Original article

Characteristics of focused and sustained attention and EEG of soccer players with recurring mild head injuries

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ABSTRACT

Injury rates are high among over 250 million soccer players with the head injury contribution ranging from 4 to 22%. The aim of this study is: to determine the probable attentional and cerebral electrical activity impairments as the consequences of mild recurring traumatic brain injury (TBI) caused by heading the ball and blows to the head. The study included the experimental sample of 70 male amateur soccer players, competing in a veteran league, with previous senior competition experience, and 70 control subjects with no soccer experience. Cognitive tests were applied on the groups as well as EEG recordings together with spectral analysis. Comparison between the groups revealed significant attention deficits in experimental group (EG) in the tasks requiring simple reaction time (SRT) and attention sustained through a longer time interval. Soccer playing experience affected all the tests' scores except for the decision response time (DRT). In EG certain EEG changes were found in the fronto-temporal region. EEG changes are attributable to existing cognitive deficits, but they are not specific for any cognitive disorder.

Key words: cognition impairment, memory deficits, attention impairment, EEG changes, football players

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INTRODUCTION

Association football is played at the professional level in more than two hundred countries, and over 250 million registered footballers regularly play it in either professional or amateur clubs. A solid research evidence base has been made on injury incidence in soccer players, the rate of which is significantly greater during competition games than during training sessions or friendly games[1]. The body parts most susceptible to injuries are the soft tissues, muscles and joints of the lower extremities[2]. Findings of numerous research studies indicate soccer injury rates to be 1,000 times higher than injury rates in all kinds of industrial jobs[3,4]. Incidence of head injuries in association football ranges from 4% to 22% of all soccer injuries[5-9]. A footballer performs 5-12 headings or “headers” per game on average, which amounts up to 150-300 headings per season[10,11]. A soccer specific form of cognitive disorder, following mild traumatic brain injury (TBI), has not been determined yet[12]. One must also keep in mind that every head injury does not inevitably cause brain injury or electroencephalographic (EEG) changes[13].

OBJECTIVE

The aim of the paper was to investigate the probable impairments of attention and electrical activity of the brain being the effect of mild recurring head injuries caused by blows to the head and/or heading the ball.

SUBJECTS AND METHODS

Cognitive tests and EEG recordings were applied on the sample of 70 Caucasian males, former amateur soccer players. The age was restricted to the range between 33 and 50 years. The control group consists of 70 peer subjects, who had no senior competition playing experience.

Exclusion criteria for health conditions for the subjects in both groups were: arterial hypertension, diabetes, stroke, cranial-cerebral injury, cranial-cerebral surgery, alcohol dependence, epilepsy, general anesthesia, drug use, any thyroid or eye illness. In the group of soccer players 6 subjects (8 %) reported subjective discomforts (headaches, dizziness), whereas only one control subject (1.5%) reported the same symptoms. Out of the total of 140 subjects in both groups, 139 were right-handed and one was left-handed. In Table 1 the data on the subjects’ age and education level are presented.

Both groups were subjected to the cognitive tests and EEG recording procedures. All the subjects gave their written informed consent for the participation in the experiment. The cognitive tests and the EEG recording have been performed and analyzed by one qualified neuropsychologist and one qualified electrencephalographer. The research was approved by the Zagreb University Clinical Hospital Zagreb Medical Research Ethical Committee and by the Zagreb Faculty of Kinesiology Research Ethical Committee.

Visual focused and distributed attention test

Three parameters are obtainable by this test: *simple reaction time* (SRT), *choice reaction time* (CRT), and *decision response time* (DRT). Simple reaction time is the time a subject needs to respond to a visual stimulus by pressing a particular key on the computer keyboard. The test is performed for the left and right hand separately. Choice reaction time is a measurement of subject’s velocity in recognizing light stimulus. Decision response time is the difference between choice reaction time and simple reaction time.[14]

Visual Sustained Attention Test

In the Visual Sustained Attention Test (VAT) the targeted stimulus is mixed with distracters. The task of the subject is to respond correctly and as quickly as possible to the observed targeted stimulus[15]. Testing is performed on 3 sets of letters. In each set only one letter changes randomly as regards the time interval and location of the letter appearance. The letter sets were presented as follows: 30 M, 30 P and 30 B with one letter in each set changing into one N, R and E, respectively. If the subject fails to recognize a letter change within 60 s, the next display is shown. The following variables were measured: letter test duration in seconds, response time in seconds, and letter response average in seconds.

