CHILDREN'S ACQUISITION OF TONE 3 SANDHI IN MANDARIN

By

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ABSTRACT

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The purpose of the dissertation is to examine Mandarin-speaking children's acquisition of a syntax-dependent phonological rule Tone 3 Sandhi (T3S). A Tone 3 (low dipping tone) is changed to a Tone 2 (mid rising tone) when it is followed by another Tone 3. Application of T3S in fact involves a complex process. In setting up the prosodic domains within which T3S applies, syntax is partially referred to. Cyclic and non-cyclic parsing strategies are used for different syntactic contexts. A non-cyclic strategy is used for flat structures (e.g. digit sequences), a cyclic strategy for NPs, and a mixture of both strategies is necessary for sentences. There is also T3S variability because of T3S optional rules. Such variability creates ambiguity in the language input for children. Very little is known about how children acquire T3S. The current work aims to bridge the gap between T3S theories and child language acquisition. This dissertation presents five studies, targeting children's application of T3S in various contexts.

Study 1 (Natural speech) examines the production data of seven children (ages 4-6) and their caretakers (five adults). There is T3S variability in children and adults.

Study 2 (Flat structures) is an elicited production study participated in by 46 children (3- and 5-year-olds) and 20 adults. We tested the use of a non-cyclic strategy in sequences of two, three, and five digits. The results show that children were able to apply T3S non-cyclically in sequences of digits. However, under-application and over-application are two common error types of children. A surface pattern produced by adults was not found in children.

Study 3 (NPs) is also an elicited production study, focusing on the cyclic strategy in NPs, Ninety-four children (ages 3 - 6) and 20 adults participated in this study. Children were able to apply T3S cyclically in three-syllable compound nouns and four-syllable NPs. However, when the structures become more complex, they may default to the non-cyclic strategy.

Study 4 (Natural Speech Repetition) and Study 5 (Robot Talk Repetition) used repetition of sentences to test T3S application at the sentence level where an integration of cyclic and non-cyclic strategies is necessary. Twenty-one children (4- and 6-year-olds) and 11 adults participated in Study 4. Forty-three children (4- and 6-year-olds) and 14 adults participated in Study 5. Children were able to repeat the 4- and 6-syllable sentences which have T3S in Study 4 (Natural Speech Repetition). However, in Study 5 (Robot Talk Repetition) where we used identical sentences, with the removal of the T3S effect, 4-year-olds have a lot of difficulty. Six-year-olds were able to integrate cyclic and non-cyclic strategies in T3S application, but they still do not have adults' mastery of T3S. Six-year-olds have all the T3S patterns adults have, and also approximate adults in their preference of the patterns.

Overall, the findings of these studies do not support early acquisition of T3S. The results indicate that although children know to change a Tone 3 to a Tone 2 when it is followed by a Tone 3, it takes time to learn how to set up the prosodic domains for T3S to apply, to develop and reach adult-like mastery of the intricacies of T3S application.

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TABLE OF CONTENTS

LIST OF TABLES……………………………………………………………………....... xiv

LIST OF FIGURES……………………………………………………………………xviii

LIST OF ABBREVIATIONS…………………………………………………………xx

CHAPTER ONE
INTRODUCTION…………………………………………………………………... 1
1.0 Introduction……………………………………………………………………………1
1.1 Study 1: Natural Speech………………………………………………………………….9
1.2 Study 2 – Study 5: T3S in various domains of application……………………………..10
1.3 Summary of findings…………………………………………………………………11
1.4 The structure of the dissertation………………………………………………………...14

CHAPTER TWO
LINGUISTIC BACKGROUND ON TONE 3 SANDHI………………………………...16
2.0 Introduction……………………………………………………………………………..16
2.1 Mandarin Tones and T3S……………………………………………………………16
2.1.1 Four lexical tones ………………………………………………………………...16
2.1.2 Tone 3 Sandhi …………………………………………………………………... 19
2.1.2.1 T3S in Flat structures……………………………………………………..19
2.1.2.2 T3S depends on syntax…………………………………………………...20
2.1.2.3 T3S variation……………………………………………………………..22
2.1.2.4 Summary…………………………………………………………………24
2.2 Two major Tone 3 Sandhi Models……………………………………………………...25
2.2.1 Word-and-Phrase level Model …………………………………………………... 25
2.2.1.1 T3S in Flat structures……………………………………………………….28
2.2.1.2 T3S depends on syntax……………………………………………................. 29
2.2.1.3 T3S variation……………………………………………………………..32
2.2.2 Stress-foot Model……………………………………………………………………34
2.2.2.1 T3S in Flat structures…………………………...…………………………..36
2.2.2.2 T3S depends on syntax…………………………...………………………... 37
2.2.2.3 T3S variation……………………………………………………………..41
2.3 Some issues……………………………………………………………………………..42
2.3.1 Word-and-Phrase level Model………………………………………………………42
2.3.2 Stress-foot Model……………………………………………………………………46
2.4 Conclusion……………………………………………………………………………... 48

CHAPTER THREE
PREVIOUS CHILD ACQUISITION STUDIES ON TONE 3 SANDHI……………………… 49
3.0 Introduction……………………………………………………………………….. 49
3.1 The acquisition of tones: an overview…………………………………………… 50
3.2 Previous acquisition studies on Mandarin tones and T3S……………………….. 50
3.2.1 Children's acquisition of Mandarin tones…………………………………... 50
3.2.2 Children's acquisition of T3S………………………………………………. 56
3.3 Conclusion……………………………………………………………………….. 66

CHAPTER FOUR
NATURAL SPEECH…………………………………………………………………. 67
4.0 Introduction……………………………………………………………………….. 67
4.1 Additional linguistic background………………………………………………… 68
4.2 T3S in natural speech……………………………………………………………... 70
4.3 Hypotheses and predictions………………………………………………………. 72
4.4 Method…………………………………………………………………………… 74
4.4.1 Subjects………………………………………………………………….... 74
4.4.2 Data Collection and transcription………………………………………….. 74
4.4.3 Coding procedures…………………………………………………………. 75
4.5 Results……………………………………………………………………………. 80
4.6 Discussion……………………………………………………………………….. 103
4.7 Conclusion………………………………………………………………………. 114

CHAPTER FIVE
FLAT STRUCTURES……………………………………………………………… 117
5.0 Introduction……………………………………………………………………… 117
5.1 T3S in Flat structures …………………………………………………………… 118
5.1.1 Previous theoretical studies………………………………………………... 118
5.1.2 Kuo et al. (2007) experimental study ……………………………………... 121
5.1.3 Re-thinking the linguistic environment for investigating flat structures…….. 126
5.2 Research questions, hypotheses, and predictions………………………………... 127
5.2.1 Research questions and Hypotheses……………………………………… 127
5.2.2 Predictions of T3S application in flat structures…………………………... 129
5.2.2.1 A two-syllable flat structure…………………………………………. 129
5.2.2.2 A three-syllable flat structure………………………………………... 129
5.2.2.3 A five-syllable flat structure…………………………………………. 131
5.3 Study 2: Flat structures………………………………………………………….. 133
5.3.1 Method……………………………………………………………………. 133
5.3.1.1 Subjects……………………………………………………………… 133
5.3.1.2 Procedure……………………………………………………………. 134
5.3.1.3 Design……………………………………………………………….. 136
5.3.1.4 Materials…………………………………………………………….. 137
5.3.1.5 Coding………………………………………………………………. 138
5.3.2 Results……………………………………………………………………... 142

5.3.2.1 Overall correct rates in control items and test items……………………………143
5.3.2.2 Surface patterns in flat structures………………………………………………144
5.3.2.3 Errors in children……………………………………………………………. 148
5.3.3 Checking hypotheses………………………………………………………………… 150
5.3.4 Discussion……………………………………………………………………………152
5.3.4.1 Correct surface patterns……………………………………………………... 152
5.3.4.2 T3S Errors……………………………………………………………………156
5.3.4.3 General discussion…………………………………………………………... 165
5.4 Conclusions…………………………………………………………………………………170

CHAPTER SIX

NPs AND EVIDENCE FOR A SNTACTIC PARSING….……………………………………...171
6.0 Introduction…………………………………………………………………………………171
6.1 Linguistic Background……………………………………………………………………...171
6.1.1 Cyclic T3S application at the Word Level…………………………………………171
6.1.2 Compound Nouns and NPs………………………………………………………...172
6.2 Research questions, hypotheses, and predictions………………………………………….. 177
6.2.1 Research questions and Hypotheses………………………………………………. 177
6.2.2 Predictions of T3S application in NPs……………………………………………..178
6.2.2.1 Three-syllable compound nouns……………………………………………..179
6.2.2.2 Four-syllable noun phrases………………………………………………….. 179
6.3 Study 3: NP Experiment…………………………………………………………………… 181
6.3.1 Method……………………………………………………………………………..182
6.3.1.1 Subjects………………………………………………………………………182
6.3.1.2 Procedure……………………………………………………………………. 182
6.3.1.3 Design ……………………………………………………………………… 183
6.3.1.4 Materials…………………………………………………………………….. 184
6.3.1.5 Coding………………………………………………………………………..187
6.3.2 Results…………………………………………………………………………….. 191
6.3.2.1 Three-syllable compound nouns……………………………………………..193
6.3.2.2 Four-syllable NPs…………………………………………………………….196
6.3.3 Discussion………………………………………………………………………… 204
6.3.3.1 Three-syllable compound nouns……………………………………………..204
6.3.3.2 Four-syllable NPs…………………………………………………………….205
6.4 Conclusions…………………………………………………………………………………207

CHAPTER SEVEN

T3S IN SENTENCES………………………………………………………………………..208
7.0 Introduction…………………………………………………………………………………208
7.1 Research questions, hypotheses and predictions…………………………………………... 209
7.1.1 Research questions…………………………………………………………………209
7.1.2 Hypotheses and predictions for both experiments…………………………………209
7.2 Study 4: NSR = Natural Speech (with Sandhi) Repetition……………………..………..211
7.2.1 Method……………………………………………………………………………..212

7.2.1.1 Subjects……………………………………………………………………… 212
7.2.1.2 Procedure……………………………………………………………………. 212
7.2.1.3 Design……………………………………………………………………….. 213
7.2.1.4 Materials…………………………………………………………………….. 223
7.2.1.5 Coding………………………………………………………………………..224
7.2.2 Results and discussion for control items in NSR……………………………………..228
7.2.3 Results and discussion for test items in NSR………………………………………....230
7.2.3.1 Results for 4w4σ and 4w6σ items………………………………………………231
7.2.3.2 Discussion for 4w4σ and 4w6σ items…………………………………………..235
7.2.3.3 Results for PRO-5w6σ and NP-5w6σ items…………………………………... 238
7.2.3.4 Discussion for PRO-5w6σ and NP-5w6σ items………………………………. 241
7.3 Study 5: RTR = Robot Talk (without sandhi) Repetition……………………….……… 244
7.3.1 Background………………………………………………………………………….. 244
7.3.2 Method……………………………………………………………………………….. 245
7.3.2.1 Subjects……………………………………………………………………… 245
7.3.2.2 Procedure……………………………………………………………………. 246
7.3.2.3 Design……………………………………………………………………….. 246
7.3.2.4 Materials…………………………………………………………………….. 247
7.3.2.5 Coding………………………………………………………………………..251
7.3.3 Results and discussion for control items in RTR……………………………………..251
7.3.4 Results and discussion for test items in RTR………………………………………... 254
7.3.4.1 Results for 4w4σ and 4w6σ items………………………………………………255
7.3.4.2 Discussion for 4w4σ and 4w6σ items…………………………………………..258
7.3.4.3 Results for PRO-5w6σ and NP-5w6σ items…………………………………… 259
7.3.4.4 Discussion for PRO-5w6σ and NP-5w6σ items……………………………….. 263
7.4 General discussion…………………………………………………………………………. 266
7.5 Conclusions…………………………………………………………………………………269

CHAPTER EIGHT

CONCLUSION……………………………………………………………………………273
8.0 Introduction………………………………………………………………………………273
8.1 Hypotheses………………………………………………………………………………..276
8.2 Summary and discussion of findings…………………………………………………… 279
8.3 Future research…………………………………………………………………………...284

APPENDICES

Appendix A Study 1 Possible frozen chucks………………………………………………...287
Appendix B Study 2 Experimental materials…………………………..…………………….289
Appendix C Study 3 List of test and control items…………………………………………..292
Appendix D Study 3 Experimental materials………………………………………………...294
Appendix E Study 4 (NSR) Experimental materials…………………………………………313
Appendix F Study 5 (RTR) Experimental materials…………………………………………319
Appendix G Predicted surface patterns for test items in Study 4 NSR and Study 5 RTR……...325
Appendix H Statistics notes…………………………………………………………………328

REFERENCES……………………………………………………………………………………332

LIST OF TABLES

Table 2.1 Four lexical tones in Mandarin Chinese…………………………………………… 17

Table 2.2 T3S variation……………………………………………………………………..23

Table 4.1 Study 1: Distribution of the subjects…………………………………………….…74

Table 4.2 Study 1: Number of T3* (adjacent and non-adjacent) and total syllables produced….80

Table 4.3 Study 1: Number of T3-sequences: two, three, and four or more T3*………………..81

Table 4.4 Study 1: T3S frequency..…………………………………………………………... 82

Table 4.5 Study 1: T3S correct rates………………………………………………………..83

Table 4.6 Study 1: Number of T3S applications within words, within constituents and across constituents……..…….……………………………………………….………………84

Table 4.7 Study 1: T3S application rates (%) within constituents and across constituents by subject……….…………………………………………………………………….. 90

Table 4.8 Study 1: Frequency (%) of cliticization of subject pronouns in two, three, and four adjacent T3*………………………………………………………………………….. 98

Table 4.9 Study 1: Two adjacent T3* that belong to two prosodic domains…………………...101

Table 4.10 Study 1: Two adjacent T3* that belong to two prosodic domains (%)……………..102

Table 4.11 List of possible frozen chucks and number of tokens produced by each participant …………………………..……………………………………………… 287

Table 5.1 List of grammatical and ungrammatical patterns in flat structures…………………. 121

Table 5.2 Study 2: Distribution of the subjects…………………………………………………133

Table 5.3 Study 2: Sample answers and their coding categories for data analysis……………..140

Table 5.4 Study 2: Sample T3S errors and their coding categories for error analysis………….142

Table 5.5 Study 2: Control items— 3-year-olds' data excluded from the analysis…………….142

Table 5.6 Study 2: Test items— 3-year-olds' data excluded from the analysis……………….. 142

Table 5.7 Study 2: Control items (non-T3 digits)………………………………………………143

Table 5.8 Study 2: Test items (T3 digits) ………………………………………………….. 144

Table 5.9 Summary of discrepancies between attested and predicted patterns in a 5-syllable flat structure……………………………………………………………………. 152

