Nonlinear Analysis of Horses
Trotting with and without Sedation

by

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Abstract

It is common to use sedatives in equine practice for surgical procedures, standing or recumbent, and for control of unruly patients. In recent years, there have been many investigations concerning the effect sedation might have on gait during lameness examination.

The aim of this research is to develop an application of the largest Lyapunov exponents to study the effects of sedation on the gait of horses with lameness. The purpose of this study is to quantify movements of the horses using the largest Lyapunov exponents. The research was also conducted by the IACUC of the College of Veterinary Medicine at Auburn University, as well as the Samuel Ginn College of Engineering at Auburn University. Data examples were recorded from nine horses with sedation or untreated during trotting. Within each group, data was generated from different time.

In conclusion, the largest Lyapunov exponents were applied successfully to study the horses' motion during trotting for each time period. It is obvious that the maximal Lyapunov exponents of horses with sedation (detomidine) were smaller and more stable than untreated horses for each time period. This means that sedation drugs had a distinct effect on lame horses' motion stability. Generally, the maximal Lyapunov exponents of horses decreased with increasing trotting time.

Future studies are needed to get more meaningful data based on horses. For further analysis, more Nonlinear Methods should be used to analyze the data, so that the examination procedure can be applied to a larger population of subjects more widely.

Acknowledgments

I want to thank my academic advisor, Dr. Dan Marghitu for providing me this opportunity to be involved in his project. With this chance, I have learned a lot about Dynamic Analysis in mechanical engineering. Thanks to Dr. Dan Marghitu for providing so much help during my master's study period at Auburn University. I also want to thank Dr. John Schumacher, who provided valuable experiments' data for my Nonlinear Analysis. I also want to thank Dr. Joseph Ragan for being my thesis committee member. Moreover, I also want to thank all the staff who provided valuable help during my thesis work.

Table of Contents

List of Figure

List of Table

List of Abbreviations

One-way ANOVA	One-way analysis of variance
Two-way ANOVA	Two-way analysis of variance
CSPW	Computer-Supported Personal Work
VRA	Virtual Recurrence Analysis
AMI	Average Mutual Information
GFNN	Global False Nearest Neighbors
Global ED	Global Embedding Dimension
LLE	Largest Lyapunov Exponents

Chapter 1

Introduction

1.1 Horse Description

Humans and horses create a locomotive ability by using their legs. With the domestication of the horses, the movement of goods became faster. Therefore, horses have become more significant throughout time.

Horses change their gaits [1] according to the need for speed. For instance, the speed of travel increases from a walk to a trot to a gallop. In order to better understand the mechanism of horses' motion and to identify lameness, many researchers have investigated horses' gaits.

Horses' gaits [2] can be divided into three categories: walk, trot, and canter or gallop. The walk is a four-beat gait. When walking, a horse moves its legs as follows: left hind leg, left front leg, right hind leg, right front leg, in a regular 1-2-3-4 beat. The trot is a two-beat gait that has the variation in speeds. For the trot, horses move their legs in unison in diagonal pairs. The canter is a three-beat gait and faster than the trot. Compared to the canter, the gallop is faster, more ground-covering and is a four-beat gait. Taking a horse's canter as an example, a horse's legs follow this sequence: left hind leg, then left front leg and right hind leg together, then right front leg and then all legs ascend simultaneously.

In this research, there were nine lame horses in the experiments. Due to the dysfunction of the locomotor system, lameness [3] is defined as an abnormal gait or stance. In the experiment horses were lame because of pain, neurologic or mechanical dysfunction. This study was performed on horses that had easily observed lameness and horses that had subtle lameness [4]. Some lameness is easily observed using subjective evaluation while subtle lameness may require

objective evaluation by using a wireless, inertial, sensor-based, motion analysis system (Lameness Locator®).

Some lameness experts [4] [5] claimed that sedation of lame horses would not appreciably change gait and even though sedatives have analgesic properties, sedation will not make horses significantly less lame. However, a study by Buchner et al. [5] showed that sedation with detomidine caused horses' gaits to change, and when lameness was subtle, sedation hampered lameness evaluation.

1.2 Horses' Gaits Previous Experiments

In 1997, according to the phenomenon of horses bearing impact during locomotion, Wilson et al. [6] used contour plots to provide a visual representation of time and frequency localization of power. Then, by drawing the time series for the hoof impact and the initial deceleration at impact, they studied the causation and prevention of injury to horses.

Four years later, Butcher and Ashley-Ross [7], in order to investigate how age influenced dorsiflexion and quick rates of fetlock joint movements, conducted experiments with four age classes of Thoroughbreds. After comparing the galloping stride's angular profile of different aged horses, they found the fetlock joint dorsiflexion from impact to mid-stance changed according to age and the change in gaits and speeds.

In 2002, Biau et al. [8] carried out a study to describe downward gait transitions in horses. During the experiments, horses were equipped with the ambulatory gait analysis system Equimetrix™ for decelerating gait transitions. Among their conclusions, they discovered that the transition type could be affected by duration, energy module and frequency.

In 2005, Lagarde et al. [9] studied the interaction between riders and horses and compared the behavior of expert riders with the behavior of novice riders. As the augment of the temporal-

oscillations' regularity of horses' trunks, horses and expert riders created a tight ensemble synchrony. Through practice, the differences of phase synchronization between expert and novice riders will be reduced gradually.

In addition, Bullimore and Burn [10] considered that different-sized horses might have similar patterns of locomotion (2005). Therefore, they measured the relative stride length and the duty factor of horses under various experimental environments. As a result, they found a "compensatory distortion" might offset the influence of different-sized horses.

In 2007, Nicodemus et al. [11] did a study to examine the differences between the joint motion measurements using the multi-planar analysis and the joint coordinate system. With a series of data collection, reduction, calculation and plotting, analysis showed that flexion/extension measurements by the multi-planar analysis or the joint coordinate system both had advantages under a different situation.

Moreover, in 2012, Pfau et al. [12] explored the relationship between a horse body leaning angle, and its radius and speed during lunging. They selected 11 training horses as the research objects and found the body leaning angles could be predicted from gravitational and centripetal forces. Unfortunately, there also existed some differences in symmetry between horses lunging directions, which should be investigated for further study.

1.3 Methods Description

The proposed analysis departs from previous research concentrated on a nonlinear analysis of experiments in horses' gaits and motions. One of the most significant methods is based on the Lyapunov exponents [13].

The dynamical system's stability can be approximated by its reaction to kinematic disturbances [13]. The dynamical system's sensitivity to small kinematic perturbations can be

quantified by the system's Lyapunov exponents (λ_i) [13]. The separation rate can vary due to the different orientations of initial separation vector. Therefore, there is a spectrum of the Lyapunov exponents, which is equal in number to the phase space's dimension. The maximal Lyapunov exponent [13] is the largest one of λ_i because it determines a predictable notion of a dynamic system. A positive maximal Lyapunov exponent indicates that the system is chaotic.

1.4 Lyapunov Exponents Previous Experiments

An example of a study using the Lyapunov exponents of Dingwella and Cusumano [14] researched the dynamic stability of people walking on a motorized treadmill by the average maximum finite-time Lyapunov exponents, λ_i. The λ_i quantified the average exponential rate of neighboring-trajectories' divergence in state space and measured the stability of the system. Finally, Dingwella and Cusumano demonstrated that a small but obvious amount of people walking on a motorized treadmill stabilized their natural locomotors kinematics.

In 2007, England and Granata [15] examined how walking velocity impacted the stability during normal gaits. They used the Lyapunov exponents, which is λ_i, to quantify the local dynamic stability. Every movement dimension of the kinematic trajectory would be matched with one Lyapunov exponent. If the sum of all Lyapunov-spectrum exponents is negative, the system is stable. From the experiments, the smaller the largest Lyapunov exponent is, the more stable the system is. They finally indicated that higher stability would result from lower walking velocities.

In 2008, Skokos [16] did a survey about the Lyapunov characteristic exponents for a dynamic system. After some attempts for a numerical evaluation of the Lyapunov characteristic exponents, based on the multiplicative ergodic theorem of Oseledec, Skokos analyzed the algorithm for the maximal Lyapunov characteristic exponents and used it as an indicator of

chaos. He also considered different discrete and continuous methods for calculating the Lyapunov characteristic exponents. At the same time, he also evaluated the Lyapunov characteristic exponents of dissipative systems and time series.

In addition, Marghitu et al. [17] applied nonlinear mathematical techniques to analyze dogs' gaits at walk and trot. They used a 2D motion analysis system for collecting kinematic data of the center pressure of the dog. The Lyapunov exponents, λ_i, served as a measurement method for the sensitivity of a system to its initial conditions. The λ_i means the rate of divergence or convergence of the nearby trajectories to figure out if the system is chaotic or non-chaotic. With experiments, Marghitu et al. provide a method to distinguish normal and abnormal gaits in dogs according to the analysis of the center pressure on dogs.

1.5 Two-way ANOVA Method Description

The one-way analysis of variance (one-way ANOVA) [18] is typically used to compare means of three or more data samples (using the F distribution). The two-way analysis of variance (two-way ANOVA) [18] is an improvement of the one-way ANOVA that compares the effect of two different categorical independent variables on one continuous dependent variable.

According to the two-way ANOVA, it is effective to evaluate the main influence of each independent variable, as well as the interaction between them.

1.6 Objective

The purpose of this research is to carry on an application of the largest Lyapunov exponents. This study is based on the experiment about the effect of sedation drugs for horses with lameness during their motion (gait).

We have developed tests and collected horses' motion data as they trotted within different time periods. The largest Lyapunov exponents for analyzing motion data about a sedative

(detomidine) effect on variability or stability of horses' gaits.

Chapter 2

Method and Equipment

2.1 Animals

Nine mature lame horses with approximately body weights and heights were used in this experiment. A full clinical examination was performed on all horses to ensure that these horses satisfied the experiment's requirements [19] [20]. The horses were amendable to the trotting protocol and measurement sessions.

2.2 Treatments

Each horse was used as its own control, and two treatments were administered to each horse: sedation and untreated. All horses were trotted for evaluation of gait for each group on different days. Horses were trotted about 25 strides every 5 minutes. To get 25 strides, horses were trotted about 12 to 13 strides turned and trotted back. So they were trotted down and back every 5 minutes. The Lameness Locator® automatically discards data from the turn arounds. For each horse, the same protocol was used.

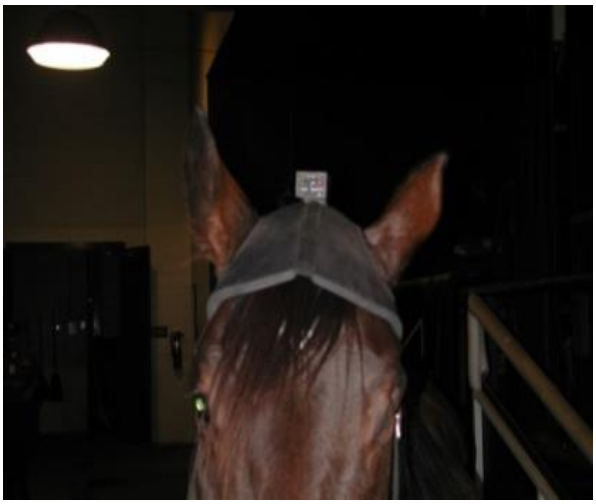
Sedation drugs are used in the symptomatic treatment of anxiety, irritability, etc.; they are sometimes used in the lameness examinations to control an unruly horse. Common sedation drugs used in the horses are xylazine and detomidine [19]. This experiment studied the effect of a sedative (detomidine) on the gait of lame horses.

2.3 Data Acquisition

The gaits analysis system used sensors and a data logger. Every 5 minutes the data were collected for a total of 45 minutes while horses were sedated or untreated. The data collected by the Lameness Locator® [19] [20] was analyzed for each of the two data collection trials.

Figure 1 from the IACUC of the College of Veterinary Medicine at Auburn University showed the measuring equipment.

Figure 1 The measuring equipment on horses



The experiment used Lameness Locator® software for data collection. The Lameness Locator® [20] uses a series of algorithms to determine symmetry while horse is trotting (the trot is a symmetrical gait). There would be an accurate determination of lameness with a Lameness Locator® according to the horses' motion data. In this study, the horses trotted in one direction in a straight line, turned, and trotted back, and then stopped after at least 25 strides were recorded.

