IMPORTANCE OF THE NONLINEAR TIME SERIES ANALYSIS IN SPORTS

Kerstin Witte and Peter Blaser
Otto-von-Guericke-University Magdeburg, Germany

New possibilities for characterizing and discussing variability are obtained by means of nonlinear techniques of time series. Calculation of the fractal dimension allows determination of a measure of the degree of freedom. This fact is demonstrated using the example of standing balance. When the conditions are difficult the fractal dimension decreases. Another fact we discovered in a study of the breaststroke: When the load is increased the efficiency of the movement and the fractal dimension are also reduced.

KEY WORDS: nonlinear dynamics, fractal dimension, standing balance, breaststroke

INTRODUCTION: Variability is a well-known characteristic of the human movement in general and of the sports movement in particular. Many authors have inquired into the nature of the variability. The answers to the theories of motor behavior can be separated into two groups:

a) Variability is a noise, which results from the complexity of the movement and there is nothing that can be done about it (Müller et al., 1997).
b) Variability is a natural phenomenon which is necessary for the movement and underlies inherent laws (Turvey, 1990; Newell & Corcos, 1993).

On the basis of our own results (Witte et al., 1995) the following study is classified in the second group. But these laws can not be discovered by means of conventional linear techniques. The use of nonlinear methods can explained by the assumption that the processes and the mechanisms in the organism are nonlinear. Furthermore the movement coordination is understood to be a comprehensive phenomenon. To describe the behavior of a system it is possible to investigate a single observable (Takens, 1980). On the foundation of the nonlinear approach describing motor behavior (Witte et al., 2000) the movement coordination can be modeled by an attractor with chaotic characteristics. The reconstruction of this attractor will be realized by a parameter representing one system . The model of an attractor with chaotic characteristics allows the variability to be interpreted : An attractor is relatively stable in a phase space, but in its volume it permits a great number of trajectories. So a relatively high variability is possible inside the attractor. The fractal dimension is a measure of the number of the degrees of freedom. We understand the term of degrees of freedom as being a measure of the number of all mechanisms and processes which contribute to motor control.
The application of nonlinear analysis of time series is demonstrated using two examples:

(1) The influence of several conditions to the standing balance
(2) The influence of the load of the efficiency of the movement technique (breaststroke).

METHODS: By means of a single variable representing a system it is possible to create an attractor in a substitute phase space. To realize this, we determined the embedding parameters in a first step with the help of the Waberproduct analysis of LIEBERT (1991). The Waberproduct is, on the one hand, a topological criterion for the decision on the right embedding and, on the other hand, the Waberproduct analysis simultaneously supplies the optimum values of the embedding dimension m and the delay τ from a relatively short time series. The fractal dimension was used for the analysis of the reconstructed attractor. This quantity characterizes the fractal geometry of the attractor.
Standing Balance: Five normal male subjects (M, G, Ni, K and B) were studied whose ages ranged from 18 to 27 years. In addition a male child (W) at an age of 6 years was investigated. Subjects stood barefoot with arms behind their backs on a force platform (by KISTLER company). The signals were recorded at 300 Hz. The lateral sway was registered by the x-component of the COP trajectory and the anteroposterior sway by the z-component. The tests were carried out under the following varying conditions: Bipedal stance and eyes open, bipedal stance and eyes closed, monopedal stance and eyes open, monopedal stance and eyes closed.

The duration of one test was 65 s, but the first 5 s were not used so as to obtain the state of stability. Every test was divided into 6 intervals of equal duration. The reason was to produce stationary signals in these intervals.

Breaststroke: This investigation was carried out with only one female member of a sports club in a swimming flume. The flow velocity was increased from 0.5 m/s in steps of 0.05 m/s. The duration of one step was 30 s. The sportswoman was able to realize 11 steps. The horizontal hip velocity was calculated by means of video analysis. We used this quantity as the parameter representing the system. To characterize the efficiency of the movement a coefficient of the phase structure was introduced (Blaser/Stucke/Witte, 1996):

$$CPS = \frac{t_{MPHl,a}}{t_{IPHl,a} + t_{TPHl,a} + t_{PPHl,a}} \cdot 100\% \qquad (1)$$

with:

$t_{MPHl,a}$ - duration of the main phase of the movement of the leg or of the arm

$t_{IPHl,a}$ - duration of the preliminary phase of the movement of the leg or of the arm

$t_{TPHl,a}$ – duration of the transition phase of the movement of the leg or of the arm

$t_{PPHl,a}$ – duration of the preparatory phase of the movement of the leg or of the arm.