Table 5.10 Possible parsing of odd number of syllables if left-to-right parsing is not the only option…………………………………………………………………..……... 153

Table 5.11 Study 2: 32 combinations of T2 and T3 in a five-digit sequence………………….. 162

Table 5.12 Study 2: Percentages of attested and unattested error patterns in children…………163

Table 5.13 Checking empirical data against theoretical predictions…………………………... 166

Table 6.1 Study 3: Predicted patterns for the structures tested..………………………………..181

Table 6.2 Study 3: Distribution of the subjects…………………………………………………182

Table 6.3 Study 3: Sample answers and their coding categories for analysis of T3S application ……………………………………………………………………..……….189

Table 6.4 Study 3: Sample T3S errors and their coding categories for error analysis………….191

Table 6.5 Study 3: Three-syllable compound nouns (Control items)— data excluded from the analysis…………………………………………………………………………192

Table 6.6 Study 3: Three-syllable compound nouns (Test items)— data excluded from the analysis………………………………………………………………………… 192

Table 6.7 Study 3: Four-syllable compound nouns (Control items)— data excluded from the analysis……….…………………………………………………………..……..192

Table 6.8 Study 3: Four-syllable compound nouns (Test items)— data excluded from the analysis…….……………………………………………………………...... 193

Table 6.9 Study 3: Correct rate (%) in three-syllable compound nouns— Control items (no T3S)…………………………………………………………………………...194

Table 6.10 Study 3: Correct rate (%) in three-syllable compound nouns— Test items (with T3S)………………………………………………………………………… 194

Table 6.11 Study 3: Correct rate (%) in four-syllable NPs— Control items (no T3S)………....197

Table 6.12 Study 3: Correct rate (%) in four-syllable NPs— Test items (with T3S)…………..198

Table 6.13 Study 3: Error types (%) in four-syllable NPs..……………………………………200

Table 6.14 Study 3: List of tests and controls in three-syllable compounds (in Appendix C).....292

Table 6.15 Study 3: List of tests and controls in four-syllable NPs (in Appendix C)…..………293

Table 7.1 Study 4: Distribution of the subjects…………………………………………………212

Table 7.2 Study 4: Tokens for test and control items…………..……………………………… 221

Table 7.3 Study 4: Sample answers and their coding categories for data analysis…………….. 226

Table 7.4 Study 4: Sample correct responses and their coding categories…………………….. 228

Table 7.5 Study 4: Number of items included (I) and excluded (E) in control items…………..228

Table 7.6 Study 4: Control items— data excluded from the analysis…………………….......... 228

Table 7.7 Study 4: Correct rates (%) in control items ……………………………...…….. 229

Table 7.8 Study 4: Test items (4w4σ and 4w6σ)— data excluded from the analysis……….... 231

Table 7.9 Study 4: Test items (PRO-5w6σ and NP-5w6σ)— data excluded from the analysis………………………………………………………………………… 231

Table 7.10 Study 4: Number of items by pattern in 4w4σ and 4w6σ test items………………..232

Table 7.11 Study 4: Number of items by pattern in PRO-5w6σ and NP-5w6σ test items…….. 238

Table 7.12 Study 5: Distribution of the subjects………………………………………………..246

Table 7.13 Study 5: Number of items included (I) and excluded (E) in control items…………252

Table 7.14 Study 5: Control items— data excluded from the analysis………………………... 252

Table 7.15 Study 5: Correct rates (%) in control items……………………………………... 252

Table 7.16 Study 5: Test items (4w4σ and 4w6σ)— data excluded from the analysis………... 254

Table 7.17 Study 5: Test items (PRO-5w6σ and NP-5w6σ)— data excluded from the analysis ……………………………………………………………………. 255

Table 7.18 Study 5: Number of items by pattern in 4w4σ and 4w6σ test items………………..255

Table 7.19 Study 5: Number of items by pattern in PRO-5w6σ and NP-5w6σ test items ……………………………………………………………………………260

Table 9.1 An example of the statistics output and the interpretation of the results…………….328

LIST OF FIGURES

Figure 1.1 Basic ingredients for T3S……………………………………………………………5

Figure 4.1 Study 1: Percentages of T3S application at three levels by subjects………………....85

Figure 5.1 Study 2: A child's hand, (a) – (c) for two, three, and five digits respectively…….... 134

Figure 5.2 Study 2: Saying a digit two, three, and five times…………………………………..138

Figure 5.3 Study 2: Total correct rates in control and test items by age groups………………..143

Figure 5.4 Study 2: Correct rates of two T3-digits by age group……………………………… 145

Figure 5.5 Study 2: Correct rates of three T3-digits by age group…………………………….. 146

Figure 5.6 Study 2: Correct rates of five T3-digits by age group……………………….……... 147

Figure 5.7 Study 2: Children's error rates by type in flat structures……………………………148

Figure 5.8 Study 2: List of materials (in Appendix B)………………………………………… 290

Figure 6.1 Study 3: Sample materials in three-syllable compound nouns……………………...185

Figure 6.2 Study 3: Sample materials in four-syllable NPs…………………………………….187

Figure 6.3 Study 3: Correct rates in three-syllable compound nouns by age………………….. 195

Figure 6.4 Study 3: Correct rates in four-syllable NPs by age………………………………… 198

Figure 6.5 Study 3: Errors in four-syllable right-branching NPs by age……………………….201

Figure 6.6 Study 3: Errors in four-syllable mixed-branching NPs by age……………………...202

Figure 6.7 Study 3: Experimental materials for three-syllable compounds (in Appendix D) ….294

Figure 6.8 Study 3: Experimental materials for four-syllable NPs (in Appendix D)………….. 299

Figure 7.1 Study 4: Sample materials…………………………………………………………..224

Figure 7.2 Study 4: Correct rates for the control items by age…………………………………229

Figure 7.3 Study 4: Correct rates in *4w4σ* and *4w6σ* sentences…………………………...…….233

Figure 7.4 Study 4: Correct rates in *PRO-5w6σ* and *NP-5w6σ* sentences……………………... 239

Figure 7.5 Study 5: Sample materials…………………………………………………………..247

Figure 7.6 Study 5: Sample Praat Spectrogram for a test item— three T3*…………………... 248

Figure 7.7 Study 5: Sample Praat Spectrogram for a test item— all T3*……………………... 249

Figure 7.8 Study 5: Sample Praat Spectrogram for a control item…………………………….. 250

Figure 7.9 Study 5: Correct rates in control items by age……………………………………... 253

Figure 7.10 Study 5: Correct rates in *4w4σ* and *4w6σ* sentences……………………………….256

Figure 7.11 Study 5: Correct rates in *PRO-5w6σ* and *NP-5w6σ* sentences……………………. 261

Figure 7.12 Study 4: List of materials (in Appendix E)……………………………………….. 313

Figure 7.13 Study 5: List of materials (in Appendix F)………………………………………...319

LIST OF ABBREVIATIONS

Ø	empty beat (in a foot)
%	intonational break (when used in derivations for phrases or sentences)
σ	syllable
4w4σ	four words, four syllables
4w6σ	four words, six syllables
CL	classifier
D	determiner
DP(s)	determiner phrase(s)
H	(syntactic) head
M-branching	mixed-branching
MRUs	Minimal rhythmic units
NH	(syntactic) nonhead
NHS	Nonhead Stress
NP-5w6σ	Subject NP, five words, six syllables
NP(s)	noun phrase(s)
NSR	Natural Speech Repetition
opt rule pattern	pattern derived from T3S optional rules
OR	Odds Ratio
P	preposition
PP(s)	prepositional phrase(s)
pro	pronoun
PRO-5w6σ	Subject pronoun, five words, six syllables
PRT	particle
R-branching	right-branching
RTR	Robot Talk Repetition
ST	surface tones (ST1 = Surface pattern 1, ST2 = Surface pattern 2…)
(T)0-(T)4	Mandarin Tone 0 (neutral tone), Tone 1, Tone 2, Tone 3, and Tone 4
T3S	Tone 3 Sandhi
T3*	Tone 3s (plural T3s)
UT	underlying tones
v	variable and can be either the sandhi tone, Tone 2, or Tone 3
V	verb
VP(s)	verb phrase(s)

CHAPTER 1

INTRODUCTION

1.0 Introduction

In acquiring their first language, children need to figure out not only the properties of the different linguistic components of the language they are acquiring (phonetics, phonology, syntax, etc.), but they also need to understand how these components interact. Although we have a good idea of the milestones in the acquisition of syntax and phonology, we know very little about the acquisition of the mapping rules between phonology and syntax. We know that infants as young as 7.5 months can use the rhythmic biases of their language to guide initial segmentation of speech (Jusczyk & Luce 2002; Werker & Curtin 2005) and by age three, children have mastered the basic properties of the phrase structure of whatever language(s) they are acquiring (Brown 1973; Guasti 2004; Hirsh-Pasek & Golinkoff 1996; Roeper 2007). We also know that prosodic structure may play a role in the acquisition of morpho-syntax (Demuth 2001; Gerken 1996; Goad & Buckley 2006; Lleó & Demuth 1999). However, very little is known about the acquisition of syntax-dependent phonological rules. This dissertation focuses on children's acquisition of a syntax-dependent phonological rule, Tone 3 Sandhi (henceforth T3S), in Mandarin Chinese.[1] In this work, I present a series of studies which aim at widening our empirical knowledge of children's acquisition of T3S.

Mandarin has four lexical tones and each morpheme generally has an underlying lexical tone, (except for functional words such as the question particles *ma* and *ne*,) and the pitch level and contour of a neutral tone vary depending on the tone that precedes it (Bao 1999; Chao 1968;

[1] I use the term Mandarin Chinese or just Mandarin to refer to Standard Mandarin or Standard Chinese.

Chen 2000; Cheng 1973; Duanmu 2000/2007; Erbaugh 1992; Jeng 1979; Lin 2007 among others). Very little is known about how children acquire T3S although this syntax-dependent rule is the most extensively studied tone sandhi phenomenon in Mandarin Chinese. The rule can be simplistically described as in (1).

(1) T3 T3 → **T2** T3 (Chen 2000:364; Shih 1997:81)

The rule in (1) states that a Tone 3 is changed to a Tone 2 when followed by another Tone 3. Given what we know about the acquisition of prosodic patterns and statistical abilities (Morgan & Saffran 1995; Pierrehumbert 2003, for example) this rule should be acquired very early, and in fact various studies have argued for early T3S acquisition in children (Jeng 1979; Jeng 1985; Li & Thompson 1977; Zhu 2002; Zhu & Dodd 2000). However, none of these works have examined T3S in a multiplicity of environments. The simplicity of (1) is quite deceptive because the application of T3S "becomes rather complicated when there are more than two T3*[2] in a word or phrase" (Lin 2007:204). T3S application is a process that involves setting up prosodic domains within which T3S applies, and both cyclic and non-cyclic strategies are used for parsing the syllables. In addition, there are optional rules, so T3S can apply, but it does not need to apply in those cases. For children to acquire T3S, it is not only a matter of learning lexical tones, the rule in (1), but also when and how to use the right parsing strategies as well as the optional rules. T3S also involves the mapping between syntax and phonology, and researchers do not always agree to what extent T3S application relies on syntax. There are competing theories to describe and explain (i) its cyclic and syntax-dependent component and (ii) its non-cyclic and syntax-independent component. In flat structures (a sequence that has no internal syntactic structure, such as a string of digits in phone numbers), researchers agree that disyllabic feet are built non-

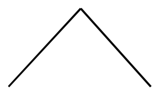
[2] In order to avoid confusion the similarity between "T3S" (Tone 3 Sandhi) and "T3s" (plural Tone 3s) may cause, "T3*" is used to refer to "plural Tone 3s (T3s)."

cyclically from left to right, and T3S applies in each foot (Chen 2000:368; Duanmu 2000/2007:239; Lin 2007:206; Shih 1986; Shih 1997). (2) shows a four-digit string which is parsed into two disyllabic feet.

(2)	wu	wu	wu	wu	
	five	five	five	five	'five-five-five-five'
	T3	T3	T3	T3	UT (= underlying tones)
→	(**T2**	T3)	T3	T3	
→	(T2	T3)	(**T2**	T3)	ST (= surface tones)

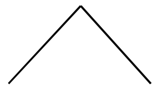
Although syllables are parsed non-cyclically in flat structures, in noun phrases and in compounds foot building is cyclic and dependent on the phrase structure of the units involved (cf. Chen 2000; Cheng 1973; Duanmu 2000/2007; Shih 1986; Shih 1997), applying first to the innermost constituent of a compound or a noun phrase, and then proceeding to the next level up as exemplified in (3) and (4).

(3)



	σσ	σ	
	[[shuiguo]	niao]	
	fruit	bird	'birds made with fruits'
	T3 T3	T3	UT
→	(**T2** T3)	T3	
→	(T2 **T2**	T3)	ST

(4)



	σ	σσ	
	[zhi	[haima]]	
	paper	seahorse	'seahorses made with paper'
	T3	T3 T3	UT
→	T3	(**T2** T3)	
→	(T3	**T2** T3)	ST

This picture is further complicated at the sentence level where a mixed system of cyclic and non-cyclic strategies are required as we see in (5).

(5)	[[xiao	[[duan	tui]	ma]]	[hen	[ke]]]	
	small	short	leg	horse	very	thirsty	‘The small short-legged horse is very thirsty.’
	3	3	3	3	3	3	UT
	3	(**2**	3)	3	3	3	
	3	(2	**2**	3)	3	3	
	(3	2	2	3)	3	3	
	(3	2	2	3)	(**2**	3)	ST

In (5), T3* applies cyclically in *xiao duan tui ma* ‘small short-legged horse.’ Starting with the innermost constituent *duan tui* ‘short-legged,’ T3S applies. In the next cycle, *ma* ‘horse’ is incorporated, and T3S applies again. When *xiao* ‘small’ is incorporated, T3S does not apply because there are no adjacent T3* at this point. T3S applies non-cyclically in the remaining syllables *hen ke* ‘very thirsty.’

Prosodic domains are not always built with reference to syntax, and consequently, they do not always map to syntactic constituents. According to one of the major T3S models, the Word-and-Phrase level Model[3] (Chen 2000; Shih 1986; Shih 1997), at the “Word level”, T3S applies cyclically, and at the “Phrase level”, T3S applies non-cyclically. However, if no foot has been parsed at the Word level, then, at the Phrase level foot building refers to syntax to form a disyllabic foot for the smallest domain first. Once a disyllabic foot has been formed for the smallest domain, the remaining syllables are parsed non-cyclically from left to right. Therefore, to be able to apply T3S involves not only knowing the rule stated in (1), but also the right parsing strategies at the right levels.

