Original Paper

Fundamentals of Chaos and Self-Organization Theory in Sports

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Keywords

Sports · Basketball · Piterbasket · Synergetics · Chaos and self-organization theory · Quasi-attractors · Psychophysiology · Pedagogical synergetics

Abstract

This paper describes the development of a new team sport called “piterbasket,” which has been secured by a patent. The importance of this type of adaptive physical activity for the quality of life of the general population, including physically challenged people, is demonstrated. This study provides the most recent data on pedagogical synergy in sports on the basis of the chaos and self-organization theory. We established the importance of educational and training processes for the structural harmonious organization of natural systems and the cerebral cortex for scientific improvement; additionally we carried out a synergy analysis of physiological bases of visual and acoustic perceptions which organize themselves on the basis of the interface of the functions of human body and functional activities of the brain.

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Published by S. Karger AG, Basel

Background

The initial training of an athlete in any sport is associated with a certain algorithm of mastering the theoretical knowledge step-by-step: the history of a certain type of sport, its main achievements, physiological features of various systems (blood circulation, respiration, locomotion, etc.), and the equipment necessary. A step-by-step system of monitoring received theoretical and practical skills is also proposed.

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Training productivity requires natural physical qualities and characteristics such as power, speed, and endurance, which are genetically predetermined. These heritable features are chaotic, and their further development or nondevelopment depends on external control actions of training processes. They are caused by the extent of interaction and mutual assistance of the trainer and the athlete based on a scientific approach to intensity and duration of physical training activities and to the development of coordination and locomotor function, and are related to metabolism regulation, depending on the nature of loadings. No less important is the psychological component of training in precompetitive and competitive periods, which is based on regular basic psychological preparation that forms steady motivation aimed at winning, overcoming uncertainty, the ability to concentrate mental efforts at the right time, and at overcoming anxiety or fear of eminent athletes at a competition.

The model of training in natural, physical, and mathematical sciences on the basis of synergetics is presented in the work of V.F. Gorbatyuk. It defines the potential of the constructive role of chaos in self-organizing systems and proposes a model of training and self-training for teachers on the basis of a cyclic model with a certain sequencing of obtaining and applying knowledge. The artificially induced chaos in groups of students brings about self-education and mutual training; this is good when studying a certain theoretical subject [1].

When training athletes initially chaos is present (uncertainty about physical and psychological standards, physiological statuses). In this case adding further elements of chaos is pointless. External control actions (dynamics of physical activities, psychological trainings, techniques of trainings, etc.) require that corrections of an athlete's body condition vector orientation are made, and parameters are determined if possible by means of developed and patent-secured programs. These programs represent a practical embodiment of fundamentals of the chaos and self-organization theory (CSOT) [2–5].

In the 1980s a theory of science called synergetics made its appearance; it dealt with cooperative actions in systems and showed that different areas of the sciences such as physics, chemistry, biology, psychology, and philosophy shared common laws. In particular, synergetics was the first theory of science that formulated universal laws of evolution applicable to both the physical (inert) and biological (live) world and society. Later it was replaced by CSOT [6].

Pedagogical synergy of sports as a system of interaction between the trainer and the athlete provides the effect of a new qualitative increase in a team's creative potential aimed at the *new purpose* implementation, that is, group training resulting in the approach to a supplementary creative product created by the efforts of students. *New means* provided by computer technology optimize communication and the development of an information product. Such pedagogics uses *new methods of information processing* for the implementation of training [7] and also accumulates the knowledge that reflects the features of human functional system activities. The activities of the trainer and the athlete are forms of creativity. The trainer's expertise deals with a material "subject," i.e. the biological object which should be transformed according to the objective (gaining a certain result). Nevertheless, it is obligatory when interacting with students, whose functional systems have chaotic alternativeness and can provide unpredictable results.