When the technique of the breaststroke is effective the coefficient of the phase structure is small because the duration of the main phase is short and is used for effective driving.

RESULTS AND DISCUSSION: Standing Balance: At first we reconstructed the substitute phase spaces for the x- and the z-component of the COP trajectories separately. With the help of the Waberproduct analysis we obtained the pairs of the embedding parameters. A sufficient embedding dimension of m = 5 was found. The Waberproduct analysis provided the accompanying delay τ for each test interval. Fig. 1a shows the fractal dimension in dependence on the several conditions, for example, for subject B. To examine these visual impressions by statistical means for all subjects, we integrated the test series into the following groups: Bipedal and monopedal stance, x- and z-component of the COP trajectories, stance with open and with closed eyes. We obtained the results in tab. 1 with help of the Wilcoxon test. In addition we also used another dimension: The correlation dimension. Tab. 1 shows not only the statistical significances of the adult subjects, it also shows the results of the child W. One may conclude from this that significant differences between monopedal and bipedal stance for both components of the COP trajectories exist. The same results are there for the child W at an age of 6 years. Variations between the x-component and the z-component of the COP trajectory are not evident. But we could find significant differences in the comparison between the stance with open eyes and with closed eyes both in the adults and the child. If we consider only the mean values we can see that the dimensions of the child are situated within the range of the dimensions of the adults. It follows that the ability of a child to maintain static equilibrium is the same as the adult.

On the basis of the results of the Waberproduct analysis and in addition the positive maximal Lyapunov exponents we can conclude that the upright stance can be described by the model of the strange attractor. We interpret the quantity of dimension as the number of the degrees of freedom. We found out that this number is individually different. We obtained interesting results in the comparison between the tests under various conditions (see tab. 1). The statistical analysis shows that the dimensions of the bipedal stance are higher than those of the monopedal stance. One plausible explanation is that in the bipedal stance the subject has more possibilities of control mechanisms by activation and deactivation of a greater number of muscles than in the monopedal stance. Also other authors (see for instance Slobounov et al., 1997 and Goldie et al., 1989) obtained different results in the investigations of bipedal and monopedal stance. But we have to note that these researches are based on statistical analysis of the force signal or of the COP trajectories.

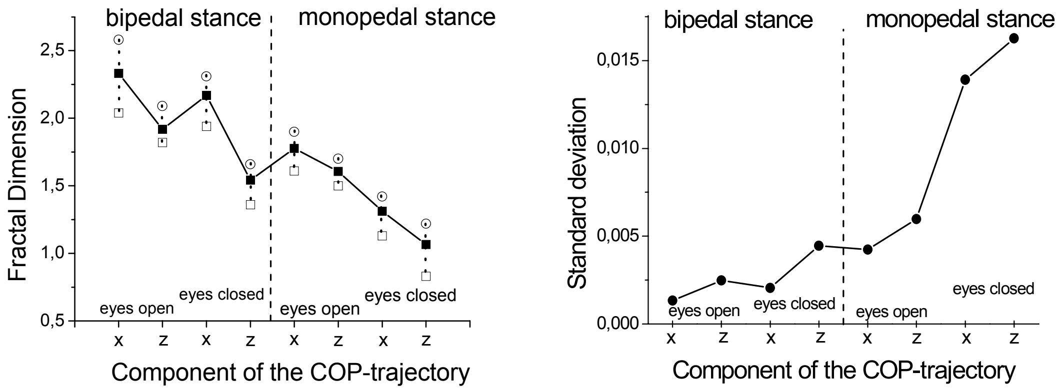

Figure 1 - Results for the standing balance in dependence on the different conditions for the subject B. 1a: Fractal Dimension, 1b: Standard deviation.