Independent of the details of each model, this brief description of T3S shows its application depends on lexical, syntactic and phonological knowledge, as schematically represented in Fig. 1.1.

[3] This model will be described and reviewed in Chapter 2.

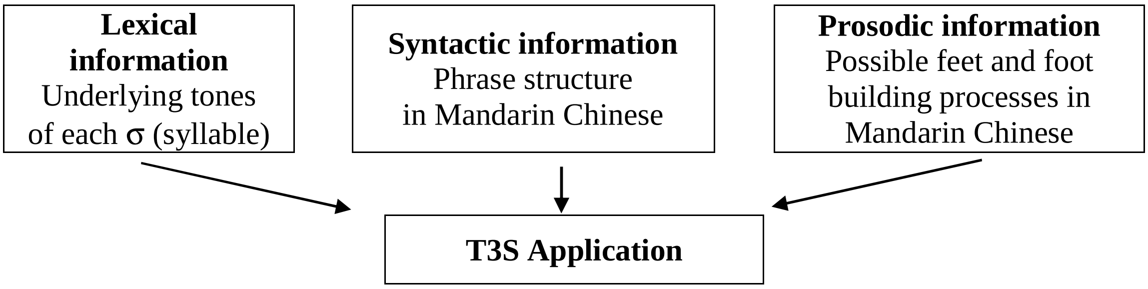


Figure 1.1 Basic ingredients for T3S

At the lexical level children need to know the underlying tones of the units they will use to build syntactic structures. In order to build syntactic structures, children need to have some knowledge of the basic phrase structure properties of Mandarin. At the prosodic level, children need to know the possible ways to build feet in Mandarin. In order to apply T3S in an adult-like manner, all three types of information must be integrated in particular ways and in many cases the syntax and prosody go hand in hand.

As if the picture was not complex enough, children will also have to deal with a fair amount of T3S variability in the input. Although there is some debate with respect to the nature of the variation, most researchers agree that some variation is associated with differences in speech rates (Chen 2000; Cheng 1973; Lin 2007; Shih 1986; Shih 1997), because larger domains can be formed in fast speech. There are two optional rules in the Word-and-Phrase level model: (i) T3S is optional across prosodic domains, and (ii) the fast speech rule. In (6) below, ST1 is derived through regular parsing. In fast speech, a larger domain is formed, and T3S applies iteratively from left to right, which gives ST2.

(6)	[wo	[xiang	[mai	bi]]]	(Lin 2007: 215)
	I	want	buy	pen	‘I want to buy pens.
	T3	T3	T3	T3	UT
	T3	T3	T3	T3	Word level: not applicable
	T3	T3	(**T2**	T3)	Phrase level: Disyllabic foot for the smallest domain, T3S
	(**T2**	T3)	(T2	T3)	Phrase level: Disyllabic foot for the rest, T3S; ST1 (surface tones, Surface pattern 1)

Optional[4] in fast speech:

(T3	T3	T3	T3)	Larger domain in fast speech
(**T2**	**T2**	**T2**	T3)	T3S from left to right; ST2 (surface tones, Surface pattern 2)

Notice that the sentence in (6), used to depict T3S variability, is fairly short. Depending on the syntactic structure, the number of adjacent T3* and the length of the sentence, the number of T3S surface patterns varies. It is not uncommon that a given T3S sentence has two or more than two T3S surface patterns. Children have to deal with and cope with variability. How do children acquire this complicated syntax-dependent phonological rule?

Not only is there an absence of studies targeting children’s T3S acquisition exclusively, there has also been a lack of experimental evidence of adults’ T3S production. In the T3S literature, the grammaticality judgments are commonly the researchers’ own judgments, but concerning multiple surface patterns, we do not have a good idea of which pattern adults tend to favor or disfavor. How the patterns are chosen and used (i.e. frequency for each T3S pattern) is relevant to acquisition studies since adult speech is crucial for acquisition. Although studies conducting experiments to obtain empirical evidence concerning adults’ T3S variability are not so difficult to create, it becomes very challenging when we consider testing both adults and children on identical tasks. This is because with children, the choice of vocabulary and the experimental design is a lot more limited. In this thesis, T3S application in various syntactic structures in children ages 3 – 6 is examined in order to learn children’s developmental path.

[4] Refer to Chapter 2 for more details on optional rules and T3S variation.

If children do acquire T3S at an early age and are almost error-free as previous studies have suggested, we expect that children ages 3-6 will have no difficulties applying T3S in phrases or sentences.

Our studies seek to investigate whether or not children can apply T3S actively in words/phrases/sentences that are novel or have combinations of morphemes/words that are not likely to have been treated by the child as frozen expressions, such as the example in (7).

(7)	[xiao	[[duan	tui]	ma]]	
	small	short	leg	horse	'(a) small short-legged horse'
	3	3	3	3	UT
	3	(**2**	3)	3	Word level: T3S
	3	(2	**2**	3)	Word level: T3S
	(3	2	2	3)	Word level: no T3S, ST
	*(2	3)	(2	3)	

In (7), although the individual words are commonly known to children, the combination of the words in the phrase is unlikely to have been learned as a frozen chunk. Therefore, children's application of T3S in (7), correctly or incorrectly, will provide useful information. For instance, cyclic application of T3S gives T3**T2T2**T3, the correct pattern, whereas non-cyclic parsing from left to right gives **T2**T3**T2**T3, the ungrammatical pattern.

If children have multi-word utterances they must have knowledge from all three components (lexical tones, phrasal structures, and setting up prosodic domains) to be able to apply T3S. We therefore ask the following questions:

1. How do children set up the domain of application of T3S?
2. Do they differ from adults and if so, how?
3. Is there T3S variability? Does the variability in the input influence the acquisition of T3S?
4. Is there a structure-less rhythmic bias or a syntactic bias at different stages of development?

In order to answer these questions, we conducted one natural speech study and four experimental studies where we examined T3S in various syntactic contexts. Since T3S involves both cyclic and non-cyclic parsing strategies, our experimental studies were designed so that cyclic and non-cyclic strategies were tested separately. Importantly, T3S in sentences where the integration of the two strategies is required was also tested.

To test the non-cyclic parsing strategy, we used flat structures which require a structure-less rhythmic foot-building from left to right.

To test the cyclic parsing strategy, we used NPs which require a syntax-based strategy. Prosodic domains within which T3S applies are built bottom-up.

To test an integration of cyclic and non-cyclic parsing strategies, we used sentences. For NPs embedded in the sentences, the cyclic strategy is expected. For the remaining syllables in the sentence, the non-cyclic parsing strategy is expected.

For all the studies, both the experimental studies and the natural speech study, we are interested in whether or not children differ from adults with respect to T3S variability and the parsing strategies they use.

Study 1 (Natural Speech) examines production data of children and their caretakers. Seven children ages 4 – 6 and their caretakers (five adults) participated in this study.

Study 2 (Flat Structures) is an elicited production study, testing non-cyclic (a left-to-right parsing strategy) T3S application in sequences of digits which have no internal structure. Forty-six children (19 3-year-olds, 27 5-year-olds) and 20 adults were tested.

Study 3 (NPs) is an elicited production study, testing cyclic (a bottom-up parsing strategy) T3S application in NPs. Ninety-four children (3-year-olds: 24, 4-year-olds: 20, 5-year-olds: 27, 6-year-olds: 23) and 20 adults participated in the study

Study 4 (Natural Speech Repetition) and Study 5 (Robot Talk Repetition) use repetition of sentences to test T3S application at the sentence level where an integration of cyclic (bottom-up) and non-cyclic (left-to-right) strategies is required. Twenty-one children (4-year-olds: 11, 6-year-olds: 10) and 10 adults participated in Study 4. Forty-three children (4-year-olds: 20, 6-year-olds: 23) and 14 adults participated in Study 5.

1.1 Study 1: Natural Speech

Many studies have demonstrated that the input children are exposed to partially determines the system they are acquiring and the rate of acquisition (Demuth 1995; Demuth 2001; Miller 2007; Miller & Schmitt 2009; Morgan 1986; Yang 2002). We also know that variability in the input can cause delays in acquisition as children take longer converging on an adult grammar (Miller 2007; Miller & Schmitt 2009).

The first step is to examine the input the child is exposed to. In particular, we are interested in (i) how much T3S is in the input; how much T3S do children produce; and (ii) the T3S variation in children and adults. Our research questions are as follows.

How much T3S do adults produce (language input for children)?

How much T3S do children produce?

Is there T3S variability within a speaker and across speakers?

In Study 1 we examine the natural speech of seven children and their caretakers, five adults, for approximately thirty minutes of talk between the children and their caretakers. Both adults and children produced T3S, and even though the sample is small, T3S variation in contexts where T3S is optional across domains was found.

1.2 Study 2 – Study 5: T3S in various domains of application

In order to apply T3S in an adult-like way, children need to have information from various linguistic levels and also need to integrate syntactic and prosodic information in particular ways in both recursive and non-recursive ways. A series of experimental studies — Study 2, Flat structures; Study 3, NPs; Study 4, Natural Speech Repetition (with Tone 3 Sandhi); and Study 5, Robot Talk Repetition[5] (without Tone 3 Sandhi) — were designed to determine how children apply T3S in flat structures, at the word, phrase, and sentence levels at different developmental stages. We ask the following questions:

1. Cyclic and non-cyclic T3S strategies:

Do children know to use non-cyclic strategies when there is no internal syntactic structure as in digit-sequences? Do children know to use cyclic strategies in NPs? Can they integrate the two strategies at the sentence level? Can children integrate the subject and the VP into a domain where T3S applies? What do children do when the non-cyclic parse (a prosody-based strategy, from left to right) and the cyclic parse (a syntax-based strategy, bottom-up) mismatch?

2. Development in T3S acquisition:

How do children go from zero T3S to adult-like T3S? Is T3S acquired early and almost error-free as previous literature indicates? If not, is there a developmental pattern? Do younger children and older children behave similarly in T3S application? Does T3S variability of children reflect that of adults?

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[5] Robot Talk Repetition is a study that used sentences in which T3S was artificially removed (See Chapter 7 for details).

The following hypotheses were tested:

Syntax-Prosody Alignment Hypothesis (Gerken 1996)

We hypothesize that T3S cases where a left-to-right parse and the phrase structure dependent parse produce the same results will cause less trouble than cases in which left-to-right domain building produces a different result than domain building based on the syntax. T3S cases where prosody and syntax mismatch are more difficult than T3S cases where prosodic domains and syntactic domains are in alignment.

Structural complexity Hypothesis

T3S at the clausal level requires the integration of DPs and compounds into a larger prosodic unit. We hypothesize that children will take longer to acquire T3S at the sentence level than at the phrasal level. Particularly it may be difficult for children to integrate the subject and the VP into a domain where T3S can apply.

Variational Hypothesis (Miller 2007; Pearl 2007; Yang 2002)

If there is more variation in particular types of structures in the input, these structures will provide evidence for more than one possible analysis, generating a certain amount of noise in the input. If the input is nosier we expect that children will require more data to converge on the adult language because certain outputs may not unambiguously support one or the other hypothesis.

1.3 Summary of findings

The research questions we asked in Study 1 (Natural speech) concern how much T3S adults and children produce, and if T3S variability is found. We found T3S variability. In addition, in most cases, T3-sequences had only two adjacent T3*. Longer sequences of T3* were much rarer. Children ages 4-6 did not appear to have trouble in T3S application in the T3-sequences.

In Study 2 (Flat structures), we asked whether or not children (age 3 and age 5) know how to use the non-cyclic parsing strategy in digit-sequences. Two-, three-, and five-digit sequences were tested. The results show that children know the non-cyclic parsing strategy. However, both under-application and over-application were found in children. In the five-digit sequence, there is a pattern in adults that was not found in children, suggesting that children may still be in the process of acquiring all the patterns that adults use.

In Study 3 (NPs), we asked whether or not children (ages 3-6) know to use the cyclic parsing strategy in NPs. We tested T3S application in three-syllable compound nouns ([σ[σσ]] and [[σσ]σ]) and four-syllable NPs (right-branching [σ[σ[σσ]]] and mixed-branching [σ[[σσ]σ]]). The results show that children knew how to use the cyclic parsing strategy. They did well in the three-syllable compound nouns. In the case of right-branching [σ[σ[σσ]]] NPs whose predicted pattern is (**T2**T3)(**T2**T3), children did not have very much difficulty. However, in the case of mixed-branching [σ[[σσ]σ]] NPs whose predicted pattern is (T3**T2T2**T3), children had a lot of difficulties. A common error found in children was *(**T2**T3)(**T2**T3). This error indicates that the parsing is non-cyclic, i.e. without reference to the morphosyntactic structure of the phrase. It appears that when the structure is more complex, they default to the left-to-right non-cyclic parsing.

In the right-branching [σ[σ[σσ]]] NPs, cyclic parsing and non-cyclic parsing produce the same result whereas in mixed-branching [σ[[σσ]σ]] NPs, cyclic parsing and non-cyclic parsing produce different results. Put differently, there is a mismatch between syntax and prosody in the mixed-branching NPs. The evidence that the mixed-branching [σ[[σσ]σ]] NPs is much more difficult than the right-branching [σ[σ[σσ]]] for children support the Syntax-Prosody Alignment Hypothesis.

In Study 4 (Natural Speech Repetition) and Study 5 (Robot Talk Repetition), the research questions asked were whether or not children can (i) integrate cyclic and non-cyclic strategies at the sentence level; (ii) integrate the subject and the VP into a domain where T3S can apply; (iii) whether a subject NP and a subject pronoun differ in how feet are formed in the sentence; and (iv) whether there is T3S variability in children and adults.

The findings show that when children age 4 and age 6 heard a correct T3S pattern in Natural Speech Repetition, they could repeat the sentence, although not always with the same surface pattern. Adults, too, did not always repeat the pattern they heard. However, in Robot Talk Repetition where T3S was artificially removed, the correct rates of children age 4 and age 6 dropped dramatically. While four-year-olds had a lot of trouble in Robot Talk Repetition, 6-year-olds had all the surface patterns adults had. This suggests that 6-year-olds know to integrate cyclic and non-cyclic strategies at the sentence level, but not 4-year-olds.

Unlike an NP, a pronoun is prosodically weak, and we asked if its behavior in T3S application is different from that in full NPs. A monosyllabic subject NP and a monosyllabic pronoun are both found to be integrated into the VP by a left-to-right strategy. However, there is a distinction between them. While a monosyllabic subject NP has the option to stand alone in its own foot, a monosyllabic pronoun does not. The subject-NP sentences can keep the subject separate from the predicate whereas the subject-pronoun sentences do not. The contrast between a subject-NP sentence and a subject-pronoun sentence lies in the frequency of forming a foot with the following syllable(s) and the inability of a monosyllabic subject pronoun to form a foot by itself. Evidence shows that 6-year-olds, but not 4-year-olds, were able to integrate the subject and the VP into a domain where T3S can apply, but they have not reached adult-like mastery.

