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Effect of Audiovisual Stimulation on the Psychophysiological Functions in Track-and-Field Athletes

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Abstract—In 18- to 23-year-old athletes specialized in field-and-track athletics, the psychophysiological status (cognitive, psychoemotional, and neurodynamic indicators) and the spectral power of the main EEG rhythms, and the heart rate variability prior to and after the course of audiovisual stimulation (AVS) training (the experimental group) were studied as compared with athletes not receiving AVS (the control group). It has been shown that the AVS training sessions in the experimental group caused improvements to the psychoemotional (the levels of anxiety and neuroticism decreased, while the motivation to achieve success and the hardiness level increased), cognitive, and neurodynamic indicators (the volume of mechanical memory and the speeds of attention switching and simple visual-motor responses increased, while the variation of anticipatory and delayed responses to a moving object became reduced). Increases have also been recorded in the high-frequency EEG α_2-subrange rhythm power and the parasympathetic nervous system activity, while the autonomic regulation contour activity was enhanced, and more efficient heart activity at rest was formed after the AVS training course in the experimental group compared to the control. This leads to the conclusion about a positive effect of the AVS training course received by athletes engaged in track-and-field athletics on their psychophysiological parameters and autonomic regulation mechanisms.

Keywords: audiovisual stimulation, track-and-field athletes, cognitive and neurodynamic indicators, bioelectric activity of the brain, heart rate variability

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The goal of all athletes in training for competitions is to prolong their optimal psychophysiological condition. The systems functioning in the body of athletes endure significant strains by the end of competition seasons [1]; therefore, there is a variety of stimulation and rehabilitation methods to improve athletic performance, including the method of audiovisual stimulation (AVS) [2–5]. The rhythmic audiovisual stimulation is the exposure to the stimuli of different modalities (visual and auditory) at the frequencies of brain biorhythms, which makes it possible to influence the biological activity of the brain and the functional state of some systems of the body. AVS is known to affect the level of cortical activation through the brain modulation systems and to shape the induced cortical bioelectrical activity that determines a human psychophysiological state [6–10]. The higher psychic processes are believed to remain undisturbed by the application of the AVS method that only creates the conditions to facilitate the voluntary regulation of psychic functions and autonomic responses, due to the formation of a certain level in the brain activity and the optimization of nervous processes in the cerebral cortex [4]. This allows the coordination of the regulatory mechanisms of visceral functions under psychoemotional and physical loads, as well as to optimize the adaptive and rehabilitation responses to extreme exposures. There are data that AVS also acts on the emotional sphere and is a pathogenic method for the correction of psychosomatic disorders [11].

Despite a great number of studies on the effects of audiovisual stimulation on the human body, there are not as many studies as necessary on the AVS effects on the psychophysiological state and the autonomic regulation mechanisms in the field of sports in order to develop some generally accepted stimulation technologies applicable at different training stages.

In light of the above considerations, the goal of this research was to study the effects of the audiovisual stimulation training course on the cognitive, psychoemotional, and neurodynamic indicators, the power of the main brain EEG rhythms, and the heart rate variability in athletes engaged in cyclic sports.

METHODS

The participants of the three-stage study were 65 track-and-field athletes (of the first and second sports qualification categories and candidates for the masters of sports) aged 18–23 years, assigned to the first health group, engaged in track-and-field athletics and specialized in middle-distance running. The training sessions were scheduled six times a week. The running load in different intensity zones was 185 to 225 km per month. The athletes were divided into the control ($n = 40$) and the experimental (exposed to AVS, $n = 25$) groups. The groups were matched with respect to age and the sports skill level. The study lasted from January to March of 2014 in both groups. The audiovisual stimulation was realized using a portative NOVA PRO audiovisual stimulator (United States). The AVS method is based on the delivery of binaural beats and light flashes at a specified frequency of the signal. It has been shown that the AVS method that stimulates the auditory and visual analyzers affects the frequency of bioelectrical rhythms of the brain [12, 13]. The training stimulation sessions were performed with eyes-closed at the 24-h intersession interval. The "moderate relaxation" program was used at a predominant stimulation frequency of 3–13 Hz with the duration of 25 min when red light flashes and double binaural beats were generated, respectively, through diode eyeglasses and headphones. The applied AVS program used the following frequencies during brain stimulation: 13 Hz for the first 2 min with a subsequent fall to 8 Hz and a slow 7-min decrease to 4 Hz, then a gradual shift towards 3 Hz with a subsequent rising up to 8 Hz. In the end of the session, the frequency of signals gradually returned to 13 Hz.

