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研究ノート

Recurrence Quantification Analysis of Human Gate Intervals

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ABSTRACT

Human gate intervals of old and young subjects were studied using recurrence quantification analysis. Linear mean gate intervals were not significantly different between old and young subjects. However, nonlinear recurrence variables of Laminarity, Vmax and Traptime could distinguish between younger versus older subjects. Our findings support the conclusion that gate intervals in the younger people were more chaotic than the older individuals.

INTRODUCTION

Human gate interval fluctuations possess nonlinear dynamical system characteristics such as fractal dynamics (Hausdorf et al, 1996). The fractal dynamics of spontaneous gate intervals are quite robust and intrinsic to the human locomotor system.

Recurrence plots (RPs) were originally designed to visualize recurring patterns and reveal hidden non-stationarities within experimental data sets (Eckmann et al., 1987). Soon, recurrence plots were quantified by the extracting 5 dynamical variables from the plots (Zbilut and Webber, 1992; Webber and Zubilt, 1994): recurrence, determinism, max diagonal line, line entropy, and trend. The methodology has been termed recurrence quantification analysis (RQA). Later, 3 more dynamical variables were added (Marwan et al., 2002): laminarity, max vertical line, trapping time. The purpose of this study was to analyze by RQA the gate intervals of older and younger subject separated by some 5 decades in age.

METHODS

Gate Interval Data

The gate interval data were downloaded from three on-line databases: Gait in Aging and Disease; Gait and Balance; and Physiobank. The human subjects consisted of 5 healthy older male adults (71-77 years old) and 5 healthy younger male adults (23-29 years old). Subjects walked at a constant pace on

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level ground around an obstacle-free path. The stride interval was measured using ultra-thin, force sensitive resistors placed inside one shoe. The analog force signal was sampled at 300 Hz with 12-bit A/D converter, using an ambulatory, ankle-worn microcomputer. Subsequently, the time between foot-strikes was automatically computed. Data were collected from the subjects as they walked in a roughly circular path for 15 minutes.

Recurrence Quantification Analysis of Gate Interval

The gate interval data was analyzed by RQA. RQA parameters were set as follows: embedding dimension=10, delay=1, rescale=max distance, norm = Euclid, radius = adjusted so that recurrence was close to 1%. Results of RQA for gate interval data for the younger and older subjects were statistically compared using the paired student t-test. The level of significant difference was selected at the P <= 0.05 level.

Recurrence Plots of the Logistic Map

Recurrence plots of the human gate data were compared against recurrence plots the logistic map. Dynamics of the logistic equation (Eq. 1) were generated by iteration of the logistic equation for four values of the control parameter (*a* = 3.679, 3.791, 3.830 and 4.000). Three of the dynamics were in the chaotic regime of the logistic attractor, save one (*a* = 3.830) which was in the period-3 window. These four steady-state dynamics were then subjected to RQA analysis using specific RQA parameters settings: embedding dimension = 3, delay = 1, rescale = max distance, norm = Euclid, radius = 20.

$$x_{i+1} = a \cdot x_i \cdot (1 - x_i) \quad (1)$$

RESULTS

Recurrence Plots of Logistic Map

Figures 1 to 4 represent the recurrence plots of logistic map for four different control parameter. Figure 1 is the special case in which a periodic window appears (*a*=3.830) amidst the surrounding chaos. This plot is filled with diagonal lines extending from border to border for this 3-point periodic process. Vertical structures and rectangular blocks are absent.

Figures 2 to 4 display the recurrence plots for the chaotic modes of the logistic attractor in three different regions (*a*=3.679, 3.79, 4.000 respectively). In all cases, vertical structures and rectangular blocks are present along with short diagonal lines. In fact, with increases in parameter *a*, the block structures shrink and the number of isolated recurrent points increase.

