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Influence of background music on children's mathematical cognition ability

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Abstract. In order to improve the analysis effectiveness of the influence of background music on Children's mathematical cognition ability, a kind of analysis model for the influence of background music on children's mathematical cognition ability based on nonlinear multistep prediction of NARX neural network is proposed. Firstly, build the model for children's mathematical cognition ability issues from the angle of mathematical ability cognition map, and find a proper neural activity sequence which never happens before; Secondly, introduce the nonlinear prediction algorithm based on NARX neural network and make model simulation evaluation, to achieve the effective analysis for influence of background music on children's mathematical cognition ability. Finally, verify the effectiveness of the proposed method through the simulation experiment.

Key words. Background music, Children mathematics, Cognitive ability, Multistep prediction, Nonlinear.

1. Introduction

The music is an art reflecting the natural phenomena and social life as well as human thoughts and feelings by using the sound. The music education is a kind of aesthetic education activities with music as the art means and content, which is an important part of aesthetic education. Music education for preprimary children is a kind of education practice with the music able to be understood and accepted by the children as the art means and content for the children at 0 – 6 years old. The music education plays an indispensable positive role in the children body and heart development. Through all kinds of music activities, the good quality, positive thinking ability and good living habit of the children can be cultivated, to facilitate the healthy growth of the children. As one main approach for implementing the art education, the music education exerts certain advantage function in this

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aspect, which can directly influence the integrated development of children morally, intellectually, physically through the artistic image.

The music is best approach facilitating the brain development, while the music education can facilitate the wisdom development. It has been said “Music embodies the human wisdom.” The implementation of music activities can make the children’s brains build more and more complex neural relation, on account of that the right brain participates in the familiarity with melody, perception to rhythm and other music activities, while for the understanding of the relation between the music nature and music, the left brain plays a decisive effect, especially most musical instruments expressing music requires two-hand coordination activities to facilitate the excitement and thinking of left and right brain, so as to facilitate the whole-brain development. More than the ear and finger involved in, the music learning may also give rise to the whole body reaction. The singing or performances accompanied by the rhythm, dance and musical instruments require the coordination of children’s ears, eyes, brain and four limbs, which can cultivate the children’s keen sense and improve the flexibility of brain reaction. Exactly as what Sukhomlinskii said: “Music education is not just the education for musicians, but the human education at first.” Starting from the children’s interest, the teachers shall provide a comprehensive and broad vision for the children, enabling them to feel the music and appreciate music with pleasure in the environment full of music atmosphere, and further create the music. Hugo had said: “Music, character and mathematics are three keys to open the human intelligence.” At present, multiple researches have verified that, music learning activities give great assistance t the listening, motility, memory and mathematical ability of the preschool children. It is generally believed that, getting involved in the music from a young age not only can improve the children’s understanding and mathematical ability, but also quicken the speed to learn language. Hence, let the note become the children’s partner, let the children sing and dance in the music, and finally more potencies can be motivated. Guideline for Kindergarten Education (Trial) explicitly points out: “As the art is main approach to implement the aesthetic education, the emotion education function of art shall be fully exerted, to facilitate the formation of children’s healthy personality”. It follows that, the art education plays a crucial role in the children growth.

This paper analyzes and researches the influence of background music on children’s mathematical cognition ability based on the neural network, and meanwhile, in order to improve the accuracy of prediction analysis, it improves the neural network algorithm by using the nonlinear multistep prediction model. The experimental result shows that, the proposed method is of more excellent performance.

