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Improvement in peak performance as a result of the inhibition of beta 2 bands (EEG) in neurofeedback-EEG training in motion

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SUMMARY

Background: The motor cortex in humans is more active during exercise than at rest. This study examined the effect of neurofeedback-EEG training, which consisted in a reduction in the amplitude of the beta2 band (20-30 Hz) during exercise, on the results of behavioural tests that evaluated attention, reaction time and the shape of the work curve. The relationships between the EEG bands during exercise and the performance of the mind were also analysed.

Material/ Methods: Electroencephalography (EEG) recordings were used to measure the bioelectrical brain activity in a group of 20 subjects performing exercise on a swimming ergometer (10 people) and an elliptical ergometer (10 people). The subjects were supposed to concentrate their attention on the visual stimuli presented on the screen installed c.a. 1 meter in front of their face. Before and after the EEG recording and after 20 neurofeedback-EEG training sessions, the subjects performed the Kraepelin work curve test (paper version).

Results: After 20 neurofeedback training sessions, the amplitude in the inhibited beta 2 band was reduced. These changes in brain activity were accompanied by a reduction in reaction time, in the attention-reaction test, and in certain measures of the Kraepelin's work curve. Simultaneously, the relationships between measures of the work curve and the beta2 bands were observed. These relationships demonstrate a longer time of maintenance of quick working rate, high energy and persistence, maintaining attention and consistency in physical activity.

Conclusions: Neurofeedback-EEG training in motion might be an effective method of improving work performance, connected with the engagement of attention while doing exercise. It can also ensure attention concentration for motion control and provide useful information about brain activity during physical activity and rehabilitation. Our data reveal that, under conditions of constant speed of movement, the brain shows stability and it even reduces its bioelectrical activity.

Key words: peak performance, bioelectrical activity, physical activity

INTRODUCTION

Although human cognition often occurs during dynamic, motor activities, most examinations of the dynamics of human brain activity have been carried out under static conditions in a lying and sitting position [1,2]. Electophysiological examinations have shown that the human motor cortex might contain cerebral attention centres [3]. This might be reflected by different attention strategies, selectively in different regions of the cerebral cortex [4]. It is assumed that rhythmical sensory tasks are accompanied by lower frequencies of oscillation for tasks and temporal dynamics [1]. As was demonstrated empirically, adjustment of a high frequency of oscillation participates in rhythmical events as a method for improvement in the response, which is the contribution of attention and reaction [5]. The recent study using PET, before and directly after the imagination of walking and running (starting from a walk), demonstrated that, using additional routes of the motor cortex and basic loops, direct cortical tracts (especially in the motor cortex) are activated [6,7,8]. Positron emission tomography (PET) and functional magnetic resonance imaging demonstrated [9] that the motor cortex is active during motion preparation and expectation, especially in the frontal areas of the brain. Theotor cortex is active if sensory modulations of rhythmical motor tasks are present [10]. Even if the tasks are performed passively, the motor cortex modulates the spinal cord signal through the midbrain in the motor region [11]. Maintaining physical activity might be modified by learning and neural plasticity [10].

Neurofeedback EEG training in physical activity and rehabilitation

Neurofeedback-EEG training in a sitting position has been used for a few years to improve the results in physical activity and rehabilitation. Previous examinations have demonstrated that subjects achieved better results through this training,. It was shown, for instance, that neurofeedback-EEG training, which increases the power of beta1and SMR waves, improves attention and motor concentration. However, all previous studies connected with neurofeedback-EEG training had been carried out in a sitting position [12,13,14] until the study [1] demonstrated that EEG might be also used to analyse the dynamics of cognitive tasks during walking and running. In order to improve work performance in physical activity and rehabilitation, we used neurofeedback-EEG training in motion on ergometers (SportArt elliptical trainer and Vasa swim trainer) with the inhibition of the beta2 band amplitude. One reason for using this protocol is the results of examinations [15] which demonstrated that efficiency in improving the results in attention and stamina tasks is connected with a reduction in the beta2 band [16]. Furthermore, the study [17] showed that regular neurofeedback-EEG training with respect to the rehabilitation of psycho-motor activity has a stimulating effect on motor activity. Analysis of brain activity during neurofeedback-EEG training in motion might be useful in planning physical activity but it might also improve diagnostics and ensure progress in rehabilitation in terms of the attention and work performed [18].