2.4 Data Analysis

The original data examples were arranged by MATLAB R2015a software. The useful data examples were put in the Computer-Supported Personal Work software and Virtual Recurrence Analysis software to find data parameters. For the effect of sedation drugs on stability during horses' walking, the software developed by M. T. Rosenstein et al. and MATLAB R2015a software were used for the Lyapunov Exponents Analysis. For the effect of sedation drugs on variability during horses' motion, the two-way ANOVA method was used.

Chapter 3

Data and Results

3.1 Time Series

A time series [21] is a sequence of data points from measurements made over a successive time interval and it is usually plotted by line charts.

Taking the data examples from Subject1 (horses with sedation were trotting at 5 minutes) as an example, Figure 2 shows the original head acceleration data.

Figure 2 The original data examples

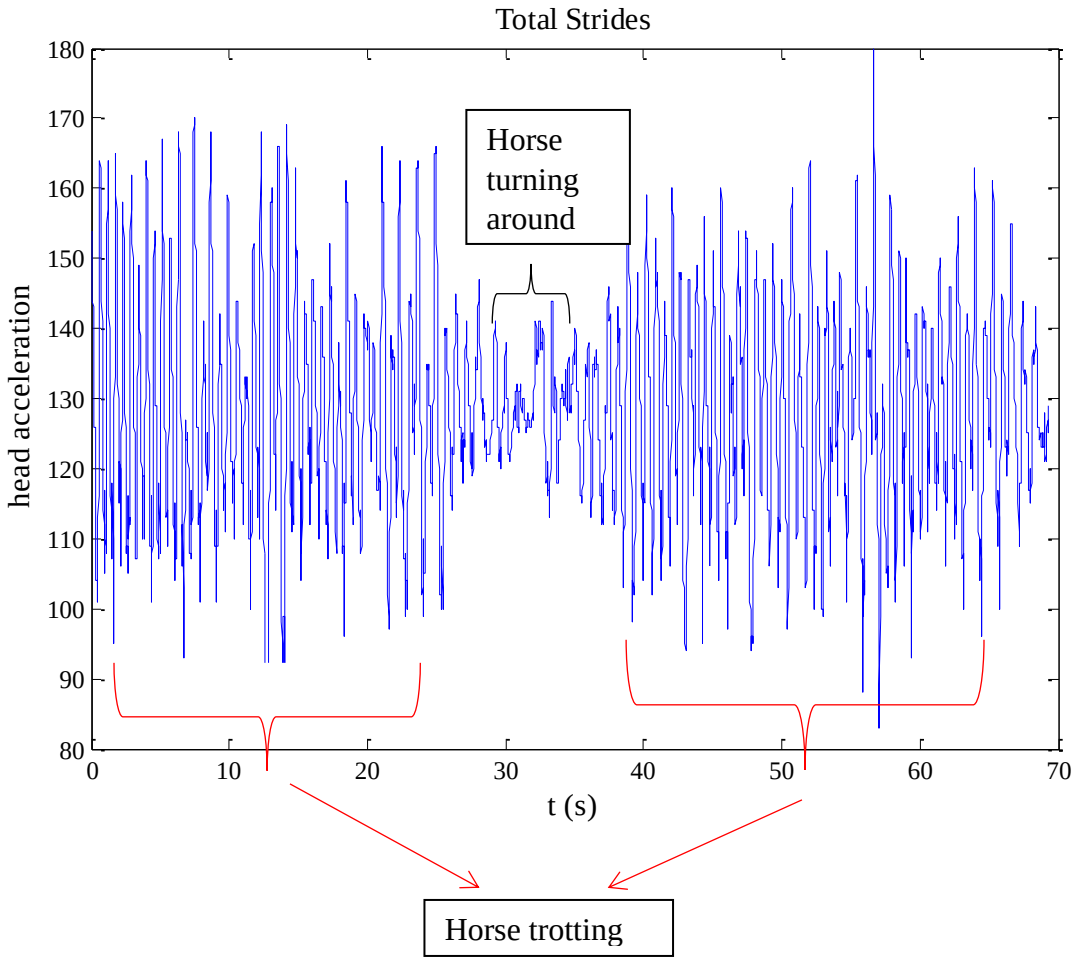


Figure 3 is the first part of data examples and the length of time series is approximately 25 seconds (the total number of data is 3000). Figure 4 is the second part of data examples and the length of time series is approximately 25 seconds (the total number of data is 3000).

Figure 3 First part data examples

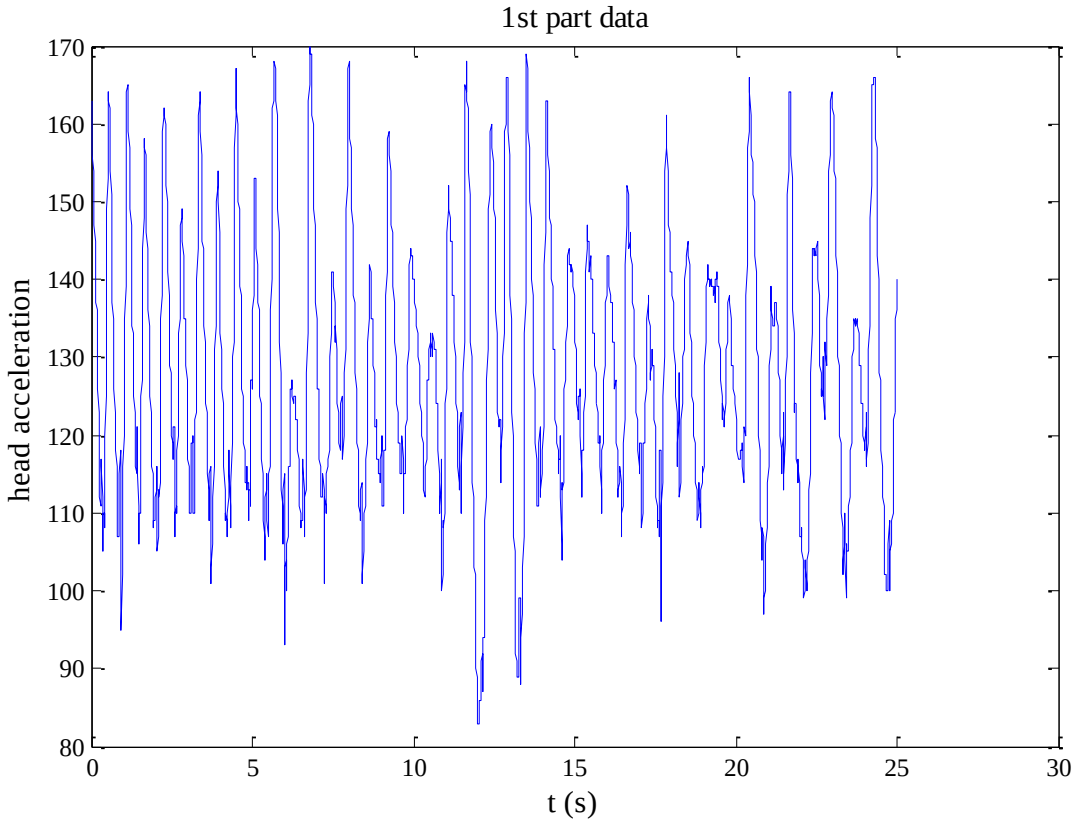
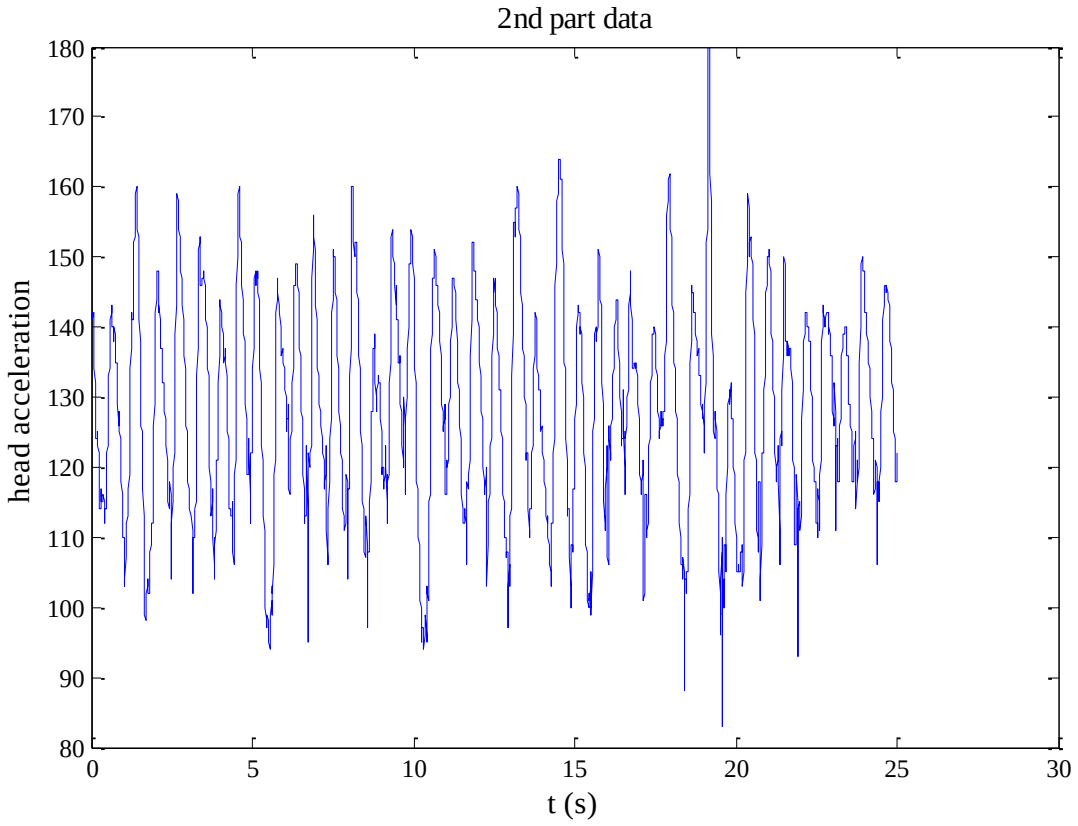


Figure 4 Second part data examples



Moreover, with a time series analysis, it is helpful to get the meaningful and significant characteristics of data examples. Figure 5 uses the start point and end point of the 1st stride's time series data and Figure 6 uses the 4th ~ 10th strides' time series data.