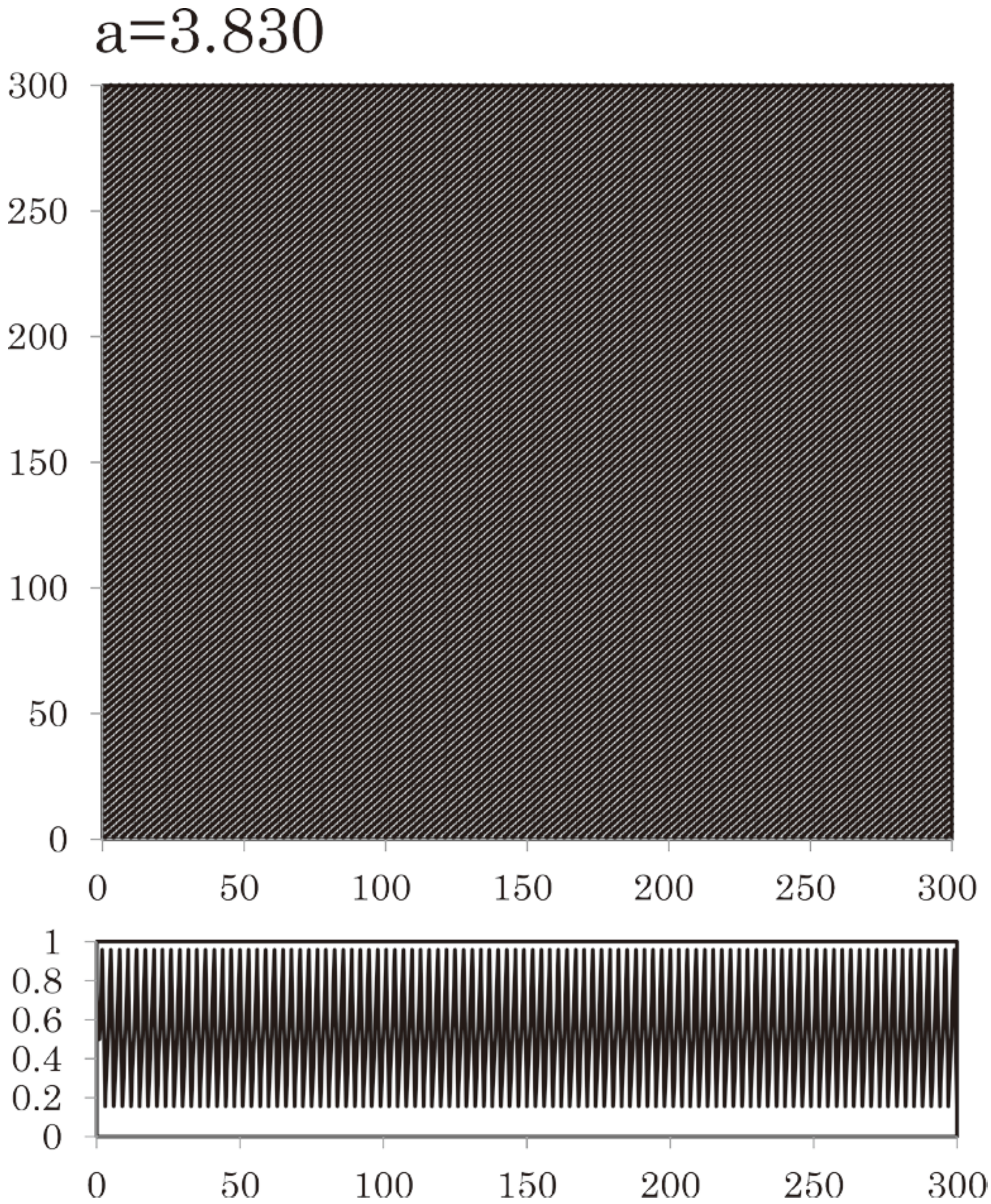

Fig. 1. 300 points of the iterated x-series of the logistic equation for control parameter *a* = 3.830 (bottom) and corresponding recurrence plot (top).

