Chapter 5

Foreign Language Learning as a Complex Dynamic System: a Microgenetic Case Study of a Chinese Child EFL Learner

---

7 This chapter is a slightly edited version of Sun, H., Steinkrauss, R., van der Steen, S., Cox, R., & de Bot, K. Foreign language learning as a complex dynamic system: a microgenetic case study of a Chinese child EFL learner, submitted to Learning and Individual Differences.
Chapter 5 Foreign Language Learning as a Complex Dynamic System

5.1 Introduction

In recent years, we have seen a substantial increase in the number of very young foreign language (FL) learners worldwide (Nikolov & Mihaljevic Djigunovic, 2011). These children, who are in their early childhood (2–7 years-old as defined by Philip, Mackey, and Oliver, 2008; 3–6 years-old as defined by Nikolov and Mihaljevic Djigunovic, 2011), receive FL instruction at bilingual schools or at private language institutes. In China, for example, 210 million children are taking English courses in more than 50,000 private English institutes (Li, 2013). Research on this growing number of young learners and the development of their language skills is, however, still rare (Zhou & McBride-Chang, 2009).

For young FL learners, initial classroom experiences could have a lasting effect on their learning motivation and outcomes in the long term (Nikolov, 2001), and the development of their learning behaviors deserves special attention. Studying the development of a child’s learning behaviors is not an easy task, as these behaviors vary from moment to moment in complex interactions with the child’s (proximal) environment (cf. Van Geert & Van Dijk, 2002). The most common way of analyzing the development (of, e.g., language skills) is, therefore, to average the measurements taken from groups of children. This, however, comes at a cost. By definition, the average learning trajectory does not apply to the individual learner (cf. Molenaar 2008), because development is a real-time idiosyncratic process (Van Geert & Steenbeek, 2005) driven by bidirectional interactions with the environment. This is why researchers from the paradigm of Complex Dynamical Systems (CDS) have developed and used (nonlinear) time series techniques to study developmental phenomena and the person-environment interactions from which they emerge (e.g., Cheshire, Muldoon, Francis, Lewis, & Ball, 2007; Cox & Van Dijk, 2013; Thelen & Smith, 1994; Van Geert, 1994; Van Geert & Steenbeek, 2005). From a CDS perspective, development can be seen as a self-organizing process, in which the state of a system (for example, the child’s language system) is shaped by multiple interactions (e.g., other children in class, the teacher, the child’s motivation, etc.). Over time, the behavior of a system may evolve from fluctuating and unstable towards certain and more adaptive stable behavioral states (i.e., attractors) (e.g., Thelen & Smith, 1994).

Despite the growing number of CDS techniques available, they have not yet been applied to early FL learning. The current paper, therefore, focuses on one three-year-old Chinese child during his first half year of English learning in a private language institute. The relationship between his verbal and nonverbal learning behaviors, as well as the developmental patterns of his verbal behaviors are explored in the context of an early childhood FL learning program. A (cross)
recurrence quantification analysis (nonlinear time series technique) is used to study the coordination between several learning behaviors over time, allowing us to obtain an in-depth understanding of the tangible patterns in the child’s learning behaviors, as well as their couplings.

5.2 Background

5.2.1 Early stages of very young children’s foreign language development

Sun, de Bot and Steinkrauss (2014) followed a group of very young EFL learners (3 years old) for their initial five months of learning English, and found three general stages (see Figure 5-1). During the first two months (the first stage), most children kept silent and relied on body language to respond to their teachers’ instructions. During the third month (the second stage), the frequency of using English repetitions surpassed the frequency of using body language. Children repeated single words and formulaic language after their teachers, as they became familiar with English pronunciation and the learning environment. In the fourth and fifth month (the third stage), the average use of English responses and mixed language (English and Chinese) grew steadily. In this stage, children tended to use single words or simple phrases to initiate/answer questions, and expressed themselves with more confidence and ease in English. They seemed to be more aware of their limitations in English, and used more Chinese to express their thoughts.

