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Brain-training for physical performance: a study of EEG-neurofeedback and alpha relaxation training in athletes

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In recent years, EEG-neurofeedback training (EEG-NFB) has been increasingly used to optimize various brain functions. Better performance in various activities was also reported after relaxation trainings, another popular method in therapeutic practice. Both these methods are used as a part of professional coaching in sports training centers. In the present study, we aimed to evaluate the impact of such holistic training on physiological (EEG) and behavioral measures on semi-professional athletes. EEG-NFB paradigm was intended for amplification of the amplitudes of SMR (12–15 Hz) and beta1 (13–20 Hz) bands and simultaneous reduction of the amplitude of theta (4–7.5 Hz) and beta2 (20–30 Hz). Participation in NFB sessions was accompanied with self-administration of relaxing, audio-visual stimulation after each daily athletic training session.
The training program resulted in the increase of alpha and beta1 power of trained participants when assessed in rest with eyes-closed. In eyes – open state, participants of the trained group maintained the same level in all frequency bands, in opposite to the control subjects, whose power decreased in the second measurement in beta1 band when compared to the first one. The trained group exhibited greater reduction of reaction times in a test of visual attention than the control group and showed improvement in several performance measures of Kraepelin's work-curve, used to evaluate speed, effectiveness and work accuracy. Together, these results present initial support for the use of holistic, neurophysiological training in sports workout.

Key words: EEG-neurofeedback, audio-visual relaxation, performance improvement, Kraepelin's work curve, sport

INTRODUCTION

EEG-neurofeedback training (EEG-NFB) has been increasingly used in recent years for the optimization of various brain functions (Gruzelier 2013). EEG-NFB was postulated to enhance creativity (Rogala et al. 2014), was used as supplementation in teaching dance (Raymond et al. 2005a), for improving musical performance (Egner and Gruzelier 2003) and optimizing effectiveness of physical work (Van Herzeele et al. 2008, Larsen et al. 2009). Other studies have reported that NFB improved function of the frontal lobe, motor reactions connected with movement coordination (Bazanowa et al. 2009) and stress-related emotional reactions (Raymond et al. 2005b, Bazanowa et al. 2009, Bradley et al. 2010). EEG-neurofeedback has been also used to improve the results achieved in competitive sport. Many studies have found improved performance in athletes following NFB (Landers et al. 1994, Cherapkina 2012, Strizhkova et al. 2012, Beauchamp et al 2012, Shaw et al. 2012).

Specifically, EEG-neurofeedback training set up to simultaneously modulate the amplitudes of multiple frequency bands, i.e.: to increase sensorimotor rhythm (SMR, 12–15 Hz) and reduce theta (4–7.5 Hz) and beta2 (20–30 Hz) amplitudes is one of the protocols widely used with the attempt to improve cognitive performance and advised as such in commercial practice. EEG-neurofeedback training in the SMR band was shown to improve sleep architecture (Hoedlmoser et al. 2008) and mood (Raymond et al. 2005b). It was shown, for instance, that NFB used to enhance amplitude of SMR and beta1 waves in archers, gymnasts, ice skaters and skiers improved attention, emotional stability and

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motor coordination and reduced fear (Hammond 2005). It was also found that increasing the amplitude of beta1 and SMR bands in cortical motor areas in competitive pistol shooters was associated with reduced activity in the muscles not involved directly with this sport, leading to optimization of psychomotor function and cognitive control (Kerick et al. 2004).

It is still unclear why the neurofeedback training in the theta, alpha, SMR and beta bands would improve so many aspects of performance: from memory to cognitive tasks and artistic performance (Rogala et al. 2014). The common base for this spectrum of tasks seems to rely on the increased attention/concentration abilities, measured i.a. by reaction time in attentional tests (Egner and Gruzelier 2001, Vernon et al. 2003, but see discussion in: Vernon 2005). Supportively, our recent animal studies have shown that increased beta band activity specifically accompanies different attentional behaviors (Wróbel et al. 2007, see: Wróbel 2014 for review).

The aim of the present work was to verify if complex EEG-NFB training protocol aiming at the upregulation of SMR (12–15 Hz) and beta1 (13–20 Hz) band with simultaneous constraints of theta and beta2 amplitudes boosts attentional performance as measured with reaction times in athletes. Learning a skill, whether it is burnishing sports excellence or acquiring ability to regulate cortical oscillation as in NFB training, requires succeeding period of rest (Marshall and Bentler 1976, Teplan et al. 2006, Klimesch et al. 2007). It serves for regeneration of the systems that have been exploited during effort and for consolidation of the trained abilities. We assessed the final improvement of performance in attention-reaction task and Kraepelin's work-curve test (Kraepelin 1922). EEG-measurements and reaction times of experimental group, undergoing both trainings were compared to the results of control group tested in the same time regime, but not subjected to NFB or relaxation sessions.

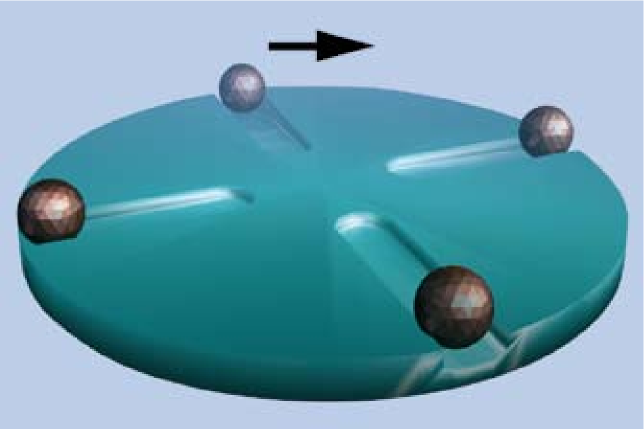

Fig. 1. Image on the screen displayed during the Neurofeedback-EEG training used in the study. The task of the study participant was to change the "trained" frequency amplitude in EEG activity. When the demanded change occurred, the Neurofeedback apparatus produced reinforcing feedbacks: movement of the four external balls to the middle of the shape accompanied by interrupting pitchy noise (the disc rotates to the right at the speed of 1 rotation/2 minutes).