The fact that synergetics is the third global paradigm (historically, the first one was deterministic and the second was stochastic) has been justified by a large bulk of data. The underestimation of this fact not only by scientists but also by the intellectual community on the whole has slowed down the dynamic development of sports and mankind in general [8]. In science complete certainty dominates within the deterministic paradigm, partial uncertainty within the stochastic paradigm, and complete uncertainty within the synergetic paradigm. Viewed from a position of synergy analysis, physiological bases of visual perception in the

training of athletes confirm one of the basic principles of the existence of complex human measuring systems. These are self-organizing [8]. This phenomenon represents an inherent quality of the athletes with the best achievements and records. The human body possesses self-organizing physiological systems at different levels, including the brain activity level, providing visual perception of harmonious movements in training and competition periods and representing the base for implementation of pedagogical ideas receiving a powerful tool for the achievement of the purposes. The conjugation of the functions of the human body with the functional activity of the brain, which determines the features of the locomotor (musculomotive) system of an individual and the character of the esthetic perception of the surrounding world by the visual apparatus, must be taken into account when teaching various sports, because even insignificant details can dramatically change the character of the athlete's training.

Every successful athlete is unique, and his or her techniques differ sometimes radically from those considered to be conventional and deterministically caused. This very uniqueness is an example of organized chaos triggered by the physiological features (not by constants) of the body of an athlete.

It is our aim to give the "piterbasket" sport scientific grounds as a restorative and rehabilitation technology from the perspective of CSOT.

Materials and Methods

We propose to use a new method to identify matrixes of interattractive distances, which allows estimating the level of influence of physical activity on a human body [3, 8]. The method is used for group comparisons (of different groups of people, different types of impacts, different types of medical and health-improving actions, physical activities, or sports) where there are some data clusters (for each group of examined persons or for each type of impact for the group of examined persons), and these clusters are described by a certain vector of human body condition (VHBC). The integrative measure of the efficiency assessment of medical or sports impact is the degree of proximity (or, in contrast, of remoteness) of these 2 quasi-attractors that were compared in the phase space of conditions (PSC). Thus, each person with his or her own set of features (VHBC components) is recorded using a point in the PSC so that the group of examinees forms a certain "cloud" (quasi-attractor) in PSC, and different groups (because of different impacts on them) form different "clouds" or quasi-attractors in PSC. Zij distances (here i and j are the numbers of groups examined) between chaotic centers of these different quasi-attractors form Z matrixes which denote all possible distances between their chaotic centers, describing the condition of different groups of examined persons prior to sports impact and after it. Moreover, the maximum differences in the distance between chaotic centers of quasi-attractors of Zij of VHBC movement of the different groups of examined persons (before and after a specific impact) correspond to the maximum efficiency of a sporting event. Their reduction requires additional adjustment in the effect of sports [3, 9].

As part of this study research was carried out in groups of students at the universities of Surgut and Samara (young men and women) with different levels of physical training. Group 1 comprised students who engaged in team sports (soccer, volleyball, and basketball); group 2 comprised students who engaged in individual sports (weightlifting and power lifting); group 3 comprised students who did not engage in physical training (PT) regularly but only 2 times a week as part of a state-sponsored PT program. Following an examination young women were provisionally divided into 2 groups: group 4 comprised students who were engaged in team sports (soccer, volleyball, and basketball); group 5 comprised students who

did not engage in PT regularly but only 2 times a week as part of a state-sponsored PT program. The Samara students were divided into groups along similar lines. Vegetative nervous system indicators (Tables 1–4) are VHBC coordinates (h_0 = SYM [sympathetic]; h_1 = PAR [parasympathetic]; x_2 = INB [Bayevsky index]; x_3 = SPO₂; x_4 = pulse).

In addition, involuntary limb movements (tremorgram) of examined persons were registered by means of patented devices and according to the received amplitude-frequency characteristics of tremorgrams in x_1 coordinates – limb shift and $x_2 = dx_1/dt$ – speed of the shift; the calculation of quasi-attractors of VSS movement in the two-dimensional phase space of the vector $x = (x_1, x_2)$ was carried out. The size of the Shannon entropy for tremor and the size of Kullback-Leibler divergence were also calculated [10].