![Figure 5-1. Three stages of very young EFL learners’ English learning behaviors in class](image)

Although the authors only discussed the most distinctive behaviors (in terms of frequency) during the three stages, it is important to note that all of them occurred during each stage (cf. Siegler, 2000). Children often combine gestures and speech during the early stages of first language (L1)
production, several months before they produce combinations of words (Goldin-Meadow, 2015). One reason for this might be the idea that body language, i.e., nonverbal behavior, supports verbal behavior during the early years of language development. According to Goldin-Meadow (2014), when children have a restricted vocabulary, body language offers them “a way to extend their communicative range” (p. 2). Children’s body language smoothen the conversation with their listeners, allowing them to indicate that they are ready to learn new words, which signals their listeners to provide finely tuned language support (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007; Vygotsky, 1986).

Not only the relationship between verbal and nonverbal learning behaviors deserves our attention, but also the development of different categories of verbal learning behaviors, which serve an important function in early L1 and FL language development. Verbal repetition, for example, is one of the most pervasive behaviors during the initial period of early FL learning (Duff, 2000; Bennett-Kastor, 1994). From a cognitive and linguistic perspective, verbal repetition helps young FL learners to memorize, recite and decompose the new language at their own speed, and to gradually integrate the information into their linguistic repertoire (Duff, 2000; Rydland & Aukrust, 2005). From a socio-cultural perspective, verbal repetition indicates that something is internalized by the learner, allowing for social, intellectual and discursive cohesion during interaction (Duff, 2000; Cekaite & Aronsson, 2004).

5.2.2 Complex Dynamical Systems (CDS) in FL learning

In sum, both verbal and nonverbal learning behaviors are crucial for a child’s early language learning (Goldin-Meadow, 2014, 2015). Previous studies, such as the one conducted by Sun et al. (2014), propose a general outline of children’s initial learning behaviors. However, it remains unclear how these behaviors evolve over time and how they interact with each other. Studying these interactions from a CDS perspective would allow us to extend our knowledge on the mechanisms of FL learning. This requires the use of microanalyses, allowing researchers to examine these behaviors for individual children in detail, and from moment to moment (Wallbott, 2003). Ultimately, combining this idiographic micro-approach with more general, nomothetic models of L2 language development allows researchers to construct models that are applicable at the individual level (cf. Nesselroade, 2001), which can, in turn, inform the educational practice.

The theory of CDS provides us with the theoretical framework and analysis methods to analyze micro-processes. From a CDS perspective, FL development should be considered an open system, consisting of a series of subsystems (e.g., different learning behaviors) undergoing continuous, as
well as abrupt changes over time due to internal and external constraints (de Bot & Larsen-Freeman, 2011; Larsen-Freeman & Cameron 2007, 2008). When introducing CDS to FL studies, the research focus shifts. Instead of asking research questions that center around a unidirectional (linear) causal relationship between variables, the interconnectedness and non-linear development of different learning components are the central focus. CDS also emphasizes the changes within a system over time, driven by the interactions between the system’s internal process of self-organization and the external environment. The term ‘internal process’ refers to dynamic (i.e., changing) variables within the learning individual, such as learning capacity and adaptability. The external environmental resources refer to dynamic variables outside the learner, such as L2 input (in terms of both quantity and quality) (de Bot & Larsen-Freeman, 2011).

5.2.3 Conceptual model

Combining the previous discussion on FL learning with the CDS principles introduced above leads to a conceptual model in which a child’s initial FL learning emerges from the child’s multilayered interactions with his/her learning environment. Specifically, the model distinguishes between a number of interactive learning behaviors, on two conceptually distinct layers: verbal and nonverbal behaviors in the first layer, and verbal repetition and verbal response, two subcomponents of verbal behaviors, in the second layer (Figure 5-2). Together, the behaviors represent the ‘interactive learning repertoire’ of the child in a concrete learning environment. Importantly, the layers should not be interpreted as being hierarchically organized, but as continuously active (to varying extents) and mutually constraining. As a result of a child’s altering language competence and constant mutual adaptation to the instructional setting, the dynamic balance (i.e., coordination) within and between the two layers changes. This changing balance is reflected by observable differences in the patterns of learning behaviors over time. The opposite is also true: the structure of a child’s learning behaviors over time contributes to his/her altering language competence (i.e., FL learning) and also influences the teacher’s instruction. This study focuses on the coordination of these learning behaviors, their development (within a single child), and the relation to the instructional setting. In other words, we focus on the temporal patterns of the child’s learning behaviors, to understand the dynamics of FL learning.
5.2.4 Research questions and hypotheses