Spectral analysis of encephalogram

The recording was performed by means of the EEG machine Nihon Koden under the standardized conditions. Recordings above frontal, temporal and occipital lobes were used in the analysis. Electroencephalographic recordings consisted of 4 sequences: eyes open, eyes closed, hyperventilation and post-hyperventilation. Thirty seconds of recording were taken for the analysis from each sequence and electrode. Using the software for spectral analysis, we were able to process the spectrum power of each individual frequency band of the spectrum[16]. Within each part of the determined frequency spectrum all the obtained spectrum power values were summed up and afterwards transformed into a numeral representing the percentage (%) contribution of an individual's frequency spectrum to the total spectrum power.

STATISTICAL METHODS

Descriptive statistics were used to process the collected data. Student t-test[17] was used to verify the significance of the differences in all the variables. Pearson's correlation coefficient was used to assess the impact of the years of soccer competition playing experience and age[18]. Wilcoxon Matched Pairs test[19] was used to analyze the scores not normally distributed in the observed variables. Spectral analysis values of EEGs of each frequency area were processed by the mentioned test. The significance level in all the tests was set at 5% of probability ($P \leq .05$).

RESULTS

Descriptive statistics results of the cognitive tests scores between footballers and controls are displayed in Table 2. The test results of simple reaction time and choice reaction time were significantly higher in the group of soccer players than in the controls. The test result of decision response time were not significantly higher in the group of footballers.

The visual sustained attention test results showed significantly higher values of the average test duration, response time and the letter test (in seconds) was significantly higher among the footballers than among the controls. The findings indicate the soccer players who suffered from repetitive mild TBI have difficulties in sustaining attention over a longer time intervals.

Age can be a key factor amongst other numerous reasons for a particular subject's poorer scores on the cognitive functioning tests. Therefore, the subjects' age was limited to the range of 33 to 50 years (Table 1). Correlation analysis was used to determine any probable association between the age of the subjects from both groups and scores. The obtained results indicated no statistically significant relations between age and test scores on the attention tasks in both groups (Table 3).

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TABLE 1. Age and years of education for the group of soccer players and controls

	Soccer players (N=70) $\bar{x}$ ± SD	Control group (N=70) $\bar{x}$ ± SD	Statistical significance
Age (years)	42.29±4.22	40.51±4.71	NS
Education (years)	13.80±1.87	14.37±2.77	NS

$\bar{x}$ = arithmetic mean, SD = standard deviation, NS = not statistically significant

TABLE 2. Juxtaposed test results of the footballers and controls on focused and distributed attention tasks and visual sustained attention tasks and the significance of the differences

	Mean EG	Mean CG	SD EG	SD CG	t-value	P
SRT/ms	282.86	263.94	59.59	45.44	2.11	0.04*
CRT/ms	337.48	315.49	60.97	50.13	2.33	0.02*
DRT/ms	54.62	51.65	29.57	20.05	0.70	0.49
Letter test duration/s	700.56	686.27	26.75	16.83	3.78	0.00*
Response time/s	70.56	55.76	26.75	17.11	3.90	0.00*
Letter response average/s	1.96	1.55	0.74	0.47	3.90	0.00*

EG=experimental group, CG=control group, SD=standard deviation, P=statistical significance

The analysis results exhibited a significant negative correlation between the years of sport competition experience and the variables. However, decision response time (DRT) was not correlated with the years of soccer playing experience (Table 4).

In the experimental group EEG pathological changes were found in 29 (42%) subjects, whereas the same was found in 11 (16%) controls. Descriptive statistics analysis revealed in all the four

TABLE 3. Correlations betweenthe test results on the focused and distributed attention tasks and visual sustained attention tasks and age of the soccer players (EG) and controls (CG)

	Age - correlation coefficient	
Variable	Experimental group	Control group
SRT/ms	0.49	0.21
CRT/ms	0.40	0.18
DRT/ms	0.17	0.13
Letter test duration/s	0.31	0.15
Response time/s	0.31	0.19
Letterresponse average/s	0.31	0.19

P<.05

TABLE 4. Correlation between test results on the focused and distributed attention tasks and visual sustained attention tasks and soccer playing experience

Experimental group	Playing experience –correlation coefficient
SRT/ms	-0.27*
CRT/ms	-0.28*
DRT/ms	-0.05
Letter test duration/s	-0.34*
Response time/s	-0.34*
Letter response average/s	-0.34*

P<0.05

recording sequences the contribution of alpha and beta rhythms, which was in accordance with literature data on the physiology of brain waves (Fig. 1).

