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SIMULTANEOUS EEG AND EMG BIOFEEDBACK FOR PEAK PERFORMANCE IN MUSICIANS

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A b s t r a c t: The aim of this study was to determine the effects of alpha neurofeedback and EMG biofeedback protocols for improvement of musical performance in violinists.

The sample consisted of 12 music students (10 violinists and 2 viola players) from the Faculty of Music, Skopje (3 males, mean age of 20 ± 0 and 9 females, mean age = 20.89 ± 2.98). Six of them had a low alpha peak frequency (APF) (< 10 Hz), and six a high APF (> 10 Hz). The sample was randomized in two groups. The students from the experimental group participated in 20 sessions of biofeedback (alpha/EMG), combined with music practice, while the students from the control group did only music practice. Average absolute power, interhemispheric coherence in the alpha band, alpha peak frequency (APF), individual alpha band width (IABW), amount of alpha suppression (AAS) and surface forehead integrated EMG power (IEMG), as well as a score on musical performance and inventories measuring anxiety, were assessed.

Alpha-EEG/EMG-biofeedback was associated with a significant increase in average alpha power, APF and IABW in all the participants and with decreases in IEMG only in high-APF musicians. The biofeedback training success was positively correlated with the alpha power, IcoH, APF, IABW and baseline level of APF and IABW.

Alpha-EEG/EMG biofeedback is capable of increasing voluntary self-regulation and the quality of musical performance. The efficiency of biofeedback training depends on the baseline EEG alpha activity status, in particular the APF.

Key words: musical performance, EEG, EMG, biofeedback**,** alpha peak frequency, individual alpha band width.

Introduction

It is a well-known fact that musical performance skills rely on cognitive processes of awareness and optimal muscle activation, without increasing the tension of muscles which do not participate in the execution (Bernstein, 1967). It can therefore be assumed that an increased sensomotor coupling is particularly important for the quality of musical performance, which becomes more precise and automatic, and one gains dexterity as well as flexibility in adapting to changes and task demands (Lotze, Scheler, Tan, Braun & Birbaumer, 2003). Also, it has been shown by a number of investigations that during musical performance highly-skilled professional musicians have an increased alpha activity and a decreased EMG activity in comparison with non-musicians and non-skilled music students, who have a decreased alpha power and an increased EMG during performance (Petsche & Etlinger, 1998; Hassler, 2000; Bazanova *et al*., 2003; Bazanova and Kondratenko, 2005).

In extended investigations carried out at Imperial College devoted to the application of theta/alpha neurofeedback in musicians in comparison with usual psycho-relaxing techniques, such as the Alexander technique, musical improvements in overall quality, musical understanding, stylistic accuracy and interpretive imagination were demonstrated (Egner & Gruzelier, 2003). Such an effect was not evident in the case of Alexandar technique trainees. Other researchers have used EMG biofeedback for reducing tension of the left arm extensor in string instrument players. Namely, there is evidence that applying biofeedback techniques which use EMG signal, improves musical execution. (Hale, 1993, 1994; Zinn & Zinn, 2003). In our case we decided to combine both: EEG and EMG biofeedback approaches.

Some investigations have shown that highly-skilled professional musicians have an increased EEG alpha activity, a parameter which is associated with enhanced cognitive processing capacity (Klimesch, Doppelmayer, Pachinger & Ripper, 1997; Klimesch *et al.,* 1999; Bazanova & Aftanas, 2005). Since the upper alpha band is correlated to the process of encoding and processing of semantic information, it is reasonable to believe that training the upper alpha can help improve accuracy of execution during psychomotor performance. Hanselmayr *et al*., 2005, observed an increase in cognitive performance only for the neurofeedback trainees who trained upper alpha, as compared to upper alpha non-responders, theta responders and theta non-responders (Hanslmayr, Sauseng, Dopplmayer, Schabus & Klimesch, 2005).

Moreover it was shown that neurofeedback training applied in order to increase or decrease the power of individual EEG frequency ranges is more efficient than neurofeedback training of standard EEG frequency ranges (Bazanova & Aftanas, 2005; Hanslmayr, *et al*., 2005).