This study follows one 3-year-old Chinese EFL learner during his first months of English language learning. The in-class interactions between the child and the teacher were coded in monthly intervals at 4 measurement times (Month 2 – Month 5), resulting in microgenetic data. Two research questions have been formulated, each directed at a specific layer of our conceptual model:

1. Layer 1: How can we characterize the coordination between the boy’s nonverbal learning behaviors (gestures and body language) and verbal learning behaviors (repetition and verbal response), and how does this coordination change over time?

2. Layer 2: How do the verbal learning behaviors (verbal repetition and verbal response) develop over time, and what is the relationship between these two learning behaviors at each monthly measurement?

For question 1, we expect that the coordination between the child’s nonverbal and verbal behaviors gets more flexible over time, because of the boy’s gradual adaptation to the English learning environment.

For question 2, we expect that the pattern of verbal repetition is less rigid than that of verbal response, because the former is more influenced by other interlocutors (teachers in particular) and the latter is more influenced by the child’s own language competence.
5.3 Methods

5.3.1 Participant information
A three-year-old boy, here called Jimmy, who had no formal English education before the current project, was followed during his first few months of English learning in one of the largest English initiation schools in southeast China, targeting 3 to 12 year-old EFL learners. The goal for the 3–5 year-old beginners in this school is to help the students become interested in English, acquaint them with English pronunciation, and help them understand and produce simple English words and phrases. The Total Physical Response (TPR) method is used to ensure children’s active participation in class (Asher, 1996). In TPR, physical movement is used to enhance the comprehension of verbal input, aiming at motivating students to participate in language activities and reducing their anxiety over participation. Every child is required to visit the educational facility twice a week, for approximately two hours in total, once for the main course taught by an American teacher and a Chinese teaching assistant together, and the other time for an activity class taught by the Chinese teaching assistant only. Due to unforeseen circumstances, the Chinese teaching assistant was replaced in month 5. The aim of the main course is to teach new words and songs, whereas the activity class is used to review what children learned in the preceding main course. The current study only used data from the main course, because these sessions are similar in content and duration. Each of these 35-minute sessions starts with a greeting, and then a video of a song or a mini-dialogue displayed on an interactive whiteboard. After watching the video, children are asked to stand up to sing and dance, mimicking their teachers and using gestures. This is followed by the introduction of new words with pictures, props or body language. Subsequently, these words are practiced in songs and games. The words and phrases that are taught can be described as “child-friendly”, depicting colors, numbers and greetings.

5.3.2 Data collection and coding
Before launching the project in class, Jimmy’s parents were asked for consent and to fill out a questionnaire about Jimmy’s background, such as his age and English learning history. To confirm that Jimmy knew little English, he was tested with 20 simple words selected from the MacArthur-Bates Communicative Development Inventories (MCDI; Fenson, Marchman, Thal, Dale, & Bates, 2007). Ten words were used to measure his production of English, and ten to measure his

---

8 Production words used: banana, fish, shoe, hand, table, ice cream, dance, listen, read, write
comprehension\textsuperscript{9}. After seeing a picture, Jimmy was expected to verbalize the depicted image in English, or to choose a target word from four images. The results of the inventory showed that he could comprehend one word and produce none before the sessions started. Jimmy was then videotaped in class for 20 weeks from September 2012 to January 2013. During these five months, all main course sessions were recorded, with some exceptions in the first month due to technical problems. Because Jimmy was present each second week of the first five months (except the first month), we selected these four sessions with balanced intervals for further analysis.

To explore Jimmy’s English learning in class, his nonverbal and verbal learning behaviors, as well as other relevant actions (being silent, murmuring) were coded in two steps using the computer program MediaCoder (Bos & Steenbeek, 2007). The first step of the coding procedure was to determine the exact points in time when an utterance or nonverbal behavior started and ended. The boundaries of the utterances were based on intonation contour and pause duration, and the boundaries of nonverbal behaviors were decided by focusing on changes in movement. The second step was to classify the utterances and nonverbal behaviors into several categories, as Table 5-1 demonstrates. For verbal behavior, three sub-categories were distinguished: English repetition, English response, and mixed use of English and Chinese. For nonverbal behavior, we distinguished two sub-categories: nonverbal repetition and nonverbal response.

