Nonlinear Neurodynamics in Representation of a Rhythm of Speech

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Abstract. The mathematical model is offered to describe an algorithm for functioning of a speech rhythm. The duration of a speech signal is divided into the numbered sequence of durations of voice and voiceless segments. All elements of this sequence will be considered as values normalized on the maximum element. We determine this sequence of the elements as a speech rhythm. 1) The model describes a speech rhythm as the recurrent relations between elements of a rhythm. 2) The model permits use of the concept of information entropy. 3) The model explains experimental findings obtained by our research group during comparative investigation of a rhythm in normal speech and stuttering. In particular, the model explains the existence of two classes of stutterers with various rhythms of speech.

Key words: Speech rhythm, Segmentation, Logistics equation, Information entropy, Stuttering, Neuron ensemble.

1. Introduction

One of fundamental concepts in biology is the concept of rhythm. The diversity of rhythms is broad – there are circadian rhythms and rhythms peculiar to locomotion, rhythms of cardiac activity, rhythms of breath. Rhythms are also observable in EEG -activity. The concept of rhythm is also basic to the performance of a speech melody. However we know nothing about the algorithm of functioning of speech rhythm, though the understanding of this algorithm is a key task of speech production theory [1]. One of the practical problems of speech production theory is finding the origins of stuttering associated with disturbance of rhythm and the rate of speech [2, 3].

First we shall describe unusual experimental findings obtained by us in the course of clinical practice. Then with the help of a pair of logistic mappings we shall demonstrate rhythm generation in normal speech and in stuttering. We demonstrate accordance between our experimental findings and the predictions of the rhythm model. We formulate also the concept of Kolmogorov information entropy in terms of our model. Further we describe some natural and artificial neurobiological systems which demonstrate behaviour similar to the rhythmic behaviour of our model.

Figure 1. Distribution of points (T, std) associated with different subjects. T is the average duration in rhythm (in msec); std is the coefficient of durations' variation in rhythm. The letter 'N' in circle indexes 95% confidence ellipse region enclosing points of subjects with normal speech. The letters 'C', 'T', and 'P' in circles indexes the 95% confidence bands enclosing points of subject with three different forms of rhythm at stuttering.

2. Segmentation and Clinical Practice

The procedure of speech signal segmentation has been used in the theory of speech for a long time. Traditionally segments in speech signal were associated with mental abstract symbols. However, recently Browman and Goldstein [4] have abandoned this traditional vision. They postulate that speech organisation can be represented with the help of observable variables such as articulatory and phonatory gestures. The main phonatory gesture is the vocal folds' oscillations associated with voice and voiceless segments in speech. Therefore we have undertaken segmentation of an acoustic speech signal according to the 'Voice/Unvoice' principle. The segmentation was carried out with the help of a computer program that used a set of temporary parameters for determination of boundaries and durations of voice and voiceless segments. We have used excerpts from Turgenev's novel 'Hunter's notes' standard text 'Vot i nastupil vecher ...' / 'The evening has occurred ...' / by length 120 syllables. This text was uttered by stutterers and nonstutterers and then its records were segmented.

Hereinafter we shall consider the sequence of segments' durations $\{T_1, T_2, T_3, \dots, T_n, \dots\}$ as the speech rhythm of some subject. The first element in this sequence is the duration of the voice segment T_1 . The second element is the duration T_2 of the voiceless segment, and so on. The elementary statistical processing included calculations of both the mean element T over the set of all elements and the standard deviation, or coefficient of variation $std = \sigma/T$ over the same set for each subject (σ is a root-mean-square deviation). Each point (T, std) is associated

with concrete subjects. We observed rather regular mapping of points (T, std) on the plane of these parameters (see Figure 1).