The main objective of the present investigation was to compare responses of musicians with high and low alpha peak frequency to usual practice and practice combined with long-term simultaneous alpha-increasing and EMG-decreasing biofeedback training, while the second aim was to investigate the impact of alpha-EEG/EMG biofeedback on electrophysiological and psychometric parameters in musicians.

Methods

Participants

The sample consisted of 12 music students from Faculty of Music, Skopje (3 males with a mean age of 20 ± 0 and 9 females, mean age 20.89 ± 2.98). All the participants were right-handed. No participant had a history of physical or mental health problems, or any prior experience or knowledge of biofeedback training. Participants were briefed before the study and gave their full written consent. Randomly, we divided all the participants into an experimental and a control group, each one containing an equal number of participants with low (below or equal to 10 Hz) APF and high (above 10 Hz) APF.

Procedure

At the beginning and at the end of the experiment all the participants performed one musical piece of their own choice of approximately 5 minutes duration. The concert performance was video taped. The musical performance of the participants was assessed by four independent musical experts (who were double blind to student group membership and date of performance) for "technique", "rhythm", "musicality", "intonation", "quality of sound" and "creativity", on a scale of one to ten. The scales were adopted from a standard set of music performance evaluation criteria (Kraus, 1982/1983). The ratings by the musical experts were averaged for each musician across all criteria.

Spielberger State and Trait Anxiety Inventory (Spielberger, Gorusuch & Lushene, 1983) and Rheinberg Self-actualization Inventory (Rheinberg, Vollmeyer & Engeser, 2003) were applied prior to the performance to asses the psychometrical characteristics of the participants. Then EEG-EMG status monitoring was provided using WinEEG equipment and software for every participant at the first and last sessions, during a baseline period of closed-eyes and open-eyes conditions, before and after practice and biofeedback, and during practising and biofeedback. EEG from baseline conditions was recorded every session prior to and after biofeedback.

After that, the experimental group did the alpha-EEG/EMG biofeedback plus practice during 20 sessions (a two months' period), while the control group did only usual practice over the same period. All of them were told that their task was to improve their quality of sound with self-control of execution and emotions. In other words, it was suggested to the participants that the aim of the training was "to attain a state at which achieving a high quality musical performance would be complimented with a feeling of easiness and comfort".

Equipment and measurements

EEG recording

EEG was recorded from 8 sites (F3, F4, C3, C4, P3, P4, O1 and O2) of the 10/20 system, using the monopolar electrode placement method with the Mitsar EEG System (St. Petersburg, Russia). Referencing was to physically linked ears. The skin was prepared by abrasion with NuPrep gel. The impedance was kept below 5 KΩ across all recording sites. The EEG was amplified (0.3 to 30Hz), sampled at 256 Hz rate and stored for off-line analyses. All EEG data were visually inspected and all epochs with artifacts due to muscle movements (eye movements, head movements) and muscle tension artifacts were removed from further analysis.

Recordings of three minutes of closed-eyes and three minutes of open-eyes EEG were used to assess the individual alpha band width (IABW), APF and the amount of alpha suppression (AAS). Alpha peak frequency (APF) was defined as the dominant frequency rhythm in the resting state, the frequency band that dominates the spectral density distribution (Angelakis E. 2002, 2004; Clark R.C. 2004). Alpha Peak frequency-APF was defined from the spectrogram in the eyes-closed condition, while EEG-reactivity indices, IABW – Individual Alpha Band Width and AAS – Alpha Amount Suppression could be determined only when comparing spectrograms in eyes-open and eyes-closed conditions. The individual Alpha Band Width (IABW) was defined as follows: we compared the EEG power values in the range 6–16 Hz from posterior EEG sites (P3, P4, O1 and O2) in the closed- and open-eyes conditions. Those frequency bands with power depressed more than 20% during the open-eyes vs. closed-eyes conditions were used as cut-off criteria for low and upper band limits. The amount of Alpha Suppression (AAS) in response to open eyes is indexed as EEG suppression amplitude (%) as compared to the eyes-close condition in the frequency interval of 1 Hz in the alpha peak range from posterior EEG sites.