2. Introduction to cognitive map of children’s mathematical ability

2.1. Overview of cognitive map

The neuroscientists believe that, the rats’ hippocampus may form a cognitive map to represent the space environment. The concept of the cognitive map of children's mathematical ability was proposed initially by Tolma.n in 1948, for overall representation of space environment. His evidence is that, the rats may make the representation similar to the map for the space environment where they are to finish the space task, which is an opinion in contrast with the stimulating response theory. As mentioned above, O'Keefe et al found the place cells in the rat hippocampus. The place cell release is strongly relative to the position of animal in the space. Therefore, the researchers think that, the hippocampus is the part forming and maintaining the cognitive map, and meanwhile, the joint connection in the hippocampus also shows that, the hippocampus may form a geometric network, and as a nerve cell entity, form a chart to express the spatial map. The chart refers to a imaginary array of place cell cluster on the abstract plane, enabling every cell to be distributed on the position of maximum release rate when reflecting the plane into the real environment. Hence, the overall release in the chart is distributed around the imaginary position at the animal head. As long as the plane array of one neuron cell enables the group activity to be distributed around one specific center, it can be called as one activated chart. In the model proposed by Muller et al. and McNaughton, the chart is corresponding to one place cell set. In one appropriately connected chart, no matter whether this chart has any practical relation to the environment, the cell cluster activities are in localized distribution. In this case, even though there is no external input, there is the chart concept in the isolated network. The mainstream researches in recent decades are to set forth the dependence relation of hippocampus to the spatial position and the features of these activities. The experimental observation shows that, when the animals run, the theta rhythm oscillation of place cell relative to the local field potential releases successively, which is called as the phase deviation. This finding shows that, the asymmetric connection in hippocampus learns the time sequence, and meanwhile, it also shows that, the chart formation and space encoding contain the symmetric connection.

O'Keefe and Nadel proposed a cognitive map theory of children's mathematical ability in 1978, pointing out that the place cell cluster activities showed the position where animals are in form of map. This theory not only shows that, different place cell activities are corresponding to different space environments, and meanwhile, it also shows that, the relation among spatial position are encoded into the whole place cell cluster and stored into the different cell connection. Therefore, no matter whether there is the immediate stimulation input, the place cell all can release at the same time. Meanwhile, the whole map orientation may change, and this orientation change can be recorded after removing the stimulation. The system does not refer to the independently stored local information, but refers to the cognitive map of whole environment. In the cognitive map, no matter whether there is the external stimulus, the spatial position information will be stored, and updated according to the external stimulus information at the same time. This internal map can be built from the spatial memory information set, or built based on the pre-configured spatial model. The concept of mathematical cognition ability exploration was proposed firstly by J.J.Hopfield. He had ever explained the mathematical cognition ability exploration in this way that when we are walking at school and being asked about how to go to the library, we may consider the position where we are and the position where the library locates, explore the possible path in the brain, and finally select a simple path to the asker. During this process, we are not required to know the answers of all path problems in advance, on the contrary, we just need to know the basic knowledge of relation among different positions, and solve a new path task in the brain by virtue of the knowledge. From the more abstract layer, all imagines relevant to multiple possibility future, all plans to behavior chain for achieving a new target, even those relevant to the thinking, can be called as the mathematical cognition ability exploration. The time scale of children's mathematical cognition ability exploration is from one second to several minutes, which contains the neuron activity evolution when animals are at quiescent state, normally following the behavior activities directly relevant to the exploration activities. If condition allowed, compared with the physical exploration, the mathematical cognition ability exploration can solve the same spatial problem faster, more efficiently (save the energy) and more safely. The mathematical cognition ability exploration is different from the "spirit time travel", of which the latter one is a generalization of significant physical exploration made before, while the mathematical cognition ability exploration is to find a proper nerve activity sequence never happened before.

2.2. Concept of nerve energy field and gradient

The concept of filed in the children's mathematical ability cognition normally is to assign a determined scalar (scalar field) or vector (vector field) for every point in one spatial sub-set. For example, the vector field on the plane can be regarded as the vector determined by assigning one size and direction for every point on the plane (Fig.2.8). The concept of field is normally used in the modeling, and a large number of excellent models are built in form of field in the physics, for example, the temperature distribution in the space consists of the temperature (scalar) field, flow velocity and direction comprise the flow (vector) field, the distribution of the size and direction of some conservative forces in the space constitutes the vector field, including the famous gravitational field and electric field, etc.