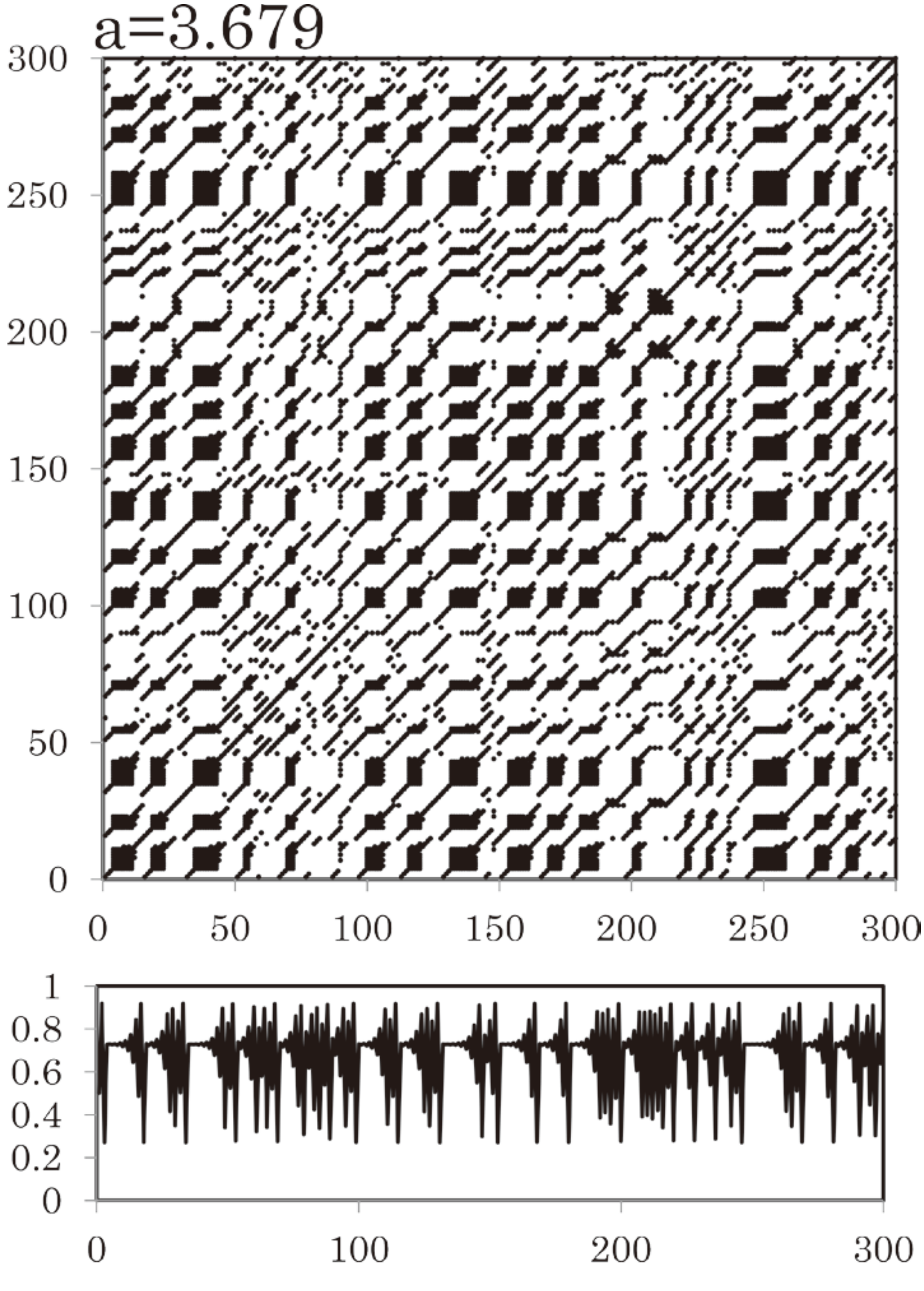

Fig. 2. 300 points of the iterated x-series of the logistic equation for control parameter a = 3.679 (bottom) and corresponding recurrence plot (top).