METHODS

Participants

The 35 student athletes involved in swimming, fencing, track and field, taekwondo, judo, five people per sport took part in the experiment. They were 18 to 25 years of age and showed similar sports skill level (national level) and trained in the same club (5 to 7 years). Examination of all the athletes in one group was aimed at determination of a general state of "readiness for exercise" which, as demonstrated, can be compared across different sports (Behncke 2004). All the subjects gave written consent to participate in the experiments. All the procedures were approved by the Bioethical Committee and were consistent with the standards of the Declaration of Helsinki.

Procedure

The experimental group consisted of 25 athletes (five people per sport in each group, 15 males and 10 females) who participated in 20 sessions of EEG-neurofeedback training for four months (every 7 days on average) and autogenic, audio-visual relaxation with eyes closed after every day athletic training (in home conditions). The EEG examination (in resting supine position with eyes open and closed), attention-reaction test and addition test for evaluation of the Kraepelin's work curve were carried out on each subject at the beginning and the end of the NFB training (see below). The control group (10 athletes, 5 males and 5 females) performed regular sport training during four to seven months between EEG recordings similarly as sportsmen from the experimental group but without parallel EEG-neurofeedback training and relaxation sessions.

NFB and relaxation training

In our experiment the feedback signal was based on the activity recorded from C3 and C4 electrodes (in the system of 10–20) and provided in visual and auditory modality. During the training, subjects were asked to perform a task that consisted of controlling the images displayed on a screen so that four balls should be placed in the middle of the screen (Fig. 1).

The balls moved towards the center when multiple conditions were fulfilled at the same time: the theta (4–7.5 Hz) and beta2 band (20–30 Hz) amplitudes were kept below a pre-set threshold and the amplitude of the SMR (12–15 Hz) and the beta1 (13–20 Hz) bands were increased (above the threshold). The voltage threshold for reducing the theta and beta2 bands was set at 40% (2.6 μV and 2 μV) above their mean amplitudes (6.5 μV, and 5 μV, correspondingly) and threshold for SMR and beta 1 bands was set at ~35% (1.4 μV and 1.6 μV) below their mean amplitudes (~3.5 and 4.5 μV correspondingly). Successful displacement of the balls was accompanied by an acoustic reinforcing signal (0.5 s long pitch repeated every 1 s under fulfilled conditions). The subjects performed this training six times (5 minutes each) during a single training session. The participants relaxed after each training session by closing their eyes for 30 seconds.

Additionally to the EEG-NFB training, a 45-minute audio-visual relaxation straining were carried out after each daily athletic training (Mikicin and Kowalczyk 2015). It consisted of exposure to a green light and auditory stimuli (high tone; 7–13 Hz) i.e. Shultz autogenic training (Davis et al. 2000, Teplan et al. 2006, Hashim 2011). The individuals were lying supine with their eyes closed, light and sound intensity were individually adjusted. Both neurofeedback and (first-time) autogenic relaxation training were conducted with assistance of certified investigators.

Evaluation of EEG effects

For pre- and post-training examination of the EEG baseline, the signal was recorded for 2 minutes in two conditions: with eyes open and eyes closed. EEG signals were recorded with 19 electrodes mounted in a 10–20 system with use of System Flex 30 and TruScan software. All impedances were kept below 5 kΩ. The recorded signals were filtered between 2 to 40 Hz. All signals were visually inspected and periods with no signal contamination were manually selected for further analysis and divided into 5 second windows. In some participants, most of the signal was largely contaminated and therefore they were not included into analysis (trained group: 7 subjects in eyes-closed, 9 in eyes-open measurements; control group: no subjects excluded). In the trained group analysis was restricted to 14 participants who have available a full set of data (eyes open and eyes closed condition in first and second measurement). Power of each of the six predefined frequency ranges was extracted from each window with use of MATLAB "bandpower" function and the resulting powers were averaged across all the windows.

The statistical analyzes were performed with use of two-way, mixed ANOVAs, with time (pre- and post-training) as within and group (trained, control) as between-subjects factors. For the control group pre- and post-training time points refer to first and second measurement interspersed with equivalent interval of time. The analysis were done separately for each frequency range. First, we checked the global influence of the training by averaging the power from all the electrodes. We also did the same analysis for left, right and rear subgroups of the electrodes, but the results did not differ from the global-average analysis and are therefore not further reported in the paper. Finally, for the bands in which we observed significant interaction effect (in power averaged across all electrodes) we did also the same analysis for single electrodes. Thus, with single electrode analysis we can define where the effect was the most pronounced.

Evaluation of behavioral effects

For examination of behavioral changes, two tests were performed. 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 (adaptation of mental game called Mind Place, USA). The task is to click the backlit image with the mouse. Total reaction time to all the images is calculated. The test was performed pre- and post-training by the trained group and with equivalent timing by the control group, and the two-way, mixed ANOVA was applied for the analysis of reaction times.

"Work curve test" (Kraepelin 1922, Arnold 1975 p. 32) was created for measurement of the speed, effectiveness and work accuracy. This test was performed

Table I

Measures calculated on the basis of Kraepelin's work curve test

Category	No.	Measure
Performance measures	1	total number of addition operations (number of operations a person performed during the test, including mistakes and corrections)
	2	number of operations in the first 3-minute time period (the score obtained during the first 3 minutes of the test, which is the indicator of the previous experience in addition)
	3	maximum number of addition operations in the 3-minute time period (without the first time period, which reflects the highest possible working rate of the person studied)
Measures of energy and persistence	4	percentage increase (difference between means of the first and the last four 3-minute time periods expressed in percentage terms)
	5	half ratio [quotient of total number of addition operations from 10 last 3-minute time periods (11–20) and the first ten windows (1–10)]
	6	location of the maximum (3-minute period number when a person studied performed the highest number of addition operations, without the first period)
Measures of the fast adaptation and effort without self-restraint	7	convexity I (difference between the general number of addition operations during the first four and last four time periods multiplied by mean elevation of the curve and divided by the number of time periods)
	8	convexity II (difference between overall number of addition operations in time for the first five and last five time periods and the number of addition operations in other middle ten time periods)
Measure of variability (or constancy)	9	index of oscillation around the even curve (average deviation from the 3rd to 18th time period)
Measures of accuracy and diligence	10	mistake ratio (overall number of mistakes as a percentage result of general number of addition operation)
	11	correction ratio (percentage result of overall number of addition operations)
Measures of additional factor	12	initial decline (difference between the number of addition operations in the first time period and the lowest number in the time periods 1 to 4)
	13	duration of the decline (determined in the four first periods when the fewest addition operations were performed)

by participants of the trained group only. The aim of this task is to perform, within one hour, as many operations of addition of two digits in the adjacent columns as possible and write down the obtained result to the right of the columns. The total correct results calculated in consecutive 3-minute time periods creates the work curve. The shape of the curve, based on the general number of addition operations performed, the number of mistakes and corrections provides the basis for interpretation of the results. The