Figure 5 First stride’s time series data

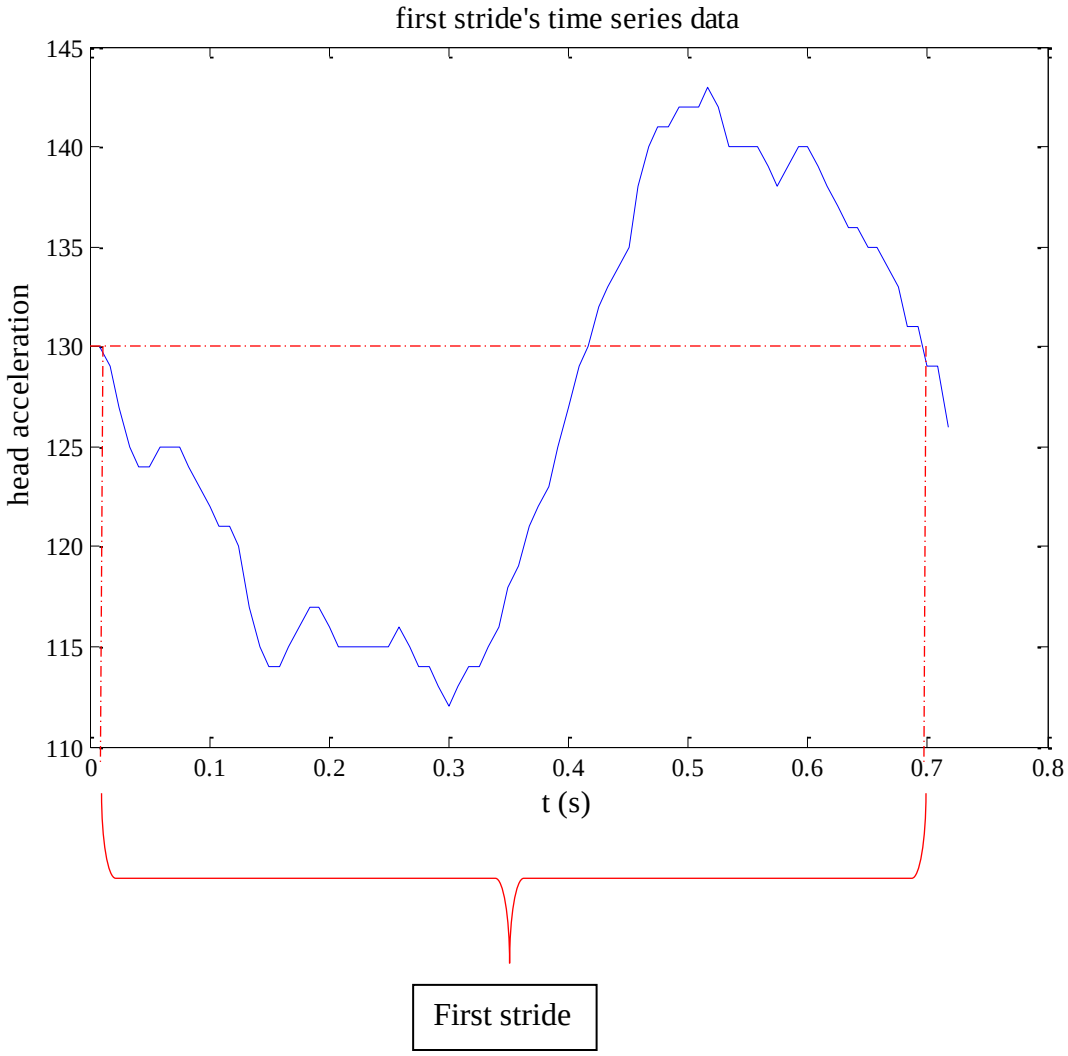
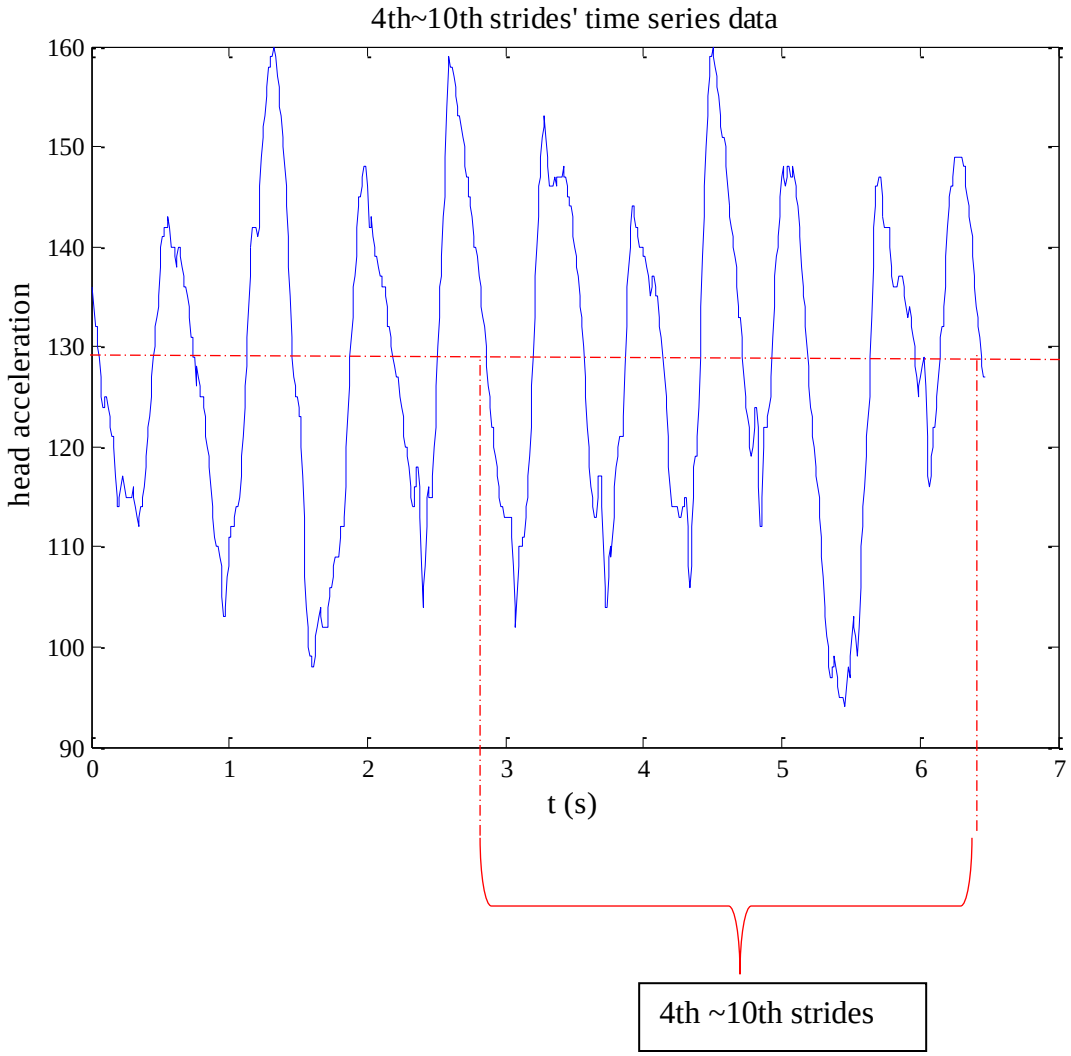


Figure 6 Fourth ~ tenth strides' time series data



3.2 Time Delay

For the time series analysis, in order to reconstruct a state space where the behavior of the system is embedded, the primary step is to find an appropriate time delay and global embedding dimension. If *x(t)* is one variable from a dynamic system, we can consider *y(t)* = [*x(t)*, *x(t+T)*... *x (t+ n*T)*] to reconstruct a *(n+1)* dimension vector — *y(t)*, where T is the time delay [21]. If T is too small, *x(t)* is very similar to *x(t+T)* so that all of the data will stay near the line *x(t)* =*x(t+T)*. If T is too big, the coordinates are independent and not able to be analyzed for more information.

Taking the data examples from Subject1 (horses without sedation were trotting at 45 minutes) as an example, I imported the data examples and calculated the average mutual information (AMI) by CSPW software. The time delay is located at the first minimum AMI of the iterative process, shown in Figure 7. In this chart, the number of data examples is 3000, and the time delay is 15.

Figure 7 Average Mutual Information

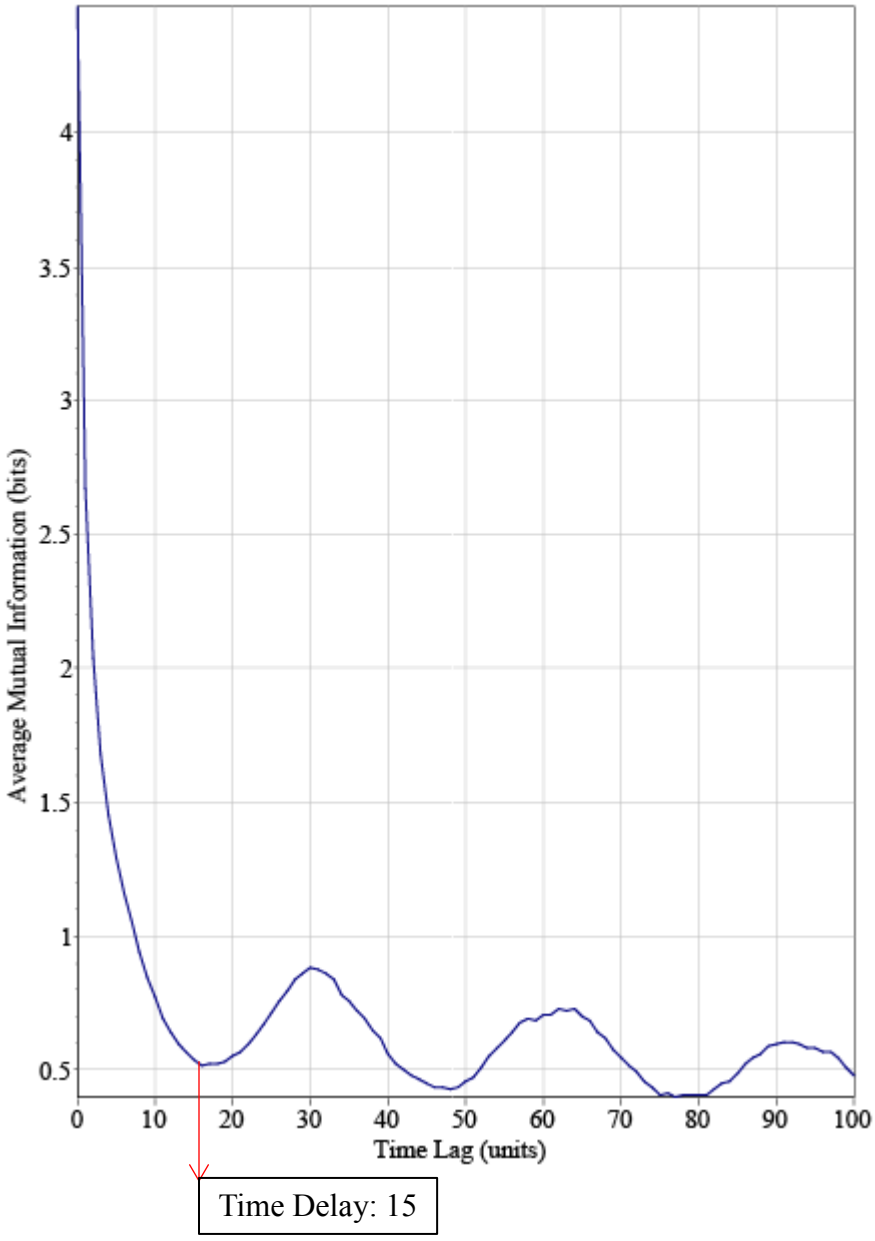
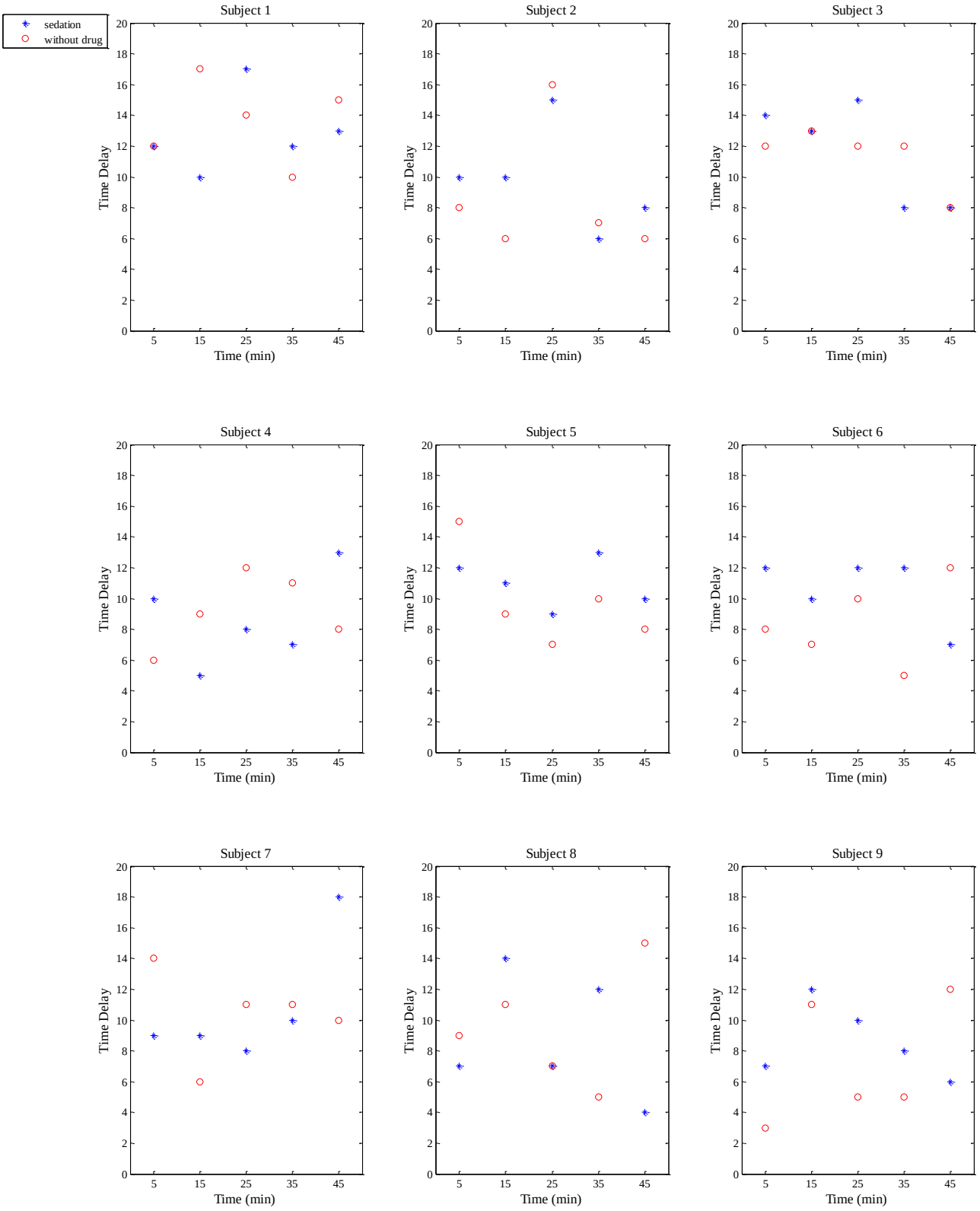


Figure 8 shows that the time delay of data examples usually fluctuated remarkably from 10 to 20, but some data's time delay was stable. At varying times, the time delay of sedation data was larger or smaller than the time delay of no treatment data.

