Human Physiology, Vol. 31, No. 3, 2005, pp. 316–323. Translated from Fiziologiya Cheloveka, Vol. 31, No. 3, 2005, pp. 84–92.

In memory of Pavel Vladimirovich Bundzen

Psychophysiological Correlates of Athletic Success in Athletes Training for the Olympics

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Received March 31, 2004

Abstract—Long-term studies related to comprehensive analysis of psychophysiological correlates of the athletic potential were performed on the basis of innovative technologies of molecular genetic and biological energy analyses using modern automated software–hardware complexes. The results were used to select indices for personalized diagnosis of the athletic potential, to analyze it comparatively at the team level, and to calculate an athletic rating correlating with athletic success. These indices make it possible to detect preclinical health disturbances, development of energy deficit, and overtraining. The approaches may be used to analyze the general well-being of a population.

Studies of athletic success have shown the importance of an optimal combination of the following factors in various sports: (1) the general psychoemotional status of an athlete, with a predominance of activity, resoluteness, and ability to work in a team (for team sports); (2) a high tone of the cardiovascular system and oxygen uptake; (3) a correspondence of the muscular structure and activity to the sports in which the athlete engages; and (4) a high level of physical training [1].

At the same time, competitive sports performance with a high level of success is characterized by some factors that distinguish it from simple physical training: (1) necessity of maximum realization of accumulated psychophysiological resources in contests and their purposeful use throughout the year in accordance with the contest schedule and (2) efficient use of relaxation and rehabilitation periods between contests to restore the spent resources.

It is important to take into account the necessity to safeguard the health of athletes and prevent overtraining and overstrain, which lead to failures and injuries.

It is the task of coaches, sports physicians, and psychologists to take into account these factors and their interrelations and synergy in practical work related to athletics. Therefore, it is important to elucidate the parameters of the psychophysiological functional state of an athlete on the whole and develop equipment and methods for prompt evaluation and monitoring of athletes' state during training and contests. The main requirements for these methods are that they be (1) informative with respect to the features of athletic activity; (2) objective and independent from the operator and the conditions of data collection; (3) capable of allowing simple and rapid measurements and analysis; (4) usable in a wide range of conditions, including those of a contest; (5) reliable as concerns the storage of large data files; (6) accessible to nonprofessional operators, including athletes (self-monitoring); and (7) capable of providing graphic and understandable information.

It is evident that only modern computerized complexes meet these requirements.

Under the guidance of Prof. P.V. Bundzen, researchers of the St. Petersburg Institute of Physical Training and the University of Information Technologies, Mechanics, and Optics (St. Petersburg) developed from 1998 to 2003 systems for comprehensive diagnosis of athletic potential. The systems include innovative technologies of molecular genetic and biological energy analyses that are based on modern automated software–hardware complexes.

METHODS

The set of parameters under study included six blocks that make it possible to evaluate the psychophysiological potential (the level of psychophysiological reserves) of an athlete (Fig. 1): (1) a valeometric block for evaluation of health quality and exercise performance; (2) a block for evaluation of the psychoemotional status by the depth and direction of changes in it; (3) a block for evaluation of autonomic and humoral control on the basis of the heart rate variability method; (4) a block for evaluation of the state of energy homeo-