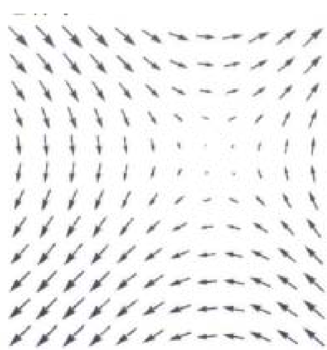

Fig. 1. Nerve energy field

The vector field of children's mathematical ability cognition also can be built by acting the gradient operator on one scalar field. Namely, the vector field V on the open set S defined in the n dimension space is called as one gradient field or conservative field. If there is a real-valued function (or scalar field) f on S, make:

$$V = \nabla f = \left(\frac{\partial f}{\partial x_1}, \frac{\partial f}{\partial x_2}, \cdots, \frac{\partial f}{\partial x_n} \right). \tag{1}$$

Therefore, in short, the scalar field gradient of children's mathematical ability cognition constitutes a vector field. The gradient vector represents the direction fastest value change between two contour surfaces in the scalar field. This feature is normally used in the gradient descent algorithm.

3. Prediction model

3.1. Nonlinear long time-domain prediction model

In order to build a long time-domain prediction model for nonlinear system of children's mathematical ability cognition, in the past researches, the researchers build a nonlinear multistep prediction model with relatively good prediction effect [7, 8] through recursive call of two-layer BP neutral network, and the structure chart of such prediction model is as shown in Fig.2.

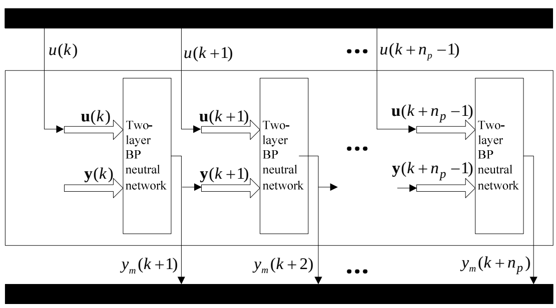

Fig. 2. Structure chart for multistep prediction model based on recursion BP neural network

However, there is one obvious defect in such prediction model, namely, the prediction time domain cannot be too long. In case the prediction time domain is too long, the prediction error at initial stage may constantly accumulate, making the prediction performance and accuracy decrease rapidly, directly influencing the effect of prediction control algorithm. If requiring the long time-domain prediction in the practical application, new nonlinear multistep prediction models must be researched and designed, to overcome the influence of prediction error accumulation.

NARX neutral network is a kind of dynamic neutral network in clear structure. It introduces the output vector of BP neutral network into the input vector through external feedback after delay remaining. Therefore, this paper replaces the two-layer BP neutral network with NARX neutral network to make long time-domain prediction, and gives out a kind of nonlinear multistep prediction model based on

NARX neutral network.

It can be known from the Fig.2 that, assuming the current time is k, the input and output relation of nonlinear multistep prediction model based on two-layer BP neutral network at the time $k+s$ is shown as follows:

$$y_m(k+s) = \sum_{i=1}^{S^1} w_{1,i}^2 f_1 \left[n_i^1(k+s-1) \right] + b_1^2 \, . \tag{2}$$

By observing the mathematical form of children's mathematical ability cognition in the Formula (1), it can be known that, the same prediction effect can be obtained if making the recursive calculation by using the NARX neutral network with its static part divided into two-layer BP network as shown in Fig. (2).

3.2. Model identification

Then, the identification method for nonlinear multistep prediction model based on NARX neutral network will be given, enabling the identified NARX neutral network to well overcome the prediction error accumulation and meet the purpose of relatively long time-domain output prediction.

Firstly, only considering the sequential relationship contained in the Formula (1), these two equations can be simplified as follows:

$$y_m(k+1) = \sum_{i=1}^{S^1} w_{1,i}^2 f_1 \left[n_i^1(k) \, . \right] + b_1^2 \tag{3}$$

$$n_i^1(k) = \sum_{j=1}^{n_u} w_{i,j}^1 u(k-j+1) + \sum_{j=1}^{n_y} w_{i,j+n_u}^1 y(k-j+1) + b_i^1 \, . \tag{4}$$