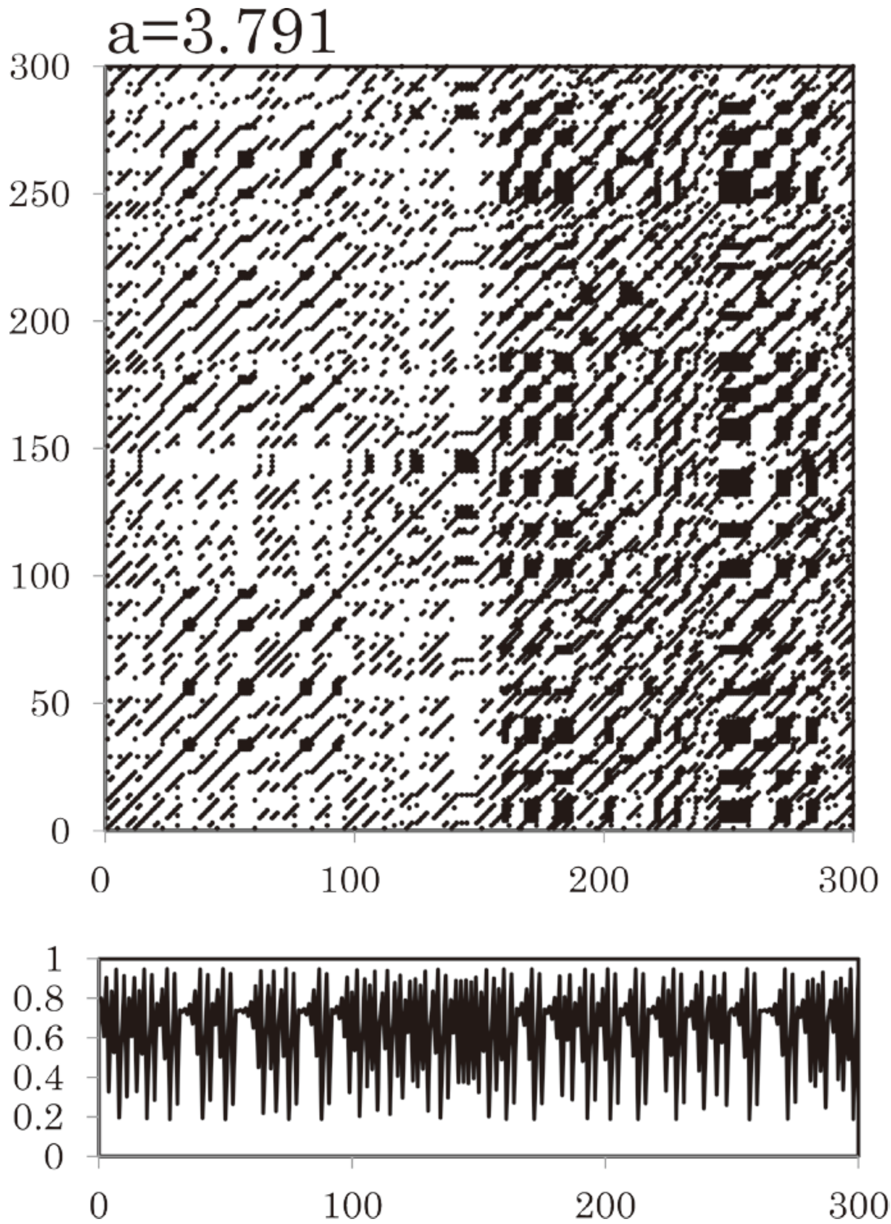

Fig. 3. 300 points of the iterated x-series of the logistic equation for control parameter a = 3.791 (bottom) and corresponding recurrence plot (top).