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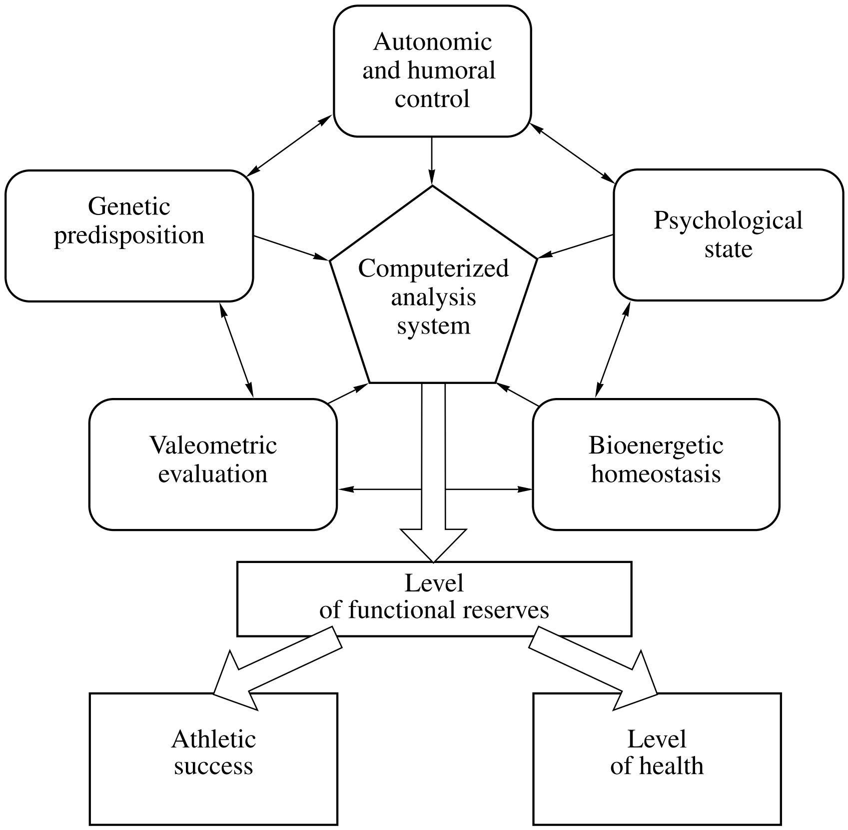

Fig. 1. Principal scheme of the Sports for Youth biotechnical system.

stasis on the basis of gas discharge visualization (GDV) bioelectrography (on the scale of energy excess–normal level–energy deficit); (5) a block for evaluation of genetic predisposition for physical activity; and (6) a block for generation of conclusions on the basis of computerized systems of artificial intelligence.

The valeometric block included the following subsystems: (1) personal data about the subject; (2) morphofunctional indices (body length, body mass, blood pressure, and heart rate at rest and during exercise); (3) current psychosomatic complaints; and (4) genetically determined and acquired risk factors.

Exercise performance was evaluated with a Quinton treadmill (United States) in the following velocity regimes: 6 km/h at the first level, 9 km/h at the second, and 12 km/h at the third. The slope was 5% and the duration of each level, 3 min. Then the angle increased to 12.5% with a duration of 1 min at each level. At the third level, where the velocity was 12 km/h, the athletes ran to capacity. The heart rate was continuously monitored using a Polar Electro system; external respiration was controlled every 3 min using a Beckman gas analyzer.

The psychoemotional status was evaluated using a Russian version of the POMS test [2], by measuring six indices: (1) anxiety (T); (2) depression (D); (3) aggressiveness (A); (4) activity (V); (5) fatigue (F); and (6) confusion (C).

Heart rate variability was assayed using Polar Electro OY and Heart Tuner cardiomonitors when a subject was in the supine position at relative physiological rest. The results were processed mathematically using the Polar Precision Performance computer program. We calculated the parameters of time area, scattergrams, and histograms [3]. Histograms were plotted with an interval of 0.05 s. In addition, absolute and relative powers of the spectrum of periodic fluctuations of the heart rate were evaluated in the standard frequency ranges: ≤0.04 (VLF), 0.04–0.1 (LF), and 0.1–0.4 Hz (HF). Spectrum amplitudes were evaluated at all frequencies with a step of 0.01 Hz.