\textsuperscript{9} Comprehension words used: book, pink, five, hair, cat, father, cherry, square, ice cream, sofa
Table 5-1. Explanations and examples of the categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| Nonverbal behavior        | Nonverbal repetition                      | Copies the teacher’s action or gesture                    | **Teacher:** Run, run, run (says “run” while running).  
**Jimmy:** Runs, mimicking the teacher (no utterance). |
|                           | Nonverbal response                        | Comprehends the teacher’s question by demonstrating it with an action | **Teacher:** Who wants to try?  
**Jimmy:** Raises his hand (no utterance). |
| Verbal behavior           | English repetition                        | Repeats (part of) the teacher’s English utterance         | **Teacher:** Sit down nicely.  
**Jimmy:** Sit nicely. |
|                           | English response (Verbal response)        | Uses English to answer the teacher’s questions or requests | **Teacher:** Ok, what’s this?  
**Jimmy:** Eraser. |
|                           | Mixed use of English and Chinese (Verbal response) | Either uses Chinese only in the utterance, or code-switches between English and Chinese | **Teacher:** Red (demonstrates “red” with a picture).  
**Jimmy:** 老师, 他没说 red (“Teacher, he didn’t say red”). |
| Others                    | Others                                   | Keeps silent or acts/murmurs without learning purpose    |                                              |

*Note.* The bold words indicate the speaker. Contextual information and utterance translations (when applicable) are in parentheses.

### 5.3.3 Data analysis

The data consist of the time series of learning, sampled at 2 Hz. The duration of most verbal and nonverbal behaviors was between half a second and one second. The sampling rate of 2 Hz can, therefore, adequately capture the dynamic nature of the learning behaviors, without overestimating relatively stable or noisy periods.

**Linear Analysis**

The relative proportion of the frequency and duration of the verbal and nonverbal behaviors, and of the verbal repetition and verbal response were calculated (for example, the frequency of verbal behaviors divided by the total frequency of behaviors; and the duration of the verbal behaviors...
divided by the total duration of the sessions). These measures provide us with a global overview of Jimmy’s learning behaviors at the macro-level, revealing the central tendency of his learning process.

**Recurrence Analysis (RQA and CRQA)**

To find the developmental patterns and coordination of different learning behaviors, recurrence quantification analysis (RQA) and cross recurrence quantification analysis (CRQA) were performed on the time series. RQA is “a particular type of nonlinear time-series analysis based on the registration of whether a system’s state at each and every point during an observation recurs, that is, repeatedly occurs” (Reuzel et al., 2013, p. 288). It has been widely used in physiology and life sciences, and has been introduced in developmental psychology and children’s language learning in recent years (e.g., Cox & van Dijk, 2013; De Graag, Cox, Hasselman, Jansen & De Weerth, 2012; Dale & Spivey, 2006; Wijnants, Hasselman, Cox, Bosman, & Van Orden, 2012). The advantage of RQA is that it offers valuable and unique information about the behavior of complex dynamical systems, and is applicable to non-stationary data, such as the data used in the current study. For more details about this approach, see Marwan, Romano, Thiel, and Kurths (2007). CRQA is an approach, based on recurrence analysis, which is used to assess the attunement of two interacting systems (Shockley, Butwill, Zbilut, & Webber, 2002). This approach has proven to be effective in the study of the coordination of verbal and nonverbal behavior in dyadic interaction, e.g., during a conversation (Reuzel et al., 2013; 2014). In such cases, recurrence reflects that the behavioral state of one system (e.g., activation of the verbal response subsystem) is matched by the other system (e.g., activation of the nonverbal response subsystem), either earlier or later in time, or at the same time (for more details on this approach, see Dale and Spivey, 2006 and Reuzel et al., 2013; 2014).