Table 1 Statistical Analysis of the Tests under Different Conditions by Means of Wilcoxon test

	Monopedal stance - bipedal stance		x-component - z-component		Open eyes – closed eyes	
	x-component	z-component	Monopedal stance	Bipedal stance	x-component	z-component.
Fdim-M	n.s.	*	n.s.	n.s.	**	*
Fdim-G	*	**	n.s.	n.s.	*	*
Fdim-B	**	**	**	**	**	n.s.
Fdim-K	**	*	n.s.	n.s.	**	*
Fdim-N	**	*	*	n.s.	**	**
Fdim-W	*	**	n.s.	n.s.	*	*

* $p < 0.05$
** $p < 0.01$

Another result is that closing the eyes decreases the dimension. Many authors were able to detect differences between the studies of balance with open eyes and with closed eyes by means of the determination of the variability of the COP trajectory. In these cases the variability under the condition of closed eyes is higher than under the condition of open eyes (for example Parys and Njihikjion, 1976, Goldie et al., 1989). But the reason for the other relation using the dimension could be the elimination of the visual control mechanism. This leads to the reduction in the number of degrees of freedom of the total system. The comparison with the values of the standard deviation shows opposite characteristics (s. fig. 1b). The cause for this is that standard deviation is a measure for the variation of the time series and the fractal dimension has a different meaning in nonlinear dynamics.

Breaststroke: The figures 2a and 2b show the coefficient of the phase structure and the fractal dimension in dependence on the flow velocity. Considering the coefficient of the phase structure it is evident that the efficiency of the movement is smallest at middle velocities (fig. 2a). But the fractal dimension has the greatest values at these velocities (fig. 2b). So we can conclude that a effective movement is characterized by a high dimension. In order to obtain a economical movement coordination it is necessary for the athletes to have a sufficient number of degrees of freedom at their disposal. We can also see that the movement efficiency is reduced when the load is high.

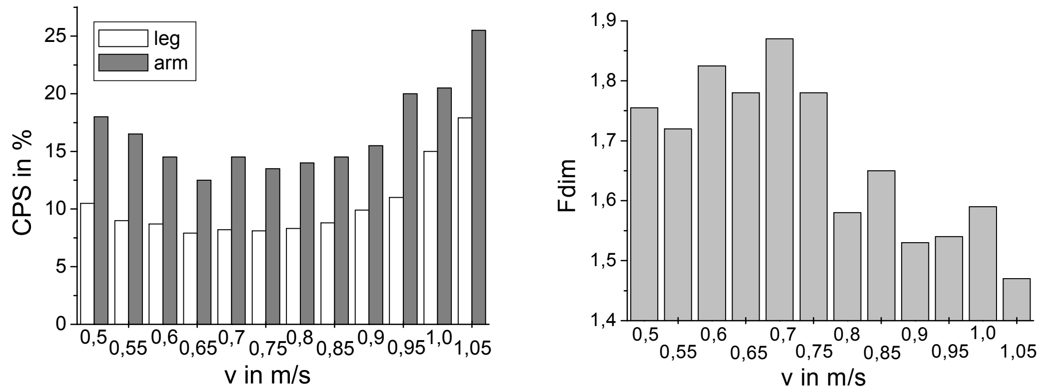

Figure 2 - Results for the breaststroke in dependence on the flow velocity. 2a: Coefficient of the phase structure, 1b: Fractal dimension.

CONCLUSION: We have shown two different possibilities of the application of methods of nonlinear time series in sports. At first the fractal dimension is a measure for the variability but in a different way than statistical variations. We interpret the fractal dimension as the number of mechanisms of motor control. So for the standing balance the fractal dimension decreases when the visual system is switched off or when the standing area is reduced. Using the example of the breaststroke we found that the fractal dimension decreases with higher load. That means a reduction of the number of mechanisms of motor control. By means of the fractal dimension it is possible to show that the movement will be stiffer under difficult conditions.

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