GDV bioelectrography is based on recording optoelectron emission of a biological object upon stimulation with short (3–5 μs) electromagnetic pulses [4]. The method makes it possible to record and quantify luminescence near the surface of the object in a high-voltage electromagnetic field (EMF) (Fig. 2). The method is used to study stimulated emission of photons, electrons, and other particles of the object exposed to an EMF or a gas discharge. Biological emission strengthens in a gas discharge and is transformed into a digital code by a video transformation system, digitalized by a computer, and imaged as a GDV-gram. The GDV-gram

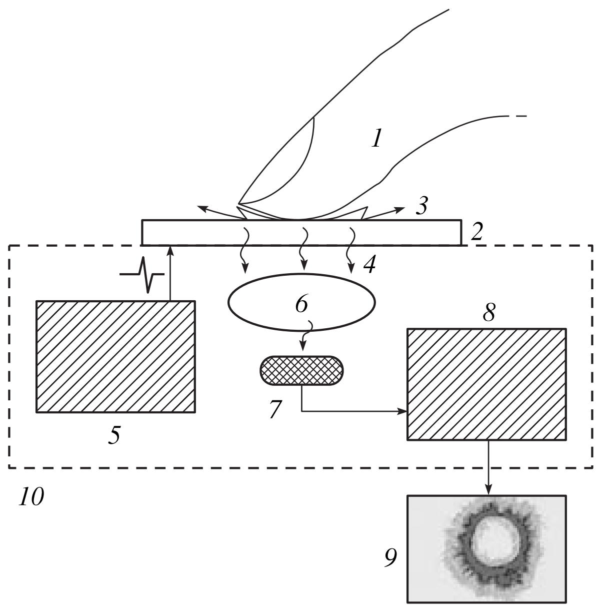

Fig. 2. Scheme of the GDV device. (*1*) Object of examination; (*2*) transparent electrode; (*3*) gas discharge; (*4*) optical emission; (*5*) generator; (*6*) optical system; (*7, 8*) video transformer; (*9*) computer; (*10*) case.

is a spatially distributed group of luminescence areas with different degrees of brightness. Parametric analysis of GDV-grams is based on computerized methods of image processing. Analysis of changes in GDV-grams includes calculation of the characteristics of their amplitude and geometric, brightness fractal, and stochastic parameters. These indices are measured for each finger; then their mean values are calculated (1) for all fingers and (2) separately for each hand. In healthy persons, mean fluctuations of the GDV-gram parameters within a day and within 10 min are 4.1 ± 0.8 and $6.6 \pm 0.7\%$, respectively. A data bank formed in cooperation with specialists from the United States, Sweden, Finland, and Slovakia made it possible to identify the normal zone of these parameters in healthy men and women at different ages [5].

GDV-gram recording is noninvasive, painless, and rapid and may be repeated many times during a therapeutic course or other procedures.

The biophysical basis of the GDV method is the running of a pulse electric current in nonconductive biological tissues, which may be ensured by intermolecular transfer of excited electrons owing to the mechanism of the tunneling effect with activated hopping of electrons in the contact area between macromolecules [6]. Transformation of electron energy in biological structures is related not only to electron transfer but also to the migration of energy of electronic excitation without separation of an electron from the donor molecule. According to present views, the inductive resonance, metabolic resonance, and exitonic mechanisms of electron excitation transfer are most important for biological systems. It is necessary to take them into account while studying energy transfer through molecular complexes, usually without discharge transfer.

Emission of electrons and photons from the skin surface is stimulated by short (3–5 μs) pulses of EMF. Measurements performed using an impulse oscillograph with a memory showed that an EMF pulse gives rise to a series of ca. 10-ns current and luminescence pulses. They develop owing to ionization of molecules of the gaseous medium by emitted electrons and photons; this phenomenon is caused by a charging of the dielectric surface and the emergence of an EMF gradient directed opposite to the initial EMF [4]. When a series of stimulating EMF pulses is presented with a frequency of 1000 Hz, emission develops during each pulse. This duration is too short for the development of ionic depolarization processes; therefore, a current may be caused by electron transport through structural complexes of biological tissue that is a part of the route of a pulse current. It is believed that the GDV method gives an indirect insight into the level of energy reserves at the molecular level of the functioning of structural protein complexes [7].