In the current study, CRQA has been used to explore the coordination of verbal and nonverbal behaviors and RQA has been adopted to investigate the developmental patterns of different verbal behaviors (i.e., verbal repetition and verbal response). To elaborate, in the case of CRQA of the verbal and nonverbal behavioral time series, all instances of matches (of which most are not at the same time) between verbal and nonverbal behaviors were registered as black dots in a two-dimensional grid, called the recurrence plot (see Figure 5-3). So a black dot in the recurrence plot shows how a verbal behavior of the child at some point in time is associated with a nonverbal behavior at the same or any other point in time during the observation. The recurrence plot thus informs us about the temporal attunement of these learning behaviors across all possible time scales within the session. In case of RQA of the verbal behavioral time series, the recurrence plot informs us about the patterns of repetition and response during a session. The black dots in the recurrence
plot would represent how Jimmy used either English repetition or response repeatedly during a session, with (possibly) some delay between their occurrences. Finally, long term changes in these patterns, as they appear in the recurrence plots across the sessions, provide information about the changing dynamics of the learning behavior.

Figure 5-3. An example of recurrence plot in Month 3. Here the horizontal axis represents the time series of nonverbal behaviors and the vertical axis that of verbal behaviors. A black dot in the plot represents an instance where a nonverbal behavior matches a verbal behavior.

(C)RQA is a method to quantify the patterns that are present in the recurrence plot. Several measures can be derived from the basic recurrences (i.e., black dots), which quantify the dynamic organization of the system under study. These measures can reveal the global structural patterns in the learning behaviors and what the dynamic relationship between the learning behaviors is. In this case, “global” refers to “general quantitative measures, with minimal dependence on statistical assumptions” (Dale & Spivey, 2006, p. 394). The measures that are relevant to the current study are explained in Table 5-2. DET and LAM reflect how much of the recurrence plot consists of global structural patterns, and TT and MaxVL reflect the average and maximal duration of such patterns, respectively.
Table 5-2. Explanations of the Recurrence Analysis measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrence Rate (RR)</td>
<td>RR is the proportion of recurrent (i.e., matching) points in the entire recurrence plot relative to the size of the recurrence plot. This measure reflects to what extent the behaviors of a system are matched by the behaviors of another system (CRQA), or of its own system (RQA) at each and every point during the observation.</td>
</tr>
<tr>
<td>Determinism (DET)</td>
<td>DET is defined as the proportion of recurrent points that form diagonal line structures in the RP (i.e., a pattern of minimally two adjacent black dots). Determinism is related to the predictability of a system’s behavior.</td>
</tr>
<tr>
<td>Laminarity (LAM)</td>
<td>LAM is defined as the proportion of recurrent points that form vertical line structures in the RP (i.e., a pattern of minimally two adjacent black dots). Laminarity is related to the occurrence of laminar states in the system, comprised of point attractors. These are instances where the same state is repeated consecutively.</td>
</tr>
<tr>
<td>Trapping Time (TT)</td>
<td>TT is calculated as the average length of all vertical lines in the recurrence plot, resulting in an estimate of the mean time that a system will stay in a specific point attractor state, reflecting the rigidity (i.e., lack of flexibility) of the system.</td>
</tr>
<tr>
<td>Maximal Length of the Vertical Lines (MaxVL)</td>
<td>MaxVL is the length of the longest vertical line in the recurrence plot. This measure expresses the system’s attractor strength.</td>
</tr>
</tbody>
</table>

A special-purpose MATLAB routine was used to perform CRQA and RQA on the time series of the verbal and nonverbal learning behaviors. For calculating the distribution of diagonal and vertical lines, the functions “dl” and “tt” from Marwan’s (2009) CRP Toolbox were used, respectively.

To check whether the temporal patterns as quantified by the RQA measures were significantly different from a random, unstructured and uncoupled pattern, the empirical time series were randomly redistributed. This signifies that each point in the measured time series received a randomly assigned new temporal location, which effectively destroys any deterministic pattern present in the original data. The shuffled data were also analyzed with CRQA and RQA using the same routines.