Alpha subbands were adjusted individually according to APF and IABW. Alpha-1 frequency band was restrained between the low boundary of IABW to APF. Alpha-2 range started from APF and finished at the upper boundary of IABW (Fig. 1). For example, if a participant had an APF of 10 Hz and IABW from 8 till 13 Hz, the alpha-1 band was defined between 8 to 10 Hz, whereas alpha-2 was defined as the range between 10 and 13 Hz. Spectral power and inter- and intra-hemispheric coherence (ICoh and IntraCoh) were calculated on individual alpha band.

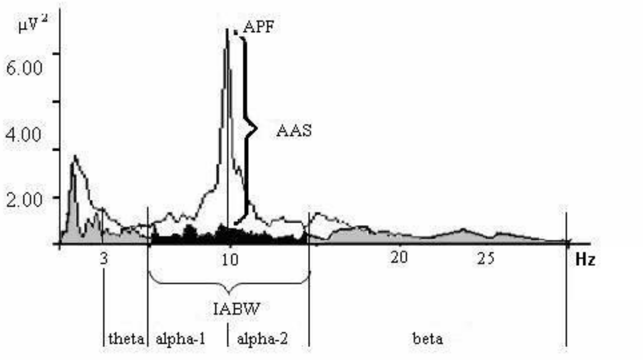

Figure 1 – Spectral EEG power in the parietal-occipital region of the head in close eyes (white) and open eyes condition (grey). The spectral power in the band of 6–16 Hz, which decreased by more than 20% after opening the eyes, compared to closed-eyes condition, gives the IABW (black). X-axis – Spectral power (μV²). Y-axis – frequency (Hz). Labels: APF – Alpha Peak Frequency; IABW – Individual Alpha Band Width; AAS – Amount of Alpha Suppression

Слика 1 – Спектрална ЕЕГ моќност во париетo-окципиталната регија на главата при очи затворени (бела боја) и очи отворени (сива боја). Спектралната моќност на опсегот од 6–16 Hz, кој се намалува за повеќе од 20% по отворање на очите, во споредба со состојбата при затворени очи, ја дава IABW (црна боја). X-оска – спектрална моќност (μV²). Y-оска – фреквенција (Hz). Кратенки: APF – алфа пик фреквенција; IABW – широчина на индивидуалниот алфа опсег; AAS – количина на алфа супресија

EMG recording

EMG was recorded by two 1.6-cm Ag/AgCl surface bipolar electrodes fixed about 3–5 cm apart and placed on the forehead. The EMG signals were acquired with a 125-Hz sampling rate, amplified and filtered with 10 Hz low pass and 350 Hz high pass filters, transformed into a gauge line and a sound signal which was sent to a PC for data visualization and storage using BOSLAB. We applied the usual approach to average the integrated EMG power (IEMG) in the signal over 100 ms (Merletti, 1999). The IEMG was therefore the area under a voltage curve, measured in microvolts.

Alpha – EEG/EMG Biofeedback

The multi-channel interface BOSLAB (Jafarova & Shtark, 1995) was used as a biofeedback unit with a standard interface for measurement of the electrophysiological parameters (IEMG and EEG) in real time, computer data acquisition and processing. Sessions of alpha-EEG/EMG biofeedback per participant were carried out with bipolar EEG electrodes placed at F3 – O1 and F4 – O2 and bipolar EMG electrodes placed at the forehead. Feedback began after initial APF and IABW assessment and took the form of "applause" sounds presented to participants. Individual alpha-2 band and IEMG had a power threshold, and simultaneous supra-threshold bursts of alpha and sub-threshold bursts of IEMG were rewarded by an "applause" sound effect. These thresholds were set manually by the experimenter and updated so that alpha power was over and IEMG power was below these thresholds for approximately 60% of the time. During the session, participants were practising in their usual style. Before the alpha-EEG/EMG biofeedback session, participants had the underlying principles of biofeedback explained to them and were instructed to practise as comfortably as possible by controlling sound quality in order to increase their upper alpha and to decrease forehead IEMG. They were told that, when they heard the "applause" sound effect, they should visualize themselves performing music in the way they most wanted to perform. The biofeedback session was carried out in an eyes-closed condition. "Successful training periods" (Fig. 2) were defined as periods during an alpha-EEG/EMG biofeedback session when the alpha-2 rhythm power increase was accompanied by a simultaneous decrease in the IEMG power. The efficiency of a biofeedback session was calculated as the ratio of the sum-duration of the successful periods during the alpha-EEG/EMG biofeedback session compared to the whole length of the session (Egner & Gruzelier, 2003).