A GDV complex used for GDV bioelectrography was approved by the Committee on New Medical Equipment of the Ministry of Health of the Russian Federation and the State Standard Committee of Russia in 1999 and is produced serially (www.kti.spb.ru).

Genetic predisposition was evaluated on the basis of detecting the II, ID, and DD genotypes of the angiotensin-converting enzyme (ACE) gene, which correlate with athletic success of highly skilled athletes training for endurance [8]. Genomic DNA was extracted from saliva; a polymorphic region of the ACE gene was amplified in the polymerase chain reaction, and the products were separated electrophoretically in 8% polyamide gel [9].

Interrelationships among the parameters under study and their importance for analyzing athletic success were evaluated using correlation and factor analyses; activity models based on the observed regularities were created using artificial intelligence methods.

RESULTS AND DISCUSSION

Psychophysiological Correlates of Athletic Success in Athletes Training for the Olympics

Our comprehensive approach was tested from 1999 through 2003. The participants in the study were Olympic champions and highly skilled athletes who attended Olympic Reserve Training Schools nos. 1 and 2 and the St. Petersburg Olympic Training Center (mean age 18.3 ± 3.5 years). More than 1100 subjects were examined during the comprehensive longitudinal study. A thorough medical examination showed that all of them were healthy. The athletes took part in international, all-Russia, and city contests in sports that require endur-

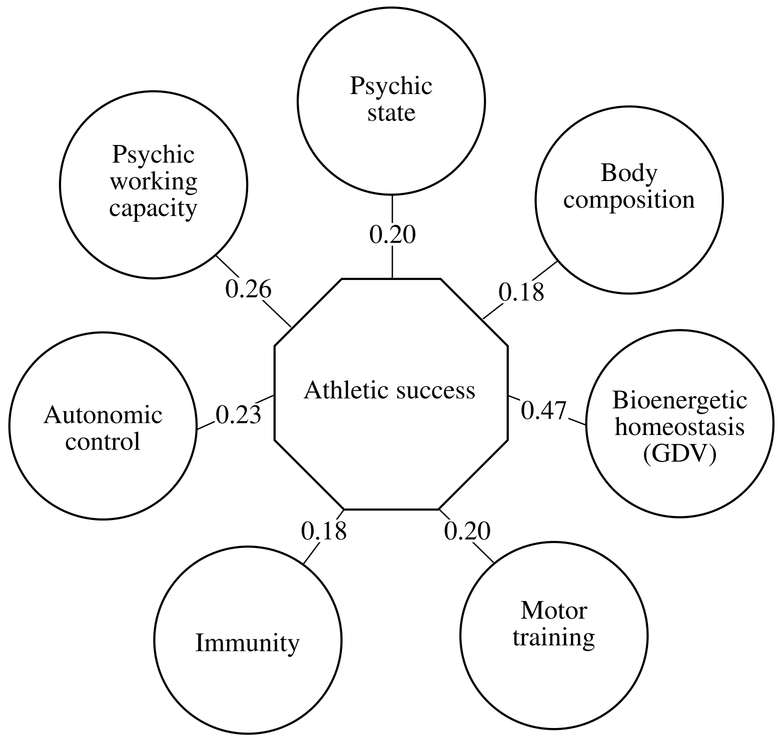

Fig. 3. Correlations between parameters in a group of 40 athletes. Spearman correlation coefficients at $P < 0.05$ are indicated.

ance, such as pentathlon, triathlon, ski racing, skating, rowing, and swimming.

The first stage of the study included calculation of the correlates between the psychophysiological parameters measured by standard methods and long-term athletic success evaluated taking into account expert opinions [10] (Fig. 3). The results were quite unexpected. It is seen from the graph that the coefficients of correlation of all parameters with athletic success were about 0.2. Naturally, it must be taken into account that these data concern highly skilled athletes. The only exception was energy homeostasis, which was calculated on the basis of the GDV parameters of finger luminescence [4]. Analyzing the results, we felt it necessary to look for more effective correlates of athletic activity, and this resulted in the formation of the aforementioned complex of psychophysiological and genetic factors [11]. Figure 4 shows an example of a correlation graph plotted for a group of athletes on the basis of the parameters considered in this work. It follows from our data that the factors selected correlate strongly with athletic success, the main index of an athlete's effectiveness. Similar results were obtained more than once by testing various groups of athletes.

