Research Article

A mathematical model for influence of physical exercises on psychophysiological adaptation of international students to learning performance at universities

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ABSTRACT

Peculiarities of influence of physical exercises and sports activities on psychophysiological adaptation (PPA) of international students to learning performance at Russian universities are considered. A mathematical model establishing relations between adaptation rate of international students and their physical activity level is proposed. The model is represented by a single ordinary differential equation with a boundary condition at the initial instant of time. The sought-for function in the equation is the level of PPA. Graphs explaining the principle of work of the model are included. Optimum physical loading for individual, group, and sports exercises is determined through analysis of results obtained using the developed model. A conclusion is drawn on the necessity of group and individual physical exercises with regularity ranging from 4 to 8 h per week depending on the intensity of sports loading. Potential applications of the model to solving problems other than the problem of adaptation of international students to studying at universities are outlined.

KEY WORDS: International students, Mathematical model, Physical exercises, Psychophysiological adaptation

INTRODUCTION

Adaptation to a foreign culture environment represents one of the major problems encountered by international students. From the very 1st day of stay at an institution of higher education, international students reside in an unaccustomed sociocultural, strange language, and ethnic environment, to which they need to adapt in the shortest possible time.

The adaptation process itself is quite complicated and includes several types of adaptation: Physiological, individual psychological, social psychological, ethnopsychological, cultural, communicatory, and other types of adaptation.[1] These types of adaptation, especially at the initial stage of studying, manifest themselves simultaneously and represent serious obstacles in both informative and communicatory activity. Therefore, determining factors promoting the increase of efficiency and acceleration of adaptation processes of international students are an integral part of a solution to the problem of adaptation of this contingent of students.

It is worth noting that in the worldwide science the problem of adaptation is an object of investigation for many fields of science: Pedagogics, psychology, biology, physiology, philosophy, and sociology. It is important to know that representatives of all scientific directions unanimously recognize that aspiration of an organism to restore and preserve "dynamic balance" with the surrounding (social) environment is the main driving force of the adaptation process.

As for the Russian school of thought, investigation of the adaptation phenomenon in pedagogics, psychology, and medical science is connected, in the first place, with names of the following Russian scientists: N. E. Vvedensky, I. A. Davydov, I. P. Pavlov, I. M. Sechenov, and A. A. Uhtomsky. The dominating role of organism's psychophysiological function in triggering the adaptation mechanisms was analyzed in works of Russian scientists: F. B. Berezin, C. P. Korolenko, and V. I. Medvedev.

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Among psychologists and sociologists from countries other than Russia, the following scientists participated in developing the adaptation concept: D. Watson, N. Miller, D. Dallard, D. Homans, R. Sirs, B. Skinner, G. Tard, M. Veber, R. Merton, D. Mid, T. Parsons, and L. Filis. It is worth noting that systematic studies of problems of social and psychological adaptation of international students appeared only after 1950. Combination of factors exerting influence on well-being of a student in a foreign culture environment has received the name "cultural shock.[2,3]" Historical development of "conventional" theories of cultural shock has led to emergence of modern theoretical approaches, such as "culture learning," "stress and coping," and "social identification". The approaches provided the theoretical basis for the effective, behavioral, and cognitive concept of overcoming the cultural shock and adaptation of international students to new conditions of housing and studying.[4]

Most scientific investigations in the field of adaptation of international students concerned pedagogical, psychological, and social aspects of this problem.[5] Therefore, at the heart of principles of modeling the adaptation processes, as a rule, there were various psychological and pedagogical conditions.[6,7]

Authors of the present work give prominence to psychophysiological adaptation (PPA) from a variety of other types of adaptation and consider it as the most essential component of the entire adaptation process. Unlike most research investigations, which are based on statistical analysis, in the present work, a mathematical model representing a boundary value problem for an ordinary differential equation is proposed. The model contains a large number of various parameters, determination of which depends on specific personalities, new and previous conditions of a student's activity. The parameters characterize, in the first place, resistance and reactivity of an organism to a new environment and various physical activities as well as biological rhythms of the organism.

Graphs explaining basic provisions of the model are provided in the paper. The most optimum physical activity of an international student for concrete values of parameters of the model is defined. It is concluded that, for improvement of processes of PPA, it is desirable for a student to do physical exercises not only in the framework of the educational process but also to additionally attend some individual classes. It is also concluded that one more factor, positively influencing the adaptation, is having, at least, minimum participation in various sports exercises.