Figure 8 Time Delay Comparison



3.3 Global Embedding Dimension

The embedding dimension [21] is the minimum number of random variables required to define a dynamic system from a given time series. The false nearest neighbor method [21] is used to determine the minimal embedding dimension—d_E, i.e. global embedding dimension [22].

With the time delay, the global embedding dimension of a dynamic system was calculated by CSPW software. Taking the data from Subject1 (horses without sedation were trotting at 45 minutes) as an example, the global embedding dimension is 5 shown in Figure 9. This chart, with 3000 data examples and a time delay of 14, shows a trend of the global false nearest neighbors reduction with the dimension increased.

Figure 9 Global Embedding Dimension

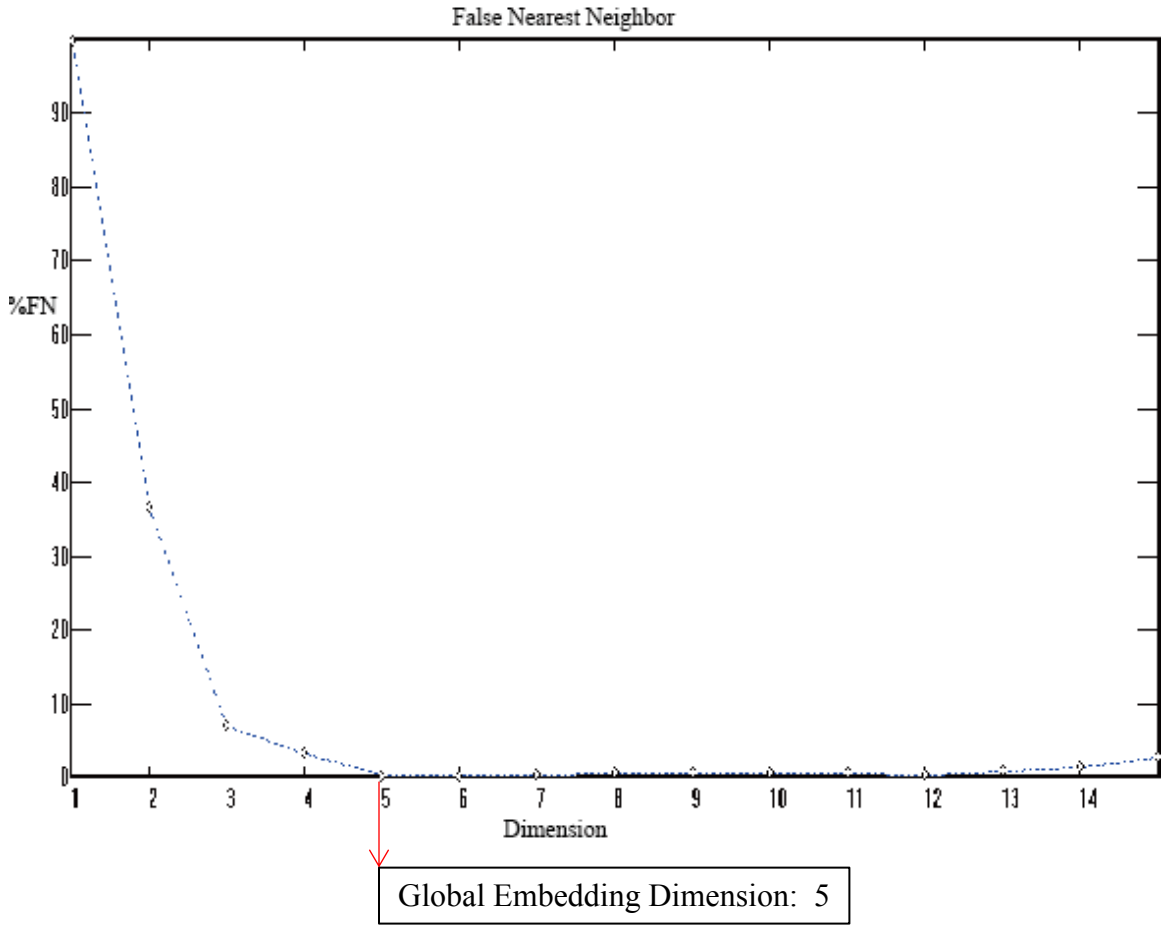
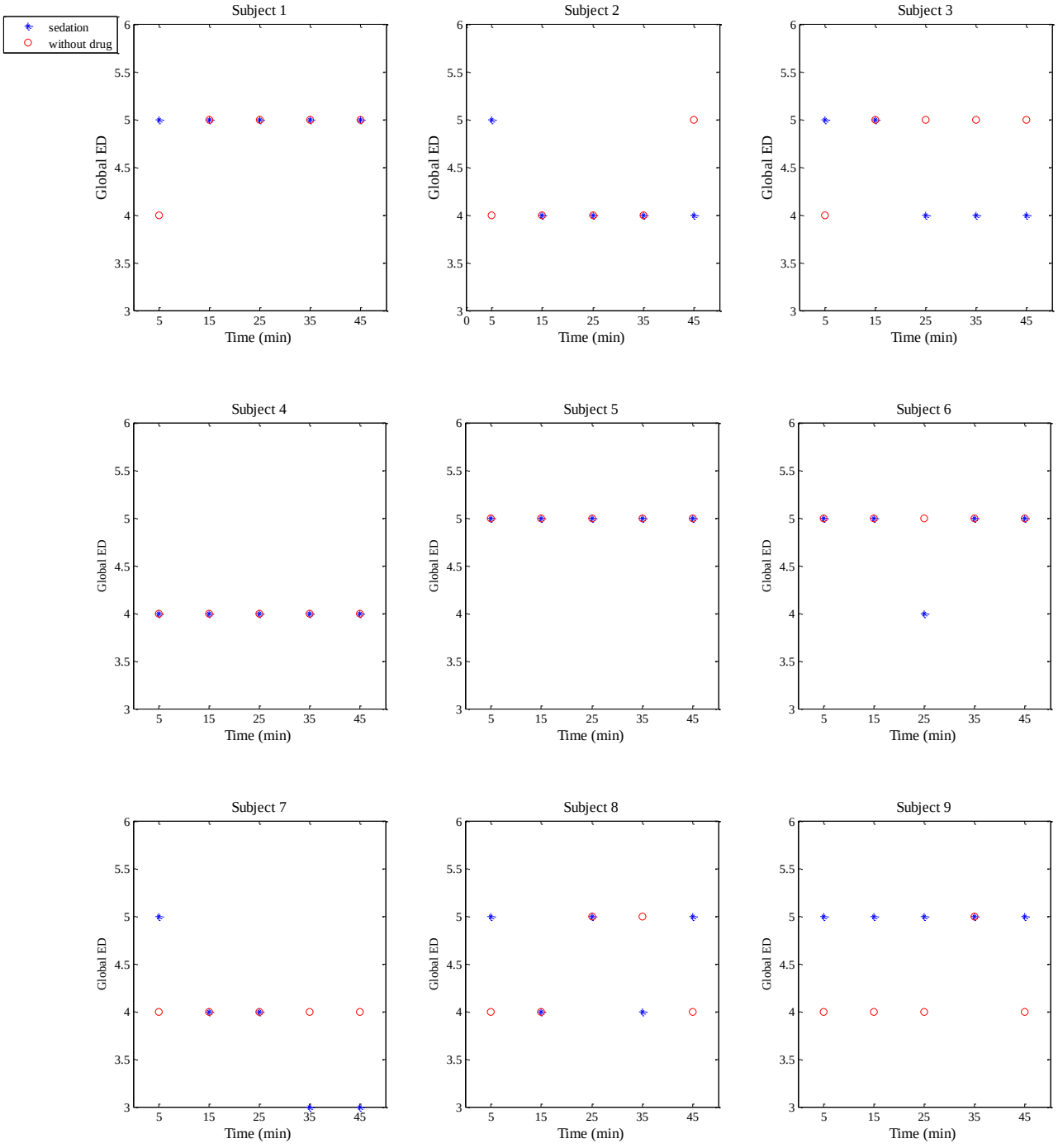


Figure 10 shows that the dimension of data typically ranged from 4 to 5 during different time periods while the global false nearest neighbors had the first minimum value (%FN —the fraction of the false nearest neighbors). There were two instances when the global embedding dimensions of sedation data and no treatment data were the same; all other examples were very similar.

Figure 10 Global Embedding Dimensions Comparison



3.4 Lyapunov Exponents Analysis

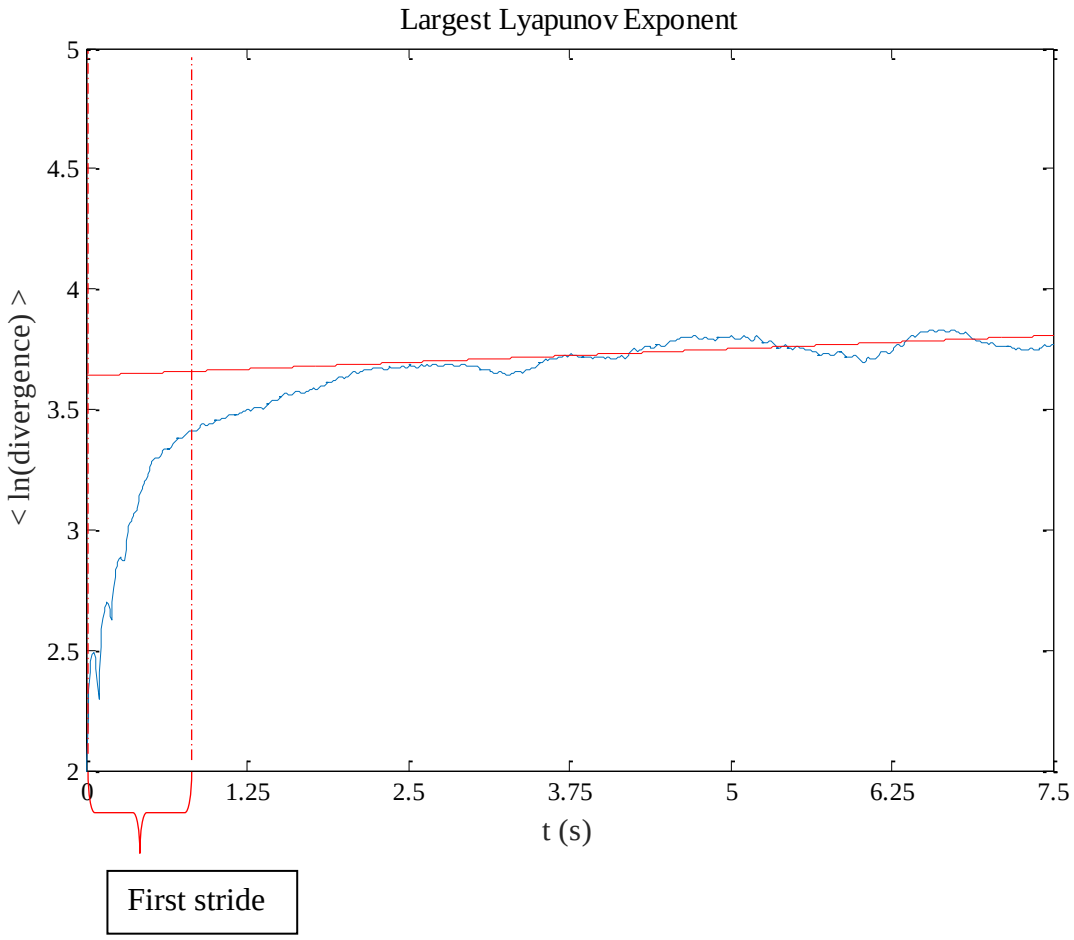
The Lyapunov exponents [13] of a dynamic system are used to quantify the separation rate of very close trajectories, and λ_i is defined as Lyapunov exponents. The maximal Lyapunov exponent [13] is the largest Lyapunov exponent.