Table II

	Trained group		Control group		Main effect of time	Main effect of group	Interaction effect
Band	Before mean (sd)	After Mean (sd)	Before Mean (sd)	After Mean (sd)	P value	P value	P value
Eyes open							
delta	2.64 (1.97)	2.23 (0.69)	2.05 (0.91)	2.93 (1.77)	0.754	0.892	0.134
theta	1.65 (0.56)	1.98 (1.01)	1.43 (0.70)	1.45 (0.59)	0.360	0.110	0.479
alpha	2.68 (1.51)	2.53 (1.76)	3.43 (3.95)	1.77 (1.62)	0.141	0.995	0.158
smr	0.56 (0.34)	0.55 (0.30)	0.51 (0.38)	0.36 (0.20)	0.325	0.280	0.291
beta1	0.90 (0.37)	0.92 (0.47)	0.99 (0.68)	0.67 (0.35)	0.179	0.641	0.067^
beta2	0.63 (0.26)	0.61 (0.31)	0.70 (0.37)	0.54 (0.21)	0.130	0.997	0.211
gamma	0.34 (0.27)	0.35 (0.27)	0.40 (0.26)	0.35 (0.26)	0.785	0.770	0.671
Eyes closed							
delta	2.91 (1.32)	2.37 (1.08)	2.45 (1.23)	2.97 (1.79)	0.767	0.868	0.135
theta	1.99 (0.98)	1.97 (0.89)	1.65 (0.76)	1.68 (0.80)	0.995	0.370	0.838
alpha	5.39 (3.16)	7.33 (4.57)	7.05 (5.82)	6.94 (6.20)	0.075^	0.748	0.095^
smr	0.77 (0.59)	0.91 (1.07)	0.53 (0.25)	0.48 (0.26)	0.510	0.230	0.265
beta1	1.16 (0.61)	1.39 (0.75)	1.09 (0.79)	0.96 (0.41)	0.291	0.350	0.030*
beta2	0.66 (0.23)	0.72 (0.39)	0.79 (0.37)	0.64 (0.27)	0.671	0.804	0.070^
gamma	0.31 (0.14)	0.29 (0.22)	0.30 (0.12)	0.31 (0.23)	0.893	0.940	0.791

* – significant effect (<0.05), ^ – trend level effect (<0.1)

Columns 2–5: mean values and standard deviations (sd) of power in each frequency band for trained and control group in eyes – open and eyes closed – states. Columns 6–8: results of two-way mixed ANOVAs with time (pre- and post-training) as within and group (trained, control) as between-subjects factors

values in the work curve allows for calculation of six separate and largely independent factors (partial measures, see Table I). Their interpretation is based on Kraepelin's studies (after: Arnold 1975 p. 32–35) and others (Takigasaki 2006, Kashiwagi et al. 2007).

The work curve test has been standardized and adapted in Germany Arbeitskurve nach Kraepelin und Pauli-Test (Mainzer Revision) and in the Czech Republic (Kraepelin Emil, Arbeitskurve nach Emil Kraepelin T 41/004).

The assessment of pre-post changes in performance measured by parameters of Kraepelin's work curve were calculated using a t-test for dependent samples (pre- and post-training).

RESULTS

EEG results

EEG-NFB training manifested differential effects in eyes-open and eyes-closed conditions (Fig. 2). In eyes-open state, two-way mixed model ANOVA showed trend level interaction between group and time only in beta1 band ($F_{1,22}$=3.72, P=0.067, eta2=0.03). *Post hoc* analysis revealed that the only significant pairwise comparison was between pre- and post-training amplitudes of beta1 band in the control group (with the amplitude decreasing from first to the second measurement, P=0.046, for values of the means see Table II). No other effects were significant.

In eyes-closed state observed changes were in alpha, beta1 and beta2 bands. Increase in amplitude was found in alpha band for the second measurement when compared to the first one, as manifested in main effect of time ($F_{1,22}$=3,49, P=0.075, eta2=0.01). This effect resulted from the increment in alpha band in the trained group as revealed by trend level interaction ($F_{1,22}$=3.04, P=0.095, eta2=0.01) and *post hoc* pairwise comparisons (P=0.045, for values of the mean see Table II). The interaction between group and time was significant in beta1 ($F_{1,22}$=5.42, P=0.03, eta2=0.02) and at the trend level in beta2 band ($F_{1,22}$=3.64, P=0.07, eta2=0.03). *Post-hoc* pairwise comparisons revealed that the amplitude of beta1 band increased from pre-training to post-training measurement in experimental group (P=0.010 for values of the means see Table II). There were no significant differences in *post-hoc* comparisons within beta2 band.

To sum up, in eyes open only difference between first and second measurement was a decreases in beta1 band in the control, untrained group, while the trained group maintains similar amplitudes of all analyzed bands in both measurements. An opposite pattern was observed in eyes-closed condition – a significant increase was present in alpha and beta1 band only in the trained group, beta2 also showed significant interaction effect, however without *post-hoc* significant differences.

In order to increase spatial precision of the observed interaction effects, we conducted similar analysis on all the electrodes separately. Further presented are only results for bands which showed significant interaction of group and time in the analysis of averaged