Secondly, design the input vector and target vector of single training sample of the prediction model as follows:

$$\mathbf{u} = \left[u(k), u(k-1), \cdots, u(k-n_u+1), y(k-n_y+1), \cdots, y(k-1), y(k) \right]^T \, . \tag{5}$$

$$\mathbf{t} = \left[y(k+1) \right]^T \, . \tag{6}$$

Then, assume that there are n_t samples in the training sample set, and select the performance index function as follows:

$$J = \sum_{m=1}^{n_t} \sum_{n=1}^{n_p} \left[y_m(k+n) - y(k+n) \right]^2 = \sum_{m=1}^{n_t} \sum_{n=1}^{n_p} \left[E(k+n) \right]^2 . \tag{7}$$

Calculate the one-order partial derivative of the structural parameter vector θ of the performance index function J on the NARX neutral network as follows:

$$\frac{\partial J}{\partial \boldsymbol{\theta}} = \sum_{m=1}^{n_t} \sum_{n=1}^{n_p} \left[y_m(k+n) - y(k+n) \right] \frac{\partial E(k+n)}{\partial \boldsymbol{\theta}} \,. \tag{8}$$

The structure parameter vector θ in the Formula (11) comprises following five kinds of parameters:

$$\left\{ w_{i,j}^1 \left| 1 \le i \le S^1, 1 \le j \le n_u \right. \right\} . \tag{9}$$

$$\left\{ w_{i,j+n_u}^1 \left| 1 \le i \le S^1, 1 \le j \le n_y \right. \right\} . \tag{10}$$

$$\left\{ b_i^1 \left| 1 \le i \le S^1 \right. \right\} . \tag{11}$$

$$\left\{ w_{1,i}^2 \left| 1 \le i \le S^1 \right. \right\} . \tag{12}$$

Respectively calculate the one-order partial derivative of the error function $E(k+n)$ against these five structure parameters as below:

$$\frac{\partial E(k+n)}{\partial w_{i,j}^1} = \sum_{i=1}^{S^1} w_{1,i}^2 \times u(k+n-j) \times \frac{\partial f_1 \left[n_i^1(k+n-1) \right]}{\partial n_i^1(k+n-1)} \,. \tag{13}$$

$$\frac{\partial E(k+n)}{\partial w_{i,n_u+j}^1} = \sum_{i=1}^{S^1} w_{1,i}^2 \times y(k+n-j) \times \frac{\partial f_1 \left[n_i^1(k+n-1) \right]}{\partial n_i^1(k+n-1)} \,. \tag{14}$$

$$\frac{\partial E(k+n)}{\partial b_i^1} = \sum_{i=1}^{S^1} w_{1,i}^2 \times \frac{\partial f_1 \left[n_i^1 \left(k+n-1\right) \right]}{\partial n_i^1 \left(k+n-1\right)} \,. \tag{15}$$

$$\frac{\partial E(k+n)}{\partial w_{1,i}^2} = f_1 \left[n_i^1(k+n-1) \right] \,. \tag{16}$$

$$\frac{\partial E(k+n)}{\partial b_1^2} = 1 \,. \tag{17}$$

The one-order partial derivative vector of the performance index function J against the structure parameter vector $\boldsymbol{\theta}$ can be calculated out. Finally, utilize the steepest descent method as shown in Formula (16), and solve the optimal structure parameter of NARX neutral network through the gradual iteration.

$$\boldsymbol{\theta}_{i+1} = \boldsymbol{\theta}_i - \alpha \times \frac{\partial J}{\partial \theta_i} \,. \tag{18}$$

Of which, α is the learning rate of steepest descent method.

Hereon, only the principle and brief process for training NARX neutral network by using steepest descent method is given. Upon practical use, many details shall be considered, including the sampling and pretreatment of training samples, initialization of neutral network weight and bias, and the learning rate selection of weight and bias, etc.

