

**Objective:** Purpose of this study was to investigate the behavioral and brain activity impairments in patients after moderate traumatic brain injury (mTBI) in comparison with the normal ranges while dual-tasks performing. We would like to evaluate dual-tasking as diagnostic and rehabilitation tool and to test hypothesis of brain aging after mTBI. **Material and Methods:** Electroencephalographic (EEG), stabilographic and clinical study was performed in 11 patients (mean age  $28.8 \pm 8.4$  years) for up to 1 - 12 months after a mTBI in comparison with 17 healthy subjects ( $26.7 \pm 5.1$  years). All the participants performed two motor and two cognitive tasks presented separately, and simultaneously (dual-tasking). **Results:** Clinical examination revealed predominantly cognitive deficit in mTBI patients with intact postural control. EEG data demonstrated coherence decrease for slow (delta-theta) rhythms in frontal-temporal areas predominantly for left hemisphere during cognitive tasks performance. In contrast, EEG coherence for slow spectral bands increased in the same areas in healthy volunteers. EEG coherence increased for fast spectral bands—alpha2 and beta, predominantly in right hemisphere while both healthy adults and patients performed motor components of dual tasks. Rehabilitation course with dual tasks, led to a predominant reduction in cognitive deficits, and EEG coherence increases at the frontal-temporal areas of the left hemisphere. **Conclusions:** Dual-tasks may be used as diagnostic tool in patients after mTBI. This approach demonstrates predominant cognitive deficit, and left hemispheric dysfunction in patients similar to elderly persons and support the hypothesis of brain aging after TBI. Pilot studies also suggested rehabilitation effect of dual-tasking in mTBI patients.

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## Keywords

Traumatic Brain Injury, Cognitive and Motor Functions, Dual-Tasks, EEG, Stabilography, Brain Aging

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## 1. Introduction

Traumatic brain injury (TBI) usually resulting from a blow to the head is most common in people of working age, although it happens in the elderly too. TBI is a result of falls, road accidents, sports injuries, etc. Posttraumatic disorders are typically multi-component and involve the damage of pathways, cortical and subcortical structures [1] [2] [3] [4] [5]. Some injuries classified as moderate (mTBI) are not accompanied by hemiparesis and other neurological deficiencies. However, there is growing evidence that even years after mTBI, cognitive, affective, and behavioral functions may change, which leads to insolvency in work, school, or in social relations. Diffuse axonal injury is frequent in TBI (including mTBI) and disintegration is a significant pathogenic factor in this form of the brain pathology [6]. Disintegrative processes including corpus callosum were described mostly in mTBI patients accompanied by disorders in different spheres [7]-[14].

Some investigations using brain imaging and other techniques have been devoted to links between brain disturbances with predominantly cognitive decline and attempts to return to former professional activity in mTBI patients [15] [16].

However, brain mechanisms of disorders during complex functional loads simulating real life after mTBI are not well understood. In context of professional human, dual-task algorithm modeling routine loads of real life is of considerable research interest in last time [17]-[24].

Different experimental situations were used for these purposes and the so-called dual-tasks are among them. Two tasks, including, as a rule, cognitive and motor components (walking and talking) have been suggested to solve [17]-[24]. Walking as a motor component combined with cognitive tasks, such as talking, calculation, memorizing of text fragments or word lists, is often used in choice of dual-task components. Although walking is an automatic activity in healthy adults, it is also needs participation of cognitive functions. In the same way as other type of motor activity, voluntary postural control can be used for dual-tasking [25]-[30].

The ability to modulate attention may play an important role in the acquisition of dual-task coordination skill. The participation of cognitive component in the maintenance of dual-tasking (motor and cognitive) in healthy persons is confirmed by experimental studies [19] [24]. Healthy individuals more often demonstrate lower quality of dual-tasking than quality of every task performed separately, while there are situations with more successful dual-task performance [31] [32]. In extreme situations, certain individuals are also known to cope with

exceptionally challenging tasks, which they are not able to carry out under the usual conditions. For example, professional athletes with their automated skills for performing motor loads are capable of higher-quality dual-task performance in compare with isolated ones [32]. Our previous data demonstrated more successful performance of dual-task vs isolated ones by healthy persons with high levels of cognitive resource—volume of attention and memory, attention switching speed and others [26].

Although postural control of standing is highly automated, combining standing with cognitive task can interfere with the execution of one or both tasks in adult healthy subjects [19] [24]. An impaired ability to maintain balance with simultaneously cognitive tasks has been associated with cognitive functional and physical decline in TBI patients [27] [29]. On the other hand, a similar decrease in performance was observed in the elderly compared with young healthy people [31] [32].

These studies propose that the elderly require more processing resources for single-task performance, therefore increasing interference during dual-tasking [31]. Results of some investigations demonstrated cognitive impairments, physical decline, etc., accompanying brain volume loss after trauma [33]. These data allowed some authors to propose accelerated brain aging after TBI [34]. They hypothesized that the discrepancy between chronological and predicted brain age would be reflected in cognitive changes and consistent with age-related cognitive impairment in older individuals and in patients after TBI [34].