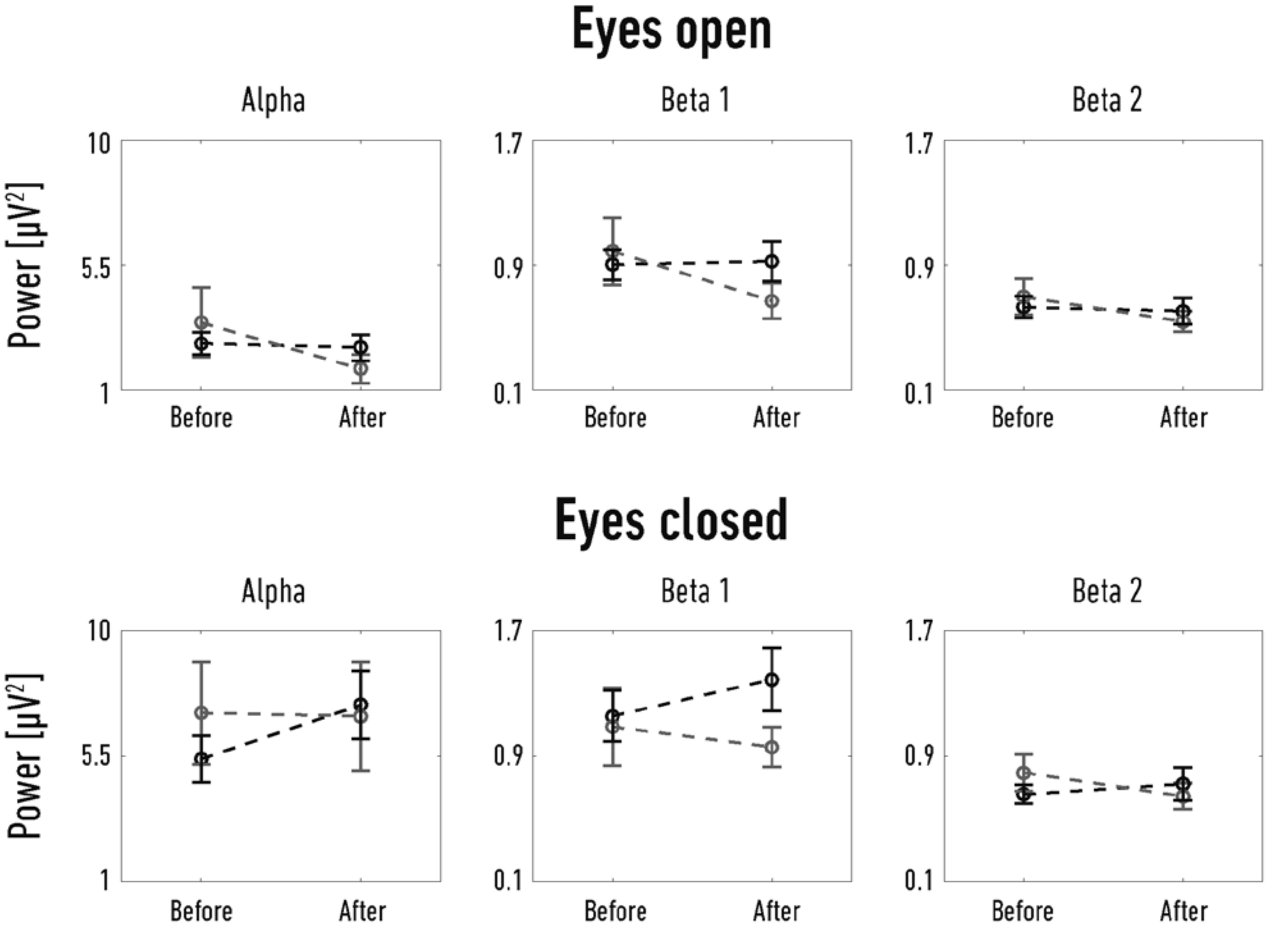

Fig. 2. Power of alpha (7.5–13 Hz), beta1 (13–20 Hz) and beta2 (20–30 Hz) bands averaged over all electrodes, for the training (black, n=14) and control (grey, n=10) groups before and after NFB training. Top row represents results for the rest with eyes open, bottom row – results for the rest with eyes closed. Error bars represent standard error of the mean.