There is T3S variability in children and adults. Although even 6-year-olds still do not have adult-like accuracy in T3S application, they are approximating their preference in the use of T3S patterns to that of adults.

In order to apply T3S, children need to have lexical information (the underlying tones of each syllable), syntactic information (phrase structure), and prosodic information (how to build prosodic domains), to integrate these ingredients to apply T3S, and on top of these, to learn appropriate T3S variation. Based on the overall findings of our studies, we conclude that T3S is not easy and it takes years for children to reach adult-like mastery of it. The results show that children know the cyclic and non-cyclic strategies. They know to apply T3S iteratively from left to right in flat structures, and they refer to the morphosyntactic structure in NPs in their T3S application. Younger children (ages 3–4) had a lot of difficulties in the more complex structures (mixed branching NPs and sentences) while older children (ages 5–6) are becoming more adult-like in many ways, including having a much higher correct rate in T3S application, and having more T3S patterns; and also, in many cases where there is T3S variability, the frequency of the use of T3S patterns in these children are fairly similar in adults.

1.4 The structure of the dissertation

The organization of the dissertation is as follows. Chapter 2 gives linguistic background on T3S and reviews two major T3S models. This chapter also provides basic information on T3S and is the foundation of how our experimental studies were designed. In addition, the discussion of T3S application in various syntactic environments will be based on the Word-and-Phrase level model, so that it is important that Chapter 2 be read before Chapter 3–Chapter 7.

Chapter 3 illustrates the findings of previous studies on children's T3S acquisition. In this chapter, I discuss what can be learned from these studies and what is lacking and needs to be learned.

Chapter 4 is a natural speech study where spontaneous speech between seven children ages 4 to 6 and their caretakers (five adults) is examined.

Chapter 5, Chapter 6, and Chapter 7 present four cross-sectional experimental studies targeting T3S application at various levels. Participants include children age 3–6 as well as adults. Chapter 5 investigates non-cyclic T3S application in flat structures. Chapter 6 studies cyclic T3S application in NPs. Chapter 7, the most complicated study in the series, examines T3S application at the sentence level where an integration of cyclic and non-cyclic parsing strategies is required. Two studies are included in Chapter 7. The experimental sentences were identical in these two studies, with tones manipulated in one study but not in the other.

Although the experimental chapters do not have to be read in order, reading sequentially is recommended as they progress from 'easy' to 'difficult' in terms of the amount of T3S application workload we required of children.

Chapter 8 summarizes the dissertation with the major findings each of our studies provides, suggests what still needs to be learned, and what future T3S studies can investigate.

CHAPTER 2

LINGUISTIC BACKGROUND OF TONE 3 SANDHI

2.0 Introduction

T3S is the most extensively studied tone sandhi phenomenon in Mandarin, and there is a lot of literature on T3S (Chen 2000; Cheng 1987; Dell 2004; Duanmu 2000/2007; Lin 2005; Lin 2007; Shih 1986; Shih 1997; Xu 1992; Zhang & Lai 2010; N. Zhang 1997; Z. Zhang 1988). To better understand children's acquisition of T3S, it is important to understand T3S application and T3S variation in various syntactic structures. The purpose of this chapter is to provide basic and crucial linguistic information on T3S, which subsequent chapters will refer to.

The organization of this chapter is as follows. Section 2.1 will provide basic information and relevant background for Mandarin tones and T3S. For the purpose of this dissertation, the focus will be placed on T3S. Section 2.2 will present two major theoretical models of T3S, the Word-and-Phrase level Model (Chen 2000: Ch 9; Shih 1986; Shih 1997) and the Stressed-foot Model (Duanmu 2000/2007). The former is adopted for predicting surface T3S patterns in the experimental studies in this dissertation. Section 2.3 will discuss some theoretical issues. Section 2.4 concludes this chapter with a brief summary.

2.1 Mandarin Tones and T3S

2.1.1 Four lexical tones

There are four phonemically contrastive tones in Mandarin Chinese, Tone 1 (T1), Tone 2 (T2), Tone 3 (T3), and Tone 4 (T4). Tones are used for distinguishing meanings, so the same syllable with a different tone is different in meaning: e.g. *mai* (T3) 'to buy' and *mai* (T4) 'to sell', and *shu* (T1) 'book' and *shu* (T4) 'tree'. In identifying the four lexical tones (T1–T4), there are two other commonly used systems. First, H (High), M (Mid), and L (Low) is often used in linguistic analysis, and such labeling efficiently communicates the pitch height. For instance, a sequence of MH indicates a tone starting with a mid-height pitch, and rises to a high pitch. Second, a system that uses numbers to express pitch heights is also widely adopted. On a scale of *1-5*, *1* is the lowest pitch level, and *5* is the highest (Chao 1968). Tonal features H (high), M (mid), and L (low) corresponds to '4 or 5,' '3,' and '1 or 2' that indicate pitch values (Lin 2007: 194). The two systems mentioned above describe the linguistic properties of the four tones in a way that the labeling of the four tones with "T1 - T4" lacks. Either a two- scale (H and L) or three-scale (H, M, and L) system is commonly used for phonological analysis.

Table 2.1 summarizes the four lexical tones in Mandarin, with the alternative naming system and examples. The Chinese characters are provided in the examples as there are homophones for identical syllables with identical tones.

Table 2.1 Four lexical tones in Mandarin Chinese

Four lexical tones	**T1**	**T2**	**T3**	**T4**
Descriptive naming	High level tone	Mid-rising tone	Low dipping tone	High falling tone
Pitching level naming (1-5)	55	35	214 (phrase final) 21 (non-phrase-final)	51 (phrase final) 53 (non-phrase-final)
Pitch level naming (H/M/L)	HH	MH	LH (phrase final) LL (non-phrase-final)	HL (phrase final) HM (non-phrase-final)
Examples	bī 逼 (to force)	bí 鼻 (nose)	bǐ 筆 (pen)	bì 必 (must)

In addition to four lexical tones, there is also what is known as neutral tone. Neutral tone occurs only in unstressed syllables (Chao 1968; Chen 2000; Cheng 1973; Duanmu 2000/2007; Jeng 1979; Lin 2007 among others). Neutral tone (T0) is relatively more limited, compared to the other four lexical tones. Also, the frequency of the neutral tone can vary depending on the variety of Mandarin. For instance, while neutral tone is found in grammatical categories as well as in content words in Beijing Mandarin, it tends to be found in functional categories, and is less common in content words in Taiwan Mandarin. A few examples with neutral tone are *ma* which is a question particle placed at the end of a sentence, classifier (CL) *ge*, the second syllable of many kinship terms such as *baba* (T4T0) 'father,' *mama* (T1T0) 'mother,' *yeye* (T2T0) 'grandpa' and *naina*i (T3T0) 'grandma.' In these four kinship terms, we see that neutral tone can be preceded by any of the four lexical tones. An example of differences in the use of neutral tone in content words is *xiansheng* 'mister' which is read as T1T1 in Taiwan Mandarin, but T1T0 in Beijing Mandarin. The neutral tone is left unmarked in the Romanization *pinyin* writing, but for the purpose of distinguishing it from the other four lexical tones, it is sometimes referred to as T0 or T5 in the linguistic literature. The use of these names (T1 - T4 and T0) is common to native speakers of Chinese as well as to linguists. Children are taught with the naming of T1 – T4 (and T0) in the elementary education of Mandarin in Taiwan. In this dissertation, for ease of presentation, I label the four lexical tones with T1, T2, T3, and T4, and the neutral tone with T0.

Lastly, in Mandarin, each morpheme has an underlying lexical tone, but functional words such as the question markers *ma* or *ne* do not have an underlying lexical tone (Chen 2000; Duanmu 2000/2007; Erbaugh 1992; Lin 2007). A lexical tone, or phonemic tone, may undergo some change and surface as a tone with different phonetic pitch through tonal rules or processes (Chao 1968; Chen 2000; Cheng 1973; Duanmu 2000/2007; Lin 2007; Shih 1986; Shih 1997; Xu 1997). One of these tonal rules is the Tone 3 Sandhi rule, which we now turn to.

2.1.2 Tone 3 Sandhi

T3S is commonly described as changing a T3 to a **T2**[6] when it is preceded by another T3 as shown in (1).

(1) T3 T3→ (**T2** T3)[7] (Chen 2000:364; Shih 1997:81)

Lin (2007) points out that the rule T3T3→(**T2**T3) is deceptively simple because T3S application becomes very complicated when there is a sequence of more than two T3* (2007: 204). Prosodic domains[8] are important for the application. (How such domains are built will be illustrated in more detail in later sections.)

2.1.2.1 T3S in flat structures

Without hierarchical internal structures, flat structures can be found in phone numbers or translated proper nouns (e.g. *Mìxīgēn* (T4T1T1) 'Michigan'). Syllables in flat structures are parsed from left to right in binary feet, and at the end, if there is an unfooted syllable, it is incorporated into the neighboring foot (Chen 2000:368; Lin 2007:206; Shih 1986; Shih 1997). Duanmu has the same view stating that in polysyllabic names and digits, disyllabic feet are built from left to right (Duanmu 2000/2007; Duanmu 2004:70).

(2)	four T3-digits				(Lin 2007:206)
	jiu	jiu	jiu	jiu	'9999'
	3	3	3	3	UT (= underlying tones[9])
→	(**2**	3)	(**2**	3)	ST (= surface tones)

---

[6] Following Lin (2007), the bold type **T2** (Tone 2) indicates a Tone 2 (sandhi tone) that is derived from Tone 3 because of the Tone 3 Sandhi rule.

[7] Following the convention in the linguistics literature, parentheses ( ) refer to prosodic domains and square brackets [ ] refer to syntactic constituents.

[8] Throughout this dissertation, *prosodic domains* refer to *T3S domains*.

[9] In this dissertation, I use numerals 1, 2, 3, 4 (and 0 for neutral tone), with the "T" omitted, in the derivations of T3S to refer to the lexical tones Tone 1, Tone 2, Tone 3, and Tone 4.

(3)		five T3-digits					(Lin 2007:206)
		jiu	jiu	jiu	jiu	jiu	'99999'
		3	3	3	3	3	UT
	→	(**2**	3)	(**2**	3)	3	
	→	(2	3)	(2	**2**	3)	ST

In (2), the four digits are parsed into two disyllabic feet. T3S applies within each foot, and the surface pattern is (**T2**T3)(**T2**T3). In (3), syllables are parsed from left to right in disyllabic feet, and T3S applies within each foot. The unparsed syllable on the right edge is then incorporated into the foot preceding it at the end and T3S applies again. The surface pattern is (**T2**T3)(**T2T2**T3).

2.1.2.2 T3S depends on syntax

Unlike in flat structures, T3S in phrases and sentences that have internal structures heavily depends on syntax, and T3S applies cyclically as shown in (4) – (7).

(4)	Three adjacent T3*			
a.	[[σσ]	σ]		
	[[laoshu]	pao]		(Lin 2007:212)
	mouse	run		'The mouse is running.'
	33	3		UT
→	(**2**3)	3		
→	(2**2**	3)		ST
	*(32	3)		
b.	[σ	[σ	σ]]	
	[mai	[mi	jiu]]]	(Lin 2007:212)
	buy	rice	wine	'to buy rice wine'
	3	3	3	UT
→	3	(**2**	3)	
→	(3	2	3)	ST1 (Surface tones, Surface Pattern 1)
or	(**2**	**2**	3)	ST2 (Surface tones, Surface Pattern 2)

In (4a) and (4b), the application of T3S starts from the innermost constituent, and then in the next step the remaining syllable, which has not been parsed yet, is incorporated into the disyllabic foot that has been formed. T3S applies one more time in (4a) in the next step when the unfooted syllable (the third syllable) is incorporated into the disyllabic foot. Crucially, (T3T2T3) is ungrammatical in (4a). In (4b), T3S applies in the first cycle, and no further application of T3S is needed in the second cycle. This is because there are no adjacent T3* after the unfooted syllable (the first syllable) is incorporated into the disyllabic foot that has been formed. In (4b), there are two surface patterns. We will discuss T3S variation in the next subsection, Section 2.1.2.3. We now turn to four-syllable structures.

(5) Four adjacent T3*

a. left-branching structure

	[[[zhanlan]		guan]	zhang]	(Chen 2000:383; Lin 2007:212)
	exhibition		hall	director	‘exhibition hall director’
	3	3	3	3	UT
→	(**2**	3)	3	3	
→	(2	**2**	3)	3	
→	(2	2	**2**	3)	ST
	*(2	3	2	3)	
	*(3)	(2	2	3)	

b. right-branching structure

	[xiao	[mu	[laohu]]]		(Lin 2007: 212)
	small	female	tiger		‘small female tiger’
	3	3	3	3	UT
→	2	3	(**2**	3)	
→	3	(3	2	3)	
→	(**2**	3	2	3)	ST1
or	(3)	(**2**	**2**	3)	ST2
or	(**2**	**2**	**2**	3)	ST3

c. mixed-branching structure (Lin 2007:207)

	[[Mi	[laoshu]]		hao]	
	Mickey	mouse		good	‘Mickey Mouse is good.’
	3	3	3	3	UT
→	3	(**2**	3)	3	
→	(3	2	3)	3	
→	(3	2	2	3)	ST
	*(2	3	2	3)	
	?/*(2	2	2	3)	

In (5a), (5b) and (5c), T3S applies cyclically from the innermost constituents, resulting in the surface patterns of (**T2T2T2**T3), (**T2**T3**T2**T3), and (T3**T2T2**T3) respectively. The difference in the surface patterns is accounted for by the syntactic differences in these structures. (5b) has two additional patterns through different parsing. For (5a), (**T2**T3**T2**T3) and (T3)(**T2T2**T3) are both ungrammatical. For (5c), **T2**T3**T2**T3 is ungrammatical, and **T2T2T2**T3 may be marginal or ungrammatical. The reason why **T2T2T2**T3 is marginal or ungrammatical is unclear.

I have shown in (4) and (5) how syntax plays a crucial role in T3S application. Next, we turn to the issue of T3S variation.

2.1.2.3 T3S variation

In this subsection, data of T3S variation are presented. Cases of two to four adjacent T3* will be used in the discussion. T3S applies when there are two adjacent T3* except that in cases where the two adjacent T3* belong to different prosodic domains, T3S is optional. Variation arises when there is an optional rule or an alternative parse.