We investigated three classes of subjects. The first class (5 men) includes persons with normal speech. Containing these points, the ellipse of 95% confidence is indexed by the letter 'N'. The second class includes stutterers who had no treatment in speech clinic (24 men with age from 17 to 54). Points of the second class are grouped in the vicinity of two branches going out from region 'N'. The dash lines enclosing these branches determine the 95% confidence bands. These bands are outlined in the assumption that the experimental points (T, std) and their polynomial approximations are normally distributed. The confidence band for the lower branch is indexed by the letter 'C' and for the upper branch by the letter 'T'. The patients from band 'C' utter such speech disfluencies as repetition of single voice sounds or syllables (e.g., 'o..o..o..' or 'sa..sa..sa..'). The patients from band 'T' utter such disfluencies as prolonged spasm-like interruptions of speech, spasm-like utterance of sounds 's' and so on. With the increasing of stuttering severity the points are displaced in the direction of increasing the parameter std irrespective of the branch. Let's define rate at stuttering as the average duration T of the element of a rhythm. It is clear, that the branch 'C' corresponds to a faster rate than the normal rate, and the branch 'T' corresponds to a slower rate.

The third class (10 people) includes stutterers, who are exposed to treatment by a method of 'prolonged' speech. The appropriate points (black squares) are grouped about the third branch located above a region 'N' and a branch 'T'. The appropriate 95% confidence band is indexed by the letter 'P'. It appears that some patients from band 'P' lose fluent speech and regress to stutter rhythms 'C' or 'T' by outcome of exterior influences. To these patients with an unstable speech rhythm there correspond points 'P' located to the left of the line 'M' (see Figure 1).

The branches 'C', 'T', 'P' and ellipse 'N' were obtained with the help of polynomial regression with polynomial order equal 2.

Similar diagrams had been obtained repeatedly during monthly inspection of the patients in the speech clinic of S.-Petersburg Research Institute of Ear, Throat, Nose & Speech. Such inspection is carried out regularly over two years. In this paper we analyze one typical diagram from the set of such monthly diagrams.

3. Mathematical Model of Rhythm Generation

For an explanation of the curve submitted on Figure 1 we have assumed [5–11] that rhythm operates in accordance with the system consisting of two discrete logistic transformations. The rhythm will start from the first element T_1 :

$$\left. \begin{aligned} T_{n+1} &= F_{r_0}(T_n) = r_0 T_n (1 - T_n) \\ T_{n+2} &= F_{r_1}(T_{n+1}) = r_1 T_{n+1} (1 - T_{n+1}) \end{aligned} \right\} \quad (1a)$$

where $0 \leq T_n \leq 1$, $n = 1, 2, 3, 4, 5, \dots$; r_0 and r_1 are abstract parameters of 'inhibition' and 'excitation'. We shall consider the behaviour of rhythm (1) in two cases:

Figure 2. The graphical interpretation of the rhythm origin at normal speech (a) and at stuttering (b). The rectangles are schematic diagrams for simplest rhythms. On Figure 2a) sole rhythm is shown (normal speech). On Figure 2b) two different rhythms are shown (stuttering speech). The one rhythm is shifted to side of less long durations in comparison with normal speech (see the lower left part of Figure 2b); another rhythm is shifted to side of more longer durations in comparison with normal speech (see the lower right part of Figure 2b).

Case a). $r_0 = r_1 = r$. The system (1) is reduced to one transformation:

$$T_{n+1} = F_r(T_n) = rT_n(1 - T_n) \quad (1a)$$

First of all we shall define the concept of a fixed point and the concept of a steady point of $F_r(x)$. The point x^* refers to as fixed point of $F_r(x)$, if the following 'mapping in self' is carried out:

$$x^* = F_r(x^*), \quad (2)$$

that is, the fixed points of mapping lie on crossings of the function $y = F_r(x)$ and bisectrix $y = x$. The fixed point x^* refers to as locally steady point if the sequence of iterations $F_r(x)$ converges to the point x^* . As the distance δ_n between the point x_n and the fixed point x^* decreases with the increasing of the order of iteration as:

$$\delta_n = |x_n - x^*| = |F_r(x_{n-1}) - x^*| = |F_r(x^* \pm \delta_{n-1})| \approx \left| \frac{d}{dx} F_r(x^*) \right| \delta_{n-1}, \quad (3)$$

then the necessary condition of local stability of fixed point is:

$$\left| \frac{d}{dx} F_r(x^*) \right| < 1. \quad (4)$$

With $r < 1$ the transformation (1a) has only one fixed point and at the same time the steady point $T_0 = 0$ (see Figure 2a, the upper part, under bisectrix), i.e. system ‘is silent’. If under some external or internal influence the control parameter r begins to grow, the mapping $T_{n+1} = F_r(T_n)$ at $1 < r < 3$ loses stability at the zero point (i.e. leaves state of ‘silence’) and acquires the single steady point T_r^* , different from zero. In this case durations of voice and voiceless segments appear to be identical. It is a pseudo-speech rhythm as ‘ta-ta-ta-...’ with equal elements. When parameter r becomes more than 3, the necessary condition of stability $|F'_r(T_r^*)| = |2 - r| < 1$ is not carried out any more. The point T_r^* loses the stability. But double mapping $y = F_r[F_r(x)]$ acquires additionally two new steady points T_{1r}^* and T_{2r}^* as crossing points of $y = F_r[F_r(x)]$ and bisectrix $y = x$ at the left and to the right of the point T_r^* (see Figure 2a). The old point T_r^* lies between T_{1r}^* and T_{2r}^* on bisectrix and has properties of ‘repeller’, that is, the points T_n run up from point T_r^* by result of iterations. The one steady point appropriates to, say, a voice segment with duration T_{1r}^* , and another steady point appropriates to a voiceless segment with duration T_{2r}^* . Stability of these points is related to a double mapping $y = F_r[F_r(x)]$. The single mapping $T_{1r}^* = F_r(T_{2r}^*)$ does not provide stability, but realizes a transition from one steady point T_{2r}^* to another steady point T_{1r}^* . The again applied single mapping $T_{2r}^* = F_r(T_{1r}^*)$ realizes an inverse transition from T_{1r}^* to T_{2r}^* . This is situation of pseudo-rhythm ‘ta-ta-ta-’ with equal durations T_{2r}^* of voice segments and equal durations T_{1r}^* of the voiceless segments, but $T_{2r}^* \neq T_{1r}^*$. At further increasing of parameter r in complete conformity with the scenario of route to chaos through the cascade of bifurcation [13] for logistic transformation, these two steady points lose their stability and new four steady points are arising additionally for mapping $y = F_r[F_r[F_r[F_r(x)]]]$. This is the situation of repetition of a two-syllable word, for example, ‘papa, papa, papa, ...’, when the first syllable is stressed (that is longer) and another one is unstressed (that is less long). Durations of the voiceless segments are not equal also. Such a bifurcation cascade will proceed so long as the system will completely lose stability, when it will transit to dynamical chaos at $r = r_\infty = 3,57$. This chaos implies that mapping (1a) loses the rhythmic regularity and begins to work as the generator of quasirandom numbers.

So, the necessary condition of existence of the simplest regular rhythm is at least presence of both two steady states and two transformations realizing transition between these states. In the case of simplest rhythms the one steady state is state of the present phonation, and another steady state is state of the absent phonation. Regular rhythm exists namely due to identical transformation ensuring transition from state of present phonation to state of absent phonation and vice versa. If these transformations are not balanced (for example, $r_1 < 1$, $r_1 < r_0 > 3$), the system will make transition from state of present phonation to the state of absent phonation. But the system cannot return back because $r_1 < 1$. Even if the phonation arises, the system comes to the state of ‘silence’ as the result of several iterations.

We shall assume that the balance of ‘excitation’ and ‘inhibition’ conforms to normal speech.