**Monte Carlo**

All MATLAB output were further analyzed using Monte Carlo (MC) permutation tests performed in Excel. MC tests were used to verify the patterns found with (C)RQA. Because the current study
only focused on one child, MC is considered appropriate because it has no required minimal sample size and no underlying assumptions (Todman & Dugard, 2001; van der Steen, 2014). Taking the data distribution into consideration, MC measures the probability that a difference (e.g., decrease of verbal repetition from M2 to M5) is caused by chance. In the current study, MC was used to compare the empirical data and the shuffled data of the (C)RQA, to check whether the patterns found in (C)RQA were above chance level, and to confirm the trend (slope) of verbal behavioral development and the trend (slope) of the coordination between verbal and nonverbal behaviors over the four months. When the empirically-found measures significantly differed from the shuffled measures \( p < 0.05 \), the result was considered statistically significant. A summary of the analytical approaches is presented below (Figure 5-4).

**Figure 5-4. Behavior categories in the current study and their analytical approaches**

### 5.4 Results

#### 5.4.1 The coordination between verbal and nonverbal behavior

**Linear Analysis**

Figure 5-5 shows the relative distribution of time and frequency using the verbal and nonverbal behaviors from Month 2 to Month 5. Both graphs reveal that at the beginning Jimmy had more distinct instances of nonverbal behaviors (approximately 70%) than verbal behaviors (approximately 30%). However, as time goes by, the use of verbal behaviors surpassed the use of nonverbal behaviors in both frequency and total time. For instance, by Month 5, the verbal behaviors encompass approximately 63% of the total duration of Jimmy’s behaviors, and the nonverbal behaviors account for less than 37%. This finding exemplifies the results of Sun et al.
(2014), who found that body language is dominant at the beginning of classes and then surpassed by verbal behaviors, not only in terms of frequency but also in the total time of use. Children might rely on nonverbal behaviors to compensate for their limited productive competence, to better their intended delivery and classroom adaptation.

Figure 5-5. Line graphs of Jimmy’s use of verbal (solid lines) and nonverbal (dotted lines) behaviors. The left graph refers to the relative proportion of frequency (number of instances) and the right one refers to the relative proportion of the two categories in terms of total time.

CRQA on Verbal and Nonverbal behavior

The coordination between verbal and nonverbal behaviors over time was further investigated using CRQA. Figure 5-6 presents the general pattern of the coordination (solid lines). It fluctuates throughout the four months with a decreasing trend. The first two months witnessed little change; however, from Month 3 to Month 4, there a sharp decrease appears, with declines in RR from 0.8% to 0.1%, LAM from 0.97 to 0.88, TT from 3.8 to 3.2, and MaxVL from 13 to 7. This signifies that the degree of coordination between verbal and nonverbal behavior decreases (RR), and that the learning behavior becomes less predictable, with fewer laminar states (LAM) in the recurrence plot. The learning patterns become somewhat more flexible (a decrease in TT), with a reduced tendency to remain in a similar behavioral state (attractor) for a longer period (a decrease in MaxVL). This indicates that Jimmy performs more flexibly over time, relying less on coupling body language and verbal production to deliver meaning. From the fourth to the fifth month, however, we see a somewhat unexpected increase in these measures. This could be due to the fact that the Chinese teaching assistant was replaced around that time, and this shift might have had an influence on Jimmy’s learning.

To confirm the decrease of the laminar states and other trends found by the CRQA, the empirical data were compared to the shuffled data. Figure 5-6 shows that the values of LAM, TT and MaxVL
of the empirical data were well above those of the shuffled (random) data, and hence, above the level of chance. Monte Carlo permutation tests confirmed that this difference between the shuffled and empirical data was significant ($p < 0.001$). In terms of the trend of the coordination between verbal and nonverbal behaviors, MC also confirmed the significance of the general decreasing tendency (for all slopes, $p < 0.001$). Overall, the results imply that Jimmy’s EFL learning behavior reorganizes over the course of the study. The coupling of verbal and nonverbal behaviors becomes more flexible, whereas Jimmy’s FL knowledge increases. When the learning environment is perturbed, viz., by the change of teacher, the coupling between his verbal and nonverbal behavior becomes more rigid again, as reflected by the increase in the CRQA measures between Month 4 and 5.