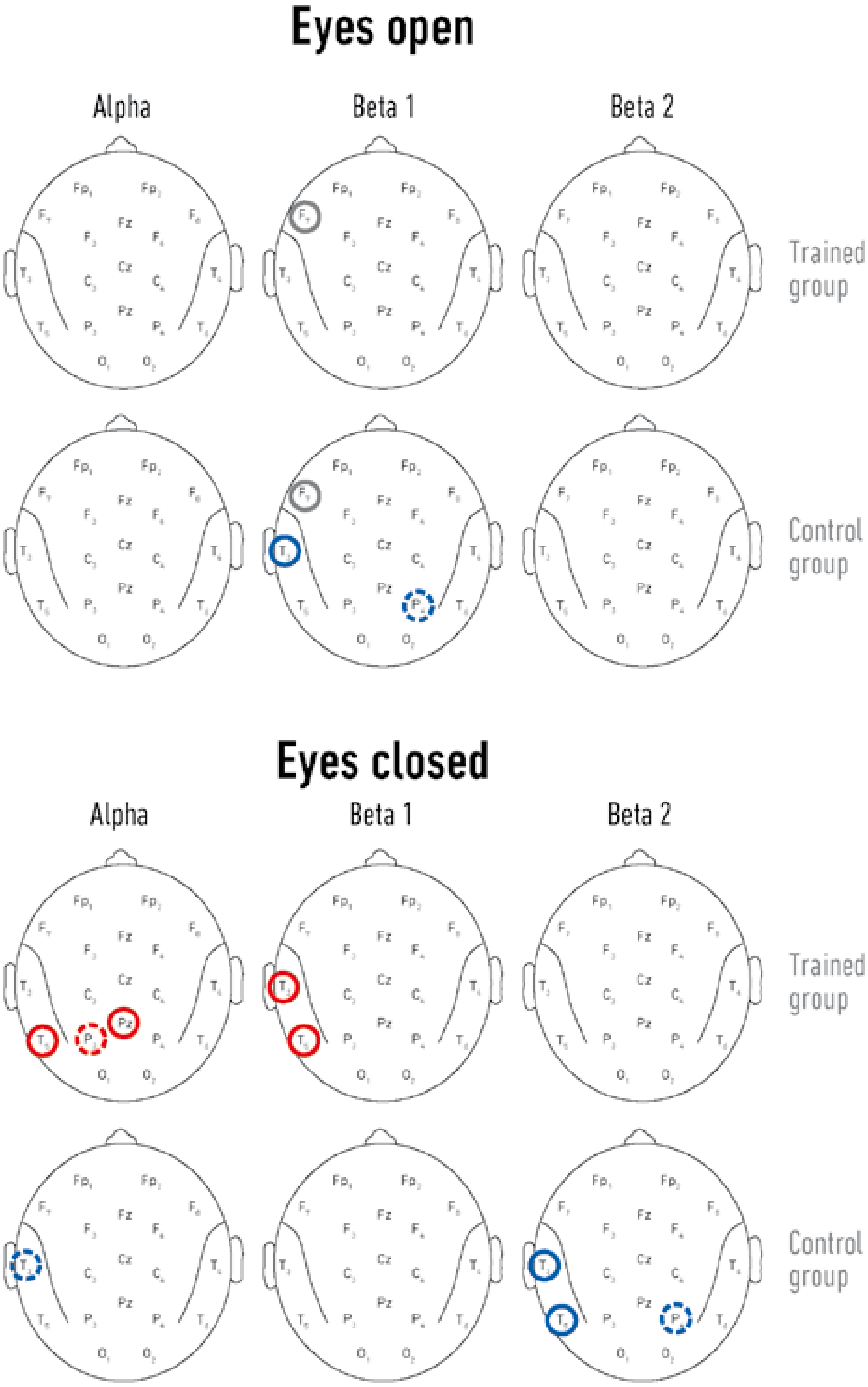

Fig. 3. Single channel analysis for six frequency bands. The channels are marked with the circles if the interaction effect of group and training was significant within the particular electrode (significance for individual electrodes was assessed only if there was the effect of interaction found in the mean from all electrodes, i.e. in beta1 for eyes-open and alpha, beta1 and beta2 bands for eyes closed. Red circles – significant increases after NFB training; blue circles – significant decreases, as revealed by post-hoc comparisons; grey circles – no significant differences in *post hoc* analysis. Solid lines represent significant results of paired t-test ($P<0.05$), dashed lines results on the trend level ($P<0.1$).

data from all channels i.e. eyes-open: beta1 and eyes-closed: alpha, beta1 and beta2 bands (Fig. 3). In eyes open condition significant or nearly significant decreases in beta1 band were present in T3, P4 in the control group, F7 showed significant interaction effect but no pairwise comparisons were significant. In eyes closed significant or nearly significant decreases were present in T3 (alpha) and P4, T3, T5 (beta2) in the control group and increases were present in Pz, P3, T5 (alpha) and T3, T5 (beta1) in the trained group.

Behavioural results

In parallel with changes of brain activity at rest the combined EEG-neurofeedback and relaxation training procedure resulted in measurable behavioral effects. We found that the athletes completing the training had shorter reaction times in test of visual attention (Fig. 4) than those from the control group (m=1.21, sd=0.13 *vs.* m=1.23, sd=0.17 before training and m=0.91, sd=0.26 *vs.* m=1.11, sd=0.29 after training). Both experimental and control groups improved their performance ($F_{1,31}$=36.11, P<0.001, eta2=0.25), but the improvement was larger for the trained group, as revealed by interaction effect at the trend level, $F_{1,31}$=4.13, P=0.051, eta2=0.03. The same analysis restricted only to the participants included in EGG analysis confirmed general improvement of performance ($F_{1,22}$=18.55, P<0.001, eta2=0.17), although interaction effect did not reach significance ($F_{1,22}$=1.82, P=0.19, eta2=0.02 probably due to reduced statistical power. Improvement in the reaction times in this subsample of the trained group (before training, m=1.12, sd=0.13 and after training, m=0.97, sd=0.25).

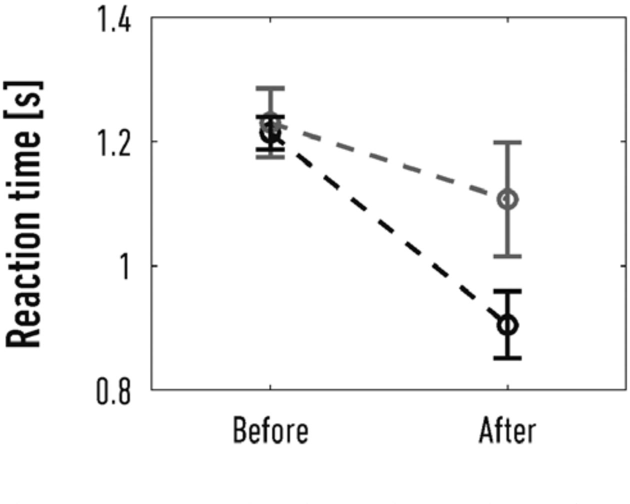

Fig. 4. Mean reaction times in attention-reaction test before and after NFB training for experimental (black, n=23) and control (grey, n=10) groups. Error bars represent standard error of the mean.

The presented series of 20 sessions of EEG-neurofeedback training accompanied by relaxations also modified the work curve, which illustrates a total number of addition operations in 20 consecutive 3-minute time periods of performing the Kraepelin test (Kraepelin 1922, Arnold 1975 p. 35). Significant changes were observed during the first half hour of the test and after its first 45 minutes (Fig. 5). Most of the mean indices that describe partial measures of the work curve also changed significantly (P<0.05) after the trainings. The measures are presented in Table I and Fig. 6 and their interpretation based on Kraepelin's (after: Arnold 1975 p. 36) and others (Takigasaki 2006, Kashiwagi et al. 2007, see: Methods) studies are presented below.

We found a significant increase in two out of three "performance measures" (1–2) which indicate an improved working rate and better skills in adding. Notably, all parameters used as measures of energy and persistence (4–6) were also changed significantly: the work curve became less steep, which might result from the initial high performance and fatigue with the high rate of work in the first half hour of the test. Both parameters of the measures of adaptation and exercise without self-restraint (7–8) were reduced significantly. This might mean longer working rates (Kraepelin 1922, Arnold 1975 p. 85). The index of oscillation around the work curve (9 – indicator of level of emotional distress during the test; Kraepelin 1922, Arnold 1975 p. 87) was not changed. Another significant observation was an increase in the percentage of corrections (11) that occurs with a reduction in the percentage of mistakes (10, non-significant). With respect to the additional measures, a reduction in the duration of the initial decline (13) occurred, which has been explained as an experience and better adaptation to the new situation.

DISCUSSION

The resting state recordings are routinely used to prove the changes of EEG control patterns (Marx et al. 2004, Barry et al. 2007). The present study demonstrated that intervention consisting of 20-week long EEG-NFB training paired with daily audio-visual relaxation sessions was related to changes in electrical brain activity in alpha and beta1 frequency bands, as measured in spontaneous, baseline activity, outside the context of the trainings.