Case b). ($r_1 < r_0$). Absolutely other rhythms arise in case of unbalanced ‘excitation’ and ‘inhibition’. To reduce the problem to a standard problem of logistic dynamics [13] we define the factor of asymmetry A in accordance with formula:

$$\begin{aligned} T_{n+2} &= F_{r_1}[F_{r_0}(T_n)] = r_1 r_0 T_n (1 - T_n) [1 - r_0 T_n (1 - T_n)] \\ &= A r_0^2 T_n (1 - T_n) [1 - r_0 T_n (1 - T_n)], \end{aligned} \quad (1b)$$

where n accepts values of a natural number series. The factor of asymmetry A is less than 1 ($r_1 < r_0$). Due to $A < 1$ at the same $r_0 = r$ as in the case a) the curve (1b) lies almost under the bisectrix. If the factor A is fixed (for example $A = 0.5$), then at $r_0 = 4$ we have situation shown on Figure 2b, the top part of the picture. Comparing Figure 2b) with Figure 2a) we see that at $A < 1$ there are neither regular rhythms, nor route to chaos in the previous sense. Nevertheless we have an opportunity to reduce the problem to the previous case by ‘breaking’ the problem into two subtasks.

1b). The first subtask is formulated as follows:

$$T_{n+1} = S_r^{(1)}(T_n) = r T_n (0.5 - T_n). \quad (1b-1)$$

Let’s consider that all elements of a rhythm vary from zero up to 0.5. Graphically, the subtask is shown on Figure 2b) (see the lower left part, where $A = 0.5$ and $r = 7$). In this case scenario of route to chaos develops similarly to the scenario in case a). The curve $T_{n+2} = S_r^{(1)}[S_r^{(1)}(T_n)]$ will go out from under a bisectrix with the increasing of a control parameter r . To appear in zone of chaos a system should pass through a cascade of bifurcations. We consider that the complexes of disfluencies at stuttering have the elementary ‘mechanical’ oscillatory rhythms originated in bifurcation zone of the scenario. Every rhythmic pattern has a rate faster than normal. As we have established experimentally in the previous section, such a faster rate is characteristic of group of stutterers marked by letter ‘C’ on Figure 1.

2b). The second subtask is formulated as follows:

$$T_{n+1} - 0.5 = S_r^{(2)}(T_n) = r (T_n - 0.5) [0.5 - (T_n - 0.5)]. \quad (1b-2)$$

All elements of this rhythm vary from 0.5 up to 1. Graphically subtask is submitted in Figure 2b) (see the lower right part, where $A = 0.5$ and $r = 6$). The scenario is completely similar to the scenario in the first subtask, but the rate is slower than normal speech rate. This rhythm will correspond to the speech behaviour of stutterers indexed by the letter ‘T’ in Figure 1.

Thus, we can receive the irregular, chaotic rhythm at $A < 1$. However we pay for it under the following account:

1. It is necessary to increase or to reduce the rate in comparison with the normal speech rate.

2. It is necessary to make disfluencies in speech, or in other words, to make mechanical rhythmic oscillations in zone of bifurcation of the scenario of 'route to chaos' due to the need of the increasing of a control parameter r from 4 (upper part on Figure 2b) up to 7 (lower left part on Figure 2b) or up to 6 (lower right part on Figure 2b).

The need for the existence of two various rates at stuttering is supported by the existence of two branches in experimental Figure 1. Further support of this model follows from findings submitted below.

4. Discussion & Conclusions

1) Thus, we consider, that disfluencies are evidence of a system's passing through a bifurcation zone on 'route to chaos'. In [10] we have found the dimension reducing of 'strange' attractor at stuttering. This reduction correlates with the partial stay of 'stuttering' system in zone of non strange attractors with zero dimension (in bifurcation zone). This reduction correlates with results of research in EEG-activity in some brain pathologies (for example, epilepsy) [13]. The time interval with a sharp decreasing of attractor dimension appears to precede the ictal phase. The thesis about a reduction of dimensionality is in the correspondence with the modern physiological concept according to which the defeat of CNS is accompanied by reduction of attractor dimension [14].