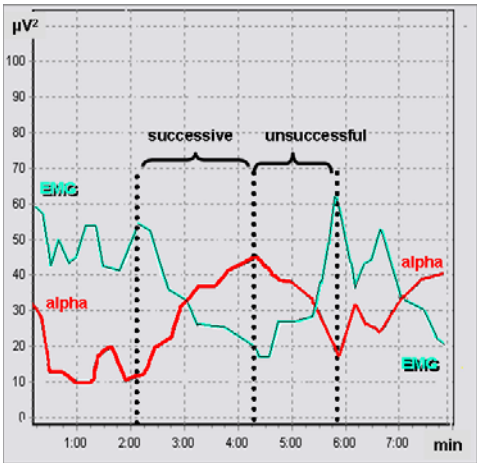

Figure 2 – "Session efficiency", also called learning coefficient. was calculated as the number of successful periods when alpha went up and EMG down for the whole length of sessions

Слика 2 – „Ефикасноста на сесијата“ или т.н. коефициент на учење, се пресметува како број на успешни периоди кога алфа оди нагоре, а EMG-то надолу во текот на целата сесија

Results

We analysed the EEG spectrum starting from 3Hz to 30Hz, in a hertz by hertz manner. Alpha Peak Frequency, Individual Alpha Band Width and Amount Alpha Suppression were used as parameters of alpha activity in our investigation. Correlation analysis was performed by using Pearson's correlation coefficient. T-test for dependant samples was also used.

At the beginning of the experiment in all participants, scores for all expert estimating criteria, except for musicality and intonation, were higher in the high APF group (t-test = 2.91 ± 0.96, $p < 0.03$) (Table 1).

Table 1 – Табела 1

Scores for expert estimation criteria in groups with low and high APF at the beginning of the experiment
Оценки дадени од експерти за квалитетот на изведбата кај групите со ниска и висока APF на почетокот од експериментот

	Technique	Intonation	Rhythm	Musicality	Sound quality	Creativity
Low APF	3.8	3.9	3.1	4.3	4.05	3.7
High APF	5	4	4.99	4.4	5.1	6.2

Participants with low Alpha Peak Frequency were more anxious and had less ability to self-actualise (self-control), t-test = 5.5 ± 9.80, $p < 0.002$ (Table 2).

Table 2 – Табела 2

Scores from Spielberger and Rheinberg tests for assessing state/trait anxiety and self-actualization
Резултати од Спилбергер-овиот и Рајнбергер-овиот тест за проценка на моменталната/постојаната анксиозност и само актуализација.

	State anxiety	Trait anxiety	Selfactualization
Low APF	50	42	30
High APF	45	40	50

For all EEG indices there was no statistically significant difference in either group, except for coherence ($t = 4.34$; $p = 0.045$, $t = 4.69$; $p = 0.048$) and Int EMG ($t = 5.42$, $p < 0.001$) (Table 3).