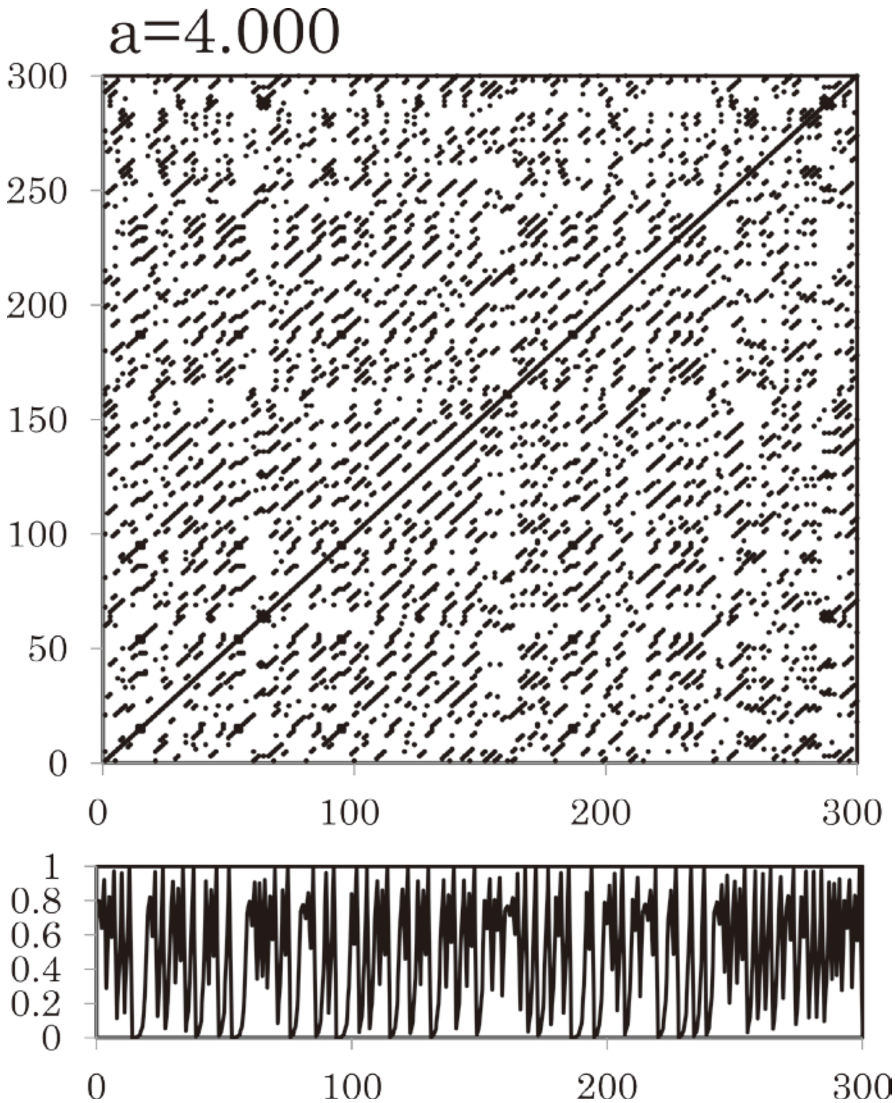

Fig. 4. 300 points of the iterated x-series of the logistic equation for control parameter *a* = 4.000 (bottom) and corresponding recurrence plot (top).

Recurrence Plots of Gate Interval Data in Younger and Older Subjects

Figures 5 and 6 represent the recurrence plots of the gate interval data for the younger and older walking subjects respectively. Both plots have uniformly scattered points with short diagonal line structures which means that the walking dynamics of both the younger and older subjects were in steady-state modes, but with chaotic characteristics (compare with Figs. 2-4).

Recurrence Quantification Analysis of Gate Interval Data in Younger and Older Subjects

Table 1 shows that while there are no statistical differences between the gate intervals of the younger and older subjects, their dynamics could be distinguished by RQA. Thus, laminarity vertical structures, and trapping time were all statistically larger for the younger group as compared against the older group. These results may indicate that the younger subjects have a higher degree of chaoticity than the older subjects. Indeed, it has been reported that gate interval dynamics in younger subjects possessed fractal structuring (Hausdorf et al. 1996) with which our results support.

CONCLUSIONS

Recurrence Quantification Analysis was using to measure the complexity of gate interval data. Subjects were 5 younger and 5 older men. The Logistic equation map was analyzed by recurrence plots to ascertain the periodic or chaotic regimes. Qualitatively, recurrence plots of both the younger and older subjects looks like chaotic modes when compared against the logistic plots. Quantitatively, the younger subjects had larger laminarity, Vmax and trapping time values than the older subjects. It is concluded that gate interval dynamics of younger subjects may be more chaotic than the older subjects. These patterns may be generated by the Central Pattern Generator which controls human locomotion.