There are different points of view on the brain mechanisms of dual-tasking performance in elderly healthy people and in TBI patients. The first one is: the same brain areas are used in both dual-task performance and separate performance of each ones. On the other hand there are data on involvement of additional brain areas and mobilization of additional brain resources in old persons or TBI patients [28] [34] [35] [36] [37]. It is specially noted mostly that the quality of performance of each component is worsened during dual-tasking in comparison with separate performance due to activity decrease of specific brain areas participating in both components of the dual-tasks in healthy persons, especially in the elderly and patients with brain damage [28] [31].

Advances in brain imaging have revealed important information regarding both structural [1] [2] and functional [23] [27] [28] alteration in healthy adults, in old persons and in TBI patients. There is now overwhelming evidence that the elderly and TBI patients use explained brain networks and increased brain activation to perform a single motor or cognitive tasks or dual-tasks [25]-[33]. The age- or traumatic-related increase in neural activation may lead to greater structural interference [38] [39] [40] [41] [42]. This hypothesis was tested in oddball task study with arithmetic and visual-motor task by looking at the increase in brain activation from single—to dual-task in shared brain regions [20]. Less upregulation in the elderly or traumatic patients compared with young adults would indicate greater structural interference. Overlapping brain activation was observed in the elderly (or TBI patients) during performance of both single as well

dual-tasks [39] [40] [41] [42]. Another often debated aspect of dual-tasking is whether it requires additional brain activation of nonspecific motor or cognitive component of dual-tasking in aged persons or TBI patients [42]. Usually balance-cognitive dual-tasking have been studied at behavioral level while in our study we would like to examine the neural correlates of balance-cognitive dual-tasking in mTBI patients compared in healthy adults using electroencephalogram (EEG).

EEG contains temporal component of the functional brain activation. EEG analysis gives the possibility to describe (both quantitatively and qualitatively) functional state of the human brain [43] [44] [45] [46]. It is the important approach for estimation of reactive changes of the brain in mTBI patients while dual-tasking. The coherent analysis of EEG is widely used to estimate interregional relationship as systemic activity of the human brain. Coherent parameters of bioelectrical activity of the human brain were rather informative in analyzing of healthy brain connectivity and allow to estimate disconnection phenomenon in patients with organic lesions including mTBI [25]-[30] [43] [44] [45]. The use of complex approach, which additionally includes a stabilographic study and quantitative clinical scales, expands the possibilities for assessing functional resources of a person in normal conditions or with various forms of cerebral pathology [46]-[52].

The aim of this investigation was to compare the efficiency of dual-task performance in mTBI patients in comparison with healthy people of the same age. We would like also to test the hypothesis of the brain aging in patients with mTBI and to estimate the effect of dual-task training as rehabilitation tool for improving the everyday life and social adaptation of patients after mTBI.

## 2. Materials and Methods

### 2.1. Participants

The study included 17 healthy subjects (11 male and 6 female aged  $26.7 \pm 5.1$ ). The group of patients included 11 subjects with mTBI (7 male and 4 female aged  $28.8 \pm 8.4$ ). The inclusion criteria to patient's group were possibility to maintain a vertical posture without support, to understand and follow physician's instructions. According to the Annett Hand Preference Questionnaire, all healthy subjects and patients were right-handed [53]. Each subject signed an informed consent for the study approved by Ethics Committee at Institute of Higher Nervous Activity and Neurophysiology of Russian Academy of Sciences.

### 2.2. Data Acquisition and Processing

#### 2.2.1. Clinical Assessment of Patients

Quantitative assessment of patient deficits in different spheres (motor, cognitive, emotional, etc.) was carried out using clinical scales (presented in **Table 1**): MPAI (Mayo-Portland Adaptability Inventory); FIM (Functional Independence Measure); MMSE (Mini Mental State Examination); Berg scale, assessing posture control [54].

**Table 1.** Summary of mTBI patients and parameters of clinical scales.

Patient	Age (years)	The period after TBI (in months)	MMSE (for healthy— 30 points)	MPAI (for healthy— 0 point)	FIM (for healthy— 126 points)	Berg scale (for healthy— 56 points)
F-v	25	2	22	30	115	56
S-v*	18	5 (7)	22 (28)	25 (15)	110 (120)	56 (56)
A-va*	25	2 (3)	17 (20)	35 (30)	52 (90)	56 (56)
D-v	27	1	26	29	120	52
R-v	17	1	26	17	51	54
M-va	22	2	25	44	110	54
I-ch	26	3	27	24	124	56
F-va*	38	1 (2)	17 (25)	35 (20)	83 (102)	53 (54)
Ch-v	28	1	25	24	126	54
Gr-ya	25	4	26	25	120	55
P-v*	31	11 (13)	26 (28)	42 (29)	113 (121)	56 (55)
<b>mean ± SD</b>	25.6 ± 5.8	3 ± 2.9	23.7 ± 3.3	30 ± 8.3	102.2 ± 27.5	54.7 ± 1.3

Note: SD—standard deviation. \*—marked patients who have undergone rehabilitation course; in brackets, the values of the clinical scales after the rehabilitation course.