Work curve in psychological tests

The effectiveness of the neurofeedback-EEG method in motion for behavioural changes is estimated in particular by the measurement of the speed and accuracy of the task intended to be performed. Similar criteria were used in the evaluation of work performance at the beginning of the twentieth century. Kraepelin [19], who attempted to find the causes of individual differences in work performance drew a 'work curve,' where he took into consideration a number of positive (motivation) and negative (fatigue) indices that determined the level of this performance. Furthermore, this researcher also demonstrated that a positive correlation is observed between the level of certain indices of the work curve and increased desynchronization in the beta band. In our study, we used indices of the Kraepelin's work curve in order to describe changes in sport performance following Neurofeedback-EEG training.

MATERIAL AND METHOD

The study was carried out at the Interfaculty Laboratory of Neurophysiology at the University of Physical Education in Warsaw, Poland, equipped in a Flex 30 EEG Holter with TruScan (Deymed) software with a neurofeedback-EEG training module and two ergometers: an elliptical trainer (SportArt) and swim trainer (Vasa). EEG recordings were performed during submaximal exercise: running or crawl stroke at a speed of 2 m/s (evaluation based on a heart rate of 130 to 150 bpm and VO2max), beta2. An experimental procedure with division into an experimental and control group was used. The choice of the procedure was justified by the purposive selection of the study participants, homogeneity of the study group and the control group and the research hypothesis which said that inhibition of the beta2 band in neurofeedback-EEG training in motion improves work performance in the Kraepelin test.

The study examined 20 subjects aged 18 to 25 years. All the study participants gave their written consent to participate in the experiment. The procedure was approved by the Ministry of Science and Higher Education, according to the standards used by the Research Bioethics Commission of the Józef Piłsudski University of Physical Education in Warsaw, Poland and the standards of the Declaration of Helsinki. The subjects from the experimental group (14 people) were for five months (on average every 7 days) subjected to 20 neurofeedback-EEG training sessions (7 people on a swimming ergometer and 7 people on an elliptical ergometer). For five months between EEG examinations, the subjects from the control group (6 people) were involved in a physical activity, similar to the study group. Before the EEG recordings and 20 neurofeedback-EEG training sessions and after 20 training sessions, all the subjects performed the Kraepelin work curve test (paper version) and the „attention and reaction" computer test.

Flex 30 Holter electrode systems based on a system of leads (10-20) with TryScan (Deymed) software and a non-invasive method of examination of brain activity in motion were used. Before each examination, the caps and electrodes were washed and disinfected. The skin on the head was degreased in order to reduce impedance of electrodes to a level below 5kOhm. The amplification was set at 100uV/10 mm and barrier filters (time constant) were used: 0.5 Hz (low-pass) and 40 Hz (high-pass). The same settings were used for each examination.

Neurofeedback-EEG training procedure during motion on ergometers

During a neurofeedback-EEG training session, the subject was expected to perform a task which consisted in a concentration of attention on the screen where a dolphins' motion was visualized for the swimming ergometer and a racket motion for the elliptical ergometer. The motion on the screens was stimulated by the activity of the EEG signal, which decreased from C3 and C4 electrodes in the beta2 band *20-30Hz). During a single series, this training exercise was performed six times, 5 minutes each (three series with recording on C3 and three series with recording on C4). The participants relaxed after each training session by closing their eyes for 30 seconds. In the beginning and at the end of the session (before and after 20 neurofeedback-EEG sessions in motion), the exercise-based EEG examination and addition test was also performed in order to obtain a Kraepelin work curve. The „attention and reaction" test was also carried out.

The „attention-reaction test" (Performance Feedback System) is a test that evaluates reaction in the visual attention state. In this test, 94 images are displayed on a computer screen individually every 500 ms (an adaptation of the mental game called Mind Place, USA). The task is to click the backlit image with the mouse. The total reaction time to all the images is calculated. During the test, a control EEG examination was also carried out. Analysis using Deymed software did not show any disturbances in EEG signals caused by hand movement while clicking a mouse.

