Chaos Analysis of the Sequential Transform of Spontaneous Movements of Early Infants: Angular Acceleration of Elbow Extension–Flexion Movements

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Abstract. Conventional clinical evaluate on of spontaneous movements in early infants is a subjective evaluation based on visual observation. To clarify the parameters for these complicated movements, chaos analysis was conducted using angular acceleration of elbow extension–flexion movements. Neurologically normal premature infants were measured every 4 weeks at 36–56 weeks post menstrual age using a three-dimensional motion analyzer. The data were used for chaos analysis (the largest Lyapunov exponent, the correlation dimension). All data had chaos dynamics. The largest Lyapunov exponent were decreased and the correlation dimension were increased. Significant difference was found among the outcomes. The parameters used to quantify complicated movements were clarified.

Keywords. chaos, premature, infant, spontaneous movements, parameter

1. Introduction

Transformation of the spontaneous movements in early infancy is often used as a parameter by child care professionals. Changes of speed and complexity, which can represent the transformation of spontaneous movements, are classified into three terms: preterm; the second term, from 0 months through the second month; and the third term, from the third month through the fourth month (Einspieler C et al. 2004; Prechtl HFR 2001; Einspieler C et al. 1997). An infant with central nervous system disorders has no transformation of spontaneous movements, so the transform of spontaneous movements has been used for clinical evaluation (Prechtl HFR et al. 1997; Ferrari F, 1990).

Conventional clinical evaluation of the spontaneous movements of early infants has been used for subjective evaluation based on visual observation (Einspieler C et al. 2004), but it is difficult to quantify evaluation. For that reason, parameter has not been provided. However, a significant difference was found in the change of speed in our earlier study, with emphasis on the angular acceleration of elbow extension–flexion movements. Results illustrate the value of quantitative evaluation of the change of speed at spontaneous movements in early infants, but the complexity of spontaneous movements cannot be used for evaluation in early infants.

Quantification of movements is regarded as useful for the elucidation of motor developmental mechanisms and for the early detection of developmental disorders. If it were possible to evaluate the transformation of spontaneous movements quantitatively using chaos analysis, then we would be able to create a new risk stratification scale and automatic evaluation systems. To clarify parameters for the complicated movements of early infants, Chaos Analysis was applied using the angular acceleration of elbow extension–flexion movements.

2. Methods

2.1 Subjects

During 36–56 weeks PMA, 19 neurologically normal premature infants (10 male, 9 female; 36 weeks > months post menstrual age (PMA)) were measured every 4 weeks. Table 1 presents characteristics of each infant.

Table 1. *Characteristics of the subject*

Subject no.	M / F	Post Menstrual Age (weeks -- day)	Birth Weight （g）	Subject no.	M / F	Post Menstrual Age (weeks -- day)	Birth Weight （g）
1	F	35 -- 3	2497	11	F	30 -- 6	1576
2	F	30 -- 0	1409	12	F	30 -- 6	1024
3	M	30 -- 0	1449	13	F	35 -- 3	1908
4	F	30 -- 0	1307	14	F	30 -- 2	1126
5	M	30 -- 6	1395	15	M	25 -- 0	800
6	M	30 -- 6	1649	16	F	25 -- 0	668
7	F	30 -- 6	1449	17	M	35 -- 1	1950
8	M	33 -- 0	1975	18	M	30 -- 2	864
9	M	23 -- 4	568	19	M	34 -- 4	1414
10	M	22 -- 2	410				
					Avg.	30 -- 1.5	1338.8
					SE.	± 6 -- 6.5	± 307.2

All parents gave written informed consent. The study was approved by the institutional review board of the Tohoku University Hospital and the Yamagata Prefectural Central Hospital.

2.2 Measurement

2.2.1 Apparatus

Infants were measured in a special bedroom at the Yamagata Prefectural Central Hospital. The three-dimensional motion analyzer (Fastrak system; Polhemus Inc.) was used to measure spontaneous movements of the upper right limb in a supine position, on a special wooden platform (120 cm width; 120 cm depth; 90 cm height with fence). A teardrop type sensor of the lightest model (diameter, 1 cm; weight, 2 g) was used.

2.2.2 Procedure

Position data were obtained from sensors attached to the right-upper limb, which were recorded for 270 s at the sampling frequency of 40 Hz. The behavioral state of the infants that showed only movements during awake and non-crying state epochs were analyzed. Exclusion criteria were less than 1500 deg / 3 min of elbow extension–flexion movements during awake and non-crying state epochs. Missing data were added for revision using Multivariate Imputation by Chained Equation (MICE), written in open source R language (van Buuren S 2007).

