Original Research

RESISTANCE TO PHYSICAL STRESS UNDER EXTREME CONDITIONS AND METHODOLOGICAL PRINCIPLES OF PARTICIPATION IN EXTREME RECREATION

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INTRODUCTION

Scientific and technological progress, as well as personal motives, dictate individuals' interest in performing under difficult conditions; some of the factors involved can cause adjustment disorders. The term "extreme conditions" is applied to such variables. The expression refers to extreme natural conditions (i.e., temperature, wind, altitude, speed, atmospheric pressure, hypoxia) as well as other situations affecting the human body to the brink of portability. The ability to resist physical stress under extreme conditions is an important factor in ensuring the safety of athletes. Extreme sports are individual rather than team-focused. Participants' core motives are the opportunity to test oneself and to meet personal challenges, usually through close engagement with the natural environment. Extreme sports have a strong counter-cultural element, with participants often snubbing authority and conventional sporting values (Chapman, Stickford, & Levine, 2010).

Winter events and extreme sports take place at low to moderate altitudes (1500-2400m); all Winter Olympic Games incorporate at least one venue at an altitude higher than 1000m. Both the acute and chronic impacts of altitude can have a substantial effect on performance outcomes.

The magnitude and scale of the body's response to altitude become particularly notable when elite athletes compete. The impact of altitude on major sporting events was infamously highlighted during the 1968 Summer Olympic Games in Mexico City (Chapman et al). At an altitude of 2240m, the partial pressure of oxygen in the air was almost 25% less than at sea level. At the time, the International Olympic Committee considered that this was unlikely to significantly affect athletic performance, and that a period of 3-4 days at the venue would provide adequate physiological acclimatisation (Chapman et al; Kasperowski, 2009). Despite complaints from athletes, trainers and scientists, the Games went ahead. Athletes who normally lived at low altitudes fared poorly in endurance events, and the winning time for the 5000m track event was the slowest in 16 years. The Australian long-distance runner Ron Clarke, who set 17 world records during his lifetime, collapsed unconscious at the end of the 10,000m race (Chapman et al; Martin, Levett, Grocott & Montgomery, 2009).

Ascent to altitude is associated with a fall in barometric pressure, and with it a decline in the partial pressure of atmospheric (and thus alveolar) oxygen. As a result, a variety of adaptive physiological processes are engaged to mitigate the fall in tissue-convective oxygen delivery which might otherwise occur (Martin et al)

The major challenge in undertaking any type of extreme sports at altitude is directly related to the hypoxic environment. Of the variety of acute compensatory responses to hypobaric hypoxia at altitude, hyperventilation is usually considered the most critical for adequate acclimatisation. Hypocapnia-induced cerebral arteriolar vasoconstriction, as well as the left-shifted oxygen dissociation curve, may reduce oxygen availability to the brain.

Since a constant supply of oxygen is essential to sustain life, organisms have evolved multiple defence mechanisms to ensure maintenance of the delicate balance between oxygen supply and demand. However, this homeostatic balance is perturbed in response to a severe impairment of oxygen supply, thereby activating maladaptive signalling cascades that result in cardiac damage (Essop, 2007).

Our understanding of the human response to exercise at altitude is largely derived from field-based research at altitudes above 3000m, in addition to laboratory studies which employ normobaric hypoxia (Moore, Niermeyer, & Zamudio, 1998).

According to a number of studies (Camm, et al., 1996; Malashenkova, 2009; Parin, Baevsky & Gazenko, 1965), the sustainability of an organism under extreme conditions is determined by the reserve capacity of its functional systems. However, in recent years (Kasperowski; Malashenkova & Nagornev, 2009; Mazzeo et al, 1991) the scientific evidence has indicated that there is a very high variability in individual human resilience to various environmental factors. The latest studies in this area have predominately focused on the morphological and functional conditions of separate systems. This gap in the research reinforces the need to study adaptation reactions in various groups of people and in different types of recreational activities. Currently, there are no scientifically proven systems that focus on the regulation of cardiovascular and respiratory adaptation to extreme conditions. Therefore, there is a need to develop a system that unifies the organisational and methodological principles of extreme recreation. By formulating and validating organisational and methodological principles of training for extreme recreation, this study supports a focus on increasing compensatory and adaptive opportunities and the functional reserves of the body while endorsing maximum safety and the need for a healthy lifestyle.