In the open eyes sequence delta rhythms occurrence rates were significantly higher in the left frontal lobe than in the left temporal and occipital lobes. The same manifestation of changes was obvious in the same regions of the right hemisphere. Theta waves analysis in the open eyes sequence of EEG imaging revealed significantly more frequent changes in the left temporal region of the subjects pertaining to the experimental group (Fig. 2).

Delta waves analysis, in the closed eyes sequence, indicated a comparable ratio of this frequency spectrum in the total power frequency spectrum in the experimental and control group. Theta waves analysis in the closed eyes sequence revealed a comparable ratio of this frequency spectrum in the total power frequency spectrum for both cerebral hemispheres as well as for particular lobes of each hemisphere (Fig. 3).

Delta waves analysis of the sequence under hyperventilation (activation procedure) exhibited

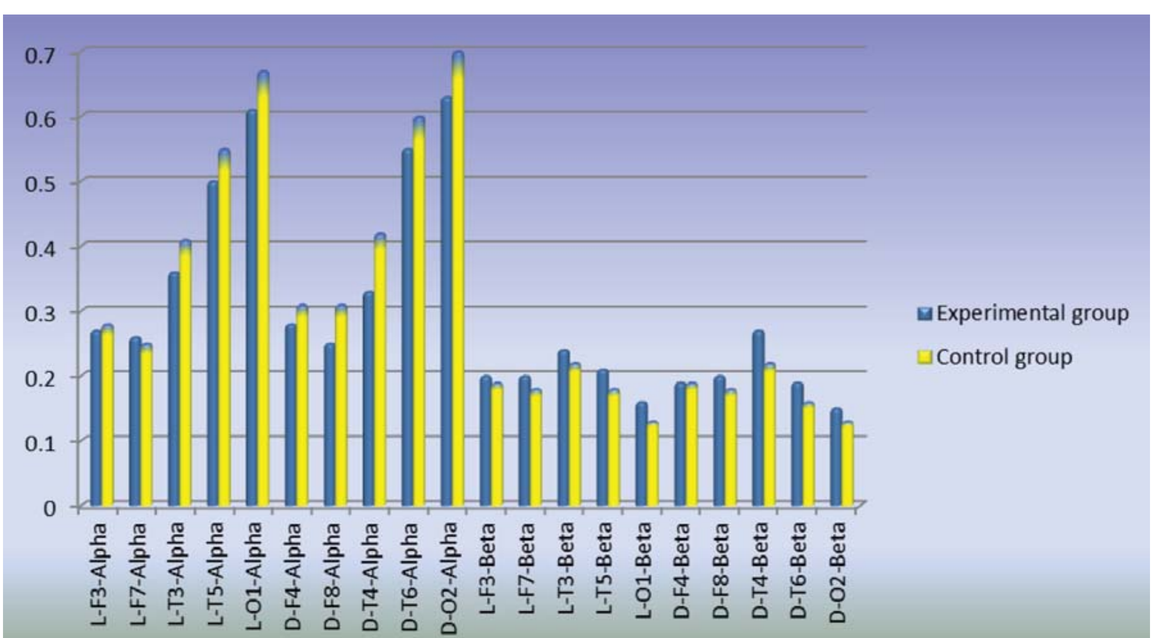

FIGURE 1. Alpha and beta rhythms in the experimental and control group.