At the first stage (background), the psychophysiological state was diagnosed in athletes under the following tests [14]: sociopsychological adaptation according to Osnitsky; assessment of psychic states according to Eysenck; state and trait anxiety according to Spielberger–Khanin; the state of aggression according to Bass–Darky; motivation for success according to Ehlers and Mehrabian; and stress-tolerance level; and personality type according to Eysenck.

The following psychophysiological parameters were assessed, using the integrated athlete health assessment software (Informregistr certificate no. 16366) [15]: the capacity of mechanical and imaginary memory, the speed of simple visual-motor response (SVMR), the speed of attention switching, as well as the level of hardiness and life satisfaction. We used the NS-PsychoTest hardware–software complex (NeuroSoft, Ivanovo, Russia) to perform psychophysiological and psychological tests and record autonomic and emotional responses. The obtained test results were distributed according to the following blocks: psychoadaptive, psychoemotional, cognitive, neurodynamic (Table 1).

EEGs were recorded using a multimodal computer-aided BOSLAB complex (Novosibirsk, Russia), using the monopolar *Pz* lead. The earlobe electrode was used as a reference electrode. The *Pz* site was used due to the α activity characteristics in the parieto-occipital region, which were the most stable and least variable when repeatedly measured [16–18]. EEGs were recorded at rest with the eyes closed (2 min) and in the eye-opening tests (30 s). The electromyogram was recorded at the occipitofrontalis muscle to control eye movements. The analysis of electroencephalographic data selected artifact-free EEG epochs, which were fractioned into 4-s segments and subjected to the fast Fourier transform (*FFT*) in the band of 3–20 Hz, using the Hann window. The output data were analyzed using the specialized WinEEG software (Mitsar, St. Petersburg, Russia) developed according to the accepted signal processing standards and represented as a table of EEG spectral power with a step of 1 Hz. We isolated and analyzed the θ-rhythm (4–7 Hz), α-rhythm (8–13 Hz), α_1-rhythm (8–10 Hz), α_2-rhythm (11–13 Hz), and β-rhythm (14–30 Hz) ranges. The boundaries of the α-rhythm ranges were established individually, depending on the frequency of the maximum α-peak and a decrease in the wave power in response to eye-opening on the left and right of the α-peak.

The heart rate variability (HRV), a marker of the autonomic regulation mechanism, was studied according to the methodical recommendations developed by a group of European and American experts [19]. The electrocardiographic signal was recorded in a supine position (for 5 min) in standard lead II with a VNS-Micro hardware-software complex for investigating the autonomic nervous system (NeuroSoft, Russia). The stress index (SI), 30–90 arbitrary units (arb. units), was taken as the main criterion for the express assessment of the predominant type of autonomic regulation [20].

At the second stage, the audiovisual stimulation (AVS) training course was conducted in the experimental group; it included 20–22 sessions performed at 24-h intervals.

At the third stage (after the completion of the AVS training course), we assessed the AVS effects on the psychoemotional and neurodynamic parameters, as well as the personal adaptive potential characteristics and specific changes of the EEG and HRV parameters in the experimental group against the control (without AVS training).

The results were treated by the generally accepted mathematical statistical methods, using Student's test for the case of parametric samples and the Wilcoxon–Mann–Whitney nonparametric criterion for variables that were not normally distributed, and considered statistically significant at $p \leq 0.05$. This program of studies was approved by the Ethics Committee of the Novosibirsk State Pedagogical University (NSPU) as part of planned studies of the Physiology of Ontogenesis Scientific-Educational Center (SEC) and by the Ethics Committee of the Research Institute of Physiology and Fundamental Medicine (RIPFM). All subjects gave their informed consent to participate in the investigations performed in conformity with the Declaration of Helsinki (1964).

Table 1. Changes in the psychophysiological status of athletes control and experimental (AVS) groups ($M \pm m$)