STATEMENT OF PURPOSE

PPA

Psychophysiological aspects of adaptation of international students have found the best reflection in works of Russian researchers; due to their efforts, the defining role of the psychophysiological sphere in the processes of adaptation of international students has become well-accepted.[8] We believe that adaptation begins with stages of biological (physiological) and psychological adaptation; social adaptation needs to be considered as the final stage of adaptation of an international student to studying in a foreign culture environment.

As investigations show, the period of PPA of international students consists of two periods: Unstable adaptation (1st and 2nd years of studying) and stable adaptation (starts in the 3rd year of studying).[8] Therefore, search for the means influencing the time (rate) of stabilization of adaptation processes represent one of the main objectives for investigations of this kind.

A literature survey has shown that practitioners underestimate the influence of physical activity on adaptation processes of international students although reserves for increasing efficiency of the process of adaptation to studying lie exactly here. Physical exercises represent a powerful tool for recovery of psychophysical well-being of international students, which helps them to cope with problems of social and individual psychological adaptation.[9,10]

We believe that, for achieving optimum indicators of PPA process rates, motion regimen of international students must be presented by, at least, three types of physical activity: Group exercises, individual (self-determined) exercises, and sports exercises (participation in sports competitions).

During group exercises, physical activity in the form of cyclic physical exercises with moderate loading as well as conjoint group activity of international students, especially in the form of action-oriented and sports games must be dominating.[9]

As is known, for achieving stable adaptation, a large role is played by the rate of mobilization of physiological reserves and adaptive mechanisms. Therefore, the more slowly an increase of physical activities occurs, the easier an organism will adapt to them. It is exactly what we take into account when selecting a mode and a form of physical exercises since at sudden change of duration or intensity of physical exercises, development of maladaptation can take place. It is important to mobilize and use physiological reserves during exercises for maximum adaptation to movements as well as to expand reserved opportunities of an organism for an increase of its resistance to the influence of various stress factors not only during physical exercises, individual activities, trainings, and competitions but also during everyday life.[11]

Adaptation of an organism to influences of the ambient environment also depends on corresponding cyclic fluctuations in a change of rates of biological reactions (biological rhythms). It is important to consider it when developing a mathematical model for PPA. If regularities of biological rhythms are known, it is possible to prevent or reduce negative adaptive shifts, which can manifest themselves during physical and sports exercises.

As for questions of developing mathematical models for the processes under consideration, no studies of that kind, to the best of our knowledge, have ever been reported in the open literature up to now. In the context of the present work, a certain interest was caused by an appeal of the authors to problems of developing models of adaptation, including an appeal to studying at institutions of higher education and mathematical modeling in physical training.[12-14]

In our opinion, developing a mathematical model of the influence of physical exercises on PPA of international students to studying represents one of the perspective directions of improvement of the pedagogical process.[15] It allows creating an algorithm of total physical activity of students providing an optimum flow of adaptation processes.

MATHEMATICAL MODEL OF PSYCHO-PHYSIOLOGICAL ADAPTATION

At first, we will establish general principles needed for developing a model of adaptation. We will assume that PPA values vary within the interval [0, 1]. Moreover, the PPA value $u(t) = 0$ corresponds to a condition of complete maladaptation of a personality, and the PPA value $u(t) = 1$ corresponds to absolute adaptation.

It is known that the rate of PPA's change decreases when PPA approaches the boundary values. Indeed, it means that it is more difficult to bring a more disbalanced or more adapted organism out of its state.

A similar correlation between the rate of PPA's change and PPA can be established through the following Bernoulli equation:

$$u'(t) = a(t)u(t)(1-u(t)) \qquad (1)$$

Where $a(t)$ is a coefficient responsible for adaptation properties of an organism. In general, it represents a time-dependent function. If $a(t)$ is constant, then the equation (1) can be solved explicitly to obtain the following equation:

$$u(t) = \frac{e^{at}}{C+e^{at}} \qquad (2)$$

Where C is a constant defined by a boundary condition. It is convenient to use the magnitude of adaptation at a zero time point as a boundary condition, i.e. $u(0) = u_0$. Then, an expression for C takes the form: $C = (1-u_0)/u_0$. Since C is nonnegative, then the value of u_0 will be in the range: $0 \le u_0 \le 1$. More details on properties of equation (1) and its solutions (2) can be found.[16]

Graphs of $u(t)$ for various values of adaptation coefficients (AC) $a(t) = a_0$ are shown in Figure 1. All the curves are monotonous and the value of $u(t)$ changes from an initial value of adaptation $u_0 = 0.5$ to a final value $u_0 = 0$ or $u_0 = 1$. Moreover, a greater value of the parameter $a_0 > 0$ leads to a faster rate of complete adaptation, i.e., to the asymptote $u(t) = 1$; a negative value leads to maladaptation, i.e. to the asymptote $u(t) = 0$.