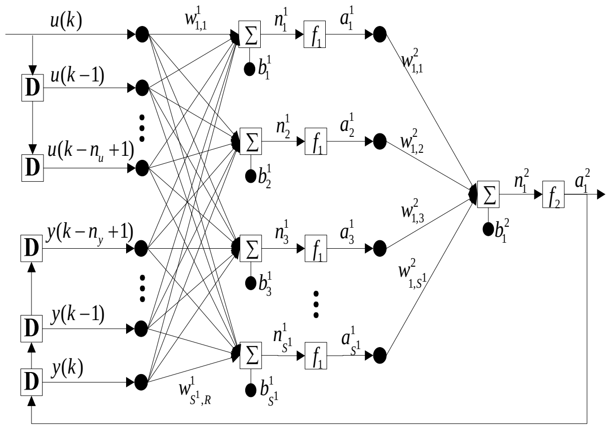

Fig. 3. Structure chart for NARX neural network

In Fig.3, n_u represents the input orders of nonlinear system; n_y represents the output orders of nonlinear system; n_u and n_y can be estimated through the model order identification method; $R = n_u + n_y$ represents the input number of the two-layer NARX neutral network; $w^1_{i,j}$ represents the connection weight between the ith neuron in hidden layer of NARX neutral network and the jth element in input vector; S^1 represents the number of neurons in the hidden layer of NARX neutral network; S^1 represents the bias of the ith neuron in the hidden layer of NARX neutral network; n^1_i represents the net input of the ith neuron in the hidden layer of NARX neutral network; $f_1(\cdot)$ represents the transmission function of the neuron in the hidden layer of NARX neutral network, at which Tan-Sigmoid function is used; a^1_i represents the output value of the ith neuron in the hidden layer of NARX neutral network; $w^2_{1,i}$ represents the connection weight between the output neuron of NARX neutral network and the ith neuron in the hidden layer; b^2_1 represents the bias of output neuron of the NARX neutral network; n^2_1 represents the net input of output neuron of the NARX neutral network; $f_2(\cdot)$ represents the transmission function of output neuron of the NARX neutral network, at which the pure linear function is used; a^2_1 represents the output value of output neuron of NARX neutral network, and also represents the prediction output value $y_m(k+1)$ of NARX neutral network at the time $k + 1$.

Assume that $n_p (n_p \geq 1)$ represents the prediction time-domain and s in the Formula (1) and (2) traverses any one element in $s = 1, 2, \cdots, n_p$, a n_p-dimensional prediction output vector $\mathbf{y}_m(k+1)$ begun at time k can be obtained, with the vector form as follows:

$$\mathbf{y}_m(k+1) = [y_m(k+1), y_m(k+2), \cdots, y_m(k+n_p)]^T \; . \tag{19}$$

Design the nonlinear prediction control rule process, namely, the process making the prediction output vector $\mathbf{y}_m(k+1)$ approximate the referred output vector $\mathbf{y}_r(k+1)$ by selecting the proper n_p-dimensional input vector $\mathbf{u}_m(k)$. The vector form of $\mathbf{u}_m(k)$ and $\mathbf{y}_r(k+1)$ is as follows:

$$\mathbf{u}_m(k) = [u(k), u(k+1), \cdots, u(k+n_p-1)]^T \ . \tag{20}$$

$$\mathbf{y}_r(k+1) = [y_r(k+1), y_r(k+2), \cdots, y_r(k+n_p)]^T \ . \tag{21}$$

4. Experimental analysis

The whole path-finding optimization process of children's mathematical ability cognition is divided into two stages. The first stage is learning. At this stage, the system randomly finds the path, for the purpose of obtaining the whole environment layout and position of target point, so as to build the place cells to a complete virtual plane. The second stage is the exploration stage based on the energy field gradient. At this stage, the system guides the mathematical cognition ability exploration in accordance with the energy field gradient, and obtains an efficient enough path within a time to the shortest extent, to navigate for the subsequent physical exploration.

The result of operation for continuous ten times is as shown in Fig.4. The large star symbol in the figure represents the target position of exploration, the small star symbol represents the position of every step, and the fine line connected between them represents the motion track. The sub-graph at the upper left corner of Fig.4 represents the first path-finding process. At the time, the target is unknown, the energy field does not generate, and the path-finding navigation vector is completely determined by the random items, which we are called as the complete random path-finding. In general, the complete random path-finding process can cover a large part of space, and the shorter the critical distance sets, the larger the area can be covered, but meanwhile, the more the steps consumed for finding the target are. Once the target is found at the first path-finding, it shows that the place cell at the position may be activated, and the later mathematical cognition ability exploration process is navigated by the energy field gradient. From Fig.4, it can be seen that, the steps for mathematical cognition ability exploration shows the descending trend in general. This example indicates that the first random path-finding finds the target by nearly 500 steps, and the mathematical cognition ability exploration process finds the target by only more than ten steps after nine times of learning and optimization based on the energy field gradient later.