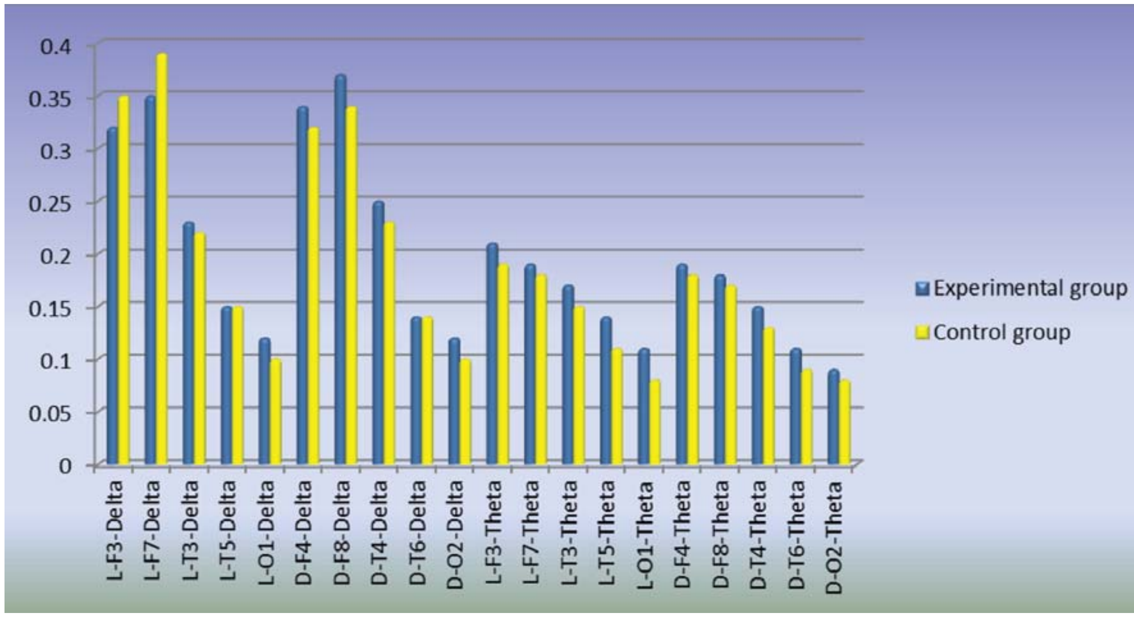

FIGURE 2. Delta and theta rhythms with the eyes open in the experimental and control group.

the same phenomenon in particular cerebral lobes and hemispheres as well as the frequency contribution to the total frequency power spectrum in both investigated groups. In the recording sequence during hyperventilation theta waves occurred comparably in the left and right cerebral hemispheres as well as in particular hemispheric lobes of the subjects from both groups (Fig. 4).

In the sequence following hyperventilation the delta waves occurrence rates were found to be statistically significantly higher in both hemispheres and in particular hemispheric lobes in both groups. In the post-hyperventilation sequence analysis among soccer players a more frequent

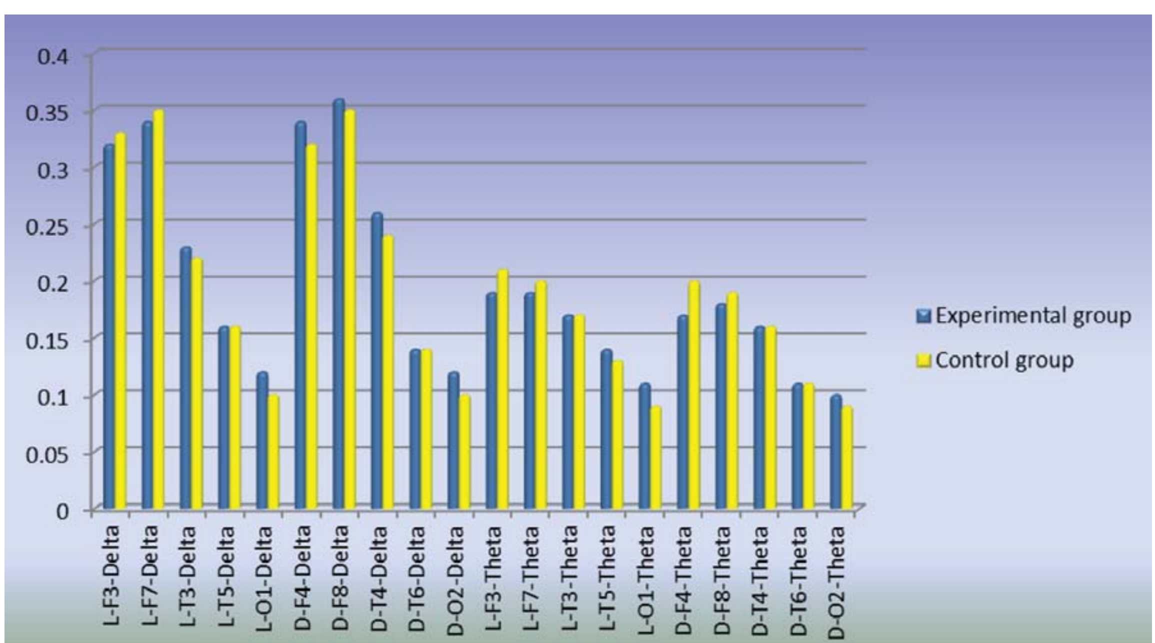

FIGURE 3. Delta and theta rhythms with the eyes closed in the experimental and control group.