The development of the methods of CSOT in studying behavior patterns of any physiological functions of the human body became the basis for creating new software products, devices, and models in the field of CSOT [11, 12]. Data processing was carried out according to a special patented program and methods which provided the phase plane development (x_1 and x_2 coordinate = dx_1/dt) according to the received frequency characteristics, cinematograms, and values of speeds received from them (after signal differentiation). It allowed to determine of the border of the movement of the hand condition vector (during tremor) in the PSC and to assess the dimension of the PSC quasi-attractor in the boundaries of the motion of the vector [13, 14].

Compartment-and-cluster modeling of these processes [13, 15] was carried out simultaneously. Two approaches to modeling were initially possible: models at the one-cluster (effector) level, for example, in the form of three-compartment systems, and in hierarchical models. It is essential that such a hierarchical system does not have direct control character [15]. In research, the results of using one-cluster, three-compartment models to describe neuromotor compositions consisting of three blocks (compartments) [16] are presented; they were used within the frames of a stochastic approach.

Results

The analysis of matrixes of inter-attractor Z_{ij} distances between chaotic centers of VHBC quasi-attractors in trained and untrained young women and young men of the city of Surgut showed, when compared to the results of the representatives of Samara before and after presentation of loading in 5-dimensional phase space, that the smallest inter-attractor distance of $Z_{32} = 3.23$ c.u. occurred when comparing group 3 and group 5 of young men and young women, respectively, and the greatest distance of $Z_{21} = 41.10$ c.u. occurred when comparing sportswomen in group 4 and young men in group 2. In this comparison, differences in gender are less significant than the loading shown as reflected in Table 1.

An analysis of the matrixes of inter-attractor distances when differentiated by gender showed the greatest inter-attractor distance to be $Z_{12} = 444.05$ c.u. when comparing the young women in group 5 with the young men in group 1 after having applied loading and when under supervision, and the smallest distance was shown to be $Z_{31} = 22.07$ c.u. when comparing the young women in group 4 with the young men in group 3. As x_i acted: x_0 – SIM, x_1 – PAR, x_2 – INB (all in c.u.), x_3 – SPO₂ (contents of oxihemoglobin in blood of the persons examined [%]), and x_4 – HF (heartbeat frequency [beats/min]).

It should be noted that long inter-attractor distances are evident when comparing all groups of young men with the young women in group 4. The situation changed when loading was applied: long inter-attractor distances should be taken into account when comparing the groups of young men with the young women in group 5. These data provide evidence for the steady influence of physical activity on the functional systems of the organism parameters

Table 1. Matrixes of identification of Zij distances between chaotic centers of quasi-attractors of the body condition vector of trained (groups 1 and 2 of young men and group 4 of young women) and untrained (group 3 of young men and group 5 of young women) students of the city of Surgut before presentation of loading in 5-dimensional phase space

Young men before loading	Young woman before loading	
	group 4 examined	group 5 examined
Group 1 examined	$Z_{11} = 36.79$	$Z_{12} = 26.78$
Group 2 examined	$Z_{21} = 41.10$	$Z_{22} = 31.00$
Group 3 compared	$Z_{31} = 12.83$	$Z_{32} = 3.23$

Table 2. Matrixes of identification of Zij distances between chaotic centers of quasi-attractors of the body condition vector of trained (groups 1 and 2 of young men and group 4 of young women) and untrained (group 3 of young men and group 5 of young women) students of the city of Surgut after presentation of loading in 5-dimensional phase space

Young men after loading	Young woman after loading	
	group 4 examined	group 5 examined
Group 1 examined	$Z_{11} = 335.32$	$Z_{12} = 444.05$
Group 2 examined	$Z_{21} = 38.75$	$Z_{22} = 147.23$
Group 3 compared	$Z_{31} = 22.07$	$Z_{32} = 128.90$