2) The connection between presence of disfluencies and stay of a system in zone of bifurcation can be seen also on a Figure 3b), where the correlation between a stutter rhythm (1b) ($A = 0.8$) and experimental rhythm for stutter I.V. is shown as function r (dash line). In a comparison with the peak of correlation in zone of chaos (solid line) for normal speech (subject K.L., the first sentence of the standard text) the additional 'stuttering peak' is shown in the bifurcation zone.

There is an additional evidence of a connection between stuttering and bifurcation. We observed the proportional ratio (3/2) of total time of present phonation in duration of reading of standard text and total time of absent phonation in speech of 21 stuttering subjects at different stages of treatment ($p < 0.05$). This proportional ratio is characteristic for bifurcation zone but not for chaos zone. Any fixed proportional ratio are not observed in speech of subjects with normal fluency.

We suppose, that on some stage of evolution there was a primitive rhythm similar to rhythm of repetitions. During evolution of speech this rhythm has moved from bifurcation zone up to zone of chaos (see Figure 3b). But in some cases the rudiment of this rhythm remains, by virtue of those or other reasons, in bifurcation zone and raises repetitions in speech.

3) Applied to equality (2) theoretical procedure of an average (with use of the equation (1b) with $r_0 = 1, 2$ and with $A = 0.7$, and also with use of fact that quadrate of a standard deviation equal to a difference between average quadrate of

Figure 3. a) Theoretical diagram 'T' versus 'std' obtained by applying the averaging to equation (2) of fixed points at 'stuttering logistic mapping' (1b) at $r = 1.2$ and $A = 0.7$. Two branches (T2 and T3) appropriate to branches 'T' and 'C' on Figure 1. Third branch (T1) appropriates to asymptotically unstable states 'P' of 'prolonged' speech. b) The comparison of correlation between model and experimental rhythm for normal speech (solid line) and stuttering (dash line). r is the control parameter; k is coefficient of correlation between model and experimental data. The triple vertical line is boundary between chaos zone (at right) and bifurcation zone (at left) in 'route to chaos'.

variable and quadrate of average variable) gives the cubic equation for calculating the average duration T of segments as functions of a standard deviation std .

The third moment of a variable's distribution is supposed to equal the product of the second and the first moments. Three solutions of the cubic equation can be presented on the plane (T, std) by three branches T1, T2 and T3 shown on Figure 3a). The comparison of Figure 3a with Figure 1 demonstrates good agreement between theoretical functions T1, T2, T3 and experimental curves. The theoretical branches T2 and T3 have appeared in results of computer experiments to be asymptotically stable. These properties of stability are accordance with experimental properties of stability for the speech behaviour of investigated patients of bands 'C' and 'T'. The states on the branch T1 are asymptotically unstable in marginal domain near $std = 0$. This finding correlates with observable unstable states of artificially 'prolonged' speech what is used often for reducing of disfluencies. Apropos, decreasing of stuttering with decreasing of coefficient of variation std (see Figure 1) well correlates with recently obtained results in studies of stuttering [2,3].

4) The similarity of a statistical behaviour of both the offered model of speech rhythm and the ensemble of carriers of rhythm allows the assumption of an ergodicity in our dynamics model. It is known, that a model with ergodicity supposes a possibility of defining the concept of an information entropy [15]. This entropy is a measure of information dissipated by this model. On the other hand the same

measure of an information can be considered as an information obtained by whom at 'reading' on one step of the discrete message, generated by this model [15].