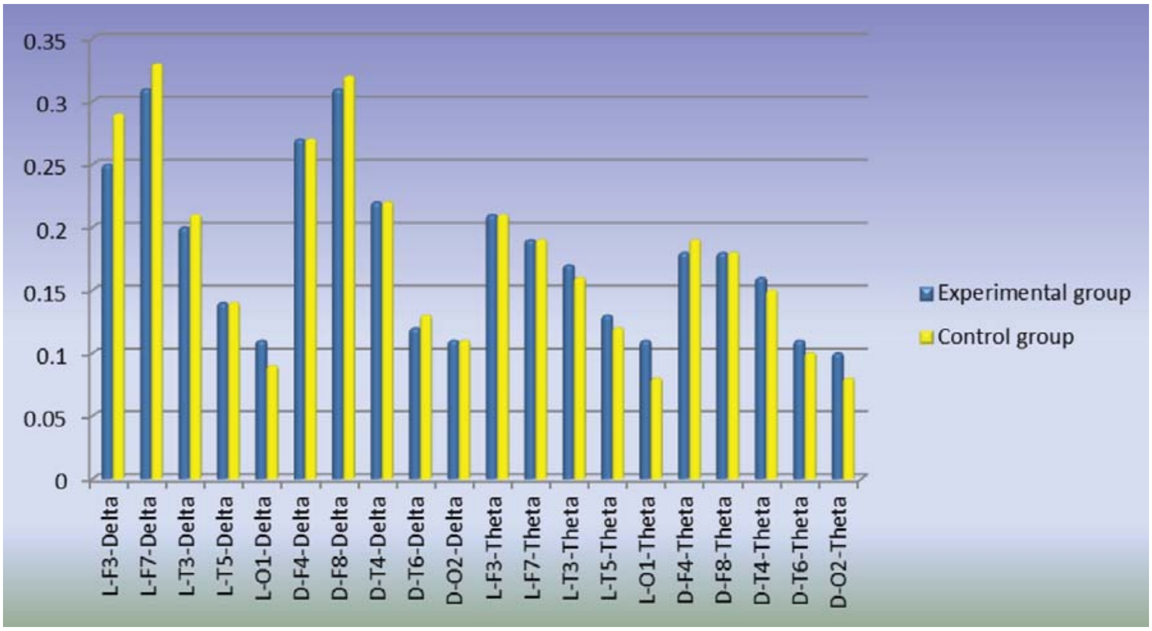

FIGURE 4. Delta and theta rhythms in the state of hyperventilation in the experimental and control group.

occurrence rate of theta waves was found in the left frontotemporal lobes with the frequency spectrum contribution to the total spectrum power (Fig. 5).

Theta waves analysis of the recording sequences with the eyes open and post-hyperventilation revealed a higher theta occurrence rate in the left cerebral temporal lobe in the soccer players than in the controls.