### 2.2.2. EEG Recording and Analysis

Monopolar EEG was recorded from 19 scalp locations, according to the international 10 - 20 system, using telemetric encephalograph (“Encephalan”, Russia) with a spectral band of 0.5 - 70 Hz and a sampling frequency of 250 Hz. As the reference, the combined ear electrode was used. EEG recording was performed throughout the experiment: at rest—maintaining a vertical posture on the stabiloplatfom and during the performance of all tasks. Primary processing of EEG was carried out manually in the software of “Encephalan” in order to remove artifacts, including artifacts associated with the eye movements, and filter in the range of 0.5 - 40 Hz. The next step of processing was the spectral-coherent analysis which was calculated with a step 0.4 Hz for the following EEG frequency bands: delta, 1.2 - 3.9 Hz; theta, 4.3 - 7.8 Hz; alpha1, 8.2 - 10.2 Hz; alpha2, 10.5 - 12.9 Hz; beta, 13.3 - 30 and gamma, 30.4 - 40 Hz. No less than nine epochs with a 5.12-s overlap were analyzed. Last 50 - 55 s EEG’s were segmented in epochs of 5.12 s (a total no less 10 epochs were taken). Fast Fourier Transformation and magnitude-squared coherence function using the MatLab 6.0 software package (Math Works Inc.) [54].

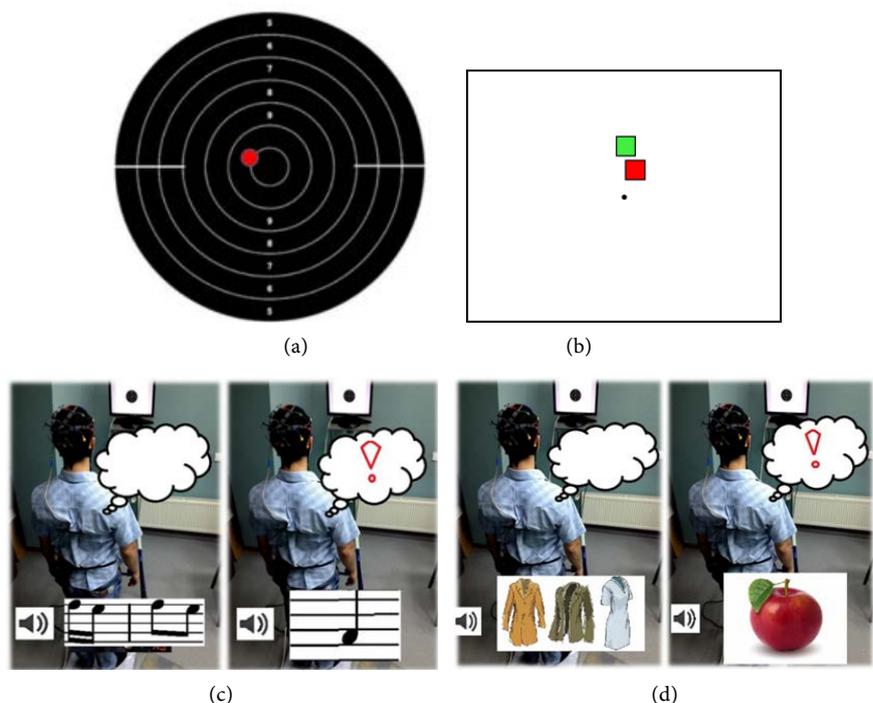
Statistical analysis of EEG data was carried out in the program Brainstorm. Multivariate analysis with FDR (false discovery rate) correction with significance level  $p < 0.01$  was used. To compare data within one group the nonparametric Wilcoxon test was used for related samples. To compare a group of patients with a group of healthy subjects, a non-parametric Mann-Whitney test with  $p < 0.01$

with FDR correction was used. To compare individual data for healthy or patients between different conditions (tasks), the nonparametric Wilcoxon test was used for related samples with a significance level of  $p < 0.01$  without FDR correction.

### 2.2.3. Stabilographic Study and Analysis

In order to perform the motor task, stabilographic platform (Stabilan 0.1, Russia) was used (Figure 1). When the subject performed the motor task, he was instructed, standing on the stabiloplatform, to keep balance maintaining the common center of pressure in the same position or to change of pressure presented on the monitor screen (9Fi 1A and B). In this study we analyzed performance quality of motor tasks performed isolatly and while dual-tasks and speed of pessure fluctuation in these experimental situation. The quality of motor task performance was assessed automatically using the stabilographic equipment as a percentage of the subject's center of pressure fixing time within the specified coordinates.

Statistical analysis of stabilographic data was carried out using the Shapiro-Wilk test for normal distribution in with a threshold  $p < 0.05$ . The distribution was abnormal, therefore, further comparison of groups of healthy subjects and patients by all indicators was carried out using the non-parametric Mann-Whitney test for independent samples in the R programming environment for statistical data processing (RStudio).The criterion of statistically significant differences between the two groups was  $p \leq 0.05$ .



**Figure 1.** The examples of experimental procedures. (a) motor static task M1, (b) motor dynamic task M2, (c) dual task C1M1, (d) dual task C2M1 (see explanation in the text).

#### 2.2.4. Diffusion Tensor MRI Tractography Study

Diffusion tensor imaging (DTI) tractography is an imaging technique that quantifies water diffusivity along the axons, enabling *in vivo* study of neural pathways including of corpus callosum [54]. MRI scan was performed using GE Signa HDxt 3.0T equipment (GE healthcare, Milwaukee, WI). Whole brain tractography was studied using ISA + BSM to reconstruct streamlines of white matter fibers using functional MRI. Along the tracts of each zone of corpus callosum, the FA was calculated, characterizing the integrity of axons. The correlation coefficient between the measurements by both experts was 0.92. Three patients from patient's group and nine healthy volunteer were included in DTI tractography study.