Kraepelin test

With its paper version, the Kraepelin's test [20,21] was created for examination of the speed, performance and accuracy of work. During the test, the person examined is supposed to perform, within one hour, as many summation operations of two digits in the adjacent columns as possible and the obtained score should be written to the right. The total of proper scores calculated in consecutive 3-minute time periods creates the work curve. The shape of the curve, with the general number of summation operations performed and the number of mistakes and corrections provides the basis for the interpretation of the test results. The values in the work curve allows for the calculation of the six separate and largely independent factors (partial measure). Their interpretation is based on the Kraepelin's study [20,21].

Partial measures:

1) Performance measures:
   - total number of summation operations
   - number of operations in the first three-minute time period

   - maximum number of summation operations in the 3-minute time period (without the first time period)
2) Measures of energy and persistence:
   - percentage increase (difference between means of the first and the last four 3-minute time periods expressed in percentage terms),
   - half ratio (quotient of total number of summation operations from the period that consists of 10 last 3-minute time periods (11-20) and the first ten windows (1-10),
   - location of the maximum (3-minute period number when a person studied performed the highest number of summation operations (without the first period);
3) Measures of the fast adaptation and effort without self-restraint
   - convexity I (the difference between the general number of summation operations during the first four and last four time periods multiplied by the mean elevation of the curve and divided by the number of time periods),
   - convexity II (the difference between overall number of summation operations in time for the first five and last five time periods and the number of summation operations in the other middle ten time periods);
4) Measure of variability (or constancy), which determines the indices of oscillation around the even curve (average deviation from the 3rd to 18th time period);
5) Measures of accuracy and diligence are determined by the mistake ratio and correction ratio;
6) Measures of additional factors are determined by the initial decline (the difference between the number of summation operations in the first time period and the lowest number in the time periods 1 to 4) and the duration of the decline (determined in the four first periods when the fewest summation operations were performed).

Statistical data analysis

Descriptive statistics were used for the calculation of the values of amplitudes for the EEG bands. The significance of the differences in the mean amplitudes was calculated using a non-parametric Wilcoxon signed-rank test. Changes in behavioural parameters in the “attention and reaction” test were calculated using the multiple regression coefficient, whereas the significance of the differences in the Kraeplin measures was calculated using the non-parametric Mann-Whitney U test. The relationships between the work curve measures and the EEG bands amplitudes were calculated using Spearman’s r correlation.

RESULTS

We observed changes in the level of the EEG amplitudes in the beta2 band inhibited during neurofeedback-EEG training and also in the untrained SMR, beta and gamma bands. It turned out that, during submaximal exercise, the level of amplitude of the beta 2 band was significantly reduced ($p<0.01$), which is likely to represent the improvement in attention concentration. Changes in amplitudes in the beta1 and gamma bands ($p<0.01$) are correlated with the visual-motor co-ordination and the processes of attention, whereas amplitudes in the SMR band ($p<0.05$) are likely to concern optimization of the psychomotor function [16]. The EEG band amplitudes before and after 20 neurofeedback-EEG sessions. The results obtained in the control group, recorded before and after four months with-out neurofeedback-EEG training, did not change significantly. This demonstrates that the changes in the level of amplitude observed in people in the study group result from this training.

Plastic changes in brain activity during submaximal exercise as a result of neurofeedback-EEG training in motion