Table 3 – Табела 3

Difference between low and high APF groups in baseline conditions.
Разлики йомеѓу груйиийе со ниска и висока APF (йочеийна основна сосйојба)

	Location	Low APF ≤ 10Hz	High APF > 10Hz	
IABW (Hz)	F3–C3	2.36 ± 0.62	2.28 ± 0.69	t = 0.99, n.s.
	F4–C4	2.13 ± 0.24	2.17 ± 0.43	t = 0.87, n.s.
	P3–O1	4.43 ± 0.83	3.57 ± 0.79	t = 0.95, n.s.
	P4–O2	5.13 ± 0.99	3.43 ± 0.73	t = 1.62, n.s.
Alpha (μV^2)	F3–C3	14.07 ± 2.21	12.85 ± 0.51	t = 2.65, n.s.
	F4–C4	15.23 ± 3.25	13.33 ± 1.45	t = 3.12, n.s.
	P3–O1	19.11 ± 4.81	16.77 ± 6.21	t = 3.53, n.s.
	P4–O2	21.23 ± 4.57	18.58 ± 7.55	t = 2.87, n.s.
Coherence in Alpha	F3–F4	0.68 ± 0.07	**0.78 ± 0.04**	t = 4.34; **p = 0.045**
	F3–C3	0.59 ± 0.17	**0.69 ± 0.07**	t = 4.69; **p = 0.048**
	F3–O1	0.17 ± 0.12	0.19 ± 0.16	T = 1.31, n.s.
IntEMG (μV2)		16.7 ± 4.13	**9.5 ± 1.45**	t = 5.42, **p < 0.001**

After two months the alpha indices for low APF participants belonging to the usual practice group decreased. After a single session of alpha-increasing and EMG-decreasing biofeedback, both groups increased the alpha indices, and decreased muscle tension. The response was more evident in the high APF group. While the condition in the control group did not improve, increasing of the alpha indices and reducing of muscle tension was evident after two months biofeedback in the experimental group (Fig. 3).

Practice combined with biofeedback caused significant increase in APF ($t = 4.58 \pm 0.46$, $p < 0.005$), IABW ($t = 5.99 \pm 1.35$, $p < 0.001$), AAS ($t = 2.92 \pm 18.17$, $p < 0.03$), power ($t = 4.05 \pm 10.53$, $p < 0.009$) and coherence ($t = 3.85 \pm 0.14$, $p < 0.01$) in the alpha band, and at the same time decreased IEMG ($t = 2.73 \pm 0.37$, $p < 0.04$).

The musical performance of the biofeedback group, according to the experts' scores, significantly increased in almost all criteria ($t = 2.64 \pm 2.16$, $p < 0.04$) in comparison with the control group, which did not improve.

Also, there were no changes in the anxiety level and self-actualization in the control group ($t = 1.63 \pm 7.02$, $p = 0.11$), while the experimental group showed lower anxiety and better self-actualization ($t = 4.00 \pm 9.83$, $p < 0.01$).

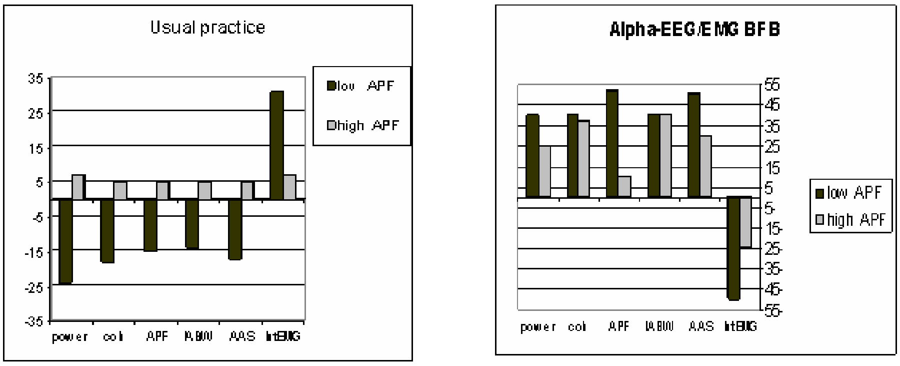

Figure 3 – EEG and EMG indices for control and experimental groups (percents)
Слика 3 – EEG и EMG карактеристики за контролната и експерименталната група (проценти)

Correlation analyses showed that APF positively correlates to technique but negatively to IEMG (the higher the IEMG – the worse the technique). On the other hand, Table 4 shows a positive correlation between creativity and IABW. The more the activation, the better the self-control. The sound quality is better when the IEMG is lower. Self actualization positively correlates AAS (the more suppression, the better self actualization).