### 2.3. Experimental Tasks

We used two cognitive and two motor tasks, which were presented initially separately and then simultaneously, using different variants. Participants performed motor tasks on the stabilographic platform with visual feedback. During the first "static" motor task (M1), the subject had to keep balance, holding the red circle, which reflects the position of his common center of pressure (CCP) on stabiloplatform, in the center of the target (**Figure 1(a)**). During the second "dynamic" motor task (M2), patient or a healthy volunteer had to change of CCP in accordance with the trajectory of movement presented on the screen. The green marker set the direction of movement (smoothly shifted to one of four sides), and the red marker displayed the participant's position of center of pressure (**Figure 1(b)**). The task was to catch up green marker and hold the red on it.

As a cognitive task we used computing-logical C1 or C2 procedures. During the first cognitive task (C1) performance, the subject was asked to listen to series of high (800 Hz) and low tones (400 Hz) of 80 ms duration each, which were presented in a random order with varying intervals (**Figure 1(c)**). The percentage of low sounds was fewer than high tones and accounted for 40% of the total number presented. The subject needed to count mentally the number of the low-pitched presented tones. The second cognitive task (C2) was a listing of the names of objects in a random order, belonging to two categories ("clothing" or "food", **Figure 1(d)**). Subject had to count number of objects belonging to one of two categories indicated by the experimenter, which also accounted for 40% of the total number of the all items. At the end of audio recording participant gave the answer. All tasks were presented for 60 s. The stimuli in two cognitive tasks were presented at a varying interval within 1.7 - 2.0 s. The quality of cognitive task performance was assessed by the number of computing operations performed per minute taking into account the number of errors.

### 2.4. The Experimental Setup

Telemetric equipment, including the electrode cap, was fixed on the head of the subject before the experiment. After, each participant was instructed about upcoming tasks and listened to the examples of cognitive tasks.

Firstly, the subject was standing on stabiloplatform with the eyes open without being instructed for 60 s while EEG was recorded. After he performed motor task M1 and then M2, also standing on the stabiloplatform. At the next stage of the study, the subject performed two cognitive tasks, standing on the floor with the eyes open (in front of the wall). After performing all isolated tasks, the participant standing again on the stabiloplatform started dual-tasking (C1M1, C2M1, C1M2, C2M2) in random order. Motor task also lasted 60 s.

## 2.5. Rehabilitation Procedure

Rehabilitation course with dual-tasks was carried out in four mTBI patients as a pilot study. It lasted 1.5 - 2 months with 2 sessions per week of 30 - 40 minutes duration for each session. Two tasks were used for simultaneous execution (cognitive and motor), differing from those used in the experiment described previously. It was done so that rehabilitation promotes learning to perform complex activities such as dual-tasks (motor and cognitive) with which patients can face in real life but not remembering of any tasks. The motor component included either walking along the corridor or performing stabilographic tasks with visual feedback. As a cognitive component, five variants of tasks were used, including a task for speech memory, attention, an understanding of the meaning of the text, spatial-visual and arithmetic tasks. Each rehabilitation session included new versions of cognitive tasks.