The software developed by M. T. Rosenstein et al. is a practical method for calculating the largest Lyapunov exponents from determined data sets. Using the data examples from Subject1, I imported the data parameters to calibrate the software, and then re-arranged the original data examples.

The algorithm from Rosenstein et al. [13] indicated that the logarithm of the distances between nearest neighbors were averaged at each point in time and outputted as a single distance vector. Thus, λ_{Max} is calculated as the slope of the linear best-fit line generated by the equation: $\lambda_{Max} = \frac{ln(divergence)}{\Delta t}$.

Taking the data examples from Subject1 (horses with sedation were trotting at 5 minutes) as an example, The MATLAB programs produced the short LLE shown in Figure 11. The short LLE is calculated for the first stride of time series. The best-fit line between the first stride of time series (with a stride length of approximately 0.7 seconds) and the slope of the best-fit line was 1.6162.

Figure 11 Short LLE



The MATLAB programs produced the long LLE shown in Figure 12. The long LLE is calculated for the 4th ~ 10th stride of time series. The best-fit line between 4~10 strides of time series (with a stride length of approximately 4 seconds) and the slope of the best-fit line was 0.0222.

Figure 12 Long LLE

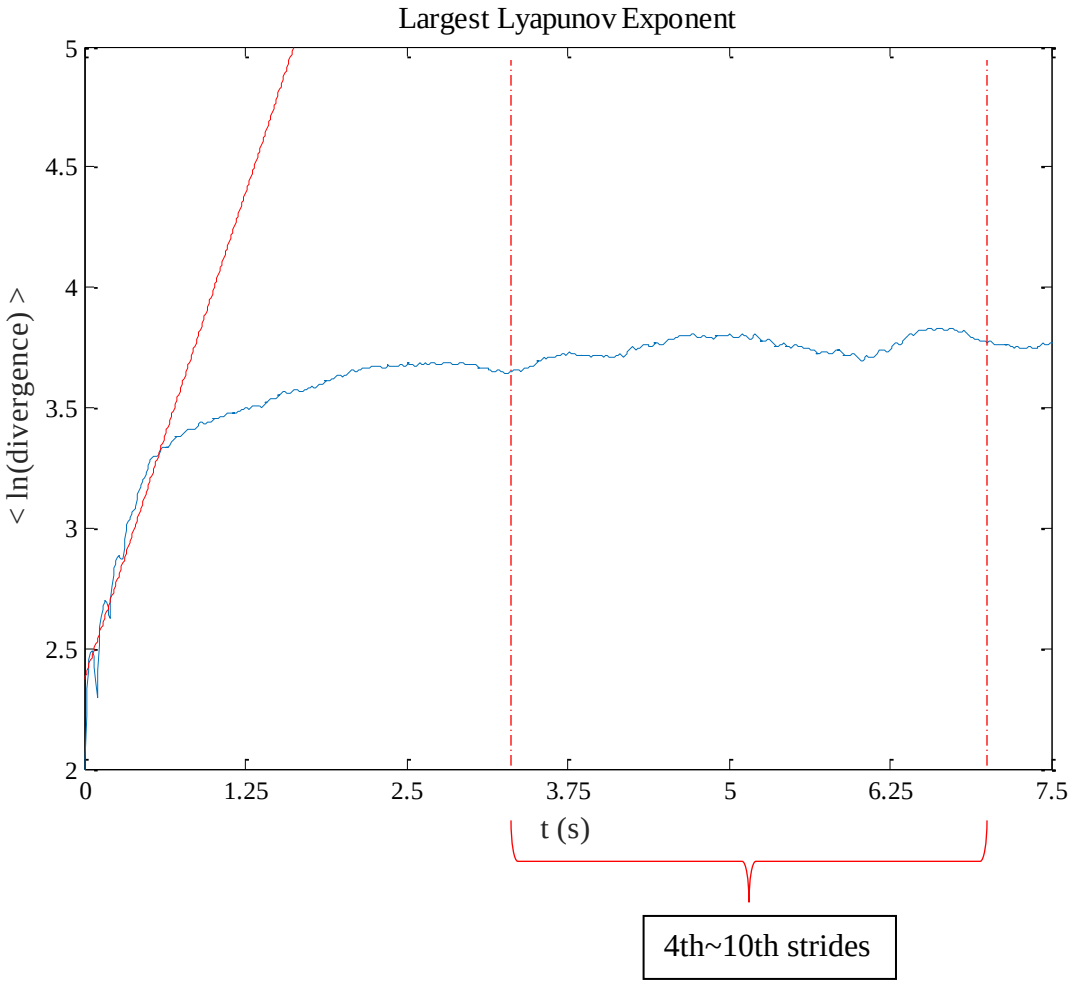
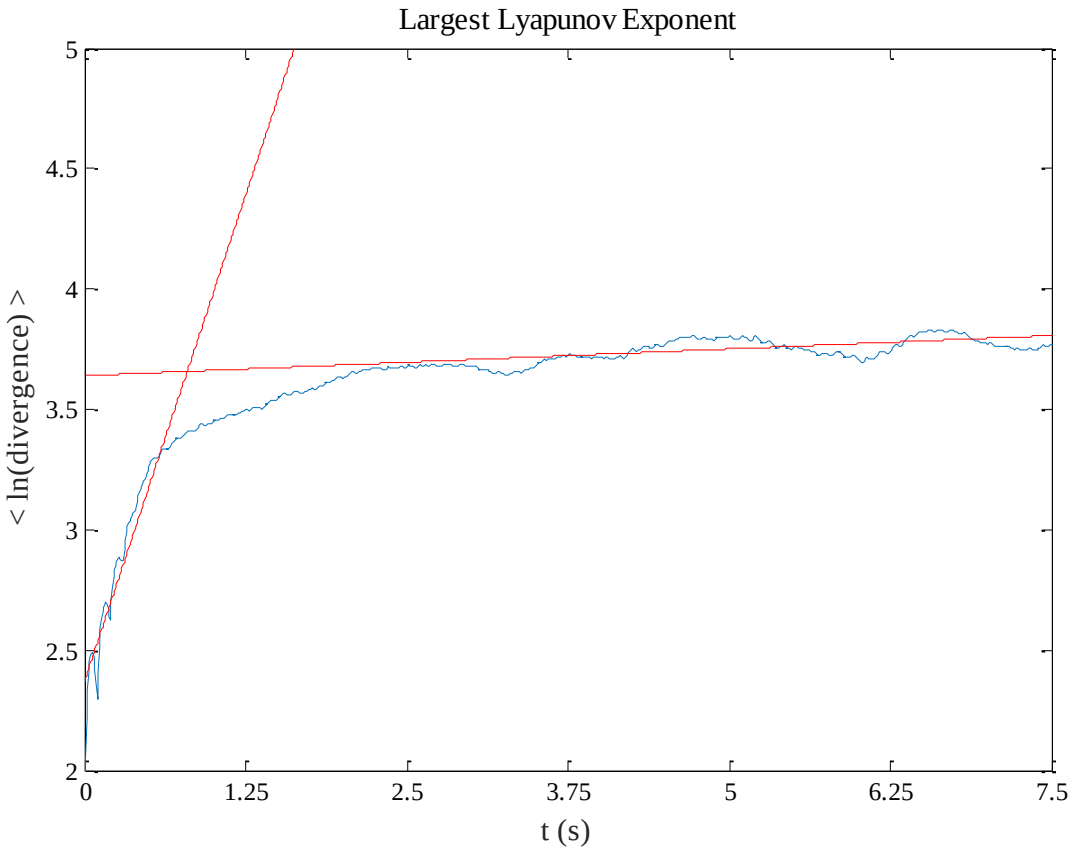


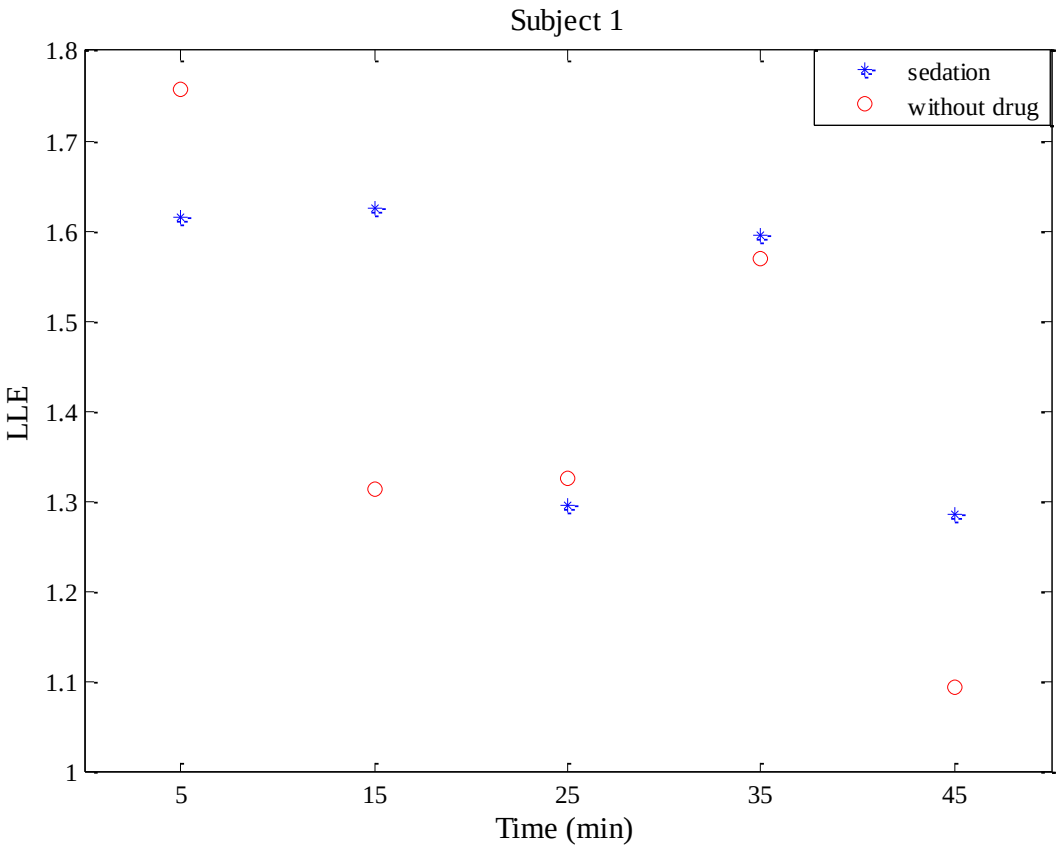
Figure 13 shows a comparison of the short LLE and the long LLE. The curve of the long LLE is smoother than the curve of the short LLE. The value of the long LLE is smaller than the slope of the short LLE.