The examples in (6) and (7) exemplify obligatory and optional T3S application respectively in cases where there are only two adjacent T3*.

(6) Two adjacent T3*

a. Two T3* belonging to the same prosodic domain

[mai	jiu]	(Chen 2000:366)
buy	wine	'buy wine'
3	3	UT
(**2**	3)	ST

b. Two T3* belonging to different prosodic domains

[Tou-nao]		[jian-dan]		(Chen 2000:373, 416-417)
brain		simple		'simple-minded'
2	3	3	1	UT
(2	3)	(3	1)	ST1; no T3S
(2	**2**)	(3	1)	ST2; optional T3S applied

In (6a), we see a sequence of two T3* surface as **T2**T3 in the output. In (6b), the two T3* belong to different prosodic domains, and T3S does not have to apply. ST1 is the surface pattern when T3S does not apply. When optional T3S applies across domains, we have the other surface pattern in ST2. In the simplest case of two adjacent T3*, we already see T3S variation. Next, let us consider three- and four-syllable cases. I will use some examples we saw in (4) and (5).

Table 2.2 T3S variation

a. Three adjacent T3* [[σσ] σ] [[laoshu] pao] (Lin 2007:212) mouse run 'The mouse is running.' 33 3 UT →(**2**3) 3 →(2**2** 3) ST	b. Three adjacent T3* [σ [σ σ]] [mai [mi jiu]]] (Lin 2007:212) buy rice wine 'to buy rice wine' 3 3 3 UT → 3 (**2** 3) → (3 2 3) ST1 or (**2** **2** 3) ST2
c. left-branching structure [[[zhanlan]guan] zhang] (Chen 2000:383; Lin 2007:212) exhibition hall director 'exhibition hall director' 3 3 3 3 UT →(**2** 3) 3 3 →(2 **2** 3) 3 →(2 2 **2** 3) ST	d. right-branching structure [xiao [mu [laohu]]] (Lin 2007:212) small female tiger 'small female tiger.' 3 3 3 3 UT → 2 3 (**2** 3) → 3 (3 2 3) → (**2** 3 2 3) ST1 or (3) (**2** **2** 3) ST2 or (**2** **2** **2** 3) ST3

Lin (2007:212) points out that expressions with the embedded constituents on the left edge usually have one surface pattern as (a) and (c) in Table 2.2 show, whereas expressions with the embedded constituents on the right edge have more than one surface pattern ((b) and (d) in Table 2.2).

Researchers do not always agree on the source of a particular surface pattern. For instance, in Table 2.2, the surface pattern ST2 (**T2T2**T3) in (b) and the surface pattern ST3 (**T2T2T2**T3) in (d) are considered a fast speech pattern where a larger domain is formed and T3S applies from left to right in one step (Chen 2000; Lin 2007; Shih 1986; Shih 1997), but Duanmu (2000) disagrees with the fast speech account and takes this pattern as a permissible alternative pattern through a different parsing strategy. I take the view that the larger domain pattern is an alternative pattern because: (i) in the experimental study of Kuo et al. (2007) where slow, normal, and fast speech T3S production were compared, the larger domain pattern was found even in slow speech; and (ii) evidence from our own experimental studies (see §5.3.2.2) showing that participants produced the larger domain pattern even though the experiments were in the normal speech setting, rather than the fast speech setting. Examples cited from previous literature will be provided with the authors' own views regarding the larger domain pattern (fast speech pattern or just a permissible alternative pattern).

Some claims of T3S variation in the T3S literature are based on the researchers' grammaticality judgments. As can be expected, there are dialectal differences.

(7)	[Gou	[[bi	ma]	xiao]]	(Zhang 1997: 315)
	dog	than	horse	small	'A dog is smaller than a horse.'
	3	3	3	3	UT
	(3)	(**2**	**2**	3)	ST1
	(**2**	**2**	**2**	3)	ST2
	(**2**	3)	(**2**	3)	ST3

In presenting the reanalysis of the sentence in (7), Wang and Lin (2011) found that ST3 was not grammatical for some native speakers of Mandarin, particularly for some (not all) Taiwan Mandarin speakers, and there is a tendency for Beijing Mandarin speakers to consider ST2 and ST3 grammatical while Taiwan Mandarin speakers consider them ungrammatical.

2.1.2.4 Summary

In this section, I have discussed several important issues. Firstly, I show how T3S applies when there is no internal syntactic structure (i.e. flat structures). Secondly, I show that syntax plays a crucial rule in T3S application in phrases and sentences where there are hierarchical syntactic structures. Thirdly, the phenomenon of T3S variation was presented and I also discussed how grammaticality judgments may differ because of dialectal differences. Dialectal differences regarding T3S variation have not attracted much attention, and the issue is worth investigating further. Variation, when interpreted in another sense, can refer to the situation where speakers vary in their own production of T3S surface patterns, producing different surface patterns at different times, and this also has to be accounted for. We now turn to two major T3S models and see how T3S is analyzed and how the T3S variation is accounted for.

2.2 Two major Tone 3 Sandhi Models

Two major T3S models are the Word-and-Phrase Level Model (Chen 2000: Ch 9; Shih 1986; Shih 1997) and the Stress-foot Model (Duanmu 2000/2007: Ch 11). The two models have the same empirical coverage for multiple T3S patterns. In what follows, I first review the Word-and-Phrase Level Model, followed by review of the Stress-foot Model.

2.2.1 Word-and-Phrase level Model (Chen 2000: Ch 9; Shih 1986; Shih 1997)

Duanmu calls this approach the “stressless-foot approach” (2000:242), to contrast his use of stress in foot-building in his model. The Word-and-Phrase level Model was developed by Chen (2000), based on Shih (1986, 1997). Lin adopts this model for T3S in a chapter on tonal processes (2007: Ch 9). I will refer to this model as the “Word-and-Phrase level Model” because its major characteristic is the separation of the Word level from the Phrase level with respect to differences in T3S application mode (cyclic vs. non-cyclic).

To know how T3S applies, we need to know how the domain within which T3S applies is defined. According to Chen (2000:366), connected speech is broken into units which are referred to as Minimal rhythmic units (MRUs), and T3S application is obligatory within MRUs. In other words, MRUs are the prosodic domain, or T3S domain, within which T3S must apply. Syllables are grouped into binary MRUs from left to right in unstructured expressions, but the building of the MRUs is sensitive to the morphosyntax in structured expressions (Chen 2000:367-369). Chen

(2000:373) points out that intra-MRU T3S application is obligatory and takes precedence over the inter-MRU T3S application, which is optional.

It should be emphasized that the formation of MRUs in structured expressions has an important condition which prevents certain elements from being split into different prosodic domains. Shih (1986, 1997) refers to as *Immediate Constituency*, defined as "join immediate constituents into disyllabic feet." In his analysis, Chen (2000:371) uses a constraint *Congruence*: "Group X forms an MRU with its closest morphosyntactic mate."

Building domains according to *Immediate Constituency* is the first step of T3S application. For the next step, Shih (1986, 1997:98) claims a constraint *Duple Meter*,[10] which is described as "scanning from left to right, join monosyllabic syllables into binary feet." Chen (2000:374) suggests that MRUs are first built for "word-size units," and then by "phrasal constructions." That is, T3S is dealt with at the Word level and then at the Phrase level. In the final step, by the incorporation rule,[11] any leftover unparsed syllable is incorporated into an adjacent binary foot (Shih 1986; Shih 1997). Shih (1997:98) points out that evidence was found for unspecified directionality for incorporation of the unparsed syllable, and more specifically, in a structure where there is a disyllabic subject followed by a verb and a disyllabic object, the verb can be incorporated in either direction. Thus, Shih (1997) suggests that the flexibility of directionality be built into the rules, a modification of her earlier work (Shih 1986), where directionality follows the syntactic branching.

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[10] The definition of this rule in Shih (1986) contains the phrase "unless they branch to the opposite direction," which was removed in the modified version of the rule in Shih (1997).

[11] In Shih (1986), this rule of incorporating an unparsed syllable has the condition "according to the direction of syntactic branching," which was removed in the modified version in Shih (1997).

In the Word-and-Phrase level model, there are two basic optional rules: (i) T3S is optional across prosodic domains, and (ii) there is a fast speech, where a larger domain is formed and T3S applies from left to right iteratively.

In what follows, I mention several aspects that need to be clarified. The notion of *Immediate Constituency* proposed by Shih (1986, 1997) is to apply T3S cyclically within what Chen (2000) states is a "closest morphosyntactic mate." This corresponds to the Word level in Lin (2007). At the Word level, T3S is applied cyclically, namely, a bottom-up parsing strategy. Lin (2007) says that in this model, compound nouns as well as NPs are both regarded to be at the Word level, though, syntactically, NPs are phrasal.

> "… a noun with a modifier that describes or specifies the noun such as *xiao laoshu* 'small mouse,' (see Chen 2000: §9.3 for details) is also treated as a word, although syntactically such a complex noun is often classified as a noun phrase. That is, a simple noun, a compound noun, and a complex noun [modifier + noun] are all treated as words rather than phrases." (Lin 2007:207)

At the Phrase level, T3S is applied non-cyclically, except when no foot is formed at the Word level, and in this case a disyllabic foot is formed for the smallest domain first, before parsing the rest of the syllables from left to right. In other words, unless no foot has been built at the Word level, and foot-building has to refer to syntax to form a disyllabic foot for the smallest constituent, a left-to-right parsing strategy is used without reference to syntax at the Phrase level.

To summarize, once the parsing is finished at the Word level, all the remaining syllables are parsed into disyllabic feet from left to right. After this step, if there is any remaining unparsed syllable, it is then incorporated into a neighboring foot.

We now take a look at some simple examples and see how their surface patterns are derived with the principles that have just been mentioned. We first look how Flat Structures are analyzed in the Word-and-Phrase level Model, followed by the role syntax plays in this model, and finally, I will discuss how T3S variation is handled in this model.

2.2.1.1 T3S in Flat structures

In this model, disyllabic feet are built from left to right in flat structures. After that, if there is any unfooted syllable, it is incorporated into the neighboring foot (Chen 2000:368; Shih 1986; Shih 1997).

(8) Four T3-digits

[jiu	jiu	jiu	jiu]	(Lin 2007:206)
nine	nine	nine	nine	'nine-nine-nine-nine'
3	3	3	3	UT
(**2**	3)	(**2**	3)	disyllabic feet from left to right, T3S; ST1

Optional in fast speech:

(**2**	**2**	**2**	3)	ST2
*(2	2	3)	(3)	

(9) Five T3-digits

[jiu	jiu	jiu	jiu	jiu]	(Lin, 2007:206)
nine	nine	nine	nine	nine	'nine-nine-nine-nine-nine'
3	3	3	3	3	UT
(**2**	3)	(**2**	3)	3	disyllabic feet from left to right, T3S
(2	3)	(2	**2**	3)	incorporation of the unparsed syllable; ST1

Optional in fast speech:

(**2**	**2**	**2**	**2**	3)	ST2
*(2	3)	(2	3)	(3)	
*(2	2	3)	(2	3)	

In (8), we see an even number of syllables, perfectly divided into two disyllabic feet. T3S applies within both feet. In (9), two disyllabic feet are parsed, and T3S applies. The unparsed syllable then joins the foot that precedes it and forms a three-syllable domain, and T3S applies again (Lin 2007: 206). In fast speech, a larger domain parsing may be used (Chen 2000; Lin 2007; Shih 1997), and therefore (8) and (9) may have an additional pattern (**T2T2T2**T3) and (**T2T2T2T2**T3) respectively. According to Chen (2000:368) and Shih (1997:98), the surface pattern of (**T2T2**T3)(**T2**T3) is ungrammatical.

(10)	Suo-	ma-	li-	ya	‘Somalia’ (Chen 2000:369)
	3	3	3	3	UT
	(**2**	3)	(**2**	3)	disyllabic foot from left to right, ST

In (10), we see that in the translation for *Somalia*, the four syllables are parsed from left to right in two disyllabic feet, and T3S applies within each foot. The procedure we see here is the same as that in sequences of digits.

2.2.1.2 T3S depends on syntax

In this subsection, the analysis of phases and sentences is presented and we will see how syntax plays a role in this model. Some of the phrases or sentences we saw earlier will be used for illustration.

(11)	Three adjacent T3*			
	[[laoshu]	pao]		(Lin 2007:212)
	mouse	run		‘The mouse is running.’
	33	3		UT
	(**2**3)	3		Word: disyllabic foot, T3S
	(2**2**	3)		Phrase: incorporation, T3S; ST

(12)	Three adjacent T3*			
	[mai	[mi	jiu]]	(Lin 2007:212-213)
	buy	rice	wine	‘to buy rice wine’
	3	3	3	UT
	3	(**2**	3)	Word: disyllabic foot, T3S
	(3	2	3)	Phrase: incorporation, T3S; ST1
	Optional in fast speech:			
	(3	3	3)	one prosodic domain in fast speech
	(**2**	**2**	3)	T3S; ST2

In (11), T3S is applied first in the inner constituent *laoshu* ‘mouse,’ and T3S applies. When *pao* ‘run’ is incorporated into this foot at the Phrase level, T3S applies again. The surface pattern is (**T2T2**T3). In (12), the normal foot-building process applies and T3S gives (T3**T2**T3), but with optional fast speech domain building, one large domain is formed and T3S applies from left to right in one step and produces ST2 (**T2T2**T3) (Lin 2007:213).

(13) left-branching structure

[[[zhanlan]		guan]	zhang]	(Chen 2000:383; Lin 2007:212)
exhibition		hall	director	'exhibition hall director'
3	3	3	3	UT
(**2**	3)	3	3	Word: disyllabic foot, T3S
(2	**2**	3)	3	Word: incorporation, T3S
(2	2	**2**	3)	Word: incorporation, T3S, ST

According to Chen (2000:383), the compound noun in (13) is a complex word and T3S must apply cyclically from the innermost constituent *zhanlan* 'exhibit,' and then to the next domain *zhanlan guan* 'exhibit hall,' and finally, to the outermost domain *zhanlan guan zhang* 'exhibit hall director.' The surface pattern is **T2T2T2**T3. The pattern derived through the optional fast speech rule is also **T2T2T2**T3.

(14) right-branching structure

[xiao	[mu	[laohu]]]		(Lin 2007: 212)
small	female	tiger		'small female tiger.'
3	3	3	3	UT
2	3	(**2**	3)	Word: disyllabic foot, T3S
3	(3	2	3)	Word: incorporation, no T3S
(**2**	3	2	3)	Word: incorporation, no T3S; ST1

Optional in fast speech I:

3	(3	3	3)	one prosodic domain for [mu [laohu]]
3	(**2**	**2**	3)	T3S from left to right
(3	2	2	3)	incorporation, no T3S; ST2

Optional in fast speech II:

(3	3	3	3)	one prosodic domain for all syllables
(**2**	**2**	**2**	3)	T3S from left to right; ST3

According to Lin (2007:213), in (14), through cyclic foot-building, the normal pattern is **T2**T3**T2**T3. In fast speech, either *mu laohu* 'female tiger' or *xiao mu laohu* 'small female tiger' in the phrase forms a larger domain, and two additional patterns are (T3**T2T2**T3) and (**T2T2T2**T3) respectively. Next, we turn to some sentences.