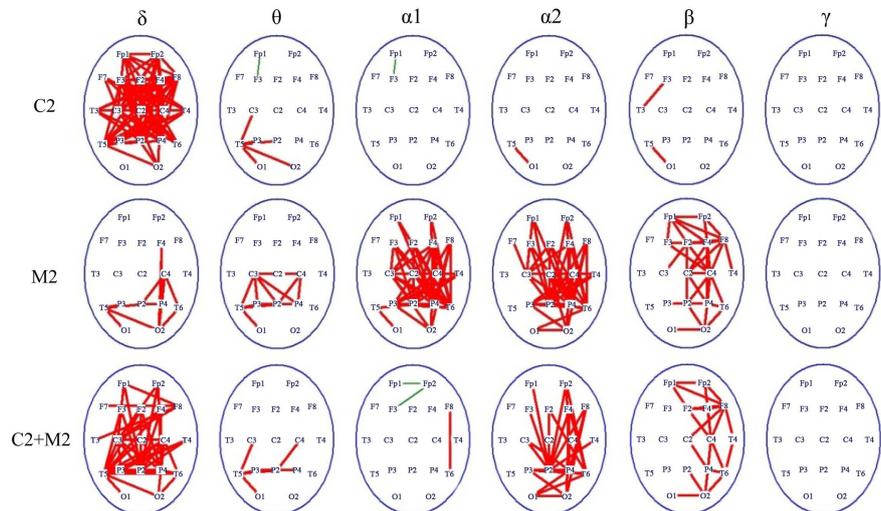
## 3. Results

### 1) EEG data during dual-tasking

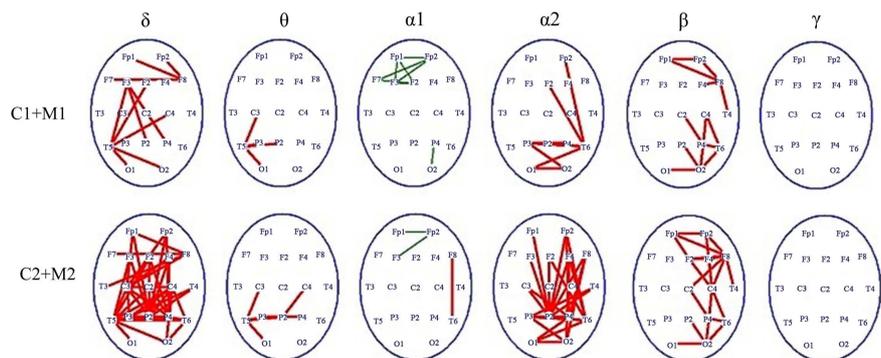
The results of the group-level EEG coherence analysis across single cognitive (C2), motor (M2) and dual-task (C2M2) performance are in **Figure 2**. It was shown an increase of EEG coherence ( $p < 0.01$ ) for slow spectral bands (delta and theta) with some shift at the left hemisphere for performance of cognitive task. These data coincides with our and others previous data as marker of brain activation for cognitive task performance while dual-task procedure included other cognitive tasks (mental calculation) [25] [26]. The single motor task performance (M2) was accompanied by an increase of EEG coherence ( $p < 0.01$ ) for fast spectral bands (alpha-1, alpha-2 and beta) with some shift at the right hemisphere.

An increase of EEG coherence for cognitive and motor component was observed as specific brain activation while dual-tasks execution. This is consistent with our and others previous findings [25] [26] [46]. The decrease of EEG coherence for alpha 1 spectral band was observed predominantly at the frontal areas described us as a “conflict of interests” zone. These EEG coherence changes may be the reflection of “competition” for attention resources while each component of dual-task was performed.

**Figure 3** shows the results of the group-level EEG coherence analysis across two-dual tasks performance: up row—while dual-task C1M1 was performed;



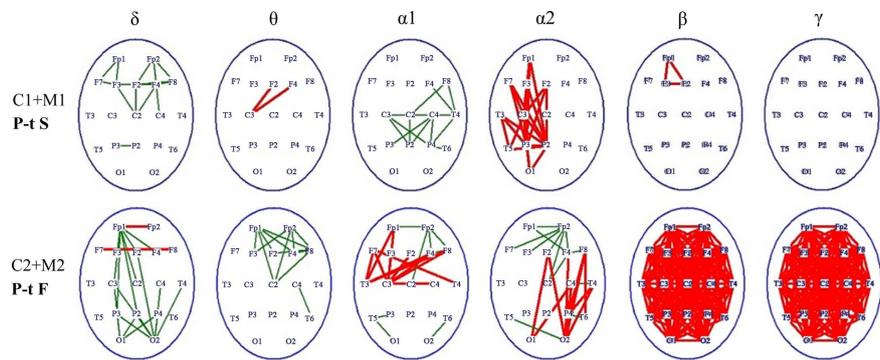
**Figure 2.** Averaged changes of EEG coherence while performing isolated C1 and M1 and also dual-tasks C1M1 in healthy subjects ( $n = 17$ ) compared to baseline state (standing on the stable platform with open eyes) ( $p < 0.01$ ). Red lines demonstrate an increase of EEG coherence, while green lines—a decrease of EEG coherence.



**Figure 3.** Averaged changes of EEG coherence while performing dual-tasks C1M1 (A) and C2M2 (B) in healthy subjects ( $n = 17$ ) were compared to baseline state ( $p < 0.01$ ). Designations as in **Figure 2**.

lower row—while dual task C2M2 was performed by healthy persons. It was shown an increase of EEG coherence ( $p < 0.01$ ) for slow spectral bands (delta and theta) with some shift at the left hemisphere for performance of both dual-tasks as a reflection of brain activation for cognitive component of dual-tasking with the most EEG coherence changes for the more difficult task (C2M2). These data coincides with our and other previous data while dual-task procedure included different cognitive task (mental calculation) and was performed by another group of healthy persons [25] [26].

**Figure 4** demonstrates the results of individual EEG coherence analysis across two dual-tasks performance in p-t S and P-t F compared to baseline state. EEG coherence changes demonstrate the lower values for dual-tasking in both patients while in healthy persons (see **Figure 2**) The most decrease was observed for delta spectral bands (cognitive component) predominantly in frontal-temporal



**Figure 4.** Changes of EEG coherence compared to baseline state ( $p < 0.01$ ) while performing dual-tasks C1M1 was performed in P-t S (18 y.o.; 5 months after TBI; MMSE—22; MPAI—25; FIM—110; Berg's scale—56) and in B P-t F. (38 y.o., 1 month after TBI; MMSE—17; MPAI—35; FIM—83; Berg's scale—53). Designations as in **Figure 2**.

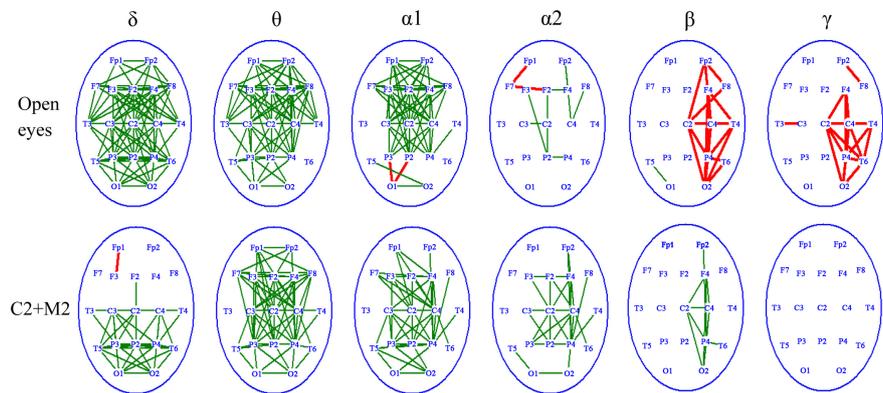
areas of the left hemisphere for P-t F while dual-task C1M1 was performed. The decrease of EEG coherence for delta spectral bands was observed for long diagonal connections between frontal and parietal-occipital areas. EEG coherence for fast spectral bands had different reactive changes including signs of hypersynchronization for beta and gamma spectral band in patient F who had the most impairment of postural control (values of Berg's scale at this patient was lower than in patient S).