During submaximal exercise, running or crawl swimming at 2 m/s (evaluation based on a heart rate in the range of 130-150 bpm and VO2max) beta2 reduced in the motor and pre-motor cortex, whereas in the visual cortex, as a result of the attention activity of the brain, all the bands analysed had the highest amplitude. The observed activity in the leads O1 and O2 is usually attributed to visual-motor coordination and attention processes. Significant differences ($p<0.01$) in the inhibited beta2 band were found between visual (occipital) cortex activity and motor (parietal), auditory (temporal) and pre-motor (frontal) cortices in signals from all the electrodes. Near the left and right pre-motor cortex, a significant reduction in the amplitude of the beta2 band was also accompanied by a reduction in the amplitude of the beta1 band ($p<0.01$), which occurred in most of the leads from the electrodes: Fp2, F3, F4, F8, T3, C3, Cz, T6, P3, O1, O2 during submaximal exercise. Furthermore, in the leads from electrodes: Fp1, C4, T4, T5, Pz, P4, the significance of differences was slightly lower ($p<0.05$). Changes in the range of the gamma band (p<,001) in all the leads: Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2 might result in the increase in attention concentration and might have an effect on non-standard activities in the future. SMR band changed to a slightly lower degree ($p<0.05$). However, it was found that the medians of EEG amplitudes in the SMR band in the leads: Fp1, Fp2, F7, F3, Fz, F4, F8, O1, O2, i.e. the areas of pre-motor and visual cortex during submaximal exercise with intensified attention before and after neurofeedback-EEG training reduced significantly ($p<0.01$), whereas in the leads T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, the changes were insignificant.

Changes in behavioural parameters

In parallel with the changes in brain activity at rest as a result of neurofeedback training we found that after the completion of the training the athletes participating in the study had shorter reaction times in the test of visual attention: 1.21 s vs. 0.92 s ($N = 25$; $R = 0.59$; $R2 = 0.34$; $p < 0.01$) yet the results for the subjects from the control group remained unchanged: 1.23 s vs. 1.10 s ($N = 10$; $R = 0.84$; $R2 = 0.68$; $p = 0.17$).

Changes in the work curve before and after neurofeedback-EEG training

Among three measures of performance of the mind, we observed significant changes ($p<0.05$) in three indices (1,2,3): the number of operations in three-minute time period (Y1), the overall number of summation operations performed in the test, pointing to the working rate and half ratio. Apart from the measures of performance, significant changes ($p<0.05$) were also found for two of the three parameters that measured energy and persistence (4,5): difference in the mean elevation of the work curve and first ten time periods. Significant changes ($p<0.05$) were also observed in both parameters of measures of adaptation and effort without self-restraint (convexity I and convexity II) (7,8), which might have been caused by the processes of neural reaction [19, 20], (Tab. 1, Fig. 1.) The results obtained by the control group (N=6) after four months without neurofeedback-EEG training did not change significantly ($p<0.05$), which demonstrates that changes in the work curve in the study group are caused by this training. This is consistent with the results of the study carried out by Arnold [56], which showed that the shape of the work curve changes insignificantly with time (in the range of up to eight months) and is specific for the person studied.

Relationships between the work curve and EEG band amplitude

In three measures of performance of the mind, we found significant relationships of the number of operation in the first three-minute time period (Y1) with the beta2 band ($r=-.77$) and the overall number of summation operations with the beta2 band ($r=-.78$) during submaximal exercise. The negative correlation between these variables indicates a high working rate with the reducing amplitude of the beta2 band (Fig. 2A, B). A positive (although not very high) correlation of half ratio with the amplitude of SMR band ($r=0.57$) is attributable to a specific tendency of maintaining energy reserves during submaximal exercise that has

Table 1. Indices of the work curve before and after training neurofeedback-EEG in the experimental group (n=20). The comparison with the use of the Wilcoxon signed rank test

Variable	before				after				Z	P
	M	SD	min	max	M	SD	min	max		
Y1	102.92	23.401	65.00	150.00	125.57	47.233	3200	218.00	**2.479**	**0.013**
Total number	2264	501.25	1538	3357	2596	634.382	1683	3596	**3.107**	**0.001**
Period I	129.42	28.335	89.00	190.00	150.28	38.847	98.00	21800	**3.044**	**0.002**
% increment	18.94	10.774	3.63	33.77	11.08	9.694	3.43	27.07	**1.789**	**0.033**
II/I ratio	1.25	0.067	1.14	1.38	1.18	0.06	1.09	1.28	**2103**	**0.035**
Peak location	16.78	2.636	12.00	19.00	13.50	5.501	100	20.00	1.686	0.091
Convexity I	45.78	16.272	13.40	68.80	21.83	10.301	2.40	32.30	**3.295**	**0.000**
Convexity II	56.50	43.968	3.00	132.00	59.21	41.348	2.00	137.00	**0.125**	**0.000**
Oscillation I	0.03	0.036	-0.07	0.07	-1.10	12.494	22.50	25.00	0.345	0.729
Mistake ratio	1.08	1.095	0.22	4.42	0.50	0.320	0.13	1.02	2.760	0.055
Correction ratio	0.96	0.809	0.17	2.96	1.30	0.984	0.40	3.24	**2.061**	**0.039**
Initial decline	11.35	7.034	0.00	24.00	10.21	6.375	0.00	22.00	0.279	0.779
Duration of the decline	2.85	1.099	0.00	4.00	2.07	1.141	0.00	4.00	**1.836**	**0.066**