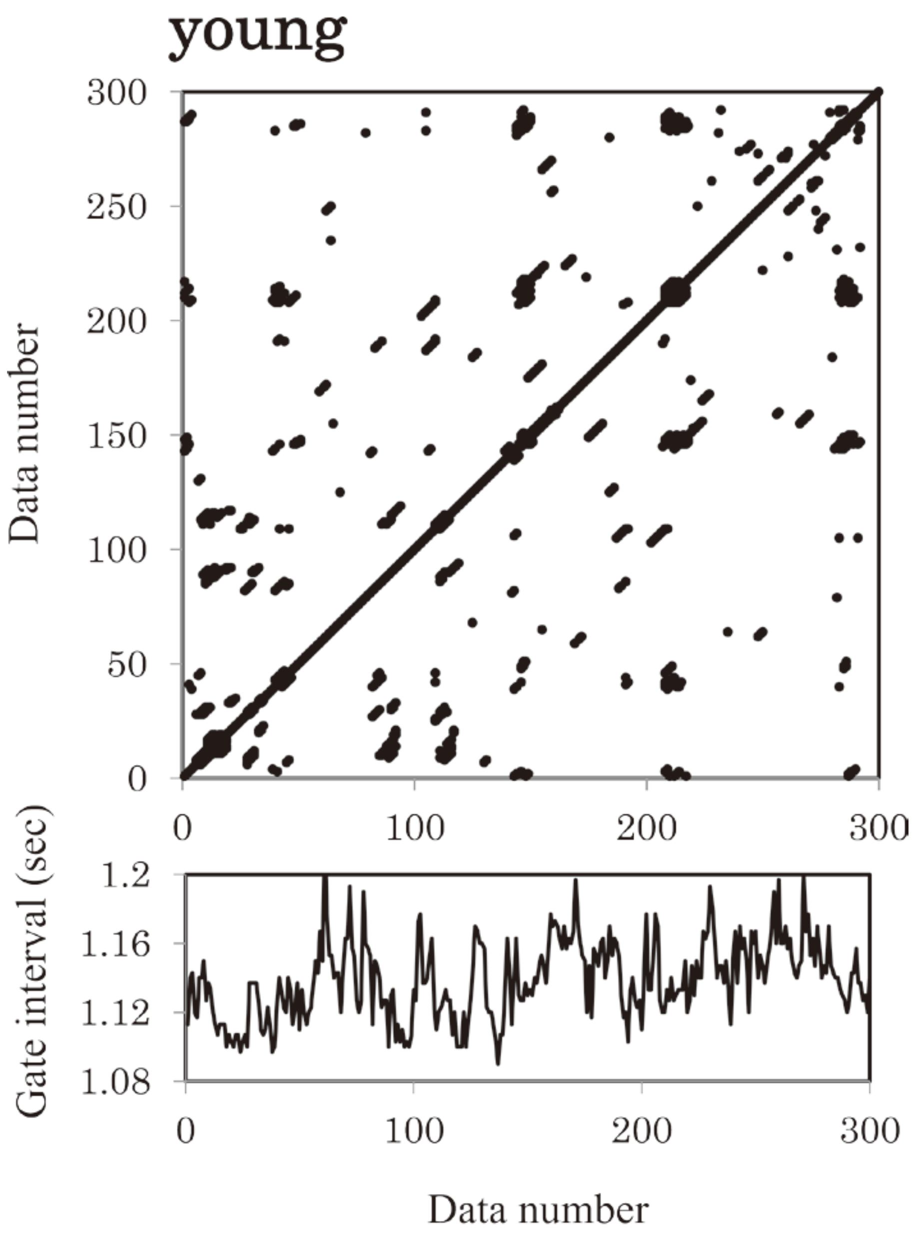

Fig. 5. 300 points of the gate interval time series from the younger subjects (bottom) and corresponding recurrence plot (top).