(15)	[[Mi	[laoshu]]	hao]	(Lin 2007: 209)
	Mickey	mouse	good	‘Mickey Mouse is good.’
	3	33	3	UT
	3	(**2**3)	3	Word: disyllabic foot; T3S
	(3	23)	3	Word: incorporation; no T3S
	(3	2**2**	3)	Phrase: incorporation; T3S

In (15), at the Word level, a disyllabic foot is parsed for the smallest domain *laoshu* ‘mouse,’ and T3S applies. Next, the unfooted syllable is incorporated into the disyllabic foot that has been built. T3S does not apply since we do not have adjacent T3* at this point. At the Phrase level, the unparsed syllable *hao* ‘good’ is incorporated into the adjacent three-syllable foot, and T3S applies (Lin 2007: 209). Now we consider a sentence with a different structure in (16).

(16)	[wo	[xiang	[mai	[bi]]]]	(Lin 2007: 215)
	I	want	buy	pen	‘I want to buy pens.’
	3	3	3	3	UT
	3	3	3	3	Word: not applicable
	3	3	(**2**	3)	Phrase: disyllabic foot for the smallest domain, T3S
	(**2**	3)	(2	3)	Phrase: disyllabic foot for the rest, T3S; ST1
	Optional in fast speech:				
	(3	3	3	3)	one prosodic domain in fast speech
	(**2**	**2**	**2**	3)	T3S from left to right; ST2

In (16), T3S is not applicable at the Word level. At the Phrase level, after the disyllabic foot is formed for the smallest domain, the rest of the syllables are parsed from left to right. The optional rule in fast speech yields the surface pattern of (**T2T2T2**T3) through left-to-right T3S application in one step (Lin 2007:214-215). Clearly, the derived surface patterns differ in (15) and (16) because of their structural differences. Let us see how T3S works in a longer sentence.

(17)	[[Mi	[laoshu]]	[xiang	[zhao	[hao	[mi	jiu]]]]]	(Lin 2007: 221)
	Mickey	mouse	want	look for	good	rice	wine	‘Mickey Mouse wants to look for good rice wine.’
	3	33	3	3	3	3	3	UT
	3	(**2**3)	3	3	3	(**2**	3)	Word: T3S
	(3	23)	3	3	(3	2	3)	Word: incorporation; no T3S
	(3	23)	(**2**	3)	(3	2	3)	Phrase: disyllabic foot from left to right, T3S, ST

In (17), disyllabic feet are formed for *laoshu* ‘mouse’ and *mi jiu* ‘rice wine’ at the Word level. In the next step, *Mi* ‘Mickey’ and *hao* ‘good’ are incorporated into their following feet. At this point, foot-building and T3S application are completed at the Word level. At the phrase level, a disyllabic foot is formed non-cyclically, from left to right. We see in (17) that T3S is applied with reference to syntax (a bottom-up strategy) at the Word level, but without reference to syntax (a left-to-right strategy) at the Phrase level.

2.2.1.3 T3S variation

In the Word-and-Phrase level model (Chen 2000: Ch 9; Shih 1986; Shih 1997), there are two basic optional rules: (i) T3S is optional across prosodic domains, and (ii) there is a fast speech where a larger domain is formed and T3S applies from left to right in one step. Let us first look at the examples we saw earlier in (11) and (12), repeated below in (18) and (19), for illustrating T3S variation.

(18) Three adjacent T3*

[[laoshu]	pao]	(Lin 2007:212)
mouse	run	‘The mouse is running.’
33	3	UT
(**2**3)	3	Word: disyllabic foot, T3S
(2**2**	3)	Phrase: incorporation, T3S; ST1

Optional in fast speech:

(33	3)	one prosodic domain in fast speech
(**22**	3)	T3S; ST2 (=ST1)

(19) Three adjacent T3*

[mai	[mi	jiu]]	(Lin 2007:212-213)
buy	rice	wine	‘to buy rice wine’
3	3	3	UT
3	(**2**	3)	Word: disyllabic foot, T3S
(3	2	3)	Phrase: incorporation, T3S; ST1

Optional in fast speech

(3	3	3)	one prosodic domain in fast speech
(**2**	**2**	3)	T3S; ST2

While there is only one surface pattern (**T2T2**T3) in (18), there are two surface patterns (T3**T2**T3) and (**T2T2**T3) in (19). This is because in (18) the cyclic application and the larger domain parsing in fast speech result in the same sequence of **T2T2**T3. In (18) and (19), we see how syntax and the optional pattern interact, giving different results— one without variants, and the other with two variants in the output.

In addition to the optional rule for fast speech, T3S is optional across prosodic domains. Lin (2007) clarifies how they are different in the derivational steps as we see in (20) and (21).

(20)	[wo	[xiang	[ma	hua]]]	(Lin 2007:215)
	I	want	buy	flower	'I want to buy flowers.'
	3	3	3	1	Word: not applicable
	3	3	(3	1)	Phrase: disyllabic foot for the smallest domain, no T3S
	(**2**	3)	(3	1)	Phrase: disyllabic feet for the rest, T3S; ST1
	Optional rule between two T3* in different prosodic domains:				
	(2	**2**)	(3	1)	T3S across domains; ST2
	Optional in fast speech:				
	(3	3	3	1)	one prosodic domain for all syllables
	(**2**	**2**	3	1)	T3S from left to right; ST3

(21)	[xiao	[mu	[yezhu]]]	(Lin 2007:215)
	small	female	boar	'small female boar'
	3	3	(31)	Word: disyllabic foot, no T3S
	3	(**2**	31)	Word: incorporation, T3S
	(3	2	31)	Word: incorporation, no T3S; ST1
	Optional in fast speech			
	(3	3	31)	one prosodic domain in fast speech
	(**2**	**2**	31)	T3S from left to right; ST2

In (20), in normal speech, T3S is not applicable at the Word level. At the Phrase level, since no foot has been formed yet, a disyllabic foot is formed for the smallest domain, *mai hua* 'buy flowers,' and T3S does not apply. In the next step, syllables are formed from left to right, and T3S applies within this foot, and ST1 (**T2**T3)(T3T1) is derived. ST2 (**T2T2**)(T3T1) surfaces when T3S applies across the domains. Alternatively, as we see in ST3, (**T2T2**T3T1) results from applying T3S from left to right in one step in fast speech. ST2 and ST3 are of the same sequence of **T2T2**T3T1, although their prosodic domains differ.

In (21), cyclic T3S application gives ST1 (T3**T2**T3T1). The parsing of one prosodic domain in fast speech gives ST2 (**T2T2**T3T1) where T3S applies from left to right in one step. While in (20) the sequence **T2T2**T3T1 can result from either one of the two paths (optional T3S across domains or one larger domain in fast speech), in (21) there is only one path in deriving **T2T2**T3T1.

(20) and (21) have the same branching and the same sequence of underlying tones, but their structural differences, along with optional T3S rules, account for the variants (20) and (21).

2.2.2 Stress-foot Model (Duanmu 2000/2007)

Duanmu (2000/2007) suggests that the alternation of strong and weak beats is an important property of stress and rhythm, and each alternation is what we call a *foot*. As *stress* is part of a foot, a stress implies the existence of a foot, and a foot implies there is stress (Duanmu 2000/2007:126). He assumes that there has to be (at least) two beats in a foot, and that if a syllable is stressed, it must be heavy (Duanmu 2000/2007:130).

For Duanmu (2000/2007), T3S domains are set up and T3S applies cyclically with reference to syntax throughout the derivation, from the smallest constituent to the sentence level. He follows Cinque (1993) in the stress assignments between heads and non-heads in the syntactic structure. For Mandarin, he suggests that the syntactic nonhead is on the left in compounds, but on the right in most phrases and, therefore, stress assignment is on the left for compounds and on the right for most phrases (Duanmu 2004:70). The central notion of the Stress-foot Model is (22).

(22) Nonhead Stress (NHS): Syntactic nonheads must have stress (Between a syntactic head and a syntactic nonhead, the nonhead has more stress). (Duanmu 2000/2007:130-131)

Duanmu (2000) uses *X*'s in showing that the stress is placed on the nonheads, based on NHS stated in (22). If we take a DP (determiner phrase), for example, the concept that non-heads get stress can be illustrated in (23).

(23) DP

```
                  X
[D    NP]→  (X    X)
```

In (23), the DP is constituted by a D (determiner) and an NP (noun phrase). Suppose the D and the NP in (23) are both monosyllabic, and they form a foot. The head of the DP is D, and the NP is a nonhead. According to NHS (22), the NP, being the nonhead, should get stress, which is marked by an X above the foot formed by the D and the NP. (24) schematically presents the steps of how a nonhead gets stress, with *H* and *NH* referring to *head* and *nonhead* respectively.

(24)

```
                  X
            (X    X)
H   NH→      H    NH
```

In (24), two syllables for *head* and *nonhead* form a foot. Recall that the existence of a foot implies stress, and vice versa (Duanmu 2000/2007:126). As a foot is formed, there has to be stress. According to NHS (22), NH gets stress, which is marked at the top line above NH in (24). Simplified marking of NHS is used in examples (25), provided by Duanmu (2000/2007) in illustrating the point of "Nonheads get stress."

(25) Examples of "Nonheads get stress" (Duanmu 2000/2007:131)

a. a DP (determiner phrase)

```
        X
a       house
[D      NP]
```

b. a PP (prepositional phrase)

	X
in	school
[P	NP]

c. a VP (verb phrase)

	X
eat	dinner
[V	NP]

In (25a) – (25c), *a*, *in*, and *eat* are the heads of the DP, PP, and VP. *House*, *school*, and *dinner*, sisters of D, P, and V respectively, are the non-heads and they must get stress according to the Nonhead Stress principle stated in (22). Rules describing how T3S operates in the Stress-foot model are in (26).

(26) T3S (Duanmu: 2000/2007: 248, 250)

a. Feet are determined by NHS (in (22)) at all branches of the syntactic tree (not just the lowest branches).

b. T3S is cyclic starting from each foot.

c. T3S need not apply between two cyclic branches.

d. A T3 can, but need not change to T2 before a T2 that came from a T3.

e. In flat structures, feet are built by left-to-right construction of syllable trochees.

In the following sections, we will see the process of foot-building and stress assignment, and how T3S is applied in this model. We begin with flat structures, followed by structured phrases or sentences. Finally, we present how this model accounts for T3S variation.

2.2.2.1 T3S in Flat structures

Regarding flat structures, Duanmu has the same view as Shih (1986, 1997) and Chen (2000), stating that in polysyllabic names and digits, disyllabic feet are built from left to right (Duanmu 2000/2007; Duanmu 2004:70).

(27)	wu	wu	wu	wu	Duanmu (2000/2007:239)
	five	five	five	five	'five-five-five-five'
	3	3	3	3	UT
	(**2**	3)	(**2**	3)	ST

(28)	yi	wu	wu	qi	Duanmu (2000/2007:239)
	one	five	five	seven	'one-five-five-seven'
	1	3	3	1	UT
	(1	3)	(3	1)	ST1
or	(1	**2**)	(3	1)	ST2

In flat structures, the Stress-foot Model has the same prediction of two disyllabic prosodic domains for (27) and (28). There is no mention of odd-number syllables in flat structures, so the position of the model regarding the incorporation of an unparsed syllable is unclear.

2.2.2.2 T3S depends on syntax

We begin with two simple examples in Duanmu (2000/2007).

(29)	X		
	[hao	jiu]	Duanmu (2000/2007:249)
	good	wine	'good wine'
	(3	3)	Foot
	(**2**	3)	T3S

(30)		X	
	[mai	jiu]	Duanmu (2000/2007:249)
	buy	wine	'buy wine'
	3	(3 Ø)	Foot (Ø =empty beat)
	3	(3 Ø)	T3S cycle 1 (no effect)
	2	(3 Ø)	T3S cycle 2

In (29), the two syllables form a foot; with the head being *jiu* 'wine,' the stress is on the non-head *hao* 'good.' T3S applies in the disyllabic foot formed by *hao* 'good' and *jiu* 'wine.' In (30), according to Duanmu (2000/2007), given that the object *jiu* 'wine' is the nonhead, it gets stress. Stress implies the presence of a foot, so *jiu* 'wine' must be in a foot. Since a foot must be composed of two beats, Duanmu (2000/2007) proposes that there is an *empty beat* (Ø) in the foot *jiu* 'wine' is in. T3S does not apply in the first cycle. Duanmu (2000/2007) states that the second cycle gives the surface form **T2**T3 (2000/2007:249).

In some cases, such as three syllables in structured expressions, *foot merger* needs to be applied. *Foot merger* happens when a monosyllabic word that carries the main stress is followed by another foot. Then the monosyllabic word and the foot can be merged and form one foot (Duanmu 2000/2007: 180). If stress on the monosyllabic word is to be maintained, the stress from the disyllabic word which the monosyllabic word is merged with must be deleted when the two words join, according to the foot merger process in Duanmu (2000/2007:133).

(31) X
X   X   X
[zhi3[12]   [lao3hu3]]→   ([3   [33]])→ v23 (Duanmu 2000/2007:249)
paper   (old)-tiger   ("v" indicates T2 or T3)
'paper tiger'

According to Duanmu (2000:249), in the inner bracket, Nonhead Stress is placed on *lao* 'old,' and in the outer bracket, stress goes to *zhi* 'paper.' Then, as *zhi* is monosyllabic, *foot merger* applies; the stress from *laohu* 'tiger' is deleted; and only stress on *zhi* 'paper' remains when the three syllables form one foot. Cyclic T3S application gives the surface pattern of T3**T2**T3 or **T2T2**T3. The variable surface patterns result from the optional rule which states T3S is optional when a T3 is followed by a derived T2 (Duanmu 2000/2007:250); therefore, T3S can optionally apply in the first syllable *zhi* 'paper,' resulting in the variation of either T3**T2**T3 or **T2T2**T3 in the output.

In (32), the derivation of *zhi laohu* 'paper tiger' is the same as that in (31), and in the last cycle, *xiao* 'small' gets stress through NHS. Because it is monosyllabic, foot merger applies, and

[12] The numbers following the syllable indicate underlying tones in Duanmu's (2000/2007) presentation.

the result is one foot with four syllables. Cyclic application gives vv23, which are **T2**T3**T2**T3, T3**T2T2**T3, or **T2T2T2**T3 (Duanmu 2000/2007:250).