Block	Indicator	Control group		AVS group	
		January	March	before training	after training
Psychoadaptive block, points	Adaptation	75 ± 1.6	75.1 ± 2.1	71.5 ± 3.1	71.1 ± 3.1
	Internal control	57.6 ± 1.0	60.1 ± 0.8*	58.6 ± 1.6	55.2 ± 1.6*#
	External control	14 ± 1.4	10.7 ± 1.6*	12.6 ± 2.2	12.6 ± 2.2
	Motivation to achieve success	142 ± 2.7	135 ± 2.5 *	152 ± 4.6	149 ± 4.6#
	Hardiness	132 ± 4.7	120 ± 6.1*	127 ± 6.1	133 ± 6.0#
Psychoemotional block, points	State anxiety	19.2 ± 1.6	19.8 ± 1.8	23.5 ± 1.8	18.3 ± 1.8*
	Trait anxiety	32.2 ± 1.5	33.2 ± 1.6	34.1 ± 1.4	35 ± 1.3
	Frustration	5.7 ± 0.5	5.5 ± 8.0	5.1 ± 0.7	3.4 ± 0.7*#
	Stress-resistance	34.2 ± 1.0	34.3 ± 1.6	33.4 ± 1.5	34.8 ± 1.6
	Neuroticism	11 ± 0.9	12 ± 1.2	9.5 ± 0.8	9.6 ± 0.9#
	Physical aggression	4.2 ± 0.3	4.1 ± 0.3	4.5 ± 0.4	4 ± 0.5
	Indirect aggression	3.9 ± 0.3	4.1 ± 0.4	4 ± 0.4	4.4 ± 0.4
	Irritation	3.1 ± 0.5	3.7 ± 0.4	3.4 ± 0.4	3.7 ± 0.5
	Negativism	1.7 ± 0.3	1.8 ± 0.3	2.3 ± 0.3	2.6 ± 0.3
	Verbal aggression	6.1 ± 0.3	6.1 ± 0.4	6.1 ± 0.3	7.1 ± 0.3*#
Cognitive block, points	Volume of mechanical memory, points	5.8 ± 0.3	6.7 ± 0.2*	5.9 ± 0.4	7.5 ± 0.4**#
	Volume of imaginative memory, points	8.5 ± 0.2	8.2 ± 0.3	8.6 ± 0.2	8.5 ± 0.2
	Speed of attention switching, s	48.5 ± 1.9	46.1 ± 3.2	49.3 ± 3.9	38.7 ± 3.9**#
Neurodynamic block, points	Simple visual motor response (SVMR), ms	182 ± 4.4	178 ± 3.4	183 ± 3.5	163 ± 3.5*#
	Reaction to a moving object (RMO) of coincidence, points	1.3 ± 0.2	1.4 ± 0.2	1.6 ± 0.2	2.7 ± 0.2**#
	Range of variability in the time of anticipation and delay (RMO)	353 ± 22	352 ± 20	322 ± 18	173 ± 18*

Significance of differences between the January and March indicators in individual groups: * $p < 0.05$, ** $p < 0.01$. Significance of differences between groups in March: # $p < 0.05$.

RESULTS

Psychoadaptive block. The athletes of the studied groups did not differ in psychoemotional indicators at the start of the experiment. The dynamics of the investigations (January—March) in the control group demonstrated a decrease in the indicators, such as the external control, the motivation to achieve success, and the level of hardiness, along with a simultaneous increase in the indicator for internal control. We believe that these changes in the control group were caused by a growing pressure of training and competitive loads on the psychic and physiological reserves in athletes from the beginning of the winter season to its end (Table 1).

The results of the sociopsychological adaptation assessment after the completion of the AVS training course in the experimental group showed a weakening in the internal control against its baseline level (Table 1), whereas some personal adaptive parameters, such as hardiness and the motivation to achieve success, did not change significantly.

Comparison of psychoadaptive intergroup parameters showed that the group taking the AVS training course had considerably higher indicators of hardiness ($p < 0.05$) and motivation to achieve success ($p < 0.05$), which indicated more successful resistance to stress, a decrease in the internal tension, and a higher adaptive potential compared to the control (Table 1).

Psychoemotional block. No significant differences have been observed in the interseasonal indicators in the dynamics of the investigations (January—March) in the control group. The self-assessment of psychic states (the Eysenck test) after the AVS training course

Table 2. Dynamics of the EEG α-rhythm power indicators in athletes of the control and experimental (AVS) groups ($M \pm m$)

Power indicators for main rhythms	Control group		AVS group	
	January	March	before training (January)	after training (March)
α_1, μV^2	17.8 ± 1.5	20.9 ± 2.5	14.8 ± 1.4	16.4 ± 1.7
α_2, μV^2	25.4 ± 3.8	22.9 ± 3.2	26.7 ± 3.3	34.0 ± 3.5*

Significance of differences between the January and March indicators in individual groups: * $p < 0.05$.

(hereinafter, the AVS group) in the experimental group has revealed a decrease in the level of state anxiety ($p < 0.05$) and frustration ($p < 0.05$). We specially mention that the level of verbal aggression grows in the AVS group ($p < 0.05$) (other forms of aggression manifestation did not change significantly). The possible causes of this effect will be discussed below. Thus, after the completion of the experiment we found a certain number of intergroup differences in some psychoemotional indicators, which play an important role in the athletic practice during the precompetition training, competition, and subsequent rehabilitation periods.