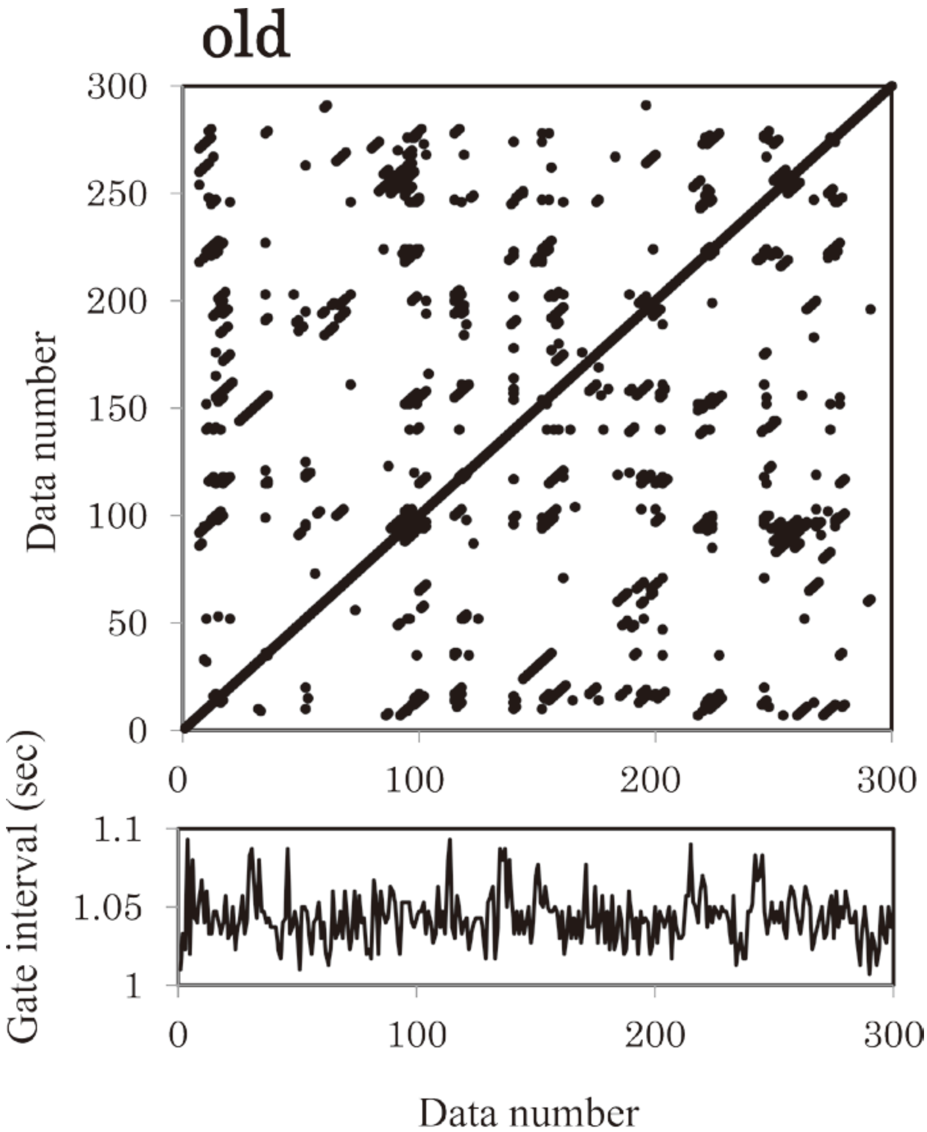

Fig. 6. Recurrence plot and time series of gate interval of an older subject. Data were first 300 interval of total 815 intervals.

Table 1. Gate interval data and RQA statistics from older and younger subjects

	%rec	%det	dmax	entropy	trend	%lam	vmax	TT	gate interval
y1	1.006	81.655	17	2.516	-1.982	42.129	10	2.696	1.140504
y2	1.016	83.023	16	2.528	-2.745	35.847	13	2.601	1.041685
y3	1.048	80.194	16	2.366	-1.21	27.259	7	2.352	1.030534
y4	1.023	83.133	16	2.493	-1.926	33.573	10	2.754	1.183921
y5	1.013	82.913	18	2.567	-1.66	38.66	9	2.885	1.116053
Mean	**1.02**	**82.1836**	**17**	**2.494**	**-1.9046**	**35.49**	**9.8**	**2.658**	**1.1025394**
SD	**0.01**	**1.12924**	**0.8**	**0.06834**	**0.501**	**5.014**	**1.94**	**0.178**	**0.0585405**
o1	1.017	82.747	16	2.557	-2.965	24.166	6	2.245	1.030661
o2	1.04	79.352	13	2.396	-1.11	20.762	6	2.198	1.167703
o3	1.037	81.183	21	2.542	-2.679	29.958	10	2.654	0.940825
o4	1.016	80.748	14	2.443	-1.902	25.111	6	2.437	0.956881
o5	1.02	79.289	13	2.392	-0.089	9.428	5	2.226	1.04214
Mean	**1.03**	**80.6638**	**15**	**2.466**	**-1.749**	**21.89**	**6.6**	**2.352**	**1.027642**
SD	**0.01**	**1.28275**	**3**	**0.07066**	**1.05175**	**6.888**	**1.74**	**0.173**	**0.0804745**
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Gate interval (sec)
** p<0.01

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