The purpose of the present study is to investigate the adaptability factors that influence the body's reserve opportunities to undertake a variety of extreme sports and recreation activities, and the major predictors of efficiency in extreme recreation, by implementing experimental procedures with a particular focus on high-altitude areas (< 2500m). The study has also developed some key organisational and methodological principles for undertaking extreme recreation.

METHODS

Participants

A total of 966 healthy people volunteered to participate in the project. The study was conducted in compliance with the Helsinki Declaration and approved by Institution ethics. The participants were instructed not to perform any additional training two hours prior to data collection.

Design

Over a period of five years, the same investigative procedures were applied to the participants at each of the seven different stages in the project. These involved recording concrete influences; noting the features of exchange processes and their neuroendocrine regulations; determining participants' psycho-physiological status; and determining the level of functioning of the cardiorespiratory system. A summary of the trials implemented within the participants is provided in Table 1.

Investigation types at each of the seven stages of the study	Number of participants at each stage (n)	Total number of investigations per stage
Investigation of physiological reactions and functional reserves of the body when conducting extreme recreational activities	483	2457
Dynamics of functional reserves under high-altitude conditions	77	462
Physiological reactions and functional reserves of the body when alpine skiing and snowboarding	70	560
Physiological reactions and functional reserves of the body when diving	34	170
Basic physiological effects of paragliding	117	936
Physiological reactions and functional reserves of the body during extreme triathlon	24	168
Physiological reactions and functional reserves of the body for identification of organisational and methodological principles for carrying out extreme kinds of recreation	161	161

Table 1: Number of participants and trials implemented with participants.

Most of these study fields followed the typical regimen of physiological measurements at sea level, at various time points at high altitude, and sometimes following descent to sea level (stages 1, 2, 3 and 6).

At one stage, depending on private tasks, the applied methods were subject to change due to the environmental variables (stage 4). The applied methods included computer spirometry; electrocardiography including Holter's monitoring (Holter, 1961); research into variability of cardiac rhythm (Baevsky et al., 1992); echocardiography; the functional condition of the cardiorespiratory system; microcirculatory, biochemical, haematological, immunologic and endocrinology research techniques; and psycho-physiological research techniques.

Variability of Cardiac Rhythm: Essential Methods of HRV Analysis

Dynamic series of cardio intervals can be obtained from analysis of any type of cartographical record (electrical, mechanical, ultrasound, etc.). However, the present study focused on the results of electrocardiogram signals. Analysis of the variability of cardiac rhythms included three stages: 1) measurement of the length of R-R intervals and presentation of the dynamic series of cardio intervals in a form of cardiointervalogramm; 2) analysis of the dynamic series of cardio intervals (the length of R-R intervals); and 3) evaluation of the results of VHR analysis. Measurement of the length of R-R intervals was executed with the use of software with an accuracy of up to 1mc. Due to differences in software recognition of R-picks from electrocardiography in different software systems, manual data recordings were implemented. The data was recorded and analysed using both statistical and geometric methods.

Bayevsky's (1992) statistical method was used to process the data on HRV at the time of investigation in order to obtain the average cardiointerval length. During its use, the cardio-intervalogram was inspected as a collection of successive time intervals, namely intervals R-R. Statistical characteristics of the dynamic row of cardio intervals includes the following: NN50 is the number of pairs of successive NN intervals, which were received over the whole of the recorded period and which have a difference of more than 50 milliseconds between them; PNN50 (%) is the percentage that NN50 make up from the total number of successive pairs of intervals which were received over the whole of the recorded period, and which have a difference of more than 50 milliseconds between them; CV is coefficient of variation.

The geometric methods (variable pulsometry) were used to analyse a variable curved line (the curved line of allocation of cardio intervals is its histogram). Its main characteristics are defined by Mo (Mode), Amo (Model's amplitude) and MxDMn (variable range).