Particular attention should be given to the relation between the parameters of GDV patterns and the wave structure of the heart rate. Filtering more than 1000 correlation coefficients at a significance level of 0.05–0.01, we found that most parameters of GDV-grams and the POMS test significantly correlated with the amplitude of spectral parameters of the heart rate. The most constant and significant coefficients of correlation between the basic and integral GDV-gram parameters were observed in the frequency bands 0.10–0.12 and 0.27–0.28 Hz. The relations identified in our study may be characterized by the following coefficients: (1) K1, the sum of the amplitudes of signals of the spectral band 0–0.08 Hz divided by that of the band 0.09–0.40 Hz; (2) K2, the amplitude of the signal with a frequency of 0.01 Hz divided by the sum of the amplitudes of signals with frequencies of 0.10 and 0.27 Hz; and (3) K3, the sum of the amplitudes of signals of the spectral band 0–0.08 Hz minus that of the band 0.09–0.40 Hz.

We found a significant correlation between these coefficients and most of the GDV-gram parameters and POMS test coefficients (Table 1).

These results testify that the parameters of the stimulated optoelectron emission recorded at relative rest correlate with the wave structure of heart rate in the VLF (0.01 Hz) and HF (0.27–0.28 Hz) bands. Notably, the maximum relative amplitude in the VLF band of the wave structure of the heart rate and the minimum amplitude in the HF band corresponded to the maximum GDV parameters. In view of the experimentally proven correlations between the parameters of the heart rate spectrum components within the VLF band and humoral metabolic control and between the parameters of the LF and HF bands and reflex sympathetic–parasympathetic control [3], there is good reason to believe that the GDV-gram parameters depend on the interac-

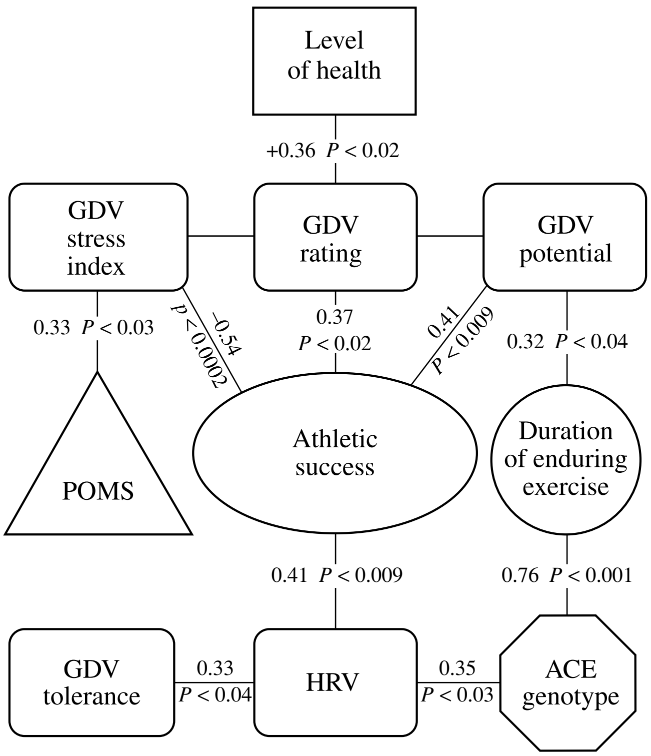

Fig. 4. Correlations between parameters in a group of 45 athletes. Spearman correlation coefficients are indicated. GDV, gas discharge visualization; HRV, heart rate variability; ACE, angiotensin-converting enzyme.

tion between these mechanisms of corticovisceral control.