Table 4 – Табела 4

Correlation s among APF, IABW, AAS, IEMG and technique, creativity. self-actualization, IEMG, sound quality, efficiency and musicality

Корелации помеѓу APF, IABW, AAS, IEMG и техниката, креативноста, само-актуализацијата, IEMG, квалитетот на звукот, ефикасноста и музикалноста

	APF	**IABW**	**AAS**	**IEMG**
Technique	r = 0.54; p < 0.002			r = -0.54; p < 0.000
Creativity		r = 0.55; p < 0.004		
Selfactualization			r = 0.43; p < 0.002	
IEMG	r = -0.53; p < 0.000			
Sound quality				r = -0.71; p < 0.008
EFC(%)			r = 0.58; p < 0.000	
Musicality		r = 0.49; p < 0.001		

Nothing happened to the level of efficiency (or success in biofeedback) in the control group (the result was the same at the first as at the last session), while low APF group participants from the biofeedback group showed an almost linear progression in increasing the learning coefficient, compared to the high APF group that showed a quite stable learning coefficient level (Fig. 4).

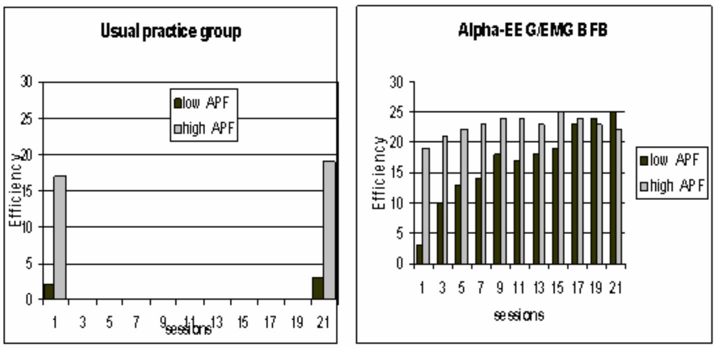

Figure 4 – Efficiency of the biofeedback training
Слика 4 – Ефикасност на биофидбек тренингот

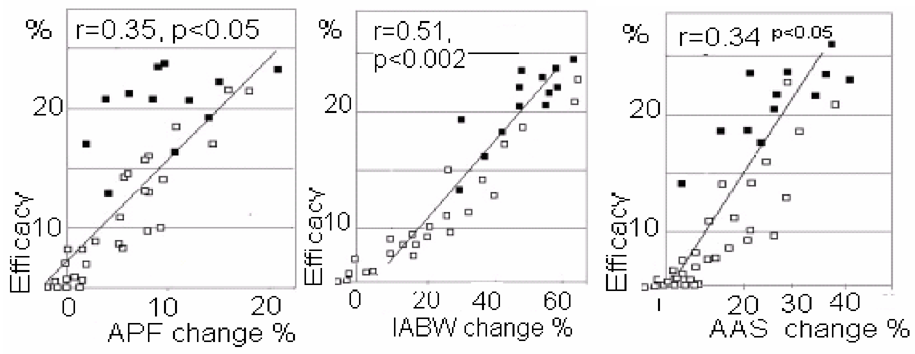

Figure 5 – Correlations between efficiency and APF, IABW and AAS
Слика 5 – Корелации помеѓу ефикасноста на биофидбек тренингот и APF, IABW и AAS

The efficiency showed a positive correlation to APF (r = 0.35, p < 0.05), IABW (r = 0.51, p < 0.002) and AAS change (r = 0.34. p < 0.05).

Discussion

In earlier studies only the EMG biofeedback was used for the purpose of the training of musicians (Hale, 1994; Segreto, 1995). After that, an alpha/theta – stimulating training was applied with the aim of relaxation and prevention of stage anxiety, as well as increasing of the creativity in musical execution (Egner & Gruzelier, 2003). Combining all the modalities, it was shown that alpha-EEG/EMG biofeedback training is effective in the alleviation of psychosomatic disturbances during musical execution (Базанова & Штарк, 2004).