Figure 13 Short and Long LLEs Comparison



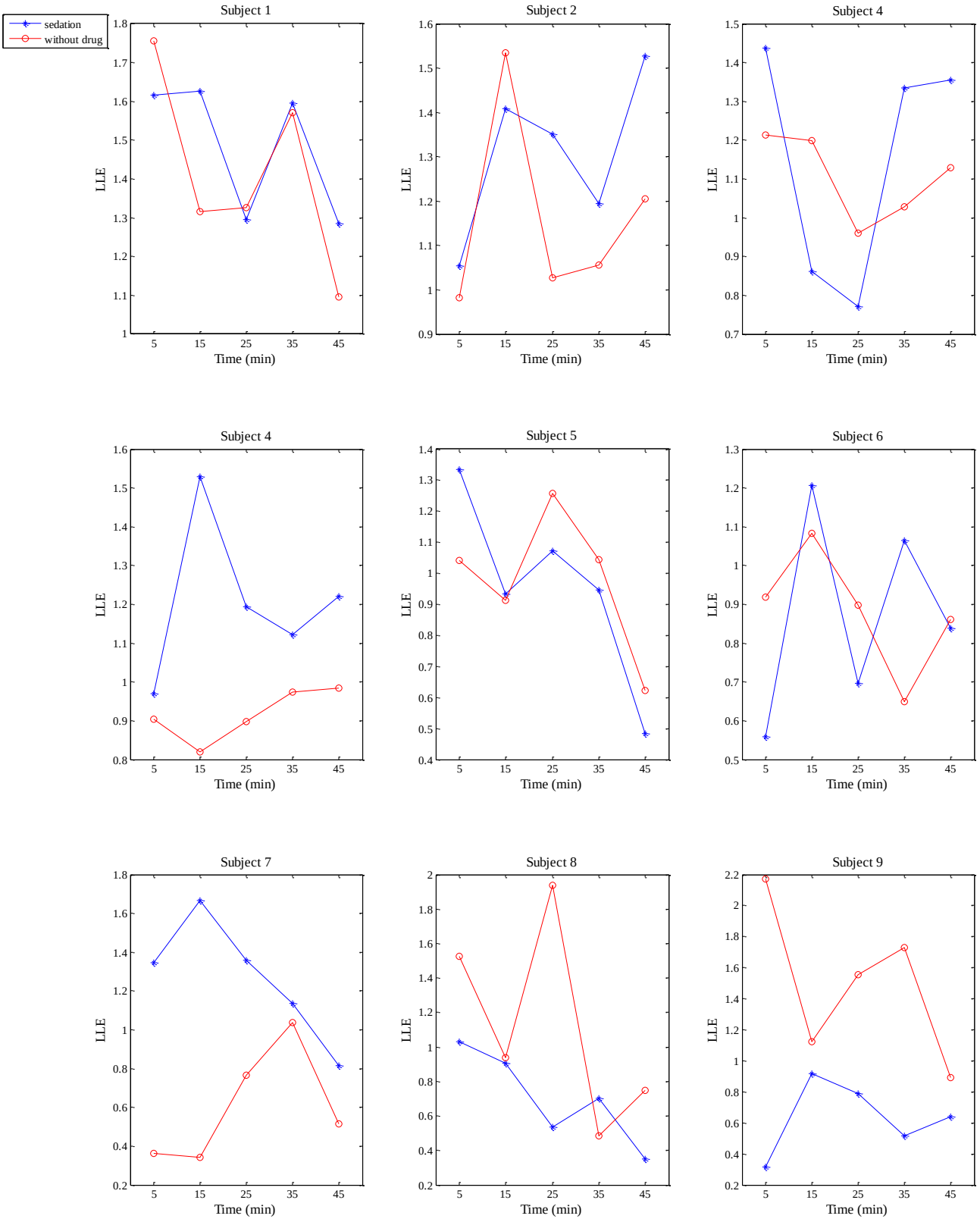
Taking the data of Subiect1 (shown in Figure 14), for instance, when the horse was trotting from 5 minutes to 45 minutes with sedated drugs, the short LLEs attached were 1.6162, 1.6263, 1.2956, 1.5954 and 1.2853; the short LLEs without drugs were 1.7563, 1.3152, 1.326, 1.5697, and 1.0947. Compared to the short LLEs without drugs, the short LLEs with sedation were smaller or larger.

Figure 14 Short LLEs Comparison of Subject1



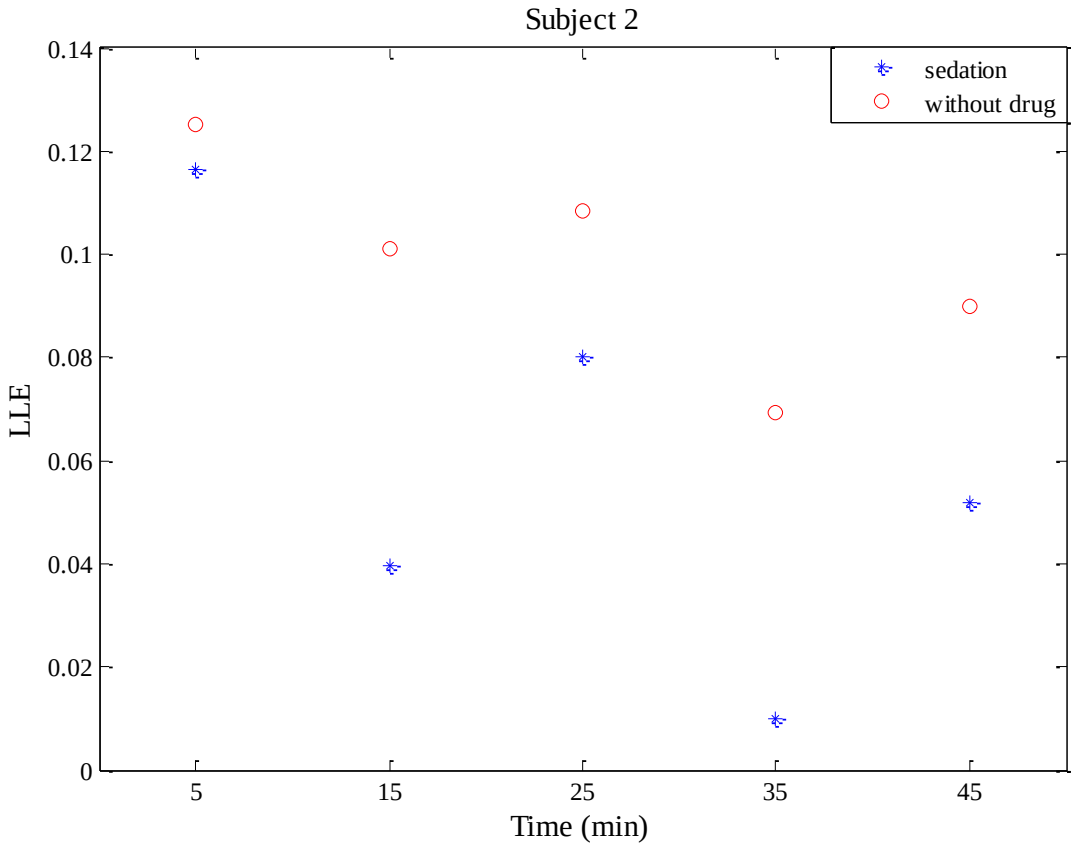
According to Table 1 and Figure 15, the short LLEs were changing a little without a clear pattern during the different time periods.

Figure 15 Short LLEs Comparison



Taking the data of Subiect2 (shown in Figure 16), for instance, when the horse was trotting from 5 minutes up to 45 minutes with sedation drugs, the long LLEs attached were 0.1165, 0.0395, 0.08, 0.0099 and 0.0519; the long LLEs without sedation were 0.125, 0.1012, 0.1084, 0.0694 and 0.0899. Compared to the long LLEs without drugs, the long LLEs with sedation were smaller. Most of the long LLEs with sedation reduced with the time increased.

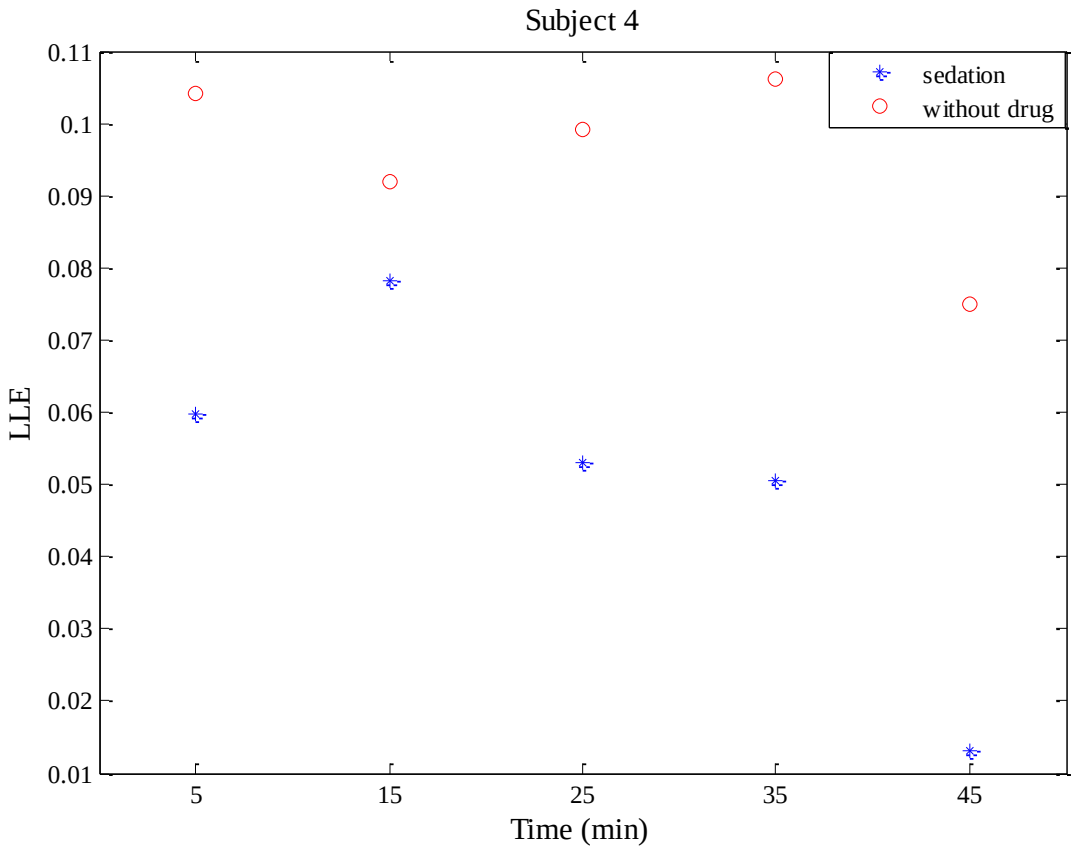
Figure 16 Long LLEs Comparison of Subject2



Taking the data of Subiect4 (shown in Figure 17), for instance, when the horse was trotting every 5 minutes up to 45 minutes with sedation drugs, the long LLEs attached were 0.0598, 0.0782, 0.053, 0.0504 and 0.0132; the long LLEs without treatment were 0.1042, 0.0919,

0.09905, 0.1062 and 0.075. Compared to the long LLEs without drugs, the long LLEs with sedation were smaller. Most of the long LLEs with sedation reduced with the time increased.

Figure 17 Long LLEs Comparison of Subject4



In Table 1 and Figure 18, the long LLEs mostly decreased as time increased. In addition, the long LLEs of no treatment data were mostly higher than the long LLEs of sedation data. The smaller the λ_{Max} *is*, the more stable the dynamic system is. Therefore, the stability of horses' motion with sedation was more stable.