(32) X
X X X
[xiao3 [zhi3 [lao3hu3]]]→ ([3 [3 [33]]])→ vv23 (Duanmu 2000/2007:250)
paper (old)-tiger
'paper tiger'

In (33), stress is placed on *zhan* 'show,' and *zhan lan* 'exhibit' is the nonhead when *guan* 'hall', which is already stressed, joins it. Finally, *zhan lan guan* 'exhibit hall' is the nonhead and should get stress by NHS, but it has stress already. Cyclic application gives only one surface pattern **T2T2T2**T3.

(33) X X
[[[zhan3 lan3] guan3] li3]→ ([[[3 3] 3]3])→ 2223 (Duanmu 2000/2007:250)
show-see hall inside
'inside of exhibition hall'

(32) and (33) show the contrast of a right-branching structure and a left-branching structure, and how their surface patterns differ because of their structural differences.

Lastly, let us look at how T3S applies in a sentence in (34), taken directly from Duanmu (2000/2007). (35) shows how the sentence is processed cyclically in stress assignment, starting with the smallest constituent, *shu* 'book.'

(34) T3S in a sentence (Duanmu 2000/2007:251)
X X
[Wo3 [xiang3 # [mai3 shu1 Ø]]]→(**2** 3) # 3 (1 Ø)
I want buy book (# indicates boundary between cyclic branches)
'I want to buy books.'

Optional rule:
(2 **2**) # 3 (1 Ø) T3S is optional across T3S domains

(35) steps of stress assignment for the sentence in (35) according to NHS

a.	b.		c.			d.			
X		X			X	X			X
(X Ø)	[mai	shu]	[xiang	[mai	shu]]	[Wo	[xiang	[mai	shu]]
[shu]	buy	book	want	buy	book	I	want	buy	book
book	'buy books'		'want to buy books'			'I want to buy books.'			
'book'									

In (34), the stress assignment in the VP *mai shu* 'buy books' is the same as the VP *mai jiu* 'buy wine' in (30). Duanmu (2000/2007:251) argues that the object *shu* 'book' is the nonhead of *mai shu* 'buy books,' so that it gets stress and forms a trochee foot with an empty beat. In *xiang mai shu* 'want to buy books,' *mai shu* 'buy books' is the nonhead, and should get stress. It already has stress (from the previous cycle). At the sentence level, *ni* 'you,' the subject of the sentence, is the nonhead and should get stress. According to Duanmu (2000/2007:251), the monosyllabic subject pronoun *wo* 'I' must form a foot with the following syllable *xiang* 'want,' and T3S applies within the two feet separately, meeting at # which indicates the boundary between cyclic branches. As can be seen in (35d), there are two stresses (on the first and last syllables), indicating that there are two feet, with the first and the second syllable being the first foot, and the third and the fourth syllable being the second foot. Even though stress assignment is cyclic, there is prosodic grouping of the first two syllables at the end, despite that they are not a constituent syntactically. In short, stress assignment is purely syntax-based in the Stress-foot Model, but this approach does not ignore prosodic well-formedness and does have the prosodic component built in.

Finally, since T3S is optional between cyclic branches, we have variable patterns. When T3S does not apply across the two domains, we have **T2**T3T3T1, and when T3S does apply across the two domains, we have **T2T2**T3T1.

2.2.2.3 T3S variation

In this model, T3S variation arises through syntactic structures as well as the optional application of T3S across domains. The right-branching structure in (32) and the left-branching structure in (33) in the previous section show that not only do the surface patterns differ, the number of surface patterns also differ. This is repeated in (36) and (37) for convenience. The multiple surface patterns in (36) arise because T3S is optional when a T3 is followed by a derived T2 (Duanmu 2000/2007:250).

(36) X
X X X
[xiao3 [zhi3 [lao3hu3]]]→ ([3 [3 [33]]])→ vv23 (Duanmu 2000/2007:250)
small paper (old)-tiger (**T2**T3**T2**T3, T3**T2T2**T3, or **T2T2T2**T3)
'small paper tiger'

(37) X X
[[[zhan3 lan3] guan3] li3]→ ([[[3 3] 3]3])→ 2223 (Duanmu 2000/2007:250)
show-see hall inside
'inside of exhibition hall'

As mentioned earlier, Lin (2007:212) points out that expressions with the embeddedness of constituents on the left edge usually have one pattern whereas those with embeddedness of constituents on the right edge have more than one surface pattern. The contrast shown in (36) and (37) is supportive evidence.

Regarding T3S variation, the Stress-foot Model is similar to the Word-and-Phrase level Model in that both *syntactic structures* and *optional T3S across domains* are the causal factors of multiple surface patterns. The differences between them are: (i) the fast speech account is used in the Word-and-Phrase level Model, but not the Stress-foot Model; and (ii) a T3 can, but need not change to T2 before a T2 that came from a T3 in the Stress-foot Model, but not in the Word-and-Phrase level Model. (38) is an example that shows T3S variation because of optional T3S across domains in the Stress-foot Model.

(38)   X   X
[([xiu1-gai3]) # ([gao3-jian4])] → (1 3) # (3 4) or (1 **2**) # (3 4) (Duanmu 2000/2007:250)
revise   manuscript
'to revise a manuscript'

In (38), the two disyllabic feet are formed for the two words, followed by independent T3S applications in these two feet, and due to the boundary between the two feet, T3S does not have to apply (Duanmu 2000/2007:250). The surface pattern (T1T3)(T3T4) in (38) will become (T1**T2**)(T3T4) if the other T3S optional rule is applied across the two feet.

2.3 Some issues

Most of the previous T3S studies focused on developing a better T3S model that can account for the multiple T3S surface patterns (Chen 2000: Ch 9; Duanmu 2000/2007: Ch11; Shih 1986; Shih 1997; Zhang 1997). From previous sections, I have established that T3S is a phonological rule that heavily depends on syntax. Both syntax and prosody play essential roles in T3S application, and without either one it is impossible to build proper T3S domains within which T3S applies. In the following sections, I will review and discuss issues concerning the two T3S models. Some general issues with T3S research will also be discussed after the review of the two models.

2.3.1 Word-and-Phrase level Model

The Word-and-Phrase level Model provides a fairly effective way to capture T3S variation. It is criticized for its fast speech account of variability, however. Duanmu (2000/2007) argues against the claim that fast speech explains a variant.

Fast speech

Fast speech is often regarded as the parsing strategy of one large domain (Chen 2000; Lin 2007; Shih 1986; Shih 1997) or larger domains (Zhang 1997). The 'fast speech' account is commonly accepted in the literature. The fast speech pattern is derived by parsing the syllables in one large domain, and then applying T3S from left to right in one step, according to the Word-and-Phrase level Model. Zhang (1997:308) states “fast speech” differently: “In a more casual or faster style of speaking, a TS domain can be larger than two syllables. It can be as large as an intonational phrase, which roughly corresponds to a syntactic clause.” Duanmu (2000/2007) argues against the explanation of T3S variability resulting from different speech rates showing that for a given expression, the variant surface patterns can be easily produced at the same speech rate (Duanmu 2000/2007:247-248).

The examples used in the literature for illustrating fast speech are often short sentences where parsing all the syllables in one large domain and applying T3S from left to right in one step is easy. It needs to be further investigated whether or not the effect of T3S application in one step still remains if the number of syllable grows. For instance, it is probably much less likely that all the syllables are parsed in one domain in a sentence of ten syllables than in a sentence of four syllables.

Optional T3S across domains

In (39), ST1 is derived through normal parsing (not fast speech parsing).

(39)	[[Mi	[laoshu]]	[xiang	[zhao	[hao	[mi	jiu.]]]]]	(Lin 2007:221)
	Mickey	mouse	want	look for	good	rice	wine	‘Mickey Mouse wants to look for good rice wine.’
	3	33	3	3	3	3	3	UT
	3	(**2**3)	3	3	3	(**2**	3)	Word: T3S
	(3	23)	3	3	(3	2	3)	Word: incorporation; no T3S
	(3	23)	(**2**	3)	(3	2	3)	Phrase: disyllabic foot from left to right, T3S; ST1
	Optional T3S across domains:							
	(3	23)	(2	**2**)	(3	2	3)	T3S applies across second and third domains; ST2

Cases with optional T3S across domains in the literature are often in the context of two domains, such as in (T2T3)(T3T1)→ (T2**T2**)(T3T1). In ST1 in (39), we see that there are two adjacent T3* belonging to two domains (in the second and the third prosodic domains). If an optional rule applies across the two domains, we have ST2.

Fast speech or optional T3S across domains?

There are two optional rules in this model: the fast speech rule and T3S across domains. The patterns predicted by these two rules sometimes produce the same sequence as we saw in (20), repeated here in (40).

(40)	[wo	[xiang	[mai	hua]]]	(Lin 2007:215)
	I	want	buy	flower	'I want to buy flowers.'
	3	3	3	1	Word: not applicable
	3	3	(3	1)	Phrase: disyllabic foot for the smallest domain, no T3S
	(**2**	3)	(3	1)	Phrase: disyllabic feet for the rest, T3S; ST1
	Optional rule between two T3* in different prosodic domains:				
	(2	**2**)	(3	1)	T3S across domains; ST2
	Optional in fast speech:				
	(3	3	3	1)	one prosodic domain for all syllables
	(**2**	**2**	3	1)	T3S from left to right; ST3

In (40), ST2 and ST3 are derived by different paths, but the sequences in the two patterns are the same. In empirical data where both analyses are possible, it may be difficult to distinguish which parsing strategy is used by the speaker. More sentences should be investigated to see whether or not positing only one optional rule can adequately account for all variation patterns.

Directionality

Shih (1986) required that at the Phrase level, syllables are parsed into disyllabic feet unless they branch in opposite directions, and in addition, the incorporation of an unparsed syllable is made according to the direction of syntactic branching. In her later work (Shih 1997:98), the component of directionality was removed due to evidence of irrelevance of directionality. The sentence in (41) shows a case where the monosyllabic verb can be parsed with the subject or the object. For ease of presentation, I adopt the derivational process presented in Lin (2007) in the following examples.

(41)	[[Lao Li]		[mai	[hao	jiu]]]	(Shih 1997:85)
	Lao	Li	buy	good	wine	'Old Li buys good wine.'
	3	3	3	3	3	UT
	(**2**	3)	3	(**2**	3)	Word: T3S
	(2	**2**	3)	(2	3)	Phrase: incorporation (leftwards), T3S; ST1
or	(2	3)	(3	2	3)	Phrase: incorporation (rightwards), no T3S; ST2
	Optional in fast speech:					
	(**2**	**2**	**2**	**2**	3)	one large domain in fast speech, T3S; ST3

In (41), ST1 results from leftward incorporation of the verb *mai* 'buy', whereas ST2 results from rightward incorporation, and both are grammatical. Leaving the directionality unspecified accounts for the flexibility of directionality in cases like (41). It is not clear, however, to what extent the irrelevance of directionality applies to other sentences of the same or similar structures. If this is found in some cases but not in others, the source of the variability should be sought. If the choice of directionality can be made freely, we are left with the consequence that there are two possible derivations at the point of incorporation at the Phrase level. Whether or not the two possibilities are always grammatical requires more investigation.

Resistance of T3S in certain cases

In short proper nouns like [*Mi*-[*laoshu*]] (T3T3T3) 'Mickey Mouse,' [*Ma* [*Yo-Yo*]] (T3T3T3) 'Yo-Yo Ma (a cellist),' or even common nouns [*ye* [*laohu*]] (T3T3T3) 'wild tigers' or [*xiao* [*laoshu*]] (T3T3T3) 'little mice,' we would expect that parsing all three syllables in one domain and applying T3S from left to right is possible, and (**T2T2**T3) should be grammatical. However, this pattern appears to be either ungrammatical or marginally acceptable.

2.3.2 Stress-foot Model

This T3S model makes reference to syntax throughout—not just at the word level, but beyond the word level up to the highest, sentential, level. Syntax is crucial in this model in that stress assignment is based on the relationship of two constituents. Foot building is through the NHS principle— nonheads get stress. Once the stress assignment for the whole expression is finished, if there are unfooted syllables, they will follow prosodic parsing (e.g. two unfooted syllables will form a foot if there is stress assigned to either of these two unfooted syllables). An advantage of this model is that there is no need to assume that speech rate is the source of a variant pattern (Duanmu 2000/2007:254). In addition, there is no need to separate the phrases or sentences into the Word level and the Phrase level.

Syntactic and prosodic components

Regarding stress assignment, the approach is purely syntactic. However, prosody also plays an important role as we saw in (34), repeated in (42) below.

(42) T3S in a sentence (Duanmu 2000/2007:251)

```
 X                        X
[Wo3  [xiang3 #  [mai3   shu1 Ø]]]→(2  3) # 3 (1 Ø)
 I       want      buy     book     (# indicates boundary between cyclic branches)
 'I want to buy books.'

 Optional rule:
 (2        2)   #  3       (1 Ø)          T3S is optional across T3S domains
```

The presence of stress indicates the presence of a foot (Duanmu 2000/2007); the stress on *wo* 'I' indicates the presence of a foot. Subsequently, *wo* 'I' is parsed with *xiang* 'want' that follows it. At this final stage, the approach relies on prosody. Although the stress assignment is purely syntax-based, foot-building is not completely syntax-based, particularly as we see in (42) that the first two syllables are grouped in a disyllabic foot not because they are a syntactic constituent, but because of prosodic well-formedness.

Empty beats

In the examples provided by Duanmu (2000), the empty beats occur 'in the final position,' including sentence-final position (e.g. Sentence-final: *Wo* (I) *xiang* (want) *mai* (buy) *shu* (book) Ø 'I want buy books' and at a major boundary (e.g. *xiang* (want) *MAI* (emphatic: BUY) Ø *gupiao* (stock) 'want to buy stocks'). The empty beats in the phrase/sentence-final position might be related to the lengthening effect in this position. However, Dell (2004) argues that empty beats in this model are a serious weakness and he argues that the environments where one can invoke empty beats need to be precisely indicated (Dell 2004: 55).

Prosodic domains

T3S application does not appear to be restricted within a foot in (30), for instance, repeated here in (43).