Cognitive block. The analysis of cognitive parameters in the AVS group revealed positive effects of this training course, such as an increased volume of mechanical memory ($p < 0.01$) and faster attention switching ($p < 0.01$). In contrast, there were no changes in the volume of imaginative memory and the speed of attention switching in the control group of athletes (Table 1), although an increased volume of mechanical memory was also observed by the end of the experiment. Thus, the conducted study has shown more expressed improvements in the cognitive functions in the AVS group, compared to the control.

Neurodynamic block. As a result of training sessions, according to the tests of SVMR and a reaction to a moving object (RMO) in the AVS group, changes have been found in the balance between the excitation and inhibition processes in the cerebral hemispheres, which was expressed in an increased number of coincidences in the RMO ($p < 0.05$), as well as in a significant reduction in the range of fluctuations between the time of anticipatory and delayed responses and the SVMR time ($p < 0.05$). No significant differences have been found in the interseasonal indicators in the control group.

Analysis of the brain bioelectrical activity (Table 2) has shown significant changes in the individual α-rhythm subranges: increases in the power of the high-frequency α_2-rhythm in the AVS group ($p < 0.05$). No changes have been found in the control group. No significant changes relative to the background measurements took place in the characteristics of the β-rhythm and θ-rhythm powers by the end of the experiment in either group. Thus, we can conclude that the AVS training course changed some EEG parameters of the brain and this manifested itself in the increase in the power of α-waves corresponded to the frequencies used in the AVS sessions.

Heart rate variability. It has been established that, after the AVS sessions, the sympathetic regulation effects and the contribution of the central levels of control to the regulation of HR decreased in athletes (mode amplitude, AMo%; and stress index, SI) (Table 3). We observed the effect of parasympathetic regulation and the enhancement of the autonomous regulatory contour (standard deviation of NN intervals, SDNN; root mean square of successive differences, RMSSD; and variation range). AVS also contributed to greater effect of respiratory waves on the heart rate, forming a more economical work of the heart. No such changes have been observed in the control group.

DISCUSSION

The results of the study have shown that the AVS effect creates marked changes in the cognitive, psychoemotional and neurodynamic spheres of athletes, which help optimize the activity of the functional systems participating in the formation of an athlete's peak condition [21–23].

First of all, one of the positive effects is that the application of AVS reduces the state of tension and anxiety, thus improving a general psychoemotional condition of athletes. This is confirmed by the questionnaire data that reflect the found differences between the indicators of anxiety, frustration, and neuroticism in the experimental and control groups. In general, the obtained differences indicate an increase in the level of emotional stability, better feeling of quietness and balance after the AVS training sessions. The AVS sessions also helped to extend the personal adaptive potential, which was expressed in increased values of the indicators characterizing hardiness and motivation to achieve success. At the same time, the balance between the excitation and inhibition processes was disturbed by the end of the winter training season in the athletes of the control group, the motivation to achieve success and the level of hardiness were falling, which can be explained by a growing tiredness and exhaustion as a result of study and training loads by the end of the winter season. The fact that training and competitive loads cause substantial psychoemotional changes in athletes has been mentioned by some authors [24, 25]. Our results also agree with

Table 3. Heart rate variability in the athletes of the control and experimental (AVS) group ($M \pm m$)

Methods	Indicator	Control group		AVS group	
		January	March	before training (January)	after training (March)
Temporal analysis	SDNN, ms	62.9 ± 3.1	52 ± 3.2*	62.4 ± 3.8	71 ± 5.2
	RMSSD, ms	54.1 ± 4.4	40.8 ± 3.1*	53 ± 4.7	73 ± 7.4*
Spectral analysis	Total power (TP), ms^2	4169 ± 350	2993 ± 315*	3620 ± 311	5919 ± 653*
	Very low frequency (VLF), ms^2	1377 ± 165	1142 ± 202	1601 ± 289	1774 ± 308
	LF, ms^2	1215 ± 145	1310 ± 232	1272 ± 219	1428 ± 270*
	HF, ms^2	1516 ± 223	967 ± 182*	1329 ± 213	2297 ± 340*
Variation pulsometry	Mo, s	1.00 ± 0.02	0.99 ± 0.03	0.96 ± 0.04	1.00 ± 0.03
	AMo, %	32.8 ± 1.62	40.3 ± 2.2*	32.7 ± 1.8	26.2 ± 1.2*
	RT, s	0.33 ± 0.01	0.28 ± 0.02*	0.32 ± 0.02	0.41 ± 0.02*
	SI, arb. units	54.6 ± 4.7	75.1 ± 11.8	53.7 ± 8.8	39.4 ± 5.8

Mo, mode; AMo, mode amplitude; RT, response time; SI, stress index. Significance of differences between the January and March indicators in individual groups: * $p < 0.05$, ** $p < 0.01$. Significance of differences between groups in March: # $p < 0.05$.

the data that the AVS training sessions can alter the parameters of actual self-assessment and lower the level of trait anxiety [9, 11, 12]. We should also add that, according to the literature data, an improvement in the psychoemotional condition after the AVS training course is correlated closely with the strengthening of the immune status [26].