An example of energy field and gradient navigation vector is given in the Fig. 5, which is condition when the sixth path-finding is carried out at the 11th step. Two graphs at the above describe the energy field prior to the 11th step of mathematical cognition ability exploration from different angles (after rotation), in which the green lines on x-y plane represent the exploration track of the 11th step; Two graphs are the gradient vector graphs of the points in the energy fields in the above, in which

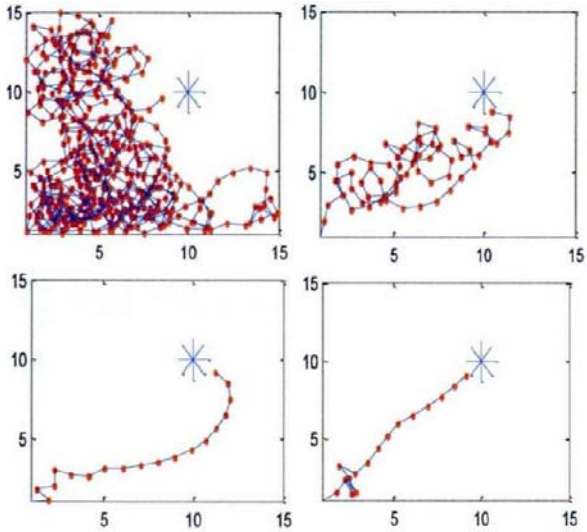

Fig. 4. Path-finding process track

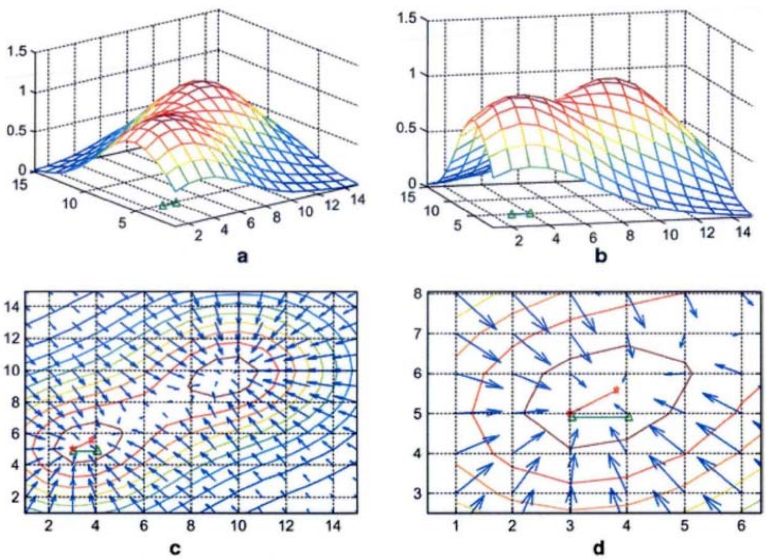

Fig. 5. Energy basin field and navigation vector

the blue arrows are corresponding to the position gradient (no unitization is made). The right graph is the local zoom of the left graph, in which the red lines are the current position gradient of the system with unitization made and the navigation vector for next step of exploration, and the green line has the consistent meaning with that in the above graph. From the graph, it can be seen that, there is certain degree of difference between the navigation vector and practical motion track, which is due to the random noise existence. In some cases, there will be greater difference between these two vectors, which is due to the large norm of random vector.

5. Conclusion

This paper verifies that the synaptic plasticity is of great importance on the spatial memory and mathematical cognition ability exploration through the energy encoding theory, and proves the strong advantage of applying the brain global encoding theory to the neutral information treatment and mathematical cognition ability exploration. The results in this paper show that, the synaptic connection among the place cells has decisive influence on the distribution form of energy field, so as to influence the energy field gradient, namely, the navigation vector, while the navigation vector change influences the path search upon mathematical cognition ability exploration. The repetition of old path or the generation of new path are corresponding to the release sequence of the corresponding place cells, on the contrary, it also changes the synaptic connection strength.

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