We will consider a situation, in which a person and adaptation properties associated with the person $a(t)$ are exposed to cyclic oscillations. It will be assumed that the organism is in adaptation equilibrium, and the only factor, to which it is exposed, is cyclic oscillations. Then, AC can be written in the form: $a(t) = b \sin ct$. In this case, equation (1) can be also solved explicitly as follows:

$$u(t) = \exp\left\{-\frac{b}{c}\cos ct\right\} \Big/ \left(C + \exp\left\{-\frac{b}{c}\cos ct\right\}\right) \qquad (3)$$

The parameter c can be chosen as $c = \pi/2$ (week^{-1}), which corresponds to a 4-week cycle.

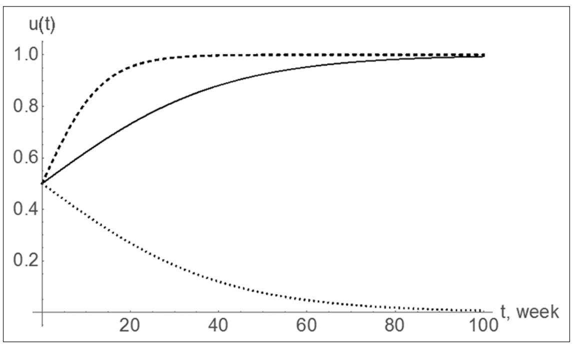

Figure 1: Dependence of adaptation $u(t)$ on time t for the case of a constant adaptation coefficient a_0. Initial adaptation is $u_0 = 0.5$. The solid line corresponds to the case of $a_0 = 0.05$, the dashed line is for $a_0 = 0.15$, the dotted line is for $a_0 = -0.05$

We will consider a more general case, in which the factors stimulating the adaptation with cyclic oscillations will be presented. Then, equation (1) will take the following form:

$$u'(t) = (a+b \sin ct)u(t)(1-u(t)) \quad (4)$$

Moreover, an explicit solution to the equation becomes as follows:

$$u(t)=\exp\left\{E-\frac{b}{c}\cos ct\right\}/\left(\exp\left\{-\frac{b}{c}\right\}+\exp\left\{at-\frac{b}{c}\cos ct\right\}\right) \quad (5)$$

Results of calculations of PPA through expression (5) are presented in Figure 2. Unlike graphs presented in Figure 1, curves of Figure 2 are not monotonous and oscillate; amplitude of the oscillations depends on values of the oscillation coefficient b.

MATHEMATICAL MODEL OF PSYCHO-PHYSIOLOGICAL ADAPTATION AT THE PRESENCE OF PHYSICAL ACTIVITIES

We will consider the influence of physical activities on AC. Zero influence is assumed for zero activity, and AC is assumed to increase with increase of activities and to reach a maximum value. The following function is selected:

$$f_k(x_k)=\alpha_1^k \frac{x_k}{x_k+\alpha_2^k} \quad (6)$$

Where parameter α_1^k corresponds to the maximum value, AC tends to reach this asymptotic value when large physical activities are present; α_2^k characterizes the degree of dependence of AC on activity's type (at large values of α_2^k, growth of the curve with increase of x_k occurs more slowly).

Graphs of AC for different types of physical activities are shown in Figure 3. AC for sports activities (the dotted line) increases faster, but it provides a smaller contribution to adaptation at the maximum activity. AC for group activities has an identical maximum value coinciding with that for individual activities, but it grows most slowly.

Next, we will touch on questions of the negative influence of various processes connected with physical exercises on adaptation characteristics. First, we will consider hypodynamia. For shortage of movement, we obtain a negative value of AC. We describe the process function in the following form:

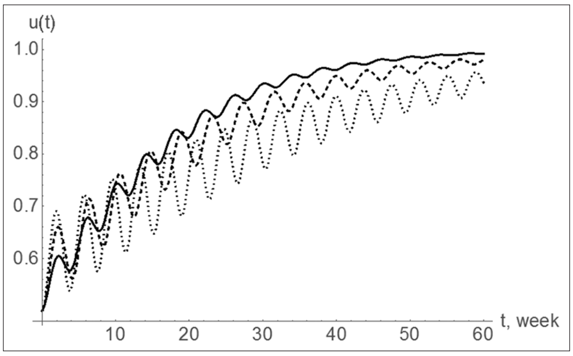

Figure 2: Dependence of adaptation u(t) on time t for the case of an oscillating adaptation coefficient a(t). Initial adaptation is $u_0 = 0.5$. The solid line corresponds to the case of a = 0.08, b = 0.2, c = π/2, the dashed line is for a = 0.06, b = 0.4, c = π/2.1, the dotted line is for a = 0.04, b = 0.6, c = π/1.9