Abbreviations: M – mean, SD – standard deviation, min – the lowest score, max – the highest score

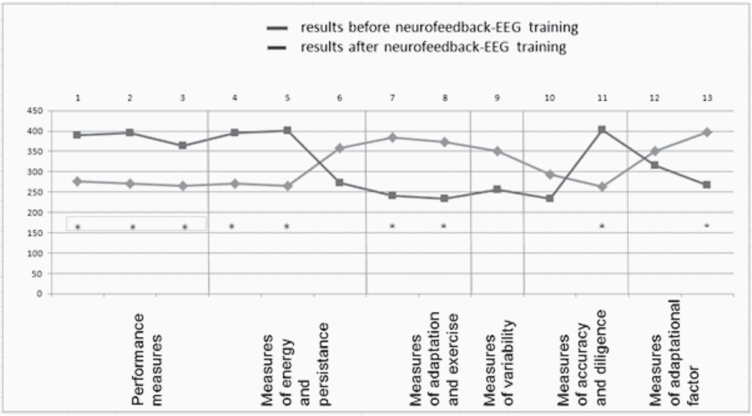

Fig. 1. Indices of the work curve after 20 sessions of Neurofeedback-EEG training Numbers from 1 to 13 present other values of measures of the work curve: 1 – Y1, 2 – total number of summation operations, 3 – half ratio, 4 – increase, 5 – maximum, 6 – location of the maximum, 7 – initial decline, 8 – duration of the initial decline, 9 – convexity I, 10 – convexity II, 11 – oscillation, 12 – mistake ratio, 13 – correction ratio. N=14

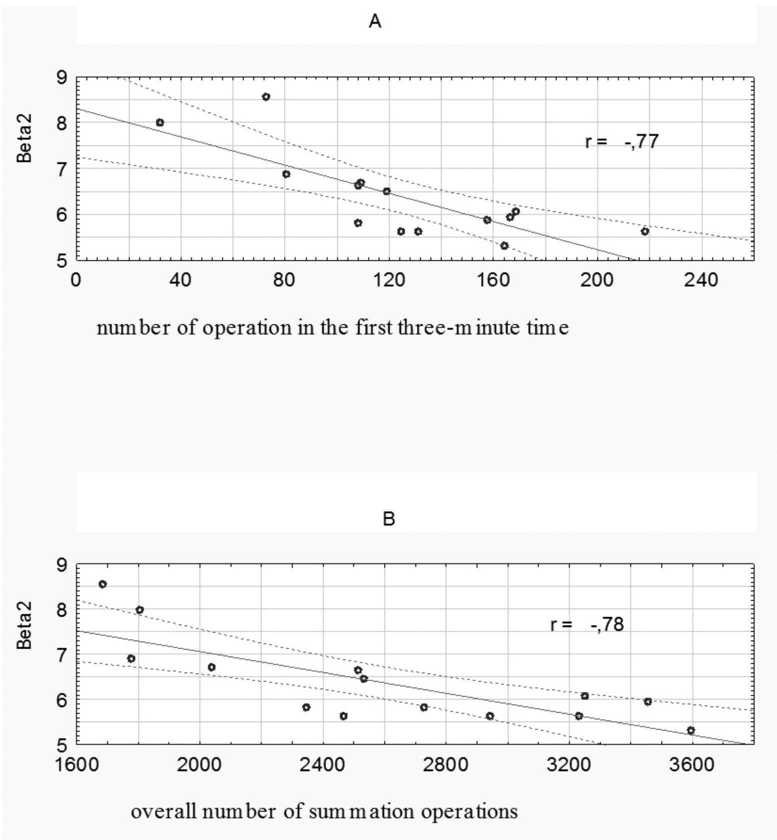

Fig. 2. Correlations of Spearman's R between measures of energy, persistence and variability with EEG band amplitude: the number of operation in the first three-minute time period Y1 with beta2 band (A) and total number of summations with beta2 (B)