Figure 18 Long LLEs Comparison

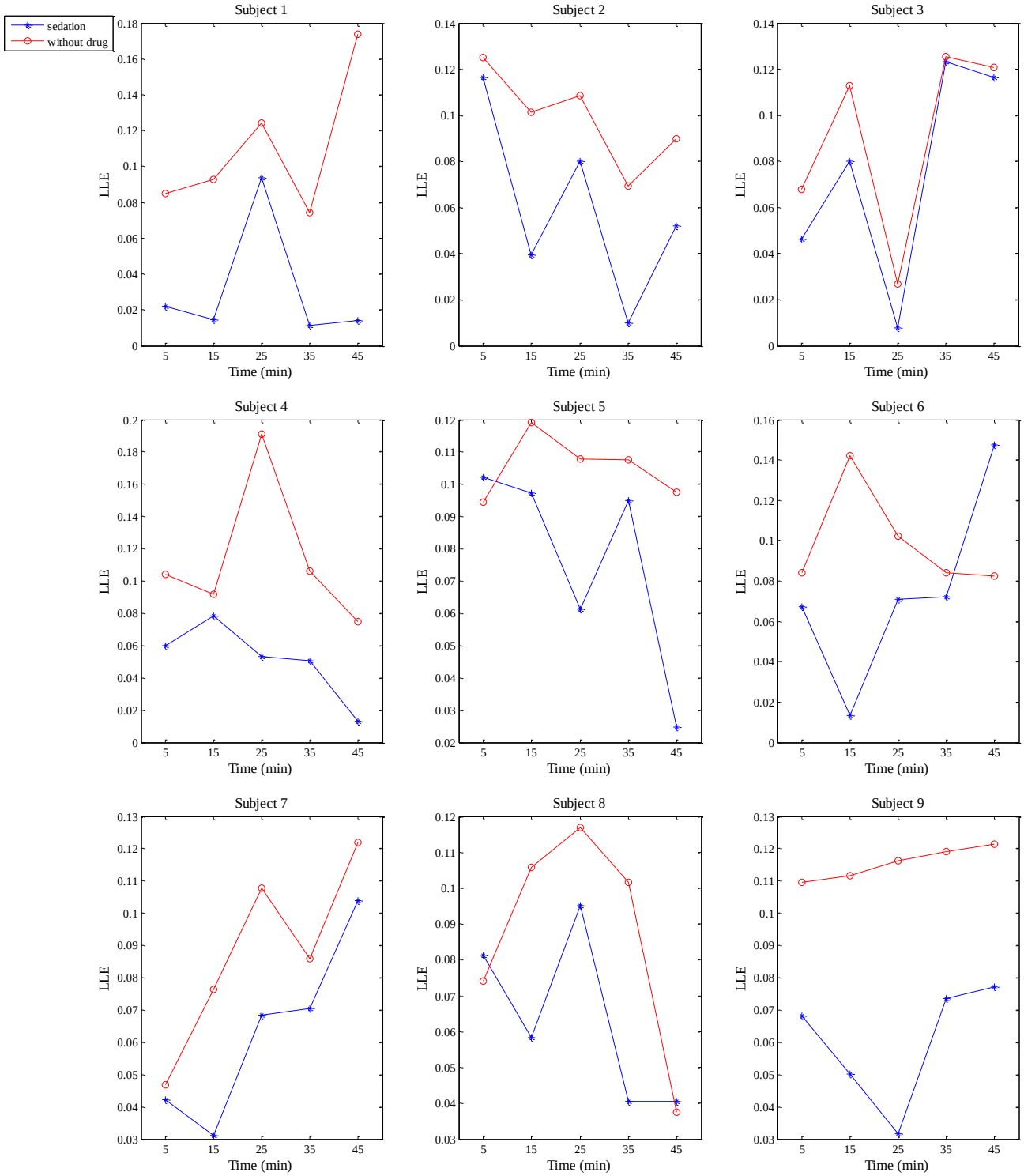


Table 1 The data table

		Sedation				**No sedation**			
	Time (min)	Time Delay (T)	Global Embedding Dimension	short LLE	long LLE	Time Delay (T)	Global Embedding Dimension	short LLE	long LLE
SUBJECT 1	05	12	5	1.6162	0.0222	12	4	1.7563	0.0851
	15	10	5	1.6263	0.0145	17	5	1.3152	0.0928
	25	17	5	1.2956	0.0937	14	5	1.326	0.1242
	35	12	5	1.5954	0.0114	10	5	1.5697	0.0743
	45	13	5	1.2853	0.0139	15	5	1.0947	0.1736
SUBJECT 2	05	10	5	1.0533	0.1165	8	4	0.9817	0.125
	15	10	4	1.4077	0.0395	6	4	1.5339	0.1012
	25	15	4	1.35	0.08	16	4	1.0263	0.1084
	35	6	4	1.194	0.0099	7	4	1.0557	0.0694
	45	8	4	1.5269	0.0519	6	5	1.2049	0.0899
SUBJECT 3	05	14	5	1.4363	0.0461	12	4	1.2131	0.068
	15	13	5	0.8622	0.0799	13	5	1.1983	0.1127
	25	15	4	0.7712	0.0079	12	5	0.9605	0.0267
	35	8	4	1.3351	0.1231	12	5	1.0287	0.1254
	45	8	4	1.3558	0.1166	8	5	1.1291	0.1206

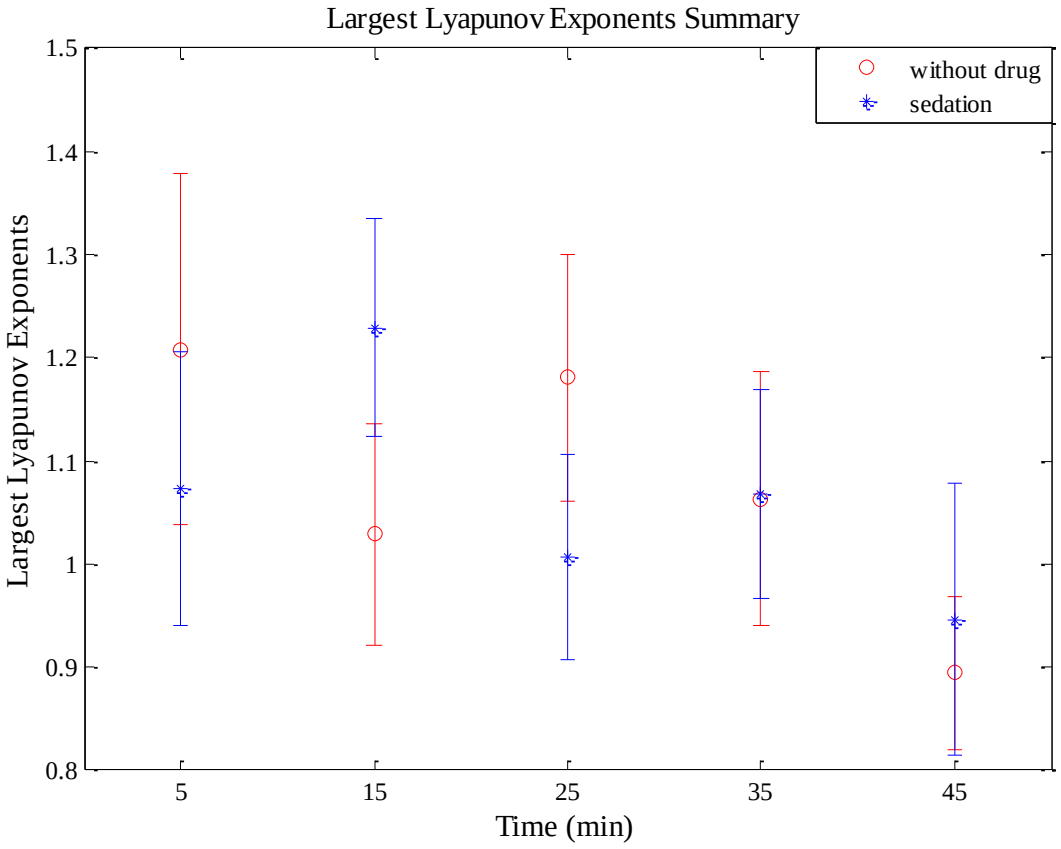
SUBJECT 4	05	10	4	0.9703	0.0598	6	4	0.9036	0.1042
	15	5	4	1.5299	0.0782		4	0.8204	0.0919
	25	8	4	1.194	0.053	12			
	35	7	4	1.1218	0.0504	11	4	0.9734	0.1062
	45	13	4	1.2213	0.0132	8	4	0.9843	0.075
SUBJECT 5	05	12	5	1.3346	0.1021	15	5	1.0409	0.0945
	15	11	5	0.934	0.0972	9	5	0.9137	0.1191
	25	9	5	1.0722	0.0612	7	5	1.2571	0.1079
	35	13	5	0.9461	0.095	10	5	1.0446	0.1075
	45	10	5	0.4835	0.0247	8	5	0.6232	0.0976
SUBJECT 6	05	12	5	0.5576	0.0672	8	5	0.918	0.084
	15	10	5	1.2065	0.0134	7	5	1.0824	0.1421
	25	12	4	0.6954	0.0708	10	5	0.898	0.1021
	35	12	5	1.0646	0.0722	5	5	0.6488	0.084
	45	7	5	0.8381	0.1474	12	5	0.8612	0.0826
SUBJECT 7	05	9	5	1.344	0.0422	14	4	0.3611	0.0468
	15	9	4	1.6683	0.0311	6	4	0.3402	0.0763
	25	8	4	1.3569	0.0685	11	4	0.7651	0.1078
	35	10	3	1.1359	0.0704	11	4	1.0365	0.086
	45	18	3	0.8134	0.1038	10	4	0.5147	0.1219
SUBJECT 8	05	7	5	1.0329	0.074	9	4	1.5277	0.0813
	15	14	4	0.9055	0.1058	11	4	0.9358	0.0583
	25	7	5	0.5357	0.1168	7	5	1.9374	0.0952

	35	12	4	0.7032	0.1015	5	5	0.4833	0.0405
	45	4	5	0.3497	0.0375	15	4	0.7494	0.0405
SUBJECT 9	05	7	5	0.3143	0.0683	3	4	2.172	0.1095
	15	12	5	0.9189	0.0501	11	4	1.1213	0.1117
	25	10	5	0.7869	0.0316	5	4	1.5552	0.1162
	35	8	5	0.5144	0.0737	5	5	1.7284	0.1191
	45	6	5	0.6398	0.0771	12	4	0.8935	0.1213

3.5 Two- Way ANOVA Analysis

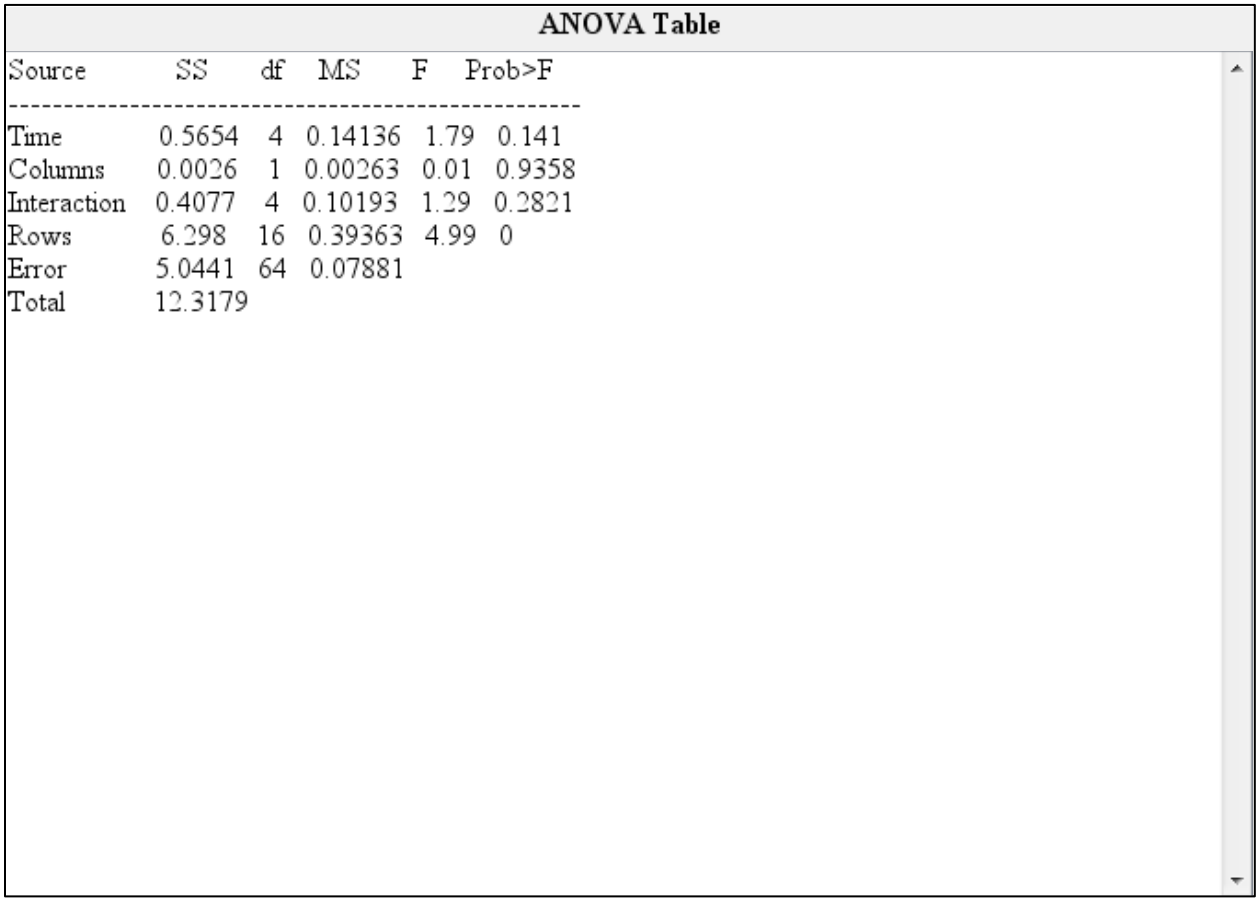
The two-way ANOVA [18] compares the effect of two different categorical independent variables on one continuous dependent variable. Figure 19 shows the short LLEs summary produced by the two-way ANOVA method [18]. The mean and the standard deviation of sedation data or no treatment data varied, but the total tendency of the standard deviation decreased as the time periods increased.