Table 3. Matrixes of identification of Zij distances between chaotic centers of quasi-attractors of the body condition vector of trained (groups 1 and 2 of young men and group 4 of young women) and untrained (group 3 of young men and group 5 of young women) students of the city of Samara before presentation of loading in 5-dimensional phase space

Young men before loading	Young woman before loading	
	group 4 examined	group 5 examined
Group 1 examined	$Z_{11} = 2.33$	$Z_{12} = 10.64$
Group 2 examined	$Z_{21} = 29.60$	$Z_{22} = 39.03$
Group 3 compared	$Z_{31} = 11.91$	$Z_{32} = 2.56$

Table 4. Matrixes of identification of Zij distances between chaotic centers of quasi-attractors of the body condition vector of trained (groups 1 and 2 of young men and group 4 of young women) and untrained (group 3 of young men and group 5 of young women) students of the city of Samara after presentation of loading in 5-dimensional phase space

Young men after loading	Young woman after loading	
	group 4 examined	group 5 examined
Group 1 examined	$Z_{11} = 155.66$	$Z_{12} = 201.47$
Group 2 examined	$Z_{21} = 58.94$	$Z_{22} = 104.88$
Group 3 compared	$Z_{31} = 75.54$	$Z_{32} = 29.21$

of students being trained and also show a certain uniformity in the reactions to loadings of the functional systems of trained persons (Table 2).

When analyzing matrixes of Z_{ij} distances between chaotic centers of quasi-attractors of VHBC in trained and untrained young women and young men of Samara before the application of loading in the 5-dimensional phase space, the smallest was $Z_{32} = 2.56$ c.u. in comparison with groups 3 and 5 of young men and young women, respectively, was obtained (as also noted in a similar comparison in Surgut). When comparing group 1 with group 4, $Z_{11} = 2.33$ was obtained, and the greatest difference was shown when comparing the young sportswomen in group 5 with the young men in group 2 where $Z_{22} = 39.03$ c.u. (Table 3).

Table 4 describes the matrixes of inter-attractor distances when differentiated according to gender after loading. It can easily be noticed that the greatest inter-attractor distance $Z_{12} = 201.47$ c.u. is observed when comparing the young women in group 5 with the young men in group 1 when under supervision (the situation in Surgut was similar) and the smallest distance $Z_{32} = 29.21$ c.u. when comparing the young women in group 5 with the young men in group 3. The analysis showed similar results when comparing the young men and women in the 2 cities. However, in Samara the distance was twice shorter than in Surgut, which suggests that the influence of the conditions of accommodation on the parameters of their functional systems was huge.

Real biological dynamical systems (BDS) possess 5 basic (synergistic) characteristics, and their description should be consistent with the 13 main differences of random objects from objects with deterministic and stochastic characteristics. Real BDS are “scintillating” objects continuously evolving at the same time. This means (as a part of CSOT) that the state vector of any biological system (with complexity and synergy, and self-organizing characteristics) is permanently moving in PSC within certain volumes (called quasi-attractors) and these objects V_G (quasi-attractors) are drifting, too (BDS evolution). The simplest way of formalizing this is to define the parameters of quasi-attractors, to consider the distribution of VHBC as equal, and to substantiate scientifically the external controlling actions for the prediction of BDS behavior in PSC. However, we have to abandon the rule of three sigma (in stochastics, values beyond the three sigma are rejected), to introduce an analog for the law of large numbers in the CSOT, to consider 5 characteristics of real BDS as well as to strictly take into account all 13 main differences between CSOT and the determinist-stochastic approach [9, 12, 13, 17].

One of the main problems of the tremor organization and control is associated with the level (degree) of chaotic behavior taking place in the processes under consideration. In other words, arbitrary or involuntary movements underlie the postural tremor. However, this problem is related to broader theoretical assumptions and concerns the global problem of the role of chaos in the life support system of specific animal and human organisms in particular. For information on improving the physical and mental abilities of younger pupils when playing a modified piterbasket game, please see Kozhemov et al. [18].