The observed growth of the values of the "verbal aggression" indicator in the experimental group causes interest, and this can be considered from two viewpoints. On the one hand, verbal aggression is treated in psychology as a negative sign that reflects a general growth of aggression in the contemporary society, especially, among the youth, but on the other hand, as Il'in notes [1], the sport-related aggression is an aggressive behavior regulated by sports rules, which is a necessary precondition for success in a competitive activity. We believe that the increased indicator of verbal aggression in the experimental group in our case reflects a general precondition for more successful performance of athletes and can be regarded in this context as an adaptive sign.

Of interest are the results on the AVS effect on changes in individual bioelectrical activity parameters, in particular, the α-rhythm power. It is known that the α-rhythm is given an important functional significance in the processes of attention, memory, emotions and motivation [23, 27–31], successfulness in cognitive performance [30, 32–34] and optimal functioning [35–39], i.e., the parameters whose improvement took place after the AVS course. An increased α_2-rhythm power is observed in the AVS group in the eye-opening test in March, compared to January, whereas this parameter tended to decrease in the control group. It is not excluded that, on the one hand, the obtained intergroup differences could be explained by the impossibility to show an increase in the α-activity with eyes-closed by the control group's subjects, due to tiredness and increased psychoemotional tension by the end of the winter training season. On the contrary, the enhanced power of waves in the individual high-frequency α_2-range after AVS can be an indicator of decreased general tension and improved functional state of the central nervous system, which is accompanied by a growth of the regulation efficiency of cognitive processes, increasing the volume of mechanical memory and the speed of attention switching and improving the simple visuomotor response indicators in the AVS group of athletes.

The changes in the HRV indicators observed after the AVS training course, which reflected the enhanced parasympathetic effects and the increased activity of the autonomic regulatory contour over the central mechanisms, corresponded to the general hypothesis of an AVS-generated relaxing effect. This effect can be used in training courses for recovery after hard training and precompetition sessions. In contrast to the data obtained in the AVS group, the cumulative activity of neurohumoral influences and the contribution of respiratory waves to the variability formation significantly decreased in the control group, which can be explained by the exhaustion of the parasympathetic regulation reserves during training sessions in the end of the training season. The values of the vagosympathetic balance and centralization index indicators can point in the control group at an increased tension in the regulatory systems.

On the basis of our studies, we can suggest that both an excessive activation of brain structures due to stress, anxiety, and aggression and an insufficient activation due to the development of tiredness and the absence of motivation to acquire new skills and mobilize the maximum of adaptation reserves in the body of athletes reflect their nonoptimal functional condition [40]. The level of psychoemotional condition has a significant effect on the functional level of the systems ensuring the autonomic supply under psychophysical loads, primarily, the mechanisms of cardiovascular regulation. The audiovisual stimulation helps to ensure the psychophysiological adequacy of the response to the total set of specific factors met in sports activity, upgrade the effectiveness of professional activity, and eliminate with extra loads on the systems of autonomic supply.

CONCLUSIONS

A significant number of intergroup differences in the psychoadaptive and psychoemotional indicators (anxiety, internal control, the level of psychopathization or frustration, neuroticism, the motivation to achieve success, and hardiness) have been observed after an AVS training course. The experimental AVS group demonstrated improvements in cognitive and neurodynamic indicators (the volume of mechanical memory, the speed of attention focus switching, and the balance between nervous processes and the speed of a simple visuomotor response) compared to the control. The AVS training course increased the power of EEG α_2 high-frequency subrange, which did not occur in the control group. The AVS increased the parasympathetic activity in the autonomic regulation of the heart, enhanced the effect of the autonomous regulatory contour, increased the effect of respiratory waves on the heart rate, and shaped more efficient work of the heart. Thus, the AVS training sessions can be considered in the practice of sports as a way of producing a psychophysiological effect on athletes for their more successful rehabilitation after loads, better adaptation to quickly changing conditions during sports sessions and precompetition training.

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