To define the concept of information (Kolmogorov) entropy for our model we must introduce the concept of Lyapunov exponent. Lyapunov exponent $\lambda(x_0)$ is determined as the degree of exponential modification of infinitely small deviation ε from some point x_0 in accordance with dynamics. In discrete recurrent case this degree is defined as average exponential deviation during of N iterations produced by discrete transformation f :

$$\lambda(x_0) = \lim_{N \rightarrow \infty} \lim_{\varepsilon \rightarrow 0} \frac{1}{N} \ln \left| \frac{f^N(x_0 + \varepsilon) - f^N(x_0)}{\varepsilon} \right| = \lim_{N \rightarrow \infty} \frac{1}{N} \ln \left| \frac{df^N(x_0)}{dx_0} \right|. \quad (5)$$

Moreover it is possible to show, that the Lyapunov exponent determines an average value of an information dissipated by a system, in other words, this exponent is Kolmogorov entropy in accordance with its definition. Using the 'chain' rule:

$$\left. \frac{d}{dx} f^2(x) \right|_{x_0} = \left. \frac{d}{dx} f[f(x)] \right|_{x_0} = f'[f(x_0)]f'(x_0) = f'(x_1)f'(x_0); \quad x_1 \equiv f(x_0)$$

one can formulate

$$\begin{aligned} \lambda(x_0) &= \lim_{N \rightarrow \infty} \frac{1}{N} \ln \left| \frac{df^N(x_0)}{dx_0} \right| = \lim_{N \rightarrow \infty} \frac{1}{N} \ln \left| \prod_{i=0}^{N-1} f'(x_i) \right| \\ &= \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{i=0}^{N-1} \ln |f'(x_i)|. \end{aligned} \quad (6)$$

It is obvious, if all states of system have lost the stability (the condition (4) is not fulfilled), then dynamical chaos occurs ($|f'(x_i)| > 1$) and Lyapunov exponent $\lambda(x_0)$ becomes positive. This statement is correct and for our logistic model. How count up loss of an information on one iteration? Let's to divide an interval $[0, 1]$ on n equal cells. The point x_0 can be in any cell with probability equal $1/n$. If we know, that any cell contains x_0 , we have the following information in the correspondence with the definition of Shannon information:

$$I_0 = - \sum_{i=1}^n \frac{1}{n} \log_2 \frac{1}{n}. \quad (7)$$

The linear function $f(x)$ stretches a cell in $a = |f'(0)|$ time, hence, the information loss gives a magnitude:

$$\Delta I = - \sum_{i=1}^{n/a} \frac{a}{n} \log_2 \frac{a}{n} + \sum_{i=1}^n \frac{1}{n} \log_2 \frac{1}{n} = - \log_2 a = - \log_2 |f'(0)|. \quad (8)$$

The average on all iterations gives the formula for average loss of an information for one iteration (Kolmogorov entropy K):

$$\begin{aligned}
K \equiv -\overline{\Delta I} &= \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{i=1}^{N-1} \log_2 |f'(x_i)| \\
&= \frac{1}{\ln 2} \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{i=1}^{N-1} \ln |f'(x_i)| = \frac{\lambda(x_0)}{\ln 2}.
\end{aligned} \tag{9}$$

Thus for logistics transformation Kolmogorov entropy coincides (to within a constant positive factor) with Lyapunov exponent. As we saw (look the formula (6)), Lyapunov exponent is positive in zone of chaos because of instability of states of logistics transformation. Therefore the chaotic state of our rhythm model is such state, in which the rhythmic system dissipates an information.

As we saw a stutterer's rhythm represents a mixture of chaotic information rhythm and rhythm of disfluencies which do not carry any information. Thus stutter speech contains less information in comparison with normal fluent speech. The speech arising from disfluencies only does not carry any information.

5) On first sight the offered model of a rhythm can seem too simple. Really, at first, this model describes dynamics of only one variable, namely, duration of the elements of speech rhythm. Secondly, this dynamics is discrete logistics transformation which are rather well known.