In this pedagogical study, motor characteristics were tested as recommended [18–20]. As a result, we selected the following specialized tests:

- standing long-jump: “explosive power”
- shuttle run 3×10 m: speed
- balance test: “flamingo”
- small ball throwing: accuracy
- motor memory: carpal dynamometry
- attention tests: “entangled lines,” “correction task”
- test to assess verbal and logical thinking: “exclude words” and “choose the correct word”
- Kraepelin test: to determine concentration and quick-wittedness

The examination results obtained at the beginning of the experiment revealed that the pupils of the experimental and control groups showed no significant differences in terms of physical and mental characteristics.

An analysis of physical development indices after the second test at the end of the experiment revealed, almost for all tests, a significantly larger increase in the results of the experimental groups compared to those of the control groups in nearly all tests, including the standing long-jump, ball throwing, and the shuttle run 3×10 m ($p < 0.05$).

Final testing for mental agility (assessment of attention, thinking, quick-wittedness, and creativity) revealed a statistically significant improvement in the results of the experimental groups ($p < 0.05$) compared to the input diagnostic data in contrast to indicators obtained in the control groups ($p > 0.05$).

The results of the pedagogical experiment using the successive value method revealed that the fitness of children involved in the experiment improved in all classes during their years at school. Statistically reliable changes in most parameters were observed in the experimental classes, whereas in the control groups they were found only in the 3rd grade and were limited to the standing long-jump ($p < 0.05$) and to balance ($p < 0.01$).

The improvement in physical fitness of pupils in the experimental classes was on average 38% greater than in the control groups: the average improvement in the experimental groups was 67.7% whereas the average in the control groups was 29.6%.

Thus, at the beginning of the experiment the results of the standing long-jump were approximately equal in all groups and were in the experimental and control groups, respectively, 1st grade: 110 cm/117 cm; 2nd grade: 122 cm/123 cm; 3rd grade: 134 cm/137 cm; 4th grade: 140 cm/147 cm. At the end of the experiment, an improvement in the results of the control classes could only be measured in the 3rd grade (6.2%), whereas improvements in the 1st, 2nd, and 4th grades were statistically nonsignificant (4.91, 5.7, and 4.2%, respectively).

All results in the experimental classes were statistically significant, and their differences compared with the original results were: 1st grade: 13.2%; 2nd grade: 11.1%; 3rd grade 3: 9.8%; 4th grade: 7.97% ($p < 0.05$). This increase can be attributed to the large variety of motor speed-strength actions and jumps made by pupils during games. Numerous movements with changes of directions and stops typical for games specifically improved the shuttle run (3×10 m) rates. However, there were no statistically significant changes in speed rates in the control classes; some improvement can be related to the age and the biological characteristics of physical development. Speed rates in experimental classes increased in the 1st grade from 4.4 up to 5.9% and in the 2nd and 3rd grades from 5.75 up to 4.51% ($p < 0.05$).

Research data of the test for stable posture in the balance test, obtained at the end of the experiment, revealed a statistically valid improvement ($p < 0.05$) throughout all classes which followed the experimental program, whereas the control groups showed improvement only in the 3rd grade. The improvement in the results of the experimental groups at the end of the experiment was 54.8% in the 1st grade ($p < 0.05$), 42.4% in the 2nd grade ($p < 0.05$), 49.4% in the 3rd grade ($p < 0.05$), and 41.5% in the 4th grade ($p < 0.05$) versus the results in the control classes: 28.4% ($p > 0.05$), 25.9% ($p > 0.05$), 31.5%, and 17.7% ($p > 0.05$), respectively.

The nature of the changes in the results of motor memory (right and left hand) showed positive dynamics in all groups, but valid results were only obtained in the experimental groups. The difference in the results of motor memory (right hand) of 1st grade pupils was 64% ($p < 0.05$) better in the experimental classes (95.8% in experimental classes and 31% in control classes) as compared to 2nd, 3rd, and 4th grades; this test result was also better in the experimental classes: 84.5, 88.7, and 72% versus control class respondents with values of 37.5, 58.4, and 57.4%, respectively ($p < 0.05$). We obtained similar results after the analysis of motor memory indices of the left hand: all classes in the experimental groups performed better than those in the control groups.