Highly skilled athletes were characterized by some specific features of GDV-gram patterns. First, their GDV-grams were more structured than in the reference group (an age-matched group of students of athletic and other institutes and those who had applied for admission to them). The most structured GDV-grams were found in highly skilled swimmers. Second, GDV-grams of highly skilled athletes trained for endurance belonged with a high probability (87%) to types IIa and IIb according to the classification used in GDV bioelectrography [4]. Notably, both combinatorics of the GDV-gram types and their basic parameters (area and fractal and entropy characteristics) differ significantly ($P <$ 0.05–0.01) in athletes with different degrees of functional readiness, evaluated from the data of standard verification methods [5, 11].

In addition, we noted a stable correlation between the basic parameters of GDV-grams and genotypic characteristics of athletes, affecting their psychophysical endurance (for details, see [12]).

Evaluation of the athletes' psychophysical potential in the context of chronobiology enabled us to detect a correlation between the GDV-gram parameters and periods of the individual year [13, 14]. Verifying this regularity with a large sample of highly skilled athletes, we found that GDV bioelectrography demonstrated the highest level of psychoenergetic functional reserves in those who were in the so-called favorable periods of the year. Thus, it may be believed that the GDV-gram parameters that reflect conservative (genetic) and labile (psychofunctional) signs of an athlete's state have both short-term and long-term prognostic significance.

The use of a functional load in the form of simulation of contest conditions (an evoked start condition) demonstrated that highly skilled athletes with great psychophysical contest readiness are capable of immediate ideomotor modulation of GDV patterns. This phenomenon manifests itself in strengthened fragmentation of GDV-grams and, sometimes, in the formation of powerful outbursts of distant emission [15]. Studies carried out in the framework of several international programs suggest that the specific condition of the formation of distant emission is an athlete's capacity for voluntary short-term immersion in a so-called alternative state of consciousness [16]. Notably, it is known from the practice of Olympic sports [17] that the peak of achievements in many sports depends on an athlete's ability to form such states.

The regularities revealed in this study suggest that GDV-gram parameters reflecting both conservative (genetic) and labile signs (the current functional state of an athlete) may be used as prognostic markers characterizing the psychophysical potential of an athlete's body.

Our data enabled us to develop a biotechnical expert system for screening the psychophysical potential of highly skilled athletes. It is based on a block of computer programs for express analysis of GDV-grams and assessment of the following functional parameters: (1) the general level of the biological energy potential (on the scale of energy excess–normal level–energy deficit); (2) the level of psychological energy potential,

Table 1. Relationships of GDV parameters for the left (L) and right (R) hands and psychological parameters of the POMS test with heart rate variability (HRV) coefficients

Parameters	Spearman correlation coefficient	*p*-level
GDV *JS*_L and K2	0.35	0.0313
GDV *JS*_R and K1	0.48	0.0019
GDV *JS*_R and K2	0.56	0.0002
GDV *JS*_R and K3	0.49	0.0016
POMS C and K1	–0.41	0.0084
POMS *F* and K2	–0.52	0.0007
POMS T and K2	–0.46	0.0031
POMS V and K1	0.33	0.0486

Notes: Parameters of the POMS test: C, confusion; F, fatigue; T, anxiety; V, activity. K1, K2, and K3 are the GDV coefficients (see text for explanations).