Figure 19 two-way ANOVA of Short LLEs



For the ANOVA Table [18], the critical value (alpha) is 0.05. Table 2 and Figure 20 show the p-value of columns (sedation or no treatment) = 0.93585>0.05, which indicates the groups (sedation data or no treatment data) of independent variables did not show a significant relationship with the short LLEs.

Figure 20 two-way ANOVA chart (Short LLEs)



ANOVA Table

Source	SS	df	MS	F	Prob>F
Time	0.5654	4	0.14136	1.79	0.141
Columns	0.0026	1	0.00263	0.01	0.9358
Interaction	0.4077	4	0.10193	1.29	0.2821
Rows	6.298	16	0.39363	4.99	0
Error	5.0441	64	0.07881		
Total	12.3179				

Table 2 ANOVA table (Short LLEs)

Source	SS	df	MS	F	Prob>F
Time	0.5654	4	0.14136	1.79	0.1410
Columns	0.0026	1	0.00263	0.01	0.9358
Interaction	0.4077	4	0.10193	1.29	0.2821
Rows	6.2980	16	0.39363	4.99	0

Error	5.04410	64	0.07881		
Total	12.3179				

ANOVA Table Description [18]

* Source —these are the categories to be examined

*SS —these are the sum of squares associated with the three sources.

*df —these are the degrees of freedom associated with the sources of variance. (the number of the source minus one)

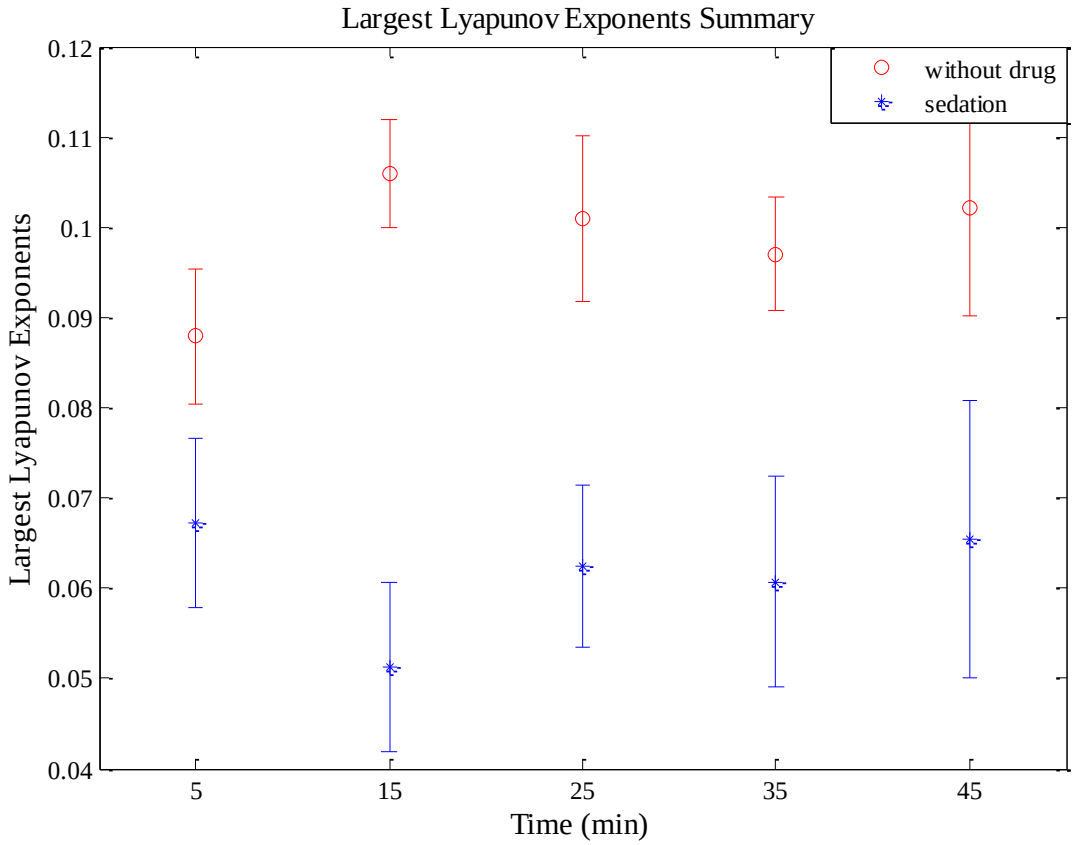
*MS —these are the mean squares, the sum of squares divided by their respective df.

*F —the value of F is the ratio of the sample variances.

* Prob>F —the p-value associated with F-value is very small, and the p-value is compared to the alpha level value.

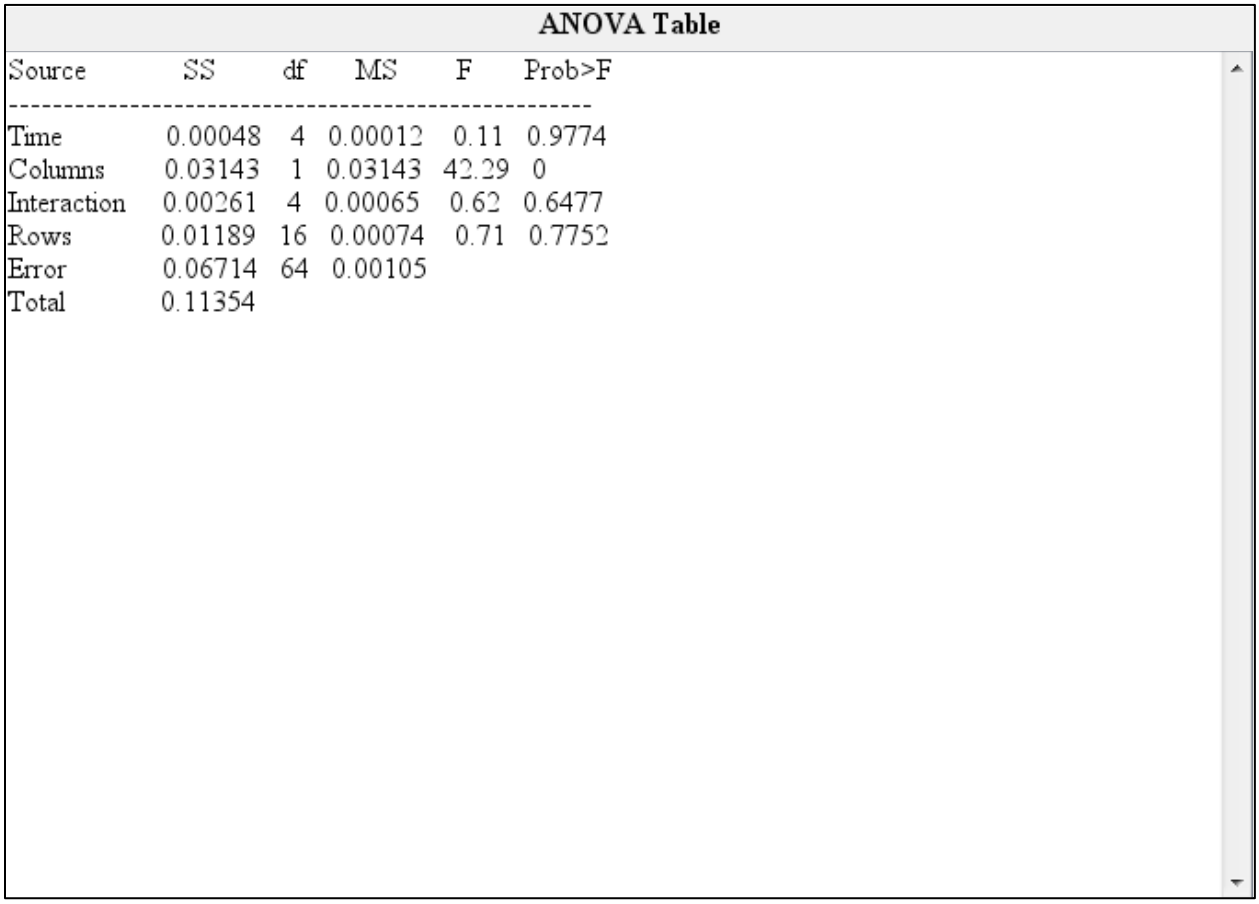
Figure 21 shows the long LLEs summary produced by the two-way ANOVA method. According to the error bar, the mean and the standard deviation of sedation data were smaller than the mean and the standard deviation of no treatment data. This means the variability of horses' motion with sedation was stable.

Figure 21 two-way ANOVA of Long LLEs



For the ANOVA Table [18], the alpha value is typically 0.05. Table 3 and Figure 22 show the p-value of columns (sedation or no treatment) = 0<0.05, which states the groups (sedation data or no treatment data) of independent variables did show a significant relationship with the long LLEs, that is, the groups could reliably predict the horses' motion.

Figure 22 two-way ANOVA chart (Long LLEs)



ANOVA Table

Source	SS	df	MS	F	Prob>F
Time	0.00048	4	0.00012	0.11	0.9774
Columns	0.03143	1	0.03143	42.29	0
Interaction	0.00261	4	0.00065	0.62	0.6477
Rows	0.01189	16	0.00074	0.71	0.7752
Error	0.06714	64	0.00105		
Total	0.11354				

Table 3 ANOVA table (Long LLEs)

Source	SS	df	MS	F	Prob>F
Time	0.00048	4	0.00012	0.11	0.9774
Columns(sedation or no sedation)	0.03143	1	0.03143	42.29	0
Interaction	0.00261	4	0.00065	0.62	0.6477
Rows	0.01189	16	0.00074	0.71	0.7752

Error	0.06714	64	0.00105		
Total	0.11354				

Chapter 4

Discussion

This research was done to develop a study of the effect of sedation on the trotting gait of lame horses using the largest Lyapunov exponents. The motion data was collected from nine horses. The largest Lyapunov exponents were used for motion data analysis.

Each group of motion data examples from the horses tested were collected with sedation or no treatment during different time periods. The motion data was analyzed by three different software—Virtual Recurrence Analysis software, Computer-Supported Personal Work software, the software developed by M. T. Rosenstein et al. and MATLAB R2015a software.

The data in Table 1 and Figure 8 indicated that the values of time delay from sedation data examples or no treatment data were varied from 10 to 20. The current study found that sedation did not have a large influence on the time delay of the horses' motion data.

The data in Table 1 and Figure 10 indicate that the values of global embedding dimension from sedation data or no treatment data changed little and ranged from 4 to 5 in this research. The data clearly indicates that sedation did not have a significant effect on the global embedding dimension during horses' gaits.

The data presented in Table 1 and Figure 15 shows that the values of short LLEs from sedation data examples and no treatment data examples had no significant trend to find. Therefore, there was not an obvious pattern observed from short LLEs.

As the data presented in Table 1 and Figure 18 shows, the values of long LLEs from sedation data or no treatment data varied, but the values of long LLEs from sedation data were

smaller than those from no treatment data. Therefore, there was a consistent pattern observed from long LLEs, which means that sedation had a significant effect on horses' motion stability.

As the data presented in Table 2 and Figure 19 shows, the two-way ANOVA method indicated that the short LLEs did not vary much ($p > 0.05$) with the various time periods or sedation drugs as horses trotted. However, the data presented in Table 3 and Figure 21 shows that the long LLEs by the two-way ANOVA method did very a great deal ($p < 0.05$) with sedation drugs during horses' gaits.

In addition, the findings of this study need stronger support, because the sample size of testing horses in this study was just nine, and the results of analysis were not sufficient to get a more accurate and significant conclusion. In further research, a larger quantity of testing samples and more analysis methods are needed for generalizing the results. In order to support the above findings, more experiments also need to be done on other effective factors for lame horses' gait.

Chapter 5

Conclusion

The objective of this research was to conduct a test on the effect of sedation on horses' gaits using the largest Lyapunov exponents. The motion data examples were tested during horses trotting with sedation and no treatment. The results of motion analysis (two-way ANOVA method) revealed that the LLEs variability of horses' gait does decrease with sedation. The findings of motion analysis using the largest Lyapunov exponents also indicated that sedation has a good influence on the movement stability of horses' gaits.

The quantity of samples used in this study was small. With only nine testing examples, the analysis could not produce an accurate conclusion. More testing samples are needed to provide a better estimation of the effect with sedation and no treatment on variability or stability during horses' gaits. In the future, there should be a more deeply and confirmed experiment about this research with more participants and analysis methods.

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