However, despite this simplicity, this model, at first, describes our experimental data; secondly, the model describes the basic features of sensory-motor functioning of the central nervous system in conditions of speech. The existence of two branches 'T' and 'C' of a supercritical rhythm can be treated as a result of a bifurcation of a base subcritical rhythm such as the rhythm of repetitions. This base rhythm we estimated with a test of rhythmic sequences of a type 'papa, papa, papa, ...'. To such rhythm there corresponds an area located more to the left of the area 'N' on a Figure 1. Such behaviour of a system allows us to describe the dynamics of a parameter of the system's order (in our case such a parameter is T) irrespective of the remaining dynamics of a complex system (Landau's theorem [15]). Thus, the existence of two forms of a rhythm at stuttering (branches 'T' and 'C') allows us to consider a task in a one-dimensional case only for durations of the elements of a rhythm.

The speech rhythm appears to have chaotic scenario, similar to the scenario of discrete logistic transformation. Such transformation describes many neurobiologic objects in conditions of external influences. This transformation describes the behaviour of single neuron, when the control parameter is external potential. The same transformation describes real neurons' ensembles in a brain, when the control parameter is the concentration of some drugs entered into nervous tissue (e.g., at research of epilepsy). Both regular and irregular rhythms were observed in these objects [16].

There are examples of a chaotic behaviour in artificial nets. Discrete dynamics of a 'total synaptic weight' in a self-learning net (Hopfield's perceptron) provides

the same transformation. Hebbian's parameter of 'learning' is the control parameter in such net. The computing simulation of this net has shown a chaotic behaviour, similar to behaviour of discrete logistics transformation [17]. But how is this 'sum synaptic weight' in Hopfield's perceptron connected to a rhythm of speech? The relation between 'sum synaptic weight' and duration of phonation is offered in [11]. But even if this relation reflects some real, there is a question: To what physiological reality there meets a discrete behavioural dynamics of Hopfield's perceptron? Such reality should be, as it is known, that this perceptron with a global feedback (MacClelland-Rumelhart's perceptron) changes a chaotic regime on bifurcation regime [17]. This finding explains effect of a feedback on fluent speech (appearance of disfluencies) in terms of our model rather sufficiently.

Discrete dynamics can be explained by rhythm perception model offered by us in [9]. We use as a substratum a self-learning net. The 'total synaptic weight' is modified under action of a perceived rhythm. 'Slow' dynamics is subject to action of a sequence of equidistant 'clicks' modulated by durations of a rhythm. The concept of clicks well agrees with modern representations concerning a structure of streams of neuron activity in acoustical cortex. These streams represent 40 sec analog chunks following one after another with an interval in 200 msec [18]. Our model reduces such chunks to delta-functions.

In our model the problem of perception of a speech rhythm is reduced to a task about a rotator excited by a sequence an exterior delta-impulses. Known to us is a neuron model of perception of speech as a model of a chaotic oscillator [19]. This model represents a task about a rotator excited by a wave of sine. However this model describes a sleep's state as a chaotic state, but this conclusion contradicts experiments. Our sensory-motor model allows to plan the approaches to explanation of stuttering in terms of disbalance between global feedback enveloping appropriate speech centres in CNS. Details of such reviewing are not proposed on account of a lack of a place.

So, the offered model describes a rhythm in conditions of normal speech and at stuttering. The model represents a pair of discrete logistics transformations with the characteristic scenario of 'route to chaos'. The model well agrees with experimental data obtained during a comparative research of a rhythm in normal speech and at stuttering.

References

1. Port, R., Tajima, K. and Cummins, F.: Speech and rhythmic behavior, in: G.J. Savelsburgh, H. Van der Maas and P.C. Van Geert (eds.), *The non-linear analysis of developmental processes*, Royal Dutch Acad. of Arts and Sci. Amsterdam, 1998, pp. 5–45.
2. Packman, A., Onslow, M. and van Doorn, A.: Syllabic stress and variability: A model of stuttering, *Clinical Linguistics & Phonetics* **10** (1996), 235–263.
3. Onslow, M., Packman, A., Stocker, S., et al.: Control of children stuttering with response-contingent time-out, *J. Speech Lang. Hear. Res.* **40** (1997), 121–133.