an effect on the optimization of psychomotor functioning [16]. Furthermore, the index of oscillation around the work curve (variability/constancy measure) is correlated with the gamma band amplitude (r=0.55). These correlations are not strong, but can point to a tendency for the engagement of attention during the performance of the motor task. Therefore, a sufficient level of beta1 and gamma band amplitudes after neurofeedback-EEG training in motion might suggest the tendency for maintaining energy and constancy in action.

DISCUSSION

To our knowledge, this study is one of the first concerning the patterns of bioelectrical brain activity with application of neurofeedback-EEG training during exercise [6,7]. The amplitude of the beta2 band, which was inhibited during 20 neurofeedback-EEG training sessions, under conditions of intensified visual attention, was, as expected, significantly reduced in all the involved brain areas. This is likely to be connected with the concentration of attention [15] and work performance [19,20,21]. Reduction in the amplitude in the beta2 band turned out to be effective in the improvement of attention tasks results. The biggest changes in the EEG amplitudes of the inhibited beta2 bands ($p<0.001$) and the non-trained adjacent SMR and gamma bands ($p<0.05$), were observed in the signals received from frontal and occipital electrodes. Changes found in the pre-motor and visual cortex reinforce the assumption [22] that the observed brain plasticity in motion determines the conscious control over physical activity. Less significant changes were observed for the amplitude of the SMR band ($p<0.05$) but also in the pre-motor and visual cortex, which is consistent with Bernstein's theory of psychomotor control [22]. This might mean a correlation with the actual motor control. The observed changes in bioelectrical brain activity in the parietal leads are usually attributed to visual-motor coordination and attention processes. The results obtained in the study are consistent with the training paradigm used in our experiment, which required the concentration of attention in visual modalities. Therefore, a faster performance of the „attention and reaction" test and the Kraepelin work curve test after a neurofeedback-EEG training session during submaximal exercise might depend on changes in the level of amplitude in the beta2 band and the beta1, gamma and SMR bands. Since the amplitude of the beta2 band during motor exercise changes in the direction stimulated with neurofeedback-EEG training, followed by changes in the amplitudes of the neighbouring bands, one can expect that these changes are accompanied by neural plasticity. Finding the specific mechanisms and brain structures connected with the observed plastic changes in the amplitudes in the individual EEG bands [23,24] and their role in the improvement of behavioural indices which are the aim of the training necessitate further research. Furthermore, specific changes in amplitudes of the same bands were correlated with measures of performance, which reflect the tendency for quick starting and performing work [19,20]. The high level of energy and persistence measures is connected with the high amplitude of the

SMR band, which points to the tendency for high energy reserves during submaximal exercise and is interpreted by Kraepelin [19] as a tendency for delaying fatigue. Furthermore, the low level of the variability measure („oscillation index"), which is associated by Arnold [20] with increased consistency in action, is accompanied by a high level of gamma band, which might have an effect on nonstandard activities in the future. Improved attention concentration during exercise determines the easiness of maintaining interest in monotonous work and patience in achieving goals [19,20,21].

CONCLUSIONS

The results of this study suggest the usefulness of EEG recording in motion [25], which helps achieve better results in physical activity, health and rehabilitation. The application of these exercises might provide an insight into the cognitive mechanisms and motor disorders, which might be also extrapolated to the prognoses in medicine. We have also demonstrated that neurofeedback-EEG training in motion might be an effective method of improvement in work performance, connected with the engagement of attention during exercise. It can also ensure attention concentration for motion control [22] and provide useful information about brain activity during physical activity and rehabilitation. Our data reveal that, under conditions of constant speed of movement, the brain shows stability and it even reduces its bioelectrical activity, until the next changes occur. In the locations of EEG recording, neurons were active during submaximal exercise, which is consistent with the results obtained for previous studies on walking and running [1].

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