According results of clinical scales examination (see **Table 1**) cognitive deficit in patients after trauma was more pronounced compared with ability to support vertical posture. The ability to maintain an upright posture has been practically intact in patients, but with greater efforts in comparison healthy persons (**Figure 4(b)** and **Figure 6(c)**). Cognitive data results at **Figure 4** demonstrate the quality decline of cognitive component during dual-tasks performance in comparing with isolated performance, it declined even more when C2M2 dual-tasks executed.

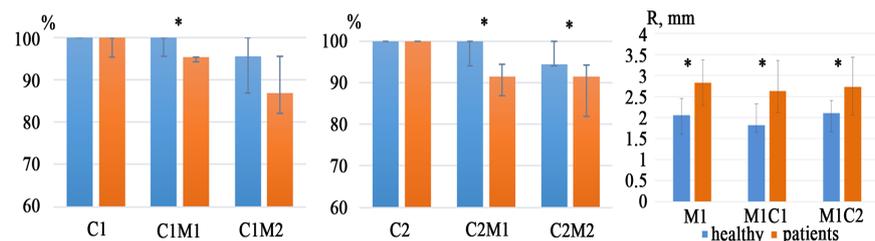
Comparison of averaged EEG coherence values in healthy persons ( $n = 17$ ) and patients with mTBI ( $n = 11$ ) in state of rest (A) and while dual-task C1M1 are presented at **Figure 5**. EEG coherence decreased mostly only for slow spectral bands, whereas increase for fast spectral bands reflects more efforts for support the vertical pose in patients comparison healthy adults in state of wakefulness (open eyes). EEG coherence when performing dual tasks decreased for most slow frequencies in patients compared with healthy people (C2 + M2). These results demonstrate the possibility of using a persistent decrease in EEG coherence for slow frequencies as a marker of cognitive status.

## 2) Behavioral and stabilographic data during dual-tasking

Behavioral and stabilographic data estimated in single versus dual-task conditions are presented in **Figure 6**. They demonstrate the most decrease of the quality of cognitive tasks performance in dual-tasking versus single tasks, especially for C2. While the quality of motor tasks performance in isolation versus dual task conditions evaluated according to stabilographic data did not reveal significant differences from normative values.



**Figure 5.** Comparison of averaged EEG coherence changes in healthy persons ( $n = 17$ ) and TBI ( $n = 11$ ) in waking state (standing with open eyes) and during dual-task ( $p < 0.01$ ). Designations as in **Figure 2**.



**Figure 6.** The quality of cognitive (C1, C2) and motor (M1) tasks performance, and single versus dual tasking conditions (in %) by healthy group ( $n = 17$ , blue bar) and by mTBI patients ( $n = 11$ , orange bar). \*—significant changes  $p < 0.05$ .

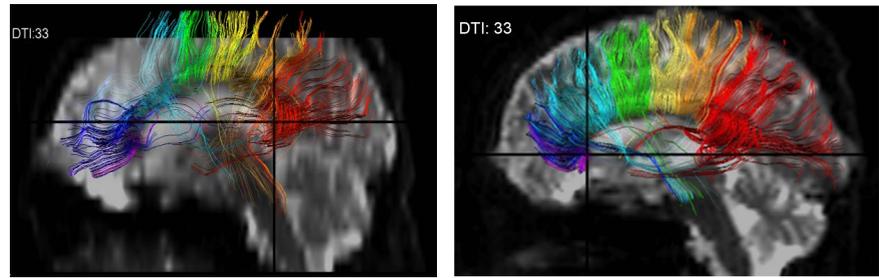
### 3) Data of diffuse tensor MRI-Tractography study

Results of diffuse tensor MRI-tractography demonstrate decreased values of fraction anisotropy of patients with the greatest decline in anterior (frontal) areas (5 - 7) in comparison with healthy subjects (**Figure 7**). These low values of p-t's fraction anisotropy correlated with cognitive decline (low values of MMSE scale) in patients in comparison normal values. The lowest values of fraction anisotropy were in p-t S, with the lowest values of MMSE scale of these patients.

### Dual-Tasking as Rehabilitation Tool

As a pilot study, we included dual tasks in a special rehabilitation course for four TBI patients. Three patients underwent a rehabilitation course in the early period (2 - 5 months after TBI) (see **Table 1**), one in the delayed period (11 months after TBI). After early rehabilitation course positive dynamics were observed in all areas, mainly in the cognitive one (See **Table 1**).

There are EEG coherence changes of P-t S-v and P-t P-v after rehabilitation course at **Figure 8**. EEG coherence increased predominantly for delta band in different parts of spectrum mostly at delta and theta with shift to left hemisphere while dual-tasking after rehabilitation course. These EEG changes and an increase of cognitive functions were observed without loss of motor task performance quality.