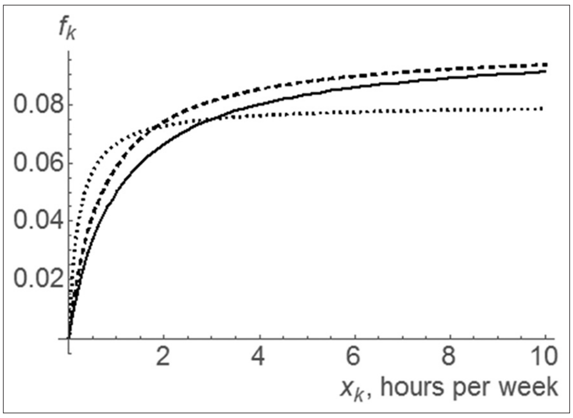

Figure 3: Functions of positive influence on PPA $f_k(x_k)$. The solid line corresponds to group activities ($\alpha_1^1=0.1,\ \alpha_2^1=1$), the dashed line is for individual activities ($\alpha_1^2=0.1,\ \alpha_2^2=0.7$), and the dotted line is for sports activities ($\alpha_1^3=0.08,\ \alpha_2^3=0.2$)

$$g_1(y^1)=g_1(x_1+\beta_1^1 x_2+\beta_2^1 x_3)=\begin{cases}-\beta_3^1(y^1-\beta_4^1)^{\beta_5^1}, & y^1<\beta_4^1,\\ 0, & y^1>\beta_4^1\end{cases} \quad (7)$$

The following values for the coefficients are adopted: $\beta_1^1=1.5,\ \beta_2^1=3.0,\ \beta_3^1=0.06,\ \beta_4^1=3.0$. In this case, 3 h of group activities per week will be sufficient to take off a negative influence of hypodynamia. On the other hand, 2 h of individual activities or 1 h of sports activities will also be sufficient for removing hypodynamia's influence. Combined options for activities are also possible. For example, one and a half hours of group activities and half an hour of sports activities will provide the same effect.

The second negative effect comes from following physical defatigation:

$$g_2(y^2) = g_2(x_1 + \beta_1^2 x_2 + \beta_2^2 x_3)$$
$$= \begin{cases} -\beta_3^2 (y^2 - \beta_4^2)^{\beta_5^2}, y^2 > \beta_4^2, \\ 0, y^2 < \beta_4^2. \end{cases} \quad (8)$$

Both of these functions of negative influence are shown in Figure 4; values of the coefficients are following: $\beta_1^1 = 1.5$, $\beta_2^1 = 3.0$, $\beta_3^1 = 0.06, \beta_4^1 = 3.0$, $\beta_1^2 = 2.5$, $\beta_2^2 = 5.0$, $\beta_3^2 = 0.1$, $\beta_4^2 = 14$, $\beta_5^2 = 1.5$. The value $\beta_2^1 = 3.0$ implies that activities of <3 h per week lead to hypodynamia, $\beta_4^2 = 14$ implies that activities of more than 14 h per week lead to defatigation. Thus, we consider that physical activities of 3-14 h per week do not provide any negative effects.

Third, we take into account the negative effects arising from intensive physical activities when a person is not related to sports; in other words, we consider minuses of "excessive" sports activities for an unprepared organism. We describe this effect using the following function:

$$g_3(x_3, y^3) = g_3(x_3, x_1 + \beta_1^3 x_2)$$
$$= \begin{cases} -\beta_2^3 (x_3 - \beta_3^3 y)^{\beta_4^3}, x_3 < \beta_3^3 y^3, \\ 0, x_3 > \beta_3^3 y^3 \end{cases} \quad (9)$$

Taking into account the reasons given above, the formula for AC takes the following form:

$$a_0 = \sum_{k=1}^{3} f_k(x_k) + \sum_{k=1}^{2} g_k(y^k) + g_3(x_3, x_1 + \beta_1^3 x_2) \quad (10)$$

We find the maximum value of a_0 determined by formula (10). For this purpose, we carry out calculations for values of the coefficients given above as well as for $\beta_1^3 = 1/3$, $\beta_2^3 = 0.1$, $\beta_3^3 = 1/9$, $\beta_4^3 = 2.0$.