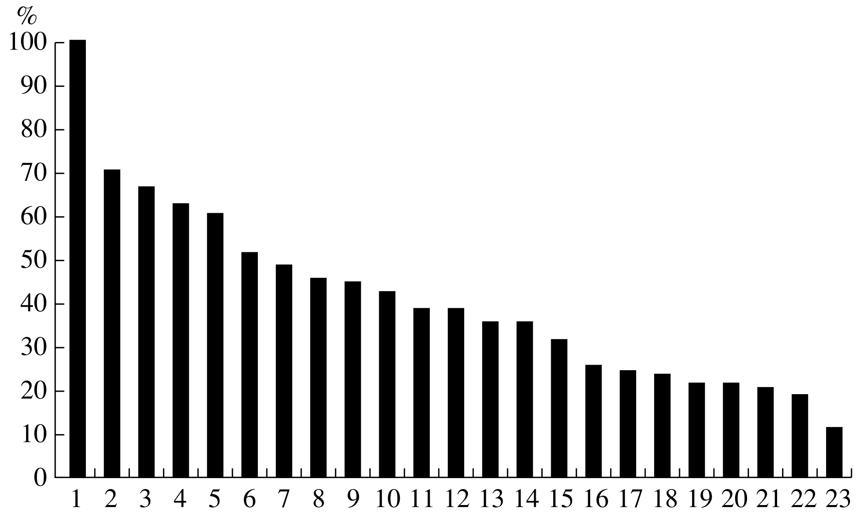

Fig. 5. Diagram of the correlation significance of various parameters relative to athletic success over two years in 196 athletes engaged in sports with high exercise loads. Abscissa: parameters of gas discharge visualization (GDV), the POMS test, etc.: (1) GDV *JS* L; (2) POMS depression; (3) health level, %; (4) GDV *JS* R; (5) *SD* of GDV *JS* L; (6) POMS diappointment; (7) yellow mass of the body; (8) GDV entropy R; (9) immunity level; (10) dynamometry L; (11) diastolic pressure, mm Hg; (12) *SD* of GDV *JS* R; (13) GDV entropy L; (14) GDV functional index; (15) POMS activity; (16) POMS tolerance; (17) body mass; (18) dynamometry R; (19) body height; (20) fat, %; (21) heart rate; (22) systolic pressure, mm Hg; (23) socialization level. R, right hand; L, left hand.

closely related to the quality of psychophysical endurance; and (3) the level of stress tolerance and capacity for psychoenergetic mobilization. It takes no more than 15 min to record the parameters of GDV-grams of finger patterns in a subject with regard for functional tests. Processing of these data makes it possible to obtain personalized characteristics of an athlete and the group rating of all subjects from the aforementioned functional parameters very rapidly. Thus, this system provides coaches and teachers with an expert evaluation of the comparative level of athletes' functional readiness for a contest. The results of testing this method at Russian Olympic Training Schools in 2001–2003 suggest that screening quantum diagnosis may be used to evaluate athletes' prospects and optimize management of training for the Olympics.

The diagnostic approaches described in this work were tested during a comprehensive examination of 196 participants in the Athletic Potential of Russia sports festival held in Orel in October 2003. Multiple correlation and factor analyses with regard to expert evaluations of athletic success confirmed the differential diagnostic significance of the parameters we studied for evaluating psychophysical endurance. Figure 5 shows a diagram of the correlation significance of these parameters over two years for athletic success in sports with high exercise loads. It is clear that the parameters of energy metabolism of an athlete's body, psychological factors, and cardiorespiratory indices play a crucial role in athletic success.

Evaluation of Health Quality Based on Measuring GDV Parameters of Fingers

On the basis of the above approaches, we developed a system for evaluating population health quality, which includes the special valeometric program HELPSY-PRO and systemic functional analysis of GDV-grams.

HELPSY-PRO is a dialog system with a necessary and sufficient minimum of instrumentally measured objective parameters, which, combined with anamnestic data (the heart rate and blood pressure), make it possible to judge about a subject's psychosomatic health quality on the basis of expert information found in the database. The method is based on an algorithm of diagnosis of psychosomatic health quality developed under Bundzen's guidance, tested during an examination of the population of northwest Russia aged 20–65 years, and approved by the Academic Council of the Ministry of Health of the Russian Federation.