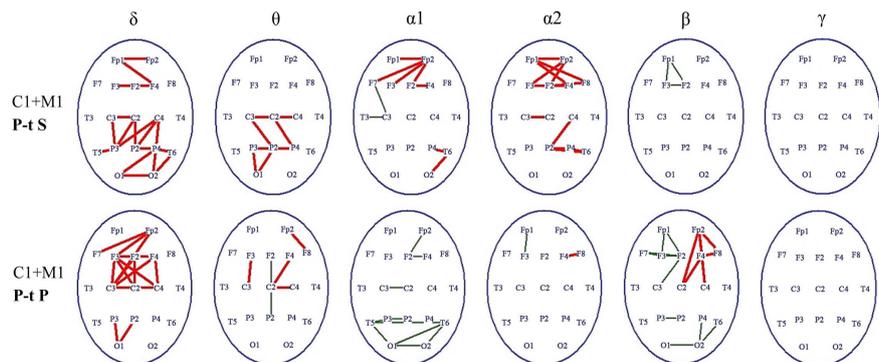
(a)

(b)

	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	MMSE	Berg's scale
P-t S	0.389	0.378	0.336	0.332	0.345	0.388	0.349	22	56
P-t G	0.459	0.44	0.492	0.455	0.433	0.381	0.327	26	55
Healthy adult Sh	0.496	0.442	0.403	0.428	0.481	0.522	0.473	30	56

(c)

**Figure 7.** (a) and (b) examples of diffuse tensor MRI tractography of corpus callosum in p-t S and P-t G and healthy adult Sh; (c) table with values of fraction anisotropy in zones 1 - 7 of corpus callosum (from posterior to anterior) and values of MMSE and Berg's scales.



**Figure 8.** Features of EEG coherence changes in two TBI patients: p-t S (MMSE—22 (28); Berg's scale—56 (56) and p-t P MMSE 26 (28); Berg's scale—56 (55)—while a dual-task C1M1 was performed after the course of rehabilitation compared with the state before it ( $p < 0.01$ ); In brackets—values of scales after rehabilitation. Designations as in **Figure 2**.

In contrast, patient P-v, performing a dual-task showed a less pronounced increase in EEG coherence, predominantly at delta range. Along with improving cognitive performance, quality of motor task decreased. The revealed differences in the effect of rehabilitation between patients can be explained by the fact that the patient S-v underwent a course earlier after injury (5 months), when recovery processes were more active. Whereas the patient P-v received his course later (11 - 13 months after injury), when recovery and compensation processes are not so actively, and cognitive deficits decrease, apparently, due to redistribution of brain resources, which affected the deterioration of the motor component.

Thus, the positive effect of rehabilitation course using dual-tasking was observed in mTBI patients. According clinical scales the most distinct positive effect was in the cognitive sphere. The EEG data demonstrate predominant increase of EEG coherence for slow spectral bands (marker of cognitive functions) with a tendency to normalization of spatial-frequency characteristics with the more changes at the frontal-temporal of the left hemisphere.

#### 4. Discussion

At the present study we found EEG data that provide support for a competition view to dual-task processing in healthy persons. They demonstrate combining of specific spatial and temporal resolution of the brain activation while motor (postural) and cognitive tasks that were performed at the same time—dual-tasking. Similar reactive changes of EEG were presented in our previous studies using other tasks. Specific EEG markers were obtained in the study while mental calculation and postural tasks were performed [25]-[30]. In previous and present studies was shown, that EEG markers of the cognitive component of single and dual-tasks were expressed changes in lower spectral bands (delta and theta) of EEG. In contrast, the performance of motor (postural) component in both experimental conditions was accompanied by increasing of EEG for fast spectral bands (alpha2 and beta).

Taking into account published data on formation and functional importance of the EEG rhythms, one can assume that high-frequency components provide more quicker processes while low-frequency components. Similar data were described for motor component in dual-tasking for patients too. These processes manifest especially clearly in patients with various forms of cerebral pathology including mTBI [8] [15] [22] [27] [28] [35]. Often patients perform the components of dual-tasking not simultaneously, but consistently, with identification of postural task performance as a priority [27] [28] [35]. These data suggest sequential performance of postural component as a more important one from the biological point of view. Our data and results of others support opinion that synchronization for fast spectral bands may provide the stronger sensorimotor integration needed for maintaining gait stability and spatial navigation [31]. Additionally with respect of this function, some authors showed that vestibular and postural dominance has been presented within right hemisphere [46]. Specific EEG markers obtained in our and other studies may to guarantee the preferential improvement and the priority of the postural component in healthy subjects too [25]-[30].

EEG markers of the cognitive component in dual-tasking were slow spectral bands (delta and theta) predominantly at the frontal-temporal areas of the left hemisphere. This phenomenon was expressed during all dual-tasks and was described at some investigations [25]-[30] [45]. A widespread increase of cortical theta- or delta-rhythms synchronization during the encoding of items was recorded from scalp EEG recording in healthy adults [47]. This publication focused

on attention on the relationship between the brain theta-rhythms and memory. So, neural synchronization at low frequencies delta and theta (<8 Hz) and the predominantly at the left hemisphere might be viewed as general neurophysiological mechanism occurring when cognitive task increase at the healthy adults [55] [56] [57].