Figure 5-6. Recurrence Rate (RR), Laminarity (LAM), Trapping Time (TT) and Maximum Vertical Line length (MaxVL) for the coordination between Jimmy’s verbal and nonverbal behaviors, as retrieved from the CRQA analysis. Solid lines refer to the empirical data and the dotted lines refer to the shuffled data.
5.4.2 The developmental patterns of verbal repetition and verbal response

Linear Analysis

Figure 5-7 presents the relative proportion of using verbal repetition and verbal response by Jimmy over the four months. As in 4.1, both the time and frequency proportions of the two categories are depicted. The two graphs show that Jimmy used a similar amount of verbal repetition and verbal response in Month 2. However, verbal response was used consistently more than verbal repetition throughout the remainder of the months, which is probably related to Jimmy’s improved command of the English language over time (cf. Sun et al., 2014).

![Figure 5-7. Line graphs of Jimmy’s use of verbal repetition (dotted lines) and verbal response (solid lines). The left graph refers to the relative proportion of frequency (number of instances) in using the two categories and the right graph refers to the relative proportion of the two categories in terms of total time.]

RQA on Verbal repetition and Verbal response

The developmental patterns and dynamics of verbal repetition and verbal response are derived from the RQA, of which the RR, LAM, TT and MaxVL measures are presented in Figure 5-8 (solid lines). Overall, only a few recurrent points were found. In terms of repetition, the developmental trend fluctuates drastically. LAM, TT and MaxVL all reveal different patterns. The laminar states of repetition decrease from Month 2 to Month 4, reflecting a decrease in rigidity; that is, a decrease in repeatedly using verbal repetition in class. In Month 5, a sharp increase is observed in LAM from 0.8 to 0.93, returning to the level reached in Month 2. TT fluctuates around a value of 3.3, with a maximum value of 4 and a minimum value of 2.5, indicating the pattern of using repetition is stable. MaxVL experiences a sharp increase at the beginning, but decreases in the following three months, implying a stronger reliance on English repetition at the beginning, but greater flexibility of use.
over time. In contrast, the pattern of development for verbal response, as indicated by its LAM, TT and MaxVL values is clearer. All three measures show a non-linear decrease over time: LAM from 0.98 to 0.95, TT from 4.4 to 3.5 and MaxVL from 13 to 7. The combined results demonstrate a decrease in the amount of laminar states (decrease in LAM). The patterns of using verbal response become more flexible (decrease in TT), with a reduced tendency to remain in a similar behavioral state (attractor) for a longer period (decrease in MaxVL). The results indicate that Jimmy becomes more flexible in producing English and Chinese in class. Overall, verbal response appears to be more predictable than verbal repetition, with higher values of LAM and TT across time.

Monte Carlo permutation tests were used to confirm the developmental trends of verbal repetition and verbal response found by the RQA. First, the values of the empirical data were well above the shuffled (randomized) data (solid line vs. dotted lines in Figure 5-8) and the difference between these shuffled and empirical data was significant (for all tests, $p < 0.001$). This indicates that the patterns for verbal repetition and verbal response are different from a random, unstructured and uncoupled pattern. In terms of the general developmental trend of verbal repetition, only the slope of MaxVL was found to significantly decrease ($p < 0.001$). This indicates a reduced tendency to remain in a similar behavioral state (attractor) for a longer period. Regarding the general decreasing trend of verbal response, all measures showed a slope that differed significantly from chance (slope of TT: $p < 0.001$; slope of MaxVL, $p < 0.001$) or were approaching significance (slope of LAM, $p = 0.072$). It seems that Jimmy’s use of verbal response tends to become more flexible over time.
Chapter 5 Foreign Language Learning as a Complex Dynamic System

Figure 5-8. Recurrence Rate (RR), Laminarity (LAM), Trapping Time (TT) and Maximum Vertical Line length (MaxVL) for the developmental pattern of verbal repetition (grey lines) and verbal response (black lines). In graphs LAM, TT and MaxVL, solid lines represent empirical data and dotted lines represent shuffled data.

5.5 Discussion and conclusions

The current study uses recurrence analysis to explore the dynamics and developmental patterns of Jimmy’s early EFL learning. By using this nonlinear time series technique, the learning behaviors found in the general stages of young EFL learners’ learning behaviors (Sun et al., 2014) are analyzed on a micro-level. We focused on the coordination between several learning behaviors over time, to obtain an in-depth understanding of the tangible patterns in a child’s learning behaviors.