The MODE is the most frequently encountered type of cardio interval in this dynamic row. Mo differs a little from mathematic expectation (M) in the case of normal allocation and high stationarity. Amo (Model's amplitude) is the number of cardio intervals appropriated to the quantity of MODE in percent to the capacity of selection. Variable range (MxDMn) reflects the grade of variability of cardio intervals' meanings in the researched dynamic row. It is calculated by the difference between maximal (Mx) and minimal (Mn) meanings of cardio intervals. When lining up histograms (or variable pulsograms), the chosen method of gathering data is of major importance. The stress index was calculated using the formula SI=AMo/2Mo*MxDMn (Essop).

The recording was made on the software complex "Varicard" (Institute of implementation of new medical technologies, Ryazan); the computer systems "Vita-Rhythm," "VNS-Rhythm," "VNS-Vita," and "VNS-Spectrum" were used (firm "Neurosoft," Ivanovo).

Biochemical, Haematological, Immunological and Endocrinological Research Techniques

Standardised haematological techniques were applied on the project. Additionally, serum proteins, metabolites, lipids, enzymes and electrolytes, as well as lysozyme, and myeloperoxidase activities and other antioxidant system components, the concentration of glucose, creatinine, triglycerides, and total cholesterol in the blood plasma were also measured. The content of haemoglobin in the blood lysate was measured with the haemoglobin cyanide method, using Medix test kits (Finland). The content of cortisol, insulin, triiodothyronine, thyroxine, methanephalin, prolactinm and testosterone in the blood serum was revealed using the method of radioimmune analysis of the gamma counter developed by the "Multigamma-1261" company LKB (Sweden). The level of beta-adrenergic receptors of erythrocyte cell membranes (β-ECM) was detected through the use of the original technique for assessing the activity of the sympatho-adrenal system.

Computer Spirometry

To investigate the impact of extreme conditions on the respiratory system, the basic forced volume vital capacity (FVC) test was used. The participant was asked to take the deepest breath they could, then exhale into the sensor as hard as possible, for as long as possible, preferably for six seconds. Spirometry provides several numeric values: the forced vital capacity (FVC) and forced expiratory volume measured over 1 second (FEV1); tidal volume (TV); peak expiratory flow (PEF); and airways obstruction, which was characterised by a decrease in the FEV1/FVC ratio and forced inspiratory flow of 25-75% or 25-50%.

Laser Doppler Measures of the Microcirculatory Blood Perfusion

Laser Doppler measures the total local microcirculatory blood perfusion including the perfusion in capillaries (nutritive flow), arterioles, venules and shunting vessels. The technique is based on the emission of a beam of laser light carried by a fibre-optic probe. It is a non-invasive ultrasonic technique that measures local blood flow velocity and direction in the proximal portions of large intracranial arteries. Two hours prior to the study, food and liquid intake were halted; additionally, participants were given 20 minutes to adapt to the conditions of the room where the tests were done. The initial record of the LDF was taken with the patient lying on their back, with arms stretched alongside their torso. The sensor was positioned close to the skin; however, at the same time, it was not possible to squeeze the surrounding tissues and reduce mobility. The local air temperature at the time of taking measurements was 20-24°C. The recording of the LDF was carried out at the 3, 5 and 10-minute mark, after which the average parameters were calculated.

Functional Condition of Cardiorespiratory System

The functional condition of the cardiovascular system was assessed using a VO2Max test, conducted on a computerised "Ergo-line 900" ergometer. Before the test, during the activity and in the recovery period (1, 2, 4, 6, 8, 10 min of the experiment), all of the patients' ECG data was taken using the thoracic leads (V1-V5) with heart-rate calculation.

Echocardiography

Ultrasound was performed on the RT-4000 (Russia) in the M-mode in line with the standard method, with the determination of the parameters of the heart structures (aorta, cavity, valve apparatus), central hemodynamic parameters (SV, Q, systolic BP, diastolic BP, HR), the contractile function of the myocardium (the rate of circular shortening of the myocardial fibres) and the ejection fraction (EF).