Interestingly, the effects differed when assessed in participants staying in rest with eyes-open and eyes-closed. When EEG spectrum was checked in eyes-open condition, we found significant decrease only in beta1 band from first to the second measurement in the control group. On the contrary, in the trained group amplitudes of analyzed bands did not change from the first to the second measurement. It should be noticed here, that eyes-open measurement resembled NFB training situation, where major part of feedback was given visually. Therefore, one possible explanation of observed results is that participants attending trainings learned to focus with eyes-open which might attenuated spontaneous decrease of beta1 band activity between first and second measurement.

Eyes-closed measurement was, on the other hand, closer to audio-visual relaxation training context. When tested with eyes-closed, subjects from the trained group had significantly increased amplitudes of alpha and beta1 bands. Increase in alpha band was stimulated by the relaxation training which, as has been shown by Mikicin and Kowalczyk (2015), itself is capable of increasing the amount of alpha oscillations in eyes-closed spontaneous activity. Increase in beta1 constituted one of the aims of EEG-NFB training protocol. Interestingly we did not find significant effects of the training on SMR band power, even though it was included in the training protocol (up-regulation) and is positioned between alpha and beta1 frequency bands, which were successfully changed.

In our previous work (Mikicin and Kowalczyk 2015), we also observed that the relaxation training led to reduction of alpha amplitude in active state when participants were engaged in attentional task. This was not directly comparable to our eyes-open condition, as one required attentive engagement and the other did not, but both effects seemed to act in similar direction: alpha power remained constant in eyes-open condition of current experiment or felt down in attentive task of previous work (Mikicin and Kowalczyk 2015). These observations might suggest that alpha oscillatory activity is more susceptible for context depending regulation after the alpha-relaxation training. This might also explain the analogous conduct of alpha and beta1 bands – the former was influenced primarily by alpha-relaxation training, the latter by NFB. We can-

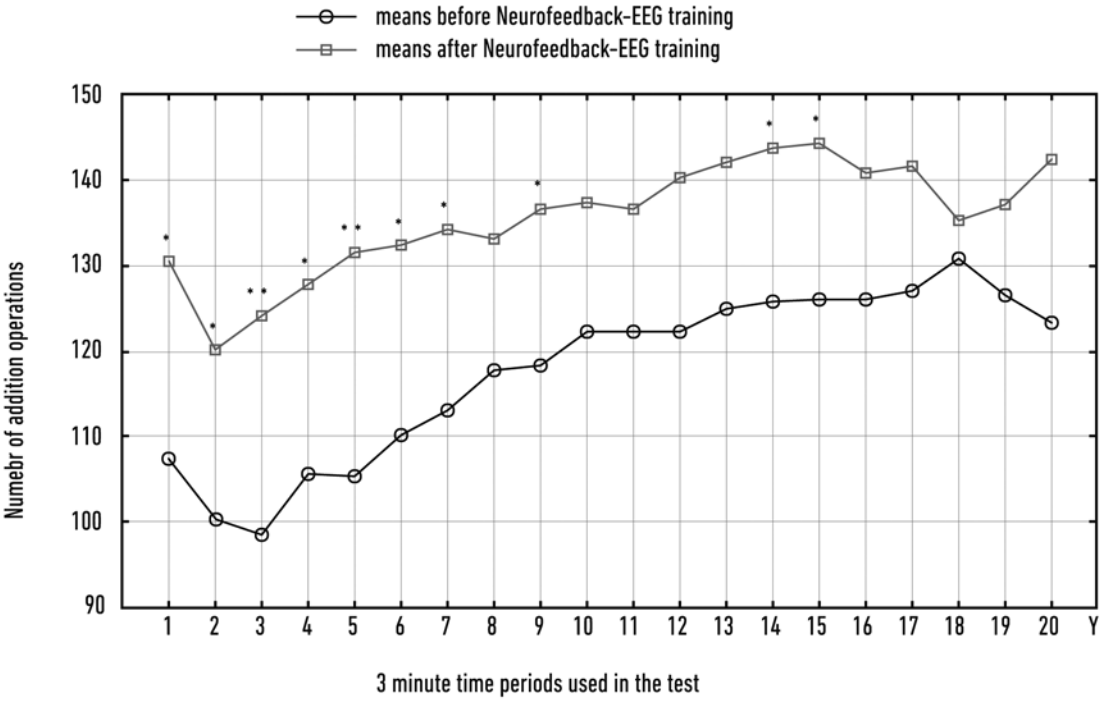

Fig. 5. Mean work curve (number of addition operations in consecutive time periods from 1st to 20th) before and after EEG-neurofeedback training; * denotes the significance level set at $P<0.05$ and ** means the significance level set at $P<0.01$. Results were obtained for the trained group, n=25.

not exclude, however, that the observed modulation of beta1 power was influenced by increased activity of alpha band and the beta 1 changes were unspecific – resulting from alpha training. The individual impact of both of these trainings, and especially – NFB training remains to be investigated in the future studies.

The changes in EEG activity were accompanied by changes in behavioural indices: reduction in reaction latency in attention-reaction test (when compared to the control group) and changes in the measures of the work curve (Kraepelin 1922, Arnold 1975 p. 36), that point to the increased rate and effectiveness of mental performance (i.e. addition of digits). As we proved in the previous work (Mikicin and Kowalczyk 2015), the repeated use of Kraepelin's test did not produce any changes in any of its indices in the control group, and therefore the differences observed in the trained group of the current experiment may be interpreted as effects of the training.

The EEG-neurofeedback training has been found before to be correlated with improved visual and auditory attention (Vernon et al. 2003). Our results are also in line with NFB experiments which showed improvement in concentration of attention (Leff 2008) and work performance (Arnold 1975). Increased power of the SMR and beta1 bands was reported to accompany improved visual attention in the experiment that evaluated perception sensitivity after EEG-NFB training (Egner and Gruzelier 2004). In our previous experiment on visual attention (Kamiński et al. 2012), we have also observed a negative correlation between the power of beta activity and reaction times. Faster performance of the attention-reaction test in the current experiment might therefore be related to simultaneous increase of beta1 band power. In line with this hypothesis, analysis conducted on single channels showed that changes observed in this study were most prominent in the leads located above parietal and temporal regions of the brain, commonly associated with processing attentive sensory information.