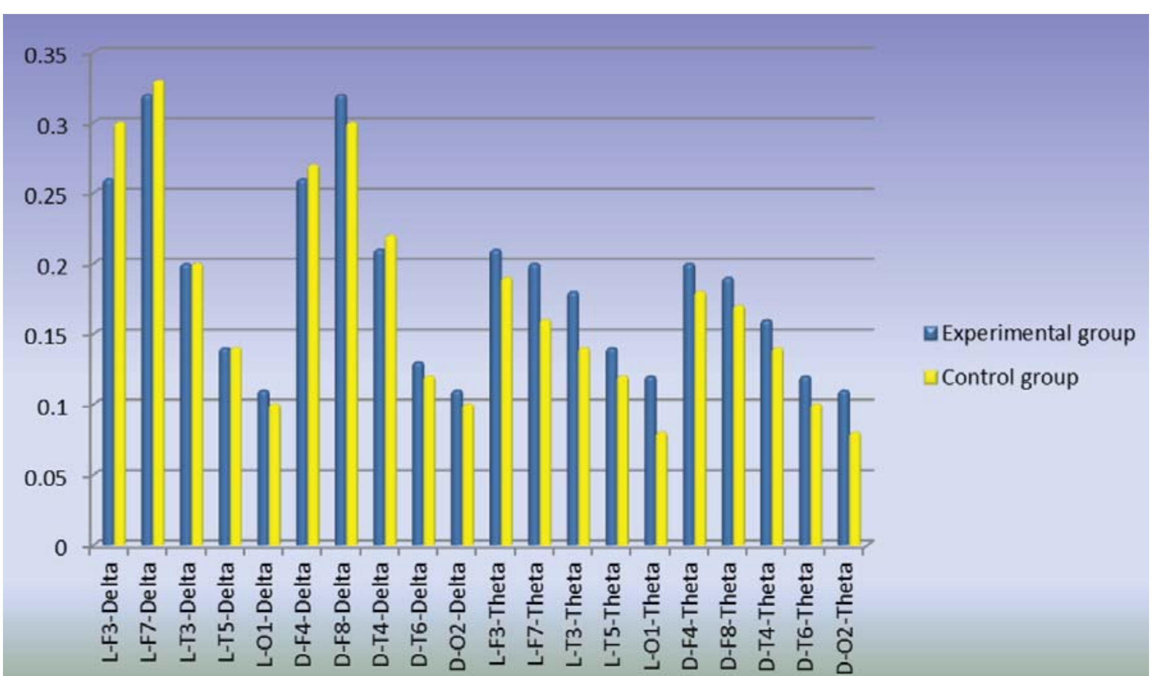

FIGURE 5. Delta and theta rhythms post-hyperventilation in the experimental and control group.

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DISCUSSION

The present study has shown significant deficits in attention tasks through a longer time interval, end EEG abnormalities particulary in the frontotemporal region with a higher occurrance rate in the left hemisphere- which were not specific for any cognitive disorder. Head injury is a high risk factor in association football. In many cases TBI symptoms remain unobserved and they are usually manifested as mild cognitive deficits, detectable only by expert comprehensive neuropsychological testing[20,21]. The attentional deficits following recurring mild head injuries might be included in the spectrum of chronic traumatic encephalopathy, which in turn, might include: behavioural, mood, cognitive, motor features[22]. New reaserch shows the existence of anatomical changes in the brain.[23,24].

The deficits in attention task might indicate impairments of basic vigilance, impairments of sensory perception or orientation, impairments of psychomotor functioning, or just inadequate motivation of the subjects. Therefore the test results should be interpreted as an effect of changed perception and not an indicator of the impaired brain regions responsible for information processing. Since response time to visual stimulus and attention sustaining time were significantly changed in the group of soccer players, it is not unreasonable to state that the central information processing performance is reduced in footballers, which was also expected in line with previous research findings[5,7,9,12,25].

Understandably, memory is closely related to proper attention functioning since the information received with distracted attention cannot be remembered well[26]. It appears that memory disorders in soccer players with recurring mild TBI are incurred secondarily due to attention impairments[27].

Our investigation indicates cognitive deficits in the observed soccer players, which are related to attention impairments. It should be highlighted that the finding of such cognitive deficits in former active soccer players may cause suspension in competing at the veteran competition level. Also, we must be aware that some former soccer players tend to underestimate memory deficits[28].

The current findings on EEG changes are comparable to the findings in previous research studies except a more frequent occurrence of theta waves in the left frontotemporal lobe of the cerebrum[29,30]. Probable further research should select soccer players according to more specific criteria, e.g. quality of competition level, playing positions, style of play, level of play, etc.[31] Occurrence of pathological waves was expected, but no cerebral region was found to be predisposed to soccer-related EEG changes after repetitive mild head injuries. The registered EEG changes in the soccer players may be linked to the results of cognitive tests , which this fact may explain the positive results of cognitive rehabilitation through EEG-biofeedback.[32,33] In our study we did not use brain CT, because we did not find specific signs of brain damage among our subjects.

The current study findings are applicable to the prevention and rehabilitation of soccer players, especially in younger age categories. It implies the necessity of cognitive tests and EEG recordings introduction into regular sports medical check up prior and post competition season. However, these tests should be further investigated for their practical applicability as well as for the protocol and interpretation standardization.

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