Statistical Analysis

Validity of testing was partly confirmed by discriminating between the same groups before and after the high-altitude appliance. CV% was categorised as poor (≥10%), moderate (5–10%) or good (≤5%), based on values used in previous research. The strength of the ICC scores was based on Pearson's correlation coefficients and regarded as trivial (0.0), small (0.1), moderate (0.3), large (0.5), very large (0.7), nearly perfect (0.9), and perfect (1.0) (Hopkins, 2008).

RESULTS AND DISCUSSION

The analysis of physiological reactions during diving activity establishes that immersion under water causes adaptive reorganisation of the human body. The functions of the cardiovascular system are directed to economise O2 expenditure and, in addition, the creation of a metabolic advantage in the supply of nutrients and oxygen to the vital organs. Under these conditions, the influence of stress on the centralisation of cardio activity strengthens the correlation between the depth of a given dive and the significance of the immersion stress reaction. It is maximal at a depth of 20m.

The current activity between sympathetic and parasympathetic divisions is a result of the reaction of multi-contour and multi-circle blood system regulations changing its parameters for the achievement of an optimal adaptive response, an indication of the adaptive reaction of the whole organism. Further analysis of individual results demonstrates that the best stress tolerance was shown by individuals who were vagotonic and normotonic. Data from these individuals covered the maximum range of the compensatory or adaptive mechanisms of the cardiovascular regulation system.

Research to date suggests that the theory of adaptation is one of the fundamental themes of modern biology and physiology. The adaptive activities of the human and animal organisms provide not only survival and evolutional development, but also daily adaptation to changes in the environment. Selye's theory (1936) of the common adaptation syndrome describes the phase nature of adaptive reactions and the leading role of consumption regulatory systems, under both acute and chronic stress, in the development of the majority of pathological conditions and diseases. Blood circulation can be regarded as the sensing indicator of the adaptive reactions of the organism as a whole (Parin, Baevsky & Gazenko, 1965). Variability of cardiac rhythm represents the degree of regulatory systems strain, accompanied by both the activation of the pituitary gland adrenal system and a reaction of the sympathoadrenal system arising in response to any stress effects.

A detailed study of HRV with the use of methods of auto-correlated and spectral analysis was conducted during the next stage of our research, which dealt with the extreme influence of paragliding on two groups of participants: professional pilots and first-time participants (passengers). The study focused on the function of the cardiorespiratory system in both groups. It was statistically ($p<0.5$) demonstrated that normal reference values of MODE in the pilot group were high following the flight and landing because of the greater physical load and the condition of fatigue. The passenger group reacted differently; the high stress and reference values/MODE at the beginning of the event were a consequence of the emotional stress caused by the expectation of the event. Reliable differences in the dynamics of HR and the activity of various components of the autonomic nervous system were also recorded. The passengers' stress index reached maximum levels before take-off, and decreased during the flight, whereas with the pilots, it increased at the most difficult stage of the flight – the descent and landing. Our findings confirmed that, in the paragliding scenario, the expressed reorganisation of the main physiological systems of an organism dictate the importance of pre-flight medical control. It is also important to inform the passengers of any potential psycho-physiological reactions during the flight.

The purpose of the second stage of the project was to investigate the influence of regular training in extreme triathlon (greater than 24-hour races) participants. The results showed the positive influence of regular training on the cardiovascular and respiratory systems, against the background of the increasing range of regulatory opportunities of an organism. Implementing this type of sport regime, that takes into account the impact of complex extreme factors (i.e., moderate hypoxia, long physical activity, sleep deprivation), allows the body to estimate its functional reserves.

The primary physiological stress-limiting factor is the dynamic equilibrium between the amount of the compensatory mechanism of sports activities and the expressiveness of stress-forming reactions and distress reactions in the human body.

Data from the study has formed the basis for the development of a system of organisational and methodological principles including: maximum safety when pursuing extreme recreation; medical monitoring and medical admissions; advanced screening tests of psycho-emotional tension; dosage influence on extreme types of recreation; attention to the functional state of an individual; the dynamic equilibrium of opportunities of regulatory and compensatory mechanisms and reaction to stress-related changes in the human body; and information on possible psycho-physiological reactions of individuals. The use of these recommendations in practical recreational activities is aimed at creating conditions of maximum safety and at increasing the compensatory and adaptive reactions, and the functional reserves of the body.