In the Kraepelin's test we observed significant changes in the measures of fast adaptation and exercise without self-restraint (convexity indices) and the measure of variability/consistency (oscillation index). According to Kraepelin the high convexity index in the work curve obtained for athletes studied in our experiment before EEG-neurofeedback training might be interpreted as the tendency for starting work very fast but also to quick

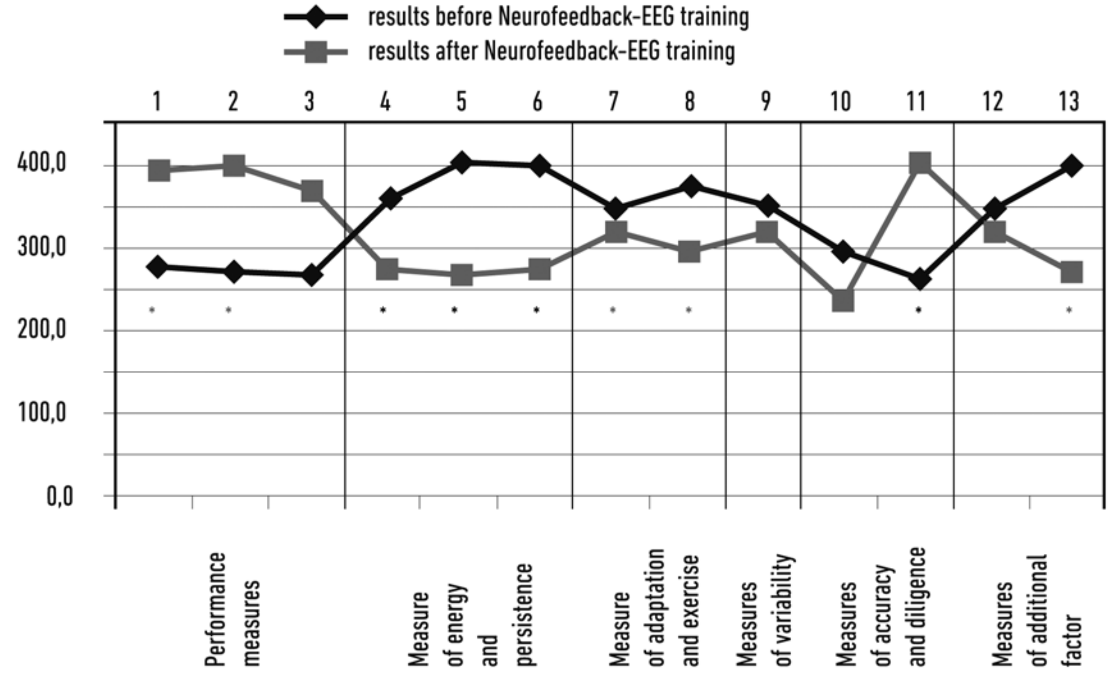

Fig. 6. Indices of the work curve before and after 20 sessions of EEG-neurofeedback training. Numbers from 1 to 13 present consecutive values of measures of the work curve, presented and described in Table I; * denotes significance set at $P<0.05$. Results were obtained for the trained group, n=25.

tiredness, impulsiveness and low accuracy in action. The results obtained by the athletes after training were characterized by lower measures of convexity for the work curve and lower level of variability (oscillation index), which can be interpreted as an increase in ability to maintain the rate of the performed activities longer and to adapt to work monotony easier.

The Kraepelin test was relatively popular in practice in the 20th century (Arnold 1975 p. 89). The scientific data from the seventies confirmed its usefulness in both vocational counseling and clinical and psychological diagnostics, even for military purposes and judicial medicine (Arnold 1975 p. 89–111). However, the test has been criticized more recently due to the fatigue observed in the subjects during its performance (Brandstätter 1995, Sugimoto et al. 2009, Steinborn et al. 2009), and the frequency of its use declined dramatically. Our study demonstrated that, with regard to healthy and motivated young people, analysis of the test based on the criteria suggested by its creators allows for achievement of the convincing conclusions.

In general, the positive results of our experiment indicated that EEG-neurofeedback combined with relaxation training might be considered as a subsidiary training for improving psychological abilities and general performance in athletes (compare with Morris 1997).

CONCLUSIONS

The visual EEG-neurofeedback training and audio-visual alpha relaxation training constitute a holistic assistance in the athletic training. It produces changes manifested in functionally different, eyes-open and eyes-closed states of the brain. The modulations observed in alpha, beta1 and beta2 bands were complemented by shortening of reaction time in attention task, and changes in the work profile measures.

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REFERENCES

Arnold W (1975) Der Pauli-Test. Anweisung zur sachgemassen Durchfurung, Auswertung und Anwendung des Kraepelinschen Arbaitsversuches (5th ed.). Springer-Verlag, Berlin, Germany. p. 1–184.

Barry RJ, Clarke AR, Johnstone SJ, Magee ChA, Rushby JA (2007) EEG differences between eyes-closed and eyes-open resting conditions. Clin Neurophysiol 118: 2765–2773

Bazanova OM, Mernaya EM, Shtark MB (2009) Biofeedback in Psychomotor Training. Neurosci Behav Physiol 39: 437–448.

Beauchamp MK, Harvey RH, Beauchamp P (2012) An integrative biofeedback and psychological skills training program for Canada's Olympic short-track speedskating team. J Clin Sport Psychol 6: 67–84.

Behncke L (2004) Mental skills training for sports: a brief review. Int J Sport Psychol 6: 1–19.

Bradley RT, McCraty R, Atkinson M, Tomasino D, Daugherty A, Arguelles L (2010) Emotion self-regulation, psychophysiological coherence, and test anxiety: results from an experiment using electrophysiological measures. Appl Psychophysiol Biofeedback 35: 261–283.

Brandstätter H (1995) Die Arbeitskurve nach Kraepelin-Pauli – doch ein Willenstest. Zeitschrift für Arbeits- und Organisationspsychologie 39: 54–66.

Cherapkina L (2012) The neurofeedback successfulness of sportsmen. JHSE 7: 116–127.

Davis M, McKay M, Eshelman ER (2000) The relaxation & stress reduction workbook. New Harbinger Press, Oakland, CA. p. 91–100.

Egner T, Gruzelier JH (2001) Learned self-regulation of EEG frequency components affects attention and event-related brain potentials in humans. Neuroreport 12: 4155–4159.