In the present work we have also shown that 30-minutes-long alpha-EEG/EMG biofeedback training improves all the EEG and EMG parameters of optimum psychomotor functioning. It is important to note that the alpha-EEG/EMG biofeedback training was used during music performance, compared to the first two mentioned studies which used biofeedback training in resting (non-practice) conditions, thus neglecting the actual ("real-time") body position, as well as the actual movements, used in the musical execution. Besides this, the novelty of this approach lies in determining the specific alpha EEG spectral parameters and applying neurofeedback protocols for optimum psychomotor functioning based on the application of these parameters.

In particular, our results showed that efficiency in psychomotor musical-performing activity is related to the level of APF, taking into account the fact that the efficiency of alpha-EEG/EMG biofeedback training was higher in the participants with a high APF. However, the competition performance success was identical in both the participants with a high and a low APF after alpha-EEG/EMG biofeedback training. Thus, the musical training efficiency as well as the biofeedback efficiency depends not only on the APF, but also on the IABW and the AAS as additional alpha activity parameters.

Thus it is possible to assume that practice combined with the alpha-2 EEG-stimulation and EMG-decreasing biofeedback caused an enhancement in the alpha indices and attenuation in muscle tension in both the low and the high IAPF groups. The parameters of efficiency of the alpha-EEG/EMG biofeedback, as well as the individual alpha activity indices in baseline condition, can be used as prognostic criteria of psychomotor ability. It can be concluded that both low and high APF groups showed improvement in the individual alpha and EMG parameters after two months alpha-increasing and EMG-decreasing biofeedback training as compared to the experimental group who did only musical practice.

Nevertheless, additional longitude investigation of the alpha-EEG/EMG biofeedback impact for enhancement of musical skills, compared to the traditional methods of musical training, should be done in future.

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Резиме

СИМУЛТАН ЕЕГ И ЕМГ БИОФИДБЕК ЗА ВРВНО ПОСТИГНУВАЊЕ КАЈ МУЗИЧАРИТЕ

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Апстракт: Целта на овој труд е да се одредат ефектите од алфа неурофидбек и ЕМГ биофидбек протоколите за подобрување на музичките перформанси кај виолинистите.

Испитуваната група се состоеше од 12 студенти (10 виолинисти и 2 виола музичари) од Музичката академија во Скопје (3 машки, со средна возраст од 20 ± 0 години и 9 женски, со средна возраст од 20,89 ± 2,98 години). Шест од нив имаа ниска алфа пик фреквенција (APF) (< 10 Hz), и шест висока APF (> 10 Hz). Испитуваната група беше поделена во две подгрупи. Студентите од експерименталната група учествуваа во 20 биофидбек (alpha/EMG) сесии, комбинирани со музички вежби, додека студентите од контролната група правеа само музички вежби. При тоа беа проценувани следните параметри: средната апсолутна моќност на алфа, интерхемисферната кохеренца во алфа опсегот, алфа пик фреквенција (APF), индивидуалната широчина на алфа опсегот (IABW), количината на алфа супресијата (AAS) и површинското интегрирано ЕМГ од челото (IEMG), како и оценката за музичката изведба и тестови за проценка на анксиозноста.

Алфа-EEG/EMG-биофидбекот беше асоциран со значајно зголемување на средната алфа моќност, APF и IABW кај сите испитаници и со намалување на IEMG само кај музичарите со висока APF. Успехот на биофидбек тренингот беше позитивно корелиран со моќноста на алфа, IcoH, APF, IABW како и почетните вредности на APF и IABW.

Со алфа-EEG/EMG биофидбек можно е зголемување на саканата само-регулација и квалитетот на музичката изведба. Ефикасноста на биофидбек тренингот зависи од вредностите на основната алфа ЕЕГ активност, поточно од APF.

Клучни зборови: музички перформанси, ЕЕГ, ЕМГ, биофидбек, алфа пик фреквенција, индивидуална широчина на алфа опсегот.

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