The use of HELPSY-PRO made it possible to divide healthy subjects into three groups (we considered as healthy subjects who had no acute and uncompensated chronic diseases that lead to disability and require special therapeutic measures [5]). The first group included subjects who did not complain about their health and had no acute or chronic diseases or genetically determined risk factors, i.e., those with a high quality of psychosomatic health. The second group consisted of subjects who had no acute or chronic diseases but complained about their health, suggesting certain psychosomatic changes of a preclinical (premorbid) character. Most of the complaints reflected mild neu-

Table 2. Mean GDV indices for groups of healthy subjects

Health group	GDV *JS*	SI of *JS*, %	Coefficient of partial energy deficit	SI of coefficients of energy deficit, %
I	–0.22 ± 0.37	52.0 ± 6.4	0.19 ± 0.11	0.06 ± 0.04
II	–1.04 ± 0.60	13.3 ± 8.2	0.28 ± 0.06	0.46 ± 0.18
III	–1.60 ± 0.84	13.2 ± 7.6	0.82 ± 0.21	0.84 ± 0.16

Note: SI, symmetry index for the parameters of the right and left hands.

ropsychic maladaptation, caused by social and other factors. The third group was formed by subjects characterized by either compensated chronic diseases or a complex of acquired risk factors, such as weakening of the protective functions of the body, chronic intoxications (smoking, alcohol consumption), and social disadaptation, combined in some cases with hypodynamia and asthenia.

Comparison of GDV bioelectrographic data in these groups demonstrated significant differences ($P < 0.05$–0.01) in their functional and energy-related indices (Table 2).

As seen from the table, the following phenomena are typical of the first group: (1) a relatively high level of the *JS* GDV parameters in the zone that absolutely coincides with the earlier identified *JS* range, which characterizes a high quality of psychosomatic health [4, 5]; (2) a high degree of symmetry of the GDV indices in both hands, which characterizes the level of bilateral functional–energy balance; and (3) low indices of partial energy deficit, noted usually only in one hand (a low coefficient of symmetry).

Thus, subjects with a high quality of psychosomatic health are characterized not only by a high power of energy emission but also by specific features of their systemic functional organization from the viewpoint of both bilateral symmetry and the distribution of the functional–energy balance in the zones of topical diagnosis.

The second group consisted of subjects with a changed psychosomatic state and an enhanced risk of diseases. Their GDV-grams demonstrated relatively low values of *JS* GDV parameters and the symmetry index and enhanced values of the partial energy deficit index. In the third group, the gap between indices was still wider. All structural–functional bioelectrographic indices testified that these subjects were characterized by manifest energy deficit states, sometimes considered in valeology as so-called premorbid autointoxication states. The whole set of the parameters testifies to an obvious exhaustion of functional reserves and weak psychophysical endurance.

This approach to the diagnosis of health quality proved to be valid on the evidence of medical examination of athletes and a correlation with the conventional methods of prenosological diagnosis.

CONCLUSIONS

The successful testing of methods developed over many years under the guidance of Prof. P.V. Bundzen for analyzing the psychofunctional state of humans suggests that the synthesis of the methods chosen for the differential diagnostic screening system considerably expands the opportunities for functional diagnosis of the quality of population health and evaluation of the athletic success level.

Examination of more than 2500 athletes and other healthy subjects in Russia, the United States, Sweden, Finland, and other countries showed that there is a well-defined GDV bioelectrographic triad that testifies to a high quality of psychosomatic health. This triad includes (1) a high general functional–energy level, (2) a high index of bilateral functional–energy balance, and (3) a low index of partial energy deficit symmetry. Subjects with such characteristics of energy emission have a high psychophysical potential of the body; are tolerant of stress situations; and, in all likelihood, possess psychoenergetic capacities for self-restoration and self-purification.

The main factor determining the importance of the methods suggested for athletic success evaluation is the correlation between the assessed parameters and the genetic predisposition for psychophysical endurance. This predisposition considerably increases the prognostic value of the said parameters in selecting athletes for training for the Olympics and their athletic specialization.

It seems plausible that the use of the methods of quantum biophysics and medicine in predicting athletic success is a key to understanding the mechanisms of psychophysical mobilization and developing scientifically substantiated and health-saving methods of accomplishing it as a basis of good health and remarkable achievements of athletes in Olympic sports.

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