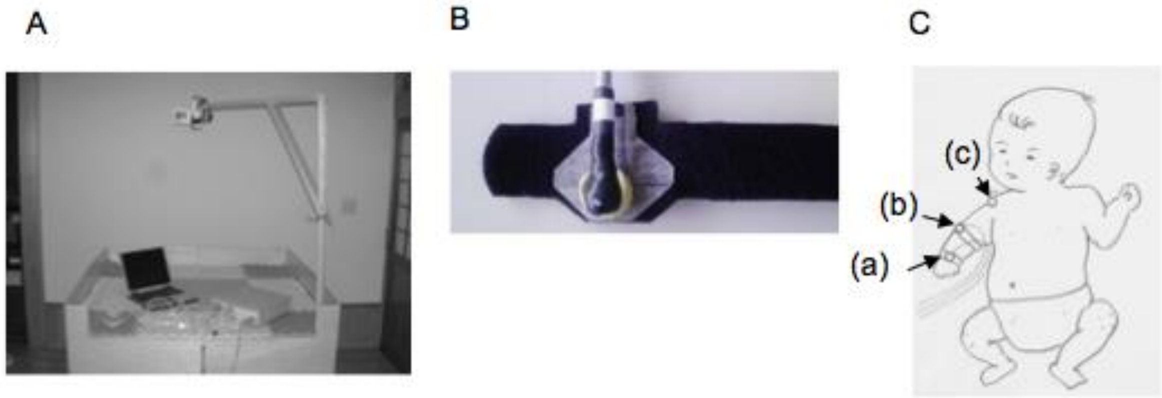

Figure 1. *Apparatus and Sensor positions:*
A, Special platform and Fastrak system; B, Tear drop type sensor attached to the belt with hook-and-loop fastener and tighten on the wrist (a) and the olecranon (b); C, sensor position of upper limb and the sensor was past on the acromion (c).

2.3 Data analysis

Position data were used to calculate the angular acceleration at the elbow. A maximum root mean square values of 180 s in 270 s data of the angular acceleration were used for Chaos Analyses, which were done using the largest Lyapunov exponent and the correlation dimension to define the fractal dimension calculated using Grassberger–Proccacia’s algorithm.

The calculated data were classified in the three terms of the 36th and the 40th week PMA (term I), the 44th and the 48th week PMA (term II), and the 52nd and the 56th week PMA (term III). The typical value was the mean value for each term. Holm’s analysis of multiple comparison was conducted for statistical analyses. Statistical analysis was used with software written in open source R language. Throughout these analyses, differences with a P value < .05 were inferred as statistically significant (Aihara K 2001).

3. Results

The largest Lyapunov exponent of all data is a positive number. Significant differences were found in the outcomes of all three terms. The mean value of term I was significantly higher than that of either term II or III. The term II mean value was significantly higher than that of term III (Figure *1 A*). However, the correlation dimension of all data has no integer. The mean value of term I was significantly less than that of term II or term III. The difference between mean values of terms II and III was not significant (Figure *1 B*).

4. Discussion

Time series of all data showed chaos dynamics because the largest Lyapunov exponent of all values was a positive number. Also, the correlation dimension of all values was not an integer.

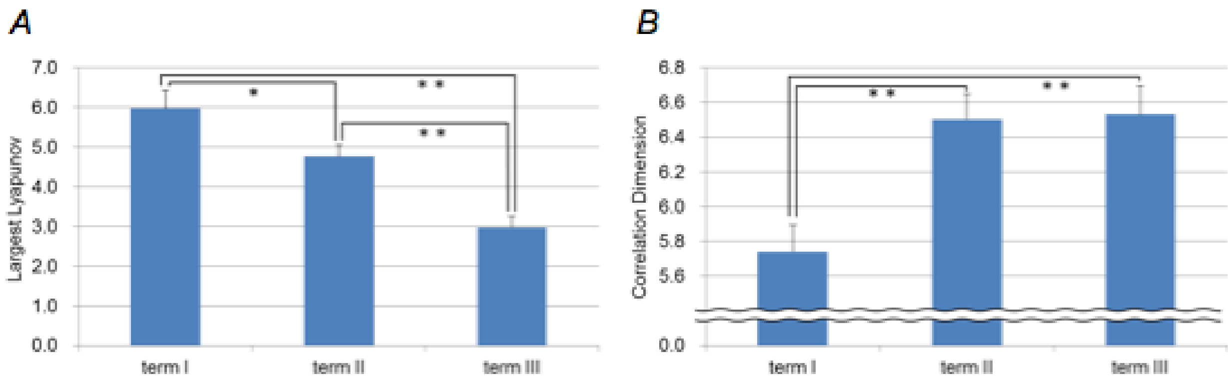

Figure 2. *A, Temporal change chart of the largest Lyapunov exponent;*
*B, Temporal change chart of the correlation dimension (P value: *, P< .05; **, P< .01).*

4.1 Perspective of the largest Lyapunov exponent

The mean value of term I was significantly greater than that of term II or III. The mean value of term II was significantly greater than that of term III. Results show a decrease in orbital instability at the time series data of elbow extension–flexion in spontaneous movements. Results suggest that flowing movements of elbow increased over time.

4.2 Perspective of the correlation dimension

The mean value of term I was significantly less than that of term II of III. Results show increased complexity of the time series data of elbow extension–flexion for spontaneous movements. Results suggest that complexity movements of the elbow increased over time.

These data suggest that the change in the largest Lyapunov exponent and the correlation dimension were affected by central nervous system development.

5. Conclusion

The time series of all data exhibited chaos dynamics. Chaos Analysis is instructive for use in expressing the complexity of spontaneous movements with angular acceleration of elbow extension–flexion movements.

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