The extreme nature of the effects of this type of recreation dictates the need to observe the maximum safety principle. This principle is directed at prevention and exclusion of unacceptable risk of injury, trauma or qualitative physical or intellectual damage to health.

Medical monitoring and medical admission are the most important safety-related actions prior to embarking on an extreme recreation activity. Specifically, the results of many experiments (in paragliding, diving, high-altitude mountain climbing and extreme triathlon) show that extreme factors can be distressing and harmful. Research into cardio-rhythm variability is enabling the formulation of criteria identifying stress index and numerically captured safety zone levels.

For some people, the 'price paid' by the body to adapt to extreme influences goes beyond the bio-social budget of the organism. As a result, they become the risk group and, for them, failure of adaptation and development of disadaptation states are the most probable results of involvement in extreme types of recreation. For example, studies into the effects of high-altitude mountain climbing have shown that the high initial (background) level of anxiety contributes to the formation of a syndrome of psycho-emotional tension which leads in turn to psychological disadaptation. Thus, an assessment of the initial psychological status of the participant is critical.

The data obtained from this project validates the critical requirement to conduct advanced screening tests for psycho-emotional tension.

Existing studies of high-altitude mountain climbing have reported a correlation between the length of stress and the reaction of the body. Moderated, repeated influence of extreme types of recreation will cause adaptive reorganisation of regulatory mechanisms of the human body and increase its functional reserves. As a result of our research, it has become clear that an individual approach is very important in preparing for extreme recreation. Different reactions to the same extreme conditions depend on the initial physiological and physiological condition of the body. According to a number of studies (Dobson & Markham, 1992; Malashenkova), the sustainability of an organism under extreme conditions is determined by the reserve capacity of its functional systems. However, in recent years, the scientific evidence indicates a very high variability in individual human resilience to various environmental factors. According to the physiological and psychological criteria established by existing studies, higher stress tolerance is recorded by vagotonic and normotonic participants. In these studies, these participants exhibited a maximum functional range of compensatory and adaptive mechanisms involved in the regulation of the cardiovascular system. These results allowed us to formulate the principle of accounting for a reference functional state of an individual.

Our study demonstrates that carrying out extreme types of recreation involving a complex of extreme factors (moderate hypoxia, sleep deprivation and prolonged physical activity) allowed for the evaluation of the functional reserves of the body. At the same time, it is necessary to find the safety threshold of the stress influence. Such detailed information allows scientists to establish the importance of the principle of a dynamic equilibrium of opportunities of regulatory and compensatory mechanisms and reaction to stress-related changes in the human body.

Finally, the principle of informing individuals of the possible psycho-physiological reactions involved in extreme recreation is crucial. This approach will lower the impact of the stress of pre-starting expectations and promote optimum performance from the vital organs and systems during recreational activities.

CONCLUSION

Comparison of data collected before and after the extreme sports and recreation activities offered to each individual participant, as well as the acquisition of long-term data and statistical analysis of that data, indicates the formation of a long-term adaptive reorganisation body mechanism, expressed in a significant increase in the functional reserves of the organism, i.e., by 36% ($p > 0.5$). Metabolic improvements in the supply of vitals with nutrients and oxygen increased in energy potential by 24%. The main outcome of the study is the recommendation of a system of organisational and methodological principles for the preparation stage, ensuring maximum safety for the athlete or person undertaking sport and recreation activities under extreme conditions.

Maria Malashenkova is an associate professor at Unitec and has specialist teaching experience in human physiology, sport physiology, human ecology and anatomy, with a total of ten years' experience supervising undergraduate students. Her qualifications include Doctor of Biological Science, PhD (physiology) and Specialist in Physical Training and Sport. Her doctorate dissertation was entitled "System of mass sports promotion and use of alpine climatic resorts' recreational potential." Her PhD dissertation dealt with "Comparative characteristics of the human organism's physiological response to extreme tourism activity." She has 45 published scientific works including a monograph, 13 articles in leading journals, and abstracts of reports in scientific digests.

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