Egner T, Gruzelier JH (2003) Ecological validity of neurofeedback: Modulation of slow wave EEG enhances musical performance. Neuroreport 14: 1221–1224.

Egner T, Gruzelier JH (2004) EEG Biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potentials. Clin Neurophysiol 115: 131–139.

Gruzelier JH, Egner T, Vernon D (2006) Validating the efficacy of neurofeedback for optimising performance. Prog Brain Res 159: 421–431.

Gruzelier JH (2013) EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants. Neurosci Biobehav Rev 44: 124–41, doi:10.1016/j.neubiorev.2013.09.015.

Hammond DC (2005) Neurofeedback to improve physical balance, incontinence, and swallowing. J Neurother 9: 27–36.

Hashim HA (2011) The Effects of Progressive Muscle Relaxation and Autogenic Relaxation on Young Soccer Players' Mood States. Asian J Sports Med 2: 99–105.

Hoedlmoser K, Pecherstorfer T, Gruber G, Anderer P, Doppelmayr M, Klimesch W, Schabus M (2008) Instrumental conditioning of human sensorimotor rhythm (12–15 Hz) and its impact on sleep as well as declarative learning. Sleep 31(10): 1401–1408.

Kamiński J, Brzezicka A, Gola M, Wróbel A (2012) Beta band oscillations engagement in human alertness process. Int J Psychophysiol 85: 125–128.

Kashiwagi S, Tanaka Y, Tsubokura K, Okuyama K, Shinrigaku K (2007) Evaluation of the Uchida-kraepelin psycho-diagnostic test based on addition work from the view of the Big Five (in Japan). Shinrigaku Kenkyu 78: 125–132.

Kerick SE, Douglass LW, Hatfield BD (2004) Cerebral cortical adaptations associated with visuomotor practice. Med Sci Sports Exerc 1: 118–129.

Klimesch W, Sauseng P, Hanslmayr S (2007) EEG alpha oscillations: The inhibition-timing hypothesis. Brain Res Rev 53: 63–88.

Kraepelin E (1922) Gedanken uber die Arbeitskurve. Psychologische Arbeiten 7: 535–547.

Landers DM, Han M, Salazar W, Petruzzello SJ, Kubitz KA, Gannon TL (1994) Effect of learning on electroencephalographic and electrocardiographic patterns in novice archers. Int J Sport Psychol 22: 56–71.

Larsen CR, Soerensen JL, Grantcharov TP, Dalsgaard T, Schouenborg L, Ottosen C, Schroeder TV, Ottesen BS (2009) Effect of virtual reality training on laparoscopic surgery: randomised controlled trial. BMJ 14: 1802.

Leff D, Aggarwal R, Rana M, Nakhjavani B, Purkayastha S, Khullar V, Darzi AW (2008) Laparoscopic skills suffer on the first shift of sequential night shifts: program directors beware and residents prepare. Ann Surg 247: 530–539.

Marshall M, Bentler PM (1976) The effects of deep physical relaxation and low-frequency-alpha brainwaves on alpha subjective reports. Psychophysiology 13: 505–516.

Marx E, Deutschländer A, Stephan T, Dieterich M, Wiesmann M, Brandta T (2004) Eyes open and eyes closed as rest conditions: impact on brain activation patterns. Neuroimage 21: 1818–1824.

Mikicin M, Kowalczyk M (2015) Audio-visual and autogenic relaxation alter amplitude of alpha EEG band, causing improvements in work performance in athletes. Appl Psychophysiol Biofeedback 40: 219–227, doi: 10.1007/s10484-015-9290-0.

Morris T (1997) Psychological skills training in sport: an overview. National Coaching Foundation, Leeds, UK.

Raymond J, Sajid I, Parkinson LA, Gruzelier JH (2005a) Biofeedback and dance performance: a preliminary investigation. Appl Psychophysiol Biofeedback 30: 65–73.

Raymond J, Varneya C, Parkinson LA, Gruzelier JH (2005b) The effects of alpha/theta neurofeedback on personality and mood. Brain Res Cogn Brain Res 23: 287–292.

Rogala J, Jurewicz K, Paluch K, Kublik E, Wróbel A (2014) The grounds for successful neurofeedback. Acta Neurobiol Exp (Wars) 74(3): 334, A15.

Shaw L, Zaichkowsky L, Wilson V (2012) Setting the balance Using biofeedback and neurofeedback with gymnasts. J Clin Sport Psychol 6: 47–66.

Steinborn MB, Flehmig HC, Westhoff K, Langner R (2009) Differential effects of prolonged work on performance measures in self-paced speed tests. Adv Cogn Psychol 5: 105–113.

Strizhkova T, Cherapkina L, Strizhkova O (2012) Neurofeedback course applying of high skilled gymnastics in competitive period. JHSE 7: 185–193.

Sugimoto K, Kanai A, Shoji N (2009) The effectiveness of the Uchida-Kraepelin test for psychological stress: an analysis of plasma and salivary stress substances. Biopsychosoc Med 3: 5–15.

Takigasaki T (2006) The work curves of Uchida-Kraepelin test in the time of mountaineering. In: Report of researches. Nippon Institute of Technology 35: 425–430.

Teplan M, Krakovska A, Stolc S (2006) EEG responses to long-term audio-visual stimulation. Int J Psychophysiol 59: 81–90.

Van Herzeele I, Aggarwal R, Neequaye S, Darzi A, Vermassen F, Cheshire NJ (2008) Cognitive training improves clinically relevant outcomes during simulated endovascular procedures. J Vasc Surg 48: 1223–1230.

Vernon DJ, Egner T, Cooper N, Compton T, Neilands C, Sheri A (2003) The effect of training distinct neurofeedback protocols on aspects of cognitive performance. Int J Psychophysiol 47: 75–85.

Vernon DJ (2005) Can neurofeedback training enhance performance? An evaluation of the evidence wit research h implications for future. Appl Psychophysiol Biofeedback 30: 347–364.

Wróbel A, Ghazaryan A, Bekisz M, Bogdan W, Kamiński J (2007) Two streams of attention dependent beta activity in the striate recipient zone of cat's lateral posterior – pulvinar complex. J Neurosci 27: 2230–2240.

Wróbel A (2014) Attentional activation in corticothalamic loops of the visual system. In: The New Visual Neurosciences (Werner JS, Chalupa LM, Eds). The MIT Press, Cambridge Mass, London, UK. p. 339–349.