A comparison of the results of throwing a ball (accuracy test) in the experimental and control groups showed that 1st grade pupils in the experimental group had improved their performance significantly by 86.7% ($p < 0.05$), whereas the control group had improved by only 36.4%. Pupils following the experimental program in the 2nd, 3rd, and 4th grade improved their performance by 83.7% ($p < 0.05$), 85.4% ($p < 0.05$), and 96.8% ($p < 0.05$) versus 50, 35.4, and 62.3% of those in the control groups, respectively. Significant changes in the results of small ball throwing in the experimental classes can be viewed as related to specific aspects of piterbasket, especially to multiple throws. Thus, the use of the author's technique, which was based on the use of a modified game – radial basketball, has significantly improved the physical fitness of students in the experimental classes. An analysis of test data assessing mental abilities, such as attention, thinking, quick-wittedness, and creativity, revealed a statistically relevant improvement in the results achieved in the experimental classes ($p < 0.05$) versus data obtained in the control classes ($p < 0.05$).

For example, a comparative analysis of the study results found that mental processes had positive dynamics in the experimental groups. A statistically significant improvement in concentration observed in the 1st grades was 42.9% ($p < 0.05$), and in 2nd grades it was 30.9% ($p < 0.05$); in the control group it was 22.9% ($p > 0.05$) and 16.2% ($p > 0.05$), respectively. In the 3rd and 4th grades it increased by 18.9 and 13.9%, respectively, in the experimental groups whereas the increase was 5.9 and 2.0% in the control groups.

Processing the test results that characterize the level of development in children's thinking ability indicated a relatively significant improvement in the results of the pupils in the 1st and 2nd grades of the experimental groups ($p < 0.05$). The improvement in the experimental groups in the 1st grade was 33.1%, in the 2nd grade 12.7%, in the 3rd grade 13.4%, and in the 4th grade 6.2%, and in the control classes it was 19.3, 10.2, 9.5, and 4.3%, respectively. These data are evidence of the effective use of a modified piterbasket game in experimental classes and of how it creates a favorable environment for creative thinking.

Processing results of tests of quick-wittedness revealed that they are statistically higher in experimental than in control classes. Thus, the increase was statistically higher in all classes and was 44.7% in the 1st grade, 26.9% in the 2nd grade, 20.9% in the 3rd grade, and 10.8% in the 4th grade versus 29.1, 20.7, 14.6, and 6.73% in the control classes, respectively.

Discussion

Physical exercises in the form of a competitive game (piterbasket playing) can restore and improve the sensorimotor activity of an athlete. Visual orientation, continuous monitoring of moving objects, timing, and methods of participation in a game situation activate visual-motor coordination mechanisms. This effect is observed particularly in the “eye-hand” system. Turns and rotations improve vestibular stability mechanisms. Manipulating, catching, passing, and throwing a ball into a ring increase tactile and kinesthetic sensitivity and lead to the development of more fine muscular differentiation of the effort. A major benefit of this type of game is to improve responsiveness and agility involving acceleration of analysis and synthesis compared to standard processes carried out in higher brain regions.

Such dynamics of organizational processes in the course of any training (especially, of piterbasket) was confirmed by the identification of the matrices of distances between attractors. Piterbasket competitions resulted in a complex impact on the improvement of motor and psychomotor functions, including emotional and intellectual areas. Interpersonal communication increases. This exercise in the form of a ball game has an enormous health potential, which can be used in different ways of psychophysical rehabilitation.

Statement of Ethics

The Ethics Committee of the Medical Institute, Tula State, approved the protocol of the present survey.

Disclosure Statement

The authors declare that there are no conflicts of interest regarding the publication of this article.

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