The maximum value of a_0 = 0.22 is achieved at x_1 = 4.5 h per week, x_2 = 2.2 h per week, and x_3 = 0.8 h per week. The value a_0 = 0.2, which is slightly smaller than the maximum value, forms the surface reminding an upside-down mushroom hat in hyperplane (x_1, x_2, and x_3). Crosscuts created by the surface for various values of x_3 are shown in Figure 5.

The analysis of graphs of Figure 5 shows optimum ratios of group and individual activities at the fixed sports activities. For example, at half-hour sports activities per week (dashed line), the curve forming an isoline can be divided into three components: Vertical (on the left), horizontal (in the lower part), and inclined line (in the upper part). The horizontal part demonstrates that individual activities of 1 h per week and group activities of 4-9 h per week give AC equal to 0.2. The vertical component shows that 2 h per week of group activities and 2-4 h per week of individual activities yield the same result. From here, it is possible to draw a conclusion that the total number of hours of non-sports activities has to make, at least, 4-5 h per week. The optimum time of non-sports activities increases until 7-8 h at the decrease in sports activities until 12 min per week.

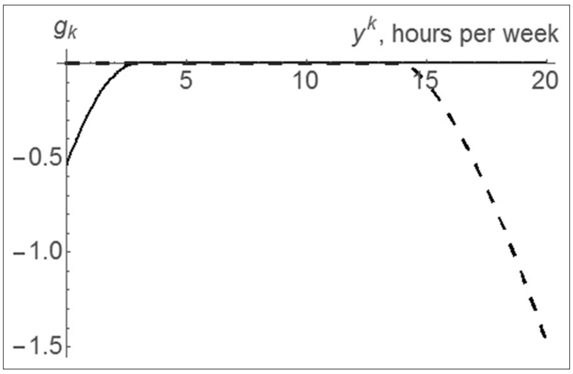

Figure 4: Functions of negative influence on PPA g_k (y^k). The solid line corresponds to influence of hypodynamia, and the dashed line is for excessive activities

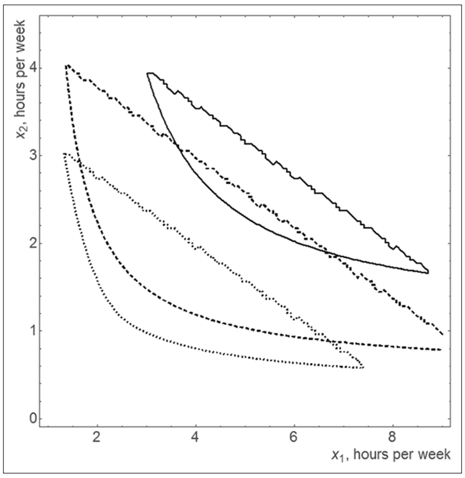

Figure 5: Contour lines for a_0 = 0.2. The solid line corresponds to sports activities of 12 min per week (x_3 = 0.2); the dashed line is for 30 min per week (x_3 = 0.5); the dotted line is for 1 h per week (x_3 = 1.0)

We note that values a_0 = 0.2 are not reached at sports activities of <8-9 min per week. Much worse results are obtained in the absence of individual or group activities. Thus, the optimum growth of PPA is reached at the presence of all types of physical activities. The smallest (worst) values of AC are reached in the total absence of group activities.

CONCLUSIONS

A mathematical model accounting for the influence of physical and sports exercises on PPA of international students to studying at universities was developed. The model is represented by a single ordinary differential equation with a boundary condition at the initial instant of time. Analysis of the developed model has allowed determining optimum physical loading for individual, group, and sports exercises.

In particular, it was revealed that optimum total loading for individual and group exercises makes 4-8 h per week. At that, group exercises are most preferable. In addition, it was revealed that having, at least, minimum sports loadings is extremely desirable for adaptation.

It is worth noting that, for gaining a better understanding of the process of general adaptation, it makes sense to consider a model that includes various components of adaptation along with interactions between the components themselves and their connection with physical exercises.

It is also noteworthy that the developed model can be adjusted not only to solving the problems of adaptation of international students to studying at universities but also to solving the problems of adaptation of any individuals to working at a new work environment. It is becoming more and more essential nowadays when new international corporations are created regularly, educational programs are globalized, and geographical expansion of labor markets occurs followed by the so-called high global labor turnover.

Results of the investigation can be potentially used by the Ministries of Health, Education, and Sport when selecting the educational programs accounting for the adaptation specifics of international students as well as by scientists-psychologists working in the field of developing techniques for decreasing stresses of patients (in particular, of international students).

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