At the present study we found greater dual task cost—increased brain activation while the most difficult cognitive component was included in dual-tasking in healthy adults. Some authors also have showed that increasing task demands from delta as well as theta frequency bands and this form of EEG activity was increased while difficult tasks were performed by healthy subjects [56] [58].

It was shown that the quality of cognitive component during dual-tasking in mTBI patients being lower than healthy persons. These behavioral data correlated with decrease values of EEG coherence namely for slow spectral bands—for delta as well as theta ones. In mTBI patients the decrease of EEG coherence for slow predominantly at the left hemisphere was observed as apposite healthy people's data. According to Babilony neuronal synchronization of delta spectral bands can be interpreted as a general neurophysiological mechanism that sets in as cognitive task increasing. Consequently, information processing within distribution of functional neural networks had been enhanced [43] [44] [45]. These authors suggested that low spectral bands may govern a long-ranged coordination of distant brain regions.

Posttraumatic brain changes are thought to be progressive in nature, and potentially increase the risk for early cognitive decline. As a rule dementia was observed in mTBI patients similar to aged individuals [8] [56] [57] [58]. Results of some investigations allowed the authors to propose accelerated brain aging after brain trauma [34]. They hypothesized that the discrepancy between chronological and predicted brain age would be reflected predominantly in cognitive sphere and consistent with age-related cognitive impairment in older individuals.

Our fMRI and EEG data revealed the most expressed pathological reactive changes in the frontal temporal areas of the left hemisphere and the brain cortical structures in patients after mTBI [59]. These results support the human brain aging HAROLD (hemispheric asymmetry reduction in elderly people) hypothesis of Cabeza, who explained the aging process mainly by a primary reduction of the left hemispheric functional activity [60]. This opinion supports some studies that demonstrate significant greater left hemisphere and left frontal lobe volume atrophy in the aged subjects than the young participants [61] [62]. From the other hand some authors support the right hemispheric aging model [63] [64]. At last some investigations provide evidence of both, left frontal and right posterior parietal activations contribute to compensatory processes in normal aging [65].

It is important that not only after mTBI, but also after a concussion, a preferential decrease of coherence was revealed for distant, especially diagonal, connections between the frontal and parietal brain areas. Behavioral impairments were observed in patients predominantly for cognitive sphere [27] [28] [37]. It is

interesting to note that in healthy people with high level of cognitive resources and the ability to successful dual-tasking, the coherence values for these diagonal connections were the highest [26]. It can be assumed that the maximum decrease of EEG coherence for slow EEG rhythms at diagonal pairs between the frontal and parietal brain areas, as well as in the left fronto-temporal region, was found in patients after mTBI. May be these changes of EEG is marker of cognitive deficit in patients with this form of cerebral pathology. Thus, a multidisciplinary approach, on the one hand, and using of dual-tasks, on the other hand, may be effective tool for diagnostic estimation of cognitive deficit in population of mTBI patients.

Damaged distant, especially diagonal connections between frontal and parietal parts of the brain were also revealed in patients after mTBI, as well as after concussions, accompanied by a predominant cognitive impairment [27] [28] [37]. It should be noted that the coherence values of diagonal connections between the same areas were maximum in healthy people with high cognitive resources, able to more successfully perform dual tasks compared to single ones [26]. It can be assumed that degradation of diagonal connections between frontal and parietal areas for slow EEG rhythms is also one of the important markers of cognitive deficit in patients after mTBI.

Thus, multidisciplinary research, coupled with dual-tasking, seems to be a promising diagnostic approach in ameliorating cognitive deficit in mTBI population. Rehabilitation programs with dual-tasking led to a decrease in cognitive deficit of brain-injured patients. According to the EEG data, this corresponded to an increase in the efficiency of functional connections for slow rhythms, mainly in left fronto-temporal areas with a trend to normalize intracortical connections. Thus, left hemisphere, on the one hand, is more sensitive to damaging effects, and on the other, and the more flexible in responding to rehabilitation procedures.

This stage of the study does not allow us to evaluate the effectiveness of the inclusion of dual tasking in the rehabilitation process due to the limited sample. Nevertheless, the results of a comprehensive EEG, stabilographic and clinical studies revealed a decrease in cognitive deficit after a rehabilitation course with dual-tasking at an early stage after mTBI. To obtain more convincing data in favor of this assumption, further studies are required, including an assessment of the rehabilitation effect at different times after mTBI. However, we do already argue that the dual-tasks are not only a diagnostic tool, but also a promising approach in creating individual rehabilitation programs for mTBI patients

## 5. Conclusion

Cognitive impairment was the most characteristic feature of patients after mTBI. According to EEG data, this corresponded to a predominant decrease of coherence for slow (delta, theta) spectral bands, most pronounced in the fronto-temporal areas of left hemisphere. The performance of cognitive tasks by healthy people was accompanied by increasing of EEG coherence for slow spectral bands, while for motor tasks the same was manifested at fast rhythms. The use of dual-tasking

in rehabilitation course created a trend towards the restoration of impaired cognitive functions with the parallel normalization of the regional-frequency characteristics of the EEG. Thus, dual-tasking is a promising diagnostic and rehabilitation tool for traumatic brain damage. Results of our studies support hypothesis about predicted brain age with traumatic-related cognitive impairment in mTBI patients.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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