We first examined the relationship between Jimmy’s verbal and nonverbal behaviors. The coupling between Jimmy’s nonverbal and verbal behavior showed a rigid pattern at the beginning, but the coordination loosened over time, allowing Jimmy to respond to the teachers’ instructions more flexibly, and to alternate more easily between his verbal and nonverbal behaviors. Focusing on the verbal behaviors, Jimmy’s use of verbal response tends to become increasingly more flexible over time, in less fixed patterns. For verbal repetition however, most RQA measures showed no significant positive or negative trend over the four months (apart from MaxVL, indicating a reduced tendency to remain in a similar behavioral state for a longer period).

These findings indicate that, first of all, nonverbal behaviors were strongly coupled to verbal production at the beginning, possibly facilitating Jimmy’s FL learning when his verbal language skills were still quite limited. As Goldin-Meadow (2014, 2015) discussed, when children lack fundamental vocabulary, gestures and body language might help them maintain interaction
momentum. From our qualitative observations, we can see that Jimmy used nonverbal behaviors in class to emphasize what he said, to attract the teachers’ attention, and to strengthen his verbal behavior (to provide a more complete picture of what he is attempting to communicate). Over time, the coordination between verbal and nonverbal behaviors changed for Jimmy (they became more flexible), which might indicate his improved adaptation to the new environment. Note that Jimmy shifted to a more rigid pattern when the Chinese teaching assistant was replaced, indicating the influence (perturbation) of an external factor on the learning system.

Furthermore, the different degrees of predictability of verbal repetition and verbal response suggest the varied influence of internal and external factors on different learning behaviors. Jimmy repeated after people (primarily his teachers), mostly to confirm what they said (Rydland & Aukrust, 2005), and the extent of using this repetition heavily depends on the behavior of other interlocutors and the specific learning environment (Duff, 2000). In other words, Jimmy’s verbal repetition was heavily influenced by external factors, such as the frequency of the teacher’s repetitions and intentional pauses, which change from moment to moment. As a result, the developmental pattern of repetition fluctuates. In contrast, Jimmy’s developmental trajectory of verbal response across sessions, such as using English responses and code-switching, seems to have been determined more by his language competence and willingness to communicate. Over time, Jimmy might have become more familiar with English, and felt more comfortable using this language voluntarily. In turn, his gradually improving language competence stabilized the developmental trajectory of his verbal response.

5.6 Limitations and implications

The above results require confirmation by studies with a larger sample size (i.e., including more children) and across more sessions (i.e., with denser and longer measurement). Due to the limited number of sessions and the fluctuation of LAM, TT and MaxVL across them, definite and generalizable conclusions about the trend could not be drawn. Note that this fluctuation is not a limitation of the study design per se, but should be taken as a fundamental and informative part of developmental systems (e.g., Van Geert & Van Dijk, 2002; 2007). As a case in point this study demonstrates the context sensitivity of FL learning and the ‘information richness’ of time-series data of learning behaviors. However, to achieve a more general and detailed description of the attractor dynamics, including the underlying processes, more (case) studies need to be added to the empirical record.
Despite these limitations, the current study represents the potential of combining a microgenetic approach with nonlinear time-series methods in exploring the dynamic relationships between the developmental trajectories of subcomponents (verbal and nonverbal behaviors) of a learning system over time (cf. Cox & Van Dijk, 2013). Compared to the linear measures that were presented at the beginning of the Results section, the non-linear measures reflect the learning process in greater detail, highlighting dynamical aspects of the behavior, such as flexibility and stability. Nonlinear techniques can help to provide perspective on the dynamic coupling of students to learning behaviors, by revealing that learning is more complex and consists of many interacting components, which cannot be fully assessed without considering the nonlinear dynamic nature of learning. Nonlinear time-series techniques are still new to social science, not mention to early FL learning studies. However, as Cox and Van Dijk (2013) claimed, “the ongoing improvements of techniques and the appearance of powerful new measures based on recurrence analysis, especially for categorical time series, will make this approach increasingly important and appealing for the study of developmental processes” (p. 314).