4. Browman, C.P. and Goldstein, L.M.: Towards an articulatory phonology, in: C. Ewan and J. Anderson (eds.), *Phology yearbook* 3, Cambridge University Press, Cambridge, 1986, pp. 219–252.
5. Skljarov, O.P.: The bifurcation model of the speech rhythm and stuttering, in: P. Perrier (ed.), *Proc. of the 1st ESCA Tutorial and Research Workshop on Speech Production Modelling: From Control Strategies to Acoustics & 4th Speech Production Seminar: Models and Data*, Stendhal University, Grenoble, 1996, pp. 89–92.
6. Skljarov, O.P.: The perception of the own delay speech as a tool for start-upping of the rhythm at the stuttering, in: W. Ainsworth and S. Greenberg (eds.), *Proc. of the ESCA Workshop on the Auditory Basis of Speech Perception*, Keele University, Keele (UK), 1996, pp. 279–282.
7. Skljarov, O.P. (Oleg S.): The self-organization nature of speech rhythm and stuttering, *J. of Fluency Disorders* **22** (1997), 139.
8. Skljarov, O.P.: The chaotical generator of speech, in: K. Ponting and R. Moore (eds.), *Proc. of NATO Advanced Study Institute Computational Models of Speech Pattern Processing*, 1, Jersey, (UK), 1997.
9. Skljarov, O.P.: Role of perception of rhythmically organized speech in consolidation process of long-term memory traces (LTM-traces) and in speech production controlling, in: G. Kokkinakis and N. Fakotakis (eds.), *Proc. of the 5th European Conference on Speech Communication and Technology (Eurospeech '97)*, 4, University of Patras, Patras, 1997, pp. 2147–2150.
10. Skljarov, O.P.: Content-independent duration model on categories of voice and unvoice segments, *Proc. of the International Conference on Spoken Language Processing. ICSPL'98*, Dec. 1998, Australia, Sydney, pp. Fr1Q11–Q14.
11. Sklyarov, O.P.: Self-organization nature of the speech rhythm (the voice source model), *Biophysics* **43**, 152–158.
12. Schuster, H.G.: *Deterministic Chaos: An Introduction*, Physik-Verlag, Weinheim, 1984.
13. Sackellares, J.C., Iasemidis, L.D., Zaveri, H.P., et al.: Measurements of chaos to localize seizure onset: Abstract, *Epilepsia* **30** (1989), 663–664.
14. Zwiener, U. Hoyer, D., Schmidt, K., et al.: Nonlinear dynamics in pathophysiology – A review. III Int. Congr. Pathophysiol., Lahti. *Pathophysiology* **5**, Suppl. 1 (1988), p. 257.
15. Nicolis, G. and Prigogine, I.: *Exploring complexity: An introduction*, W.H. Freeman & Company, New York, 1989.
16. Elbert, T., Ray, W.J., Kowalik, Z.J., et al.: Chaos and physiology: Deterministic chaos in excitable cell assemblies. *Physiol. Rev.* **74** (1994), 1–47.
17. Maas van der, H.L.J., Vershure, F.M.J. and Molenaar, P.C.M.: A note on chaotic behavior in simple neural networks, *Neural Net.* **3**, 1990, 119–122.
18. Greenberg, S.: Understanding speech understanding: Towards a unified theory of speech perception, in: W. Ainsworth and S. Greenberg (eds.), *Proc. of the ESCA Workshop on the Auditory Basis of Speech Perception*, Keele University, Keele (UK), 1996, pp. 1–8.
19. Brown, G. and Cooke, M.: Temporal synchronization in a neyral oscillator model of primitive auditory stream segregation, in: *Proc. Workshop on Comput. Auditory Scene Anal.* Montreal, 1995, pp. 40–47.