(43)		X	
	[mai	jiu]	Duanmu (2000/2007: 249)
	buy	wine	'buy wine'
	3	(3 Ø)	Foot (Ø =empty beat)
	3	(3 Ø)	T3S cycle 1 (no effect)
	2	(3 Ø)	T3S cycle 2

Unlike the Word-and-Phrase level Model where the phrase in (43) would be parsed in a foot ([mai jiu] 'buy wine' (T3T3)→(**T2**T3)) and T3S applies within a foot, we see that in the Stress-foot Model, T3S can apply outside the foot. *Mai* 'buy' is unfooted, but it still undergoes T3S. Dell (2004:50) points out that, "…some syllables are left out of foot structure, and this does not prevent them from undergoing tone sandhi." How unfooted syllables are handled and the prosodic domain within which T3S applies are not very clear. The issue with respect to the domain, or foot, within which T3S applies will need to be made clear.

2.4 Conclusion

In this chapter, I have presented two T3S models and have discussed how each model accounts for T3S in flat structures, phrases, and sentences. Although the prosodic domain within which T3S applies largely depends on syntax, it also relies on prosody. Multiple T3S surface patterns are accounted for by optional rules or an alternative parse. For the purpose of the central focus of the thesis, I adopt the Word-and-Phrase level Model in predicting surface T3S patterns and summarize what is needed for children to acquire T3S.

To acquire T3S, children will need to learn both cyclic and non-cyclic parsing strategies, and importantly, to be able to use them at the right levels. Children need to learn that for flat structures, a non-cyclic parsing strategy is used, and for NPs, a cyclic parsing strategy is used. At the sentence level, they need to integrate the two strategies. In addition to these, they also have to learn the optional rule or an alternative parse which produces multiple T3S patterns. The experimental studies in this dissertation investigate whether or not children know how to apply T3S non-cyclically in flat structures, and cyclically in NPs, and how to integrate the two strategies in sentences.

CHAPTER 3

PREVIOUS CHILD ACQUISITION STUDIES ON TONES AND TONE SANDHI

3.0 Introduction

The acquisition of tones or tone sandhi rules has not attracted much attention. Although tones have been extensively studied in Mandarin (Chao 1968; Chen 2000; Cheng 1973; Duanmu 2000/2007; Lin 2007 among others), how children acquire lexical tones and tone sandhi rules remains an area we do not know very much about. Demuth (1989:82, 85) points out that a child acquiring a language has to learn what kind of language it is: lexical tone (e.g. Chinese), grammatical tone (e.g. Sesotho and other Bantu languages), stress/intonational (e.g. English), or accentual (e.g. Japanese) and by age 2, Sesotho-speaking children are well aware of their language being a grammatical tone language. Mandarin-speaking children have also been reported to acquire tones early as well (generally by age 2) (Chang 1991; Clumeck 1977; Clumeck 1980; Jeng 1979; Jeng 1985; Li & Thompson 1977; Li 1978; Zhu 2002; Zhu & Dodd 2000). There have not been many studies on the acquisition of sandhi rules (tonal changes in certain contexts), specifically, the T3S rule in Mandarin. The main purpose of this chapter is to summarize the findings reported in previous studies on tones and tone sandhi rules, with the focus placed on the acquisition of T3S.

Section 3.1 gives an overview of children’s acquisition of tones and tone sandhi, including findings on acquisition of tones and tone sandhi rules in several languages. In Section 3.2, previous studies on children’s acquisition of Mandarin tones and T3S will be reviewed and discussed. Section 3.3 concludes the chapter with a report of major findings of previous studies on Mandarin tones and T3S, and areas which still need to be investigated.

3.1 The acquisition of tones: an overview

Previous studies have shown that Mandarin-speaking children's tonal acquisition is completed before segmental acquisition (typically by age 2) (Chang 1991; Clumeck 1977; Clumeck 1980; Jeng 1979; Jeng 1985; Li & Thompson 1977; Li 1978; Zhu 2002; Zhu & Dodd 2000). Studies on tonal acquisition of other languages report similar findings of early acquisition of lexical tones. In their study on phonological acquisition of Cantonese-speaking children, So and Dodd (1995) found that contrastive use of tones is acquired by age two.

Demuth conducted many studies on children's acquisition of Sesotho, a Southern Bantu language, and reports the acquisition of lexical tones (High tone and Low tone) by age 2 (Demuth et al. 2010; Demuth 1989; Demuth 1993; Demuth 1995; Demuth 2003; Demuth 2007). Sandhi rules are acquired later, such as the High tone spreading rule, acquired by age 3. Sandhi rules that involve OCP (Obligatory Contour Principle) are acquired later (Demuth 1995; Demuth 2003). Demuth (1989; 1993) suggests that the sandhi rules possibly impede the acquisition of lexical tones. In tonal languages, tonal rules (or sandhi rules) may greatly differ between languages.

Mandarin T3S is a type of tone sandhi rule different from the Sesotho sandhi rules. In this thesis we concentrate on the acquisition of T3S, beginning in the next section with some background on Mandarin-speaking children's acquisition of lexical tones.

3.2 Previous acquisition studies on Mandarin tones and T3S

This section reviews previous studies on Mandarin tones and T3S, with focus on the latter.

3.2.1 Children's acquisition of Mandarin tones

In this section, I review several studies on the acquisition of Mandarin-speaking children's acquisition of phonology, including studies focused on the segmental aspect, tonal aspect, or both. First, I describe chronologically the emergence of studies on phonological acquisition in Mandarin-speaking children. Then, the findings of these studies will be presented and discussed.

Chao (1951) was an early study that reported phonological acquisition of a Mandarin-speaking child. A small number of studies on child acquisition of Mandarin phonology (Clumeck 1977; Jeng 1979; Li & Thompson 1977; Li 1978) were conducted in late 1970s. Sporadic case studies of Mandarin-speaking children's tonal or segmental acquisition appeared in the 1980s and early 1990s (Clumeck 1980; Erbaugh 1992; Jeng 1985). Almost a decade had passed before a pioneering large-scale study of Chinese children's phonological acquisition was carried out in Beijing, China (Zhu & Dodd 2000). This study gave a better picture of the acquisition order of segments and tones, based on over 100 children. The scale of the study provides a large amount of empirical and systematic data, unlike most Mandarin child acquisition studies which were based on a small number of subjects.

Prosodic development in infants

Chen and Kent (2009) studied Taiwanese[13] infants' (0; 7 – 1; 6) prosodic development. Due to the fact that the babies' production of the tonal contours do not always map to the lexical tones (especially in the babbling stage and before producing the first word), prosodic patterns are

[13] Mandarin and Taiwanese are both spoken in Taiwan, with the former being the major language used in class instruction in schools and in the majority of media. In everyday life, either Mandarin or Taiwanese can be the major language spoken depending on the regions in Taiwan. A tendency is that Taiwanese is spoken more than Mandarin in southern Taiwan. The study of Chen and Kent (2009) is relevant to both Mandarin and Taiwanese since, as babies grow up, they may use either language as the major language, or use both languages equally well, although this is less likely. If the language input is one of the minority languages, such as Hakka, the child will of course acquire Hakka (not Taiwanese), along with the major language, Mandarin.

categorized as *high*, *mid*, or *low*, along with *falling*, *rising*, and *level contours* instead of lexical tones (T1 – T4)[14] in this study.

Falling contours were found to occur more often than rising or level contours in infants and in child-directed speech (no significant difference), and high prosodic patterns are produced significantly more often than mid and low prosodic patterns in infants and in child-directed speech. Chen & Kent (2009:80) also found that infants used significantly more mid prosodic patterns and fewer low(er) patterns than adults. These findings indicate that falling contours and high(er) prosodic patterns were more easily acquired and acquired early.

From Chen and Kent (2009), we know that falling, rising, and level contours were all found in infants as were high, mid, and low prosodic patterns. This study shed some light on what kind of contours and prosodic patterns appear to be easier than others in the prosodic acquisition of Taiwanese infants. Most likely, the prosodic development of the infants is closely related to the later acquisition of four lexical tones and the T3S rule. Now we turn to the acquisition of Mandarin lexical tones.

Early acquisition of lexical tones

Previous studies agree that the acquisition of tones is complete before the acquisition of segments (Clumeck 1977; Clumeck 1980; Jeng 1979; Jeng 1985; Li & Thompson 1977; Li 1978; Zhu 2002; Zhu & Dodd 2000). T1 (High level tone) and T4 (High falling tone) are reported to be acquired before T2 (Mid rising tone) and T3 (Low dipping tone) (Clumeck 1980; Jeng 1979; Jeng 1985). Li (1978: 311) studied his son (from 2 to 3 years old) and daughter (from 13 to 20 months), and suggests that children acquire tones very early and accurately. In the study of his

[14] The contours and prosodic patterns referred to in this study do not translate directly to the four lexical tones in Mandarin.

two sons' phonological development carried out in Taiwan, Jeng (1979) reports that T2 and T3 are acquired by them at about the same time, at 19.5 months for one son, and between 16.5 and 18.5 months for the other son. In another study, Jeng (1985), of a child from 0;9–2;6 in Taiwan, T1 and T4 are acquired early whereas T2 and T3 developed from 1;0 and were completed by 2;3. In Chao's (1951) study conducted in the US, his own granddaughter's (2;4) spontaneous speech was observed for a month, and T2 and T3 are reported to be produced.

Clumeck (1980) in his longitudinal study of the tonal acquisition of two Mandarin-speaking children (Child P: 2;3–3;5 and Child J 1;10–2;10), used only words uttered in isolation or in utterance-final position in order to avoid possible contextual effect on pitch. Both children showed a lower accuracy in T2 and T3 than in T1 and T4 (Clumeck 1980:268, 270). He found that both children were able to produce all four tones accurately throughout the period of study, although there were errors. Both children were reported to reach almost complete mastery of T1 and T4, but have much greater difficulty in T2 and T3, and T2 and T3 were mostly allophones of each other in those errors (Clumeck 1980:268-270). The findings suggest that the four lexical tones could be produced accurately by one child as early as 1;0. Clumeck (1980:269) reports that Child P's production of T2 and T3 had achieved almost the accuracy of T1 and T4 at the end of the study, and for Child J there was no evidence that T2 and T3 had been mastered by the end of the study. Clumeck (1980) points out that, in terms of perception, while T1 and T4 are stable in these two children, there is variation between T2 and T3. In summary, T1 and T4 appear to be easier than T2 and T3 for these two children.

Li and Thompson (1977) studied 17 Mandarin-speaking children from 1;6 to 3;0 in Taiwan. Free speech data as well as children's responses in picture-naming tasks were used. Zhu and Dodd (2000) carried out an experimental study on 129 Mandarin-speaking children (1;6–4;6) and a longitudinal study on four children (from age under two to about two years of age) in Beijing, China. Both Li and Thompson (1977) and Zhu and Dodd (2000) further distinguish the acquisition order of T2 and T3 and suggest the acquisition order T1, T4 before T2, and T3 last.

Wong et al. (2005) investigate the perception and production of T1 vs. T2 and T1 vs. T4; T2 vs. T4 and T2 vs. T3 of thirteen 3-year-olds (2;10–3; 4, mean age: 3;0) in the US. Seventy-two pictures and 72 words, were used for the picture-pointing task in the perception study and the picture-naming task in the production study. They found accurate perception of the four lexical tones by age 3, and acquisition of T1, T2, and T4 before T3 (Wong et al. 2005). This finding is slightly different than that of other studies which suggest the acquisition order T1 and T4 before T2 and T3 (Clumeck 1980; Jeng 1979; Jeng 1985) or T1 and T4 before T2, with T3 last (Li & Thompson 1977; Zhu & Dodd 2000).

Taken together, all these studies agree that T1 and T4 are acquired first and are stable from early on. Also consistent is that T3 is acquired last. There is less agreement on the acquisition order of T2. Although the age of the children studied varied in these studies and the specific age at which T2 and T3 are acquired is not always provided, the findings of these studies point to the completion of the acquisition of T2 and T3 between age 2 and age 3. Overall, these studies agree on early acquisition of four lexical tones and that these lexical tones are not acquired simultaneously. They reported slightly different acquisition orders of the four tones.

Why are T2 and T3 acquired later than T1 and T4?

From previous studies, we find that T2 and T3 are acquired later than T1 and T4. According to Li and Thompson (1977), there is confusion between T2 and T3 until the two-to-three-word stage. Phonetic similarity is believed to cause the delayed acquisition of T2 and T3 (Clumeck 1980; Li & Thompson 1977). Li and Thompson (1977:194) proposed the Similarity Hypothesis and the Difficulty Hypothesis to account for the confusion between T2 and T3. The Similarity Hypothesis refers to the perceptual similarity between T2 and T3, and the Difficulty Hypothesis refers to the greater physiological effort required for rising tones (both T2 and T3 have a rising contour) than for the other two tones (T1, a level tone, and T4, a falling tone). The similarity is in the rising part of T2 and T3 — the pitch contour '35' in T2 (Mid rising tone; 35) and the tail portion '14' in T3 (Low dipping tone; 214). The pitch changes from 3 to 5 and from 1 to 4 in T2 and T3 respectively may be very similar and cause confusion.

Clumeck (1980:274) agrees that the similarity of T2 and T3 lies in the fact that both have a rising end component which causes the difficulty. Nevertheless, Clumeck (1977; 1980) disagrees with Li and Thompson's (1977: 194) alternative account of difficulty in production, according to which a falling contour can be produced faster than a rising contour and may require less physiological strength than a rising pitch. T4 is a falling contour while T2 is a rising contour, so the fact that T2 is acquired after T4 could result from a difficulty in production. Clumeck (1977) reports that at 1;10, Child M in his study acquired T2 first, which indicates that the rising tone, T2, is not hard to produce. Furthermore, he points out that in Thai children's acquisition of tones, the rising tone is acquired before the high-level tone and the falling tone (Clumeck 1980:271). It remains controversial as to precisely what causes the delayed acquisition of T2 and T3.

Why is tonal acquisition completed before segmental acquisition?

Clumeck (1980:260) says that children have "relative ease in approximating the phonetic values of tones in the adult language." He explains that, given that there are many more segments than tones for children to acquire, it would be expected that the acquisition of tones is completed relatively quickly with ease. He acknowledges that the T3S rule may cause difficulties in the process of tonal acquisition, suggesting that it may take a longer time to arrive at the level of consistent and correct use of tonal allophones in various environments.

In a sequence of T2 and T3 in the same prosodic domain, because of the T3S rule, the T2 in the surface could be a 'true T2' (an underlying T2 surfacing as a T2) or a sandhi tone (a T2 derived through the T3S rule from an underlying T3). T3 can surface as a T2 or a T3 because of the T3S rule. For instance, in *xiao ma* 'a small horse, a pony' (T3T3→**T2**T3), the word *xiao* 'small' is produced in **T2**, but the same word *xiao* is produced in T3 in 'small' in *xiao mao* 'a small cat, a kitten' (T3T1 in both underlying tones and surface tones). Upon encountering a T2 or a T3, there may be disambiguation for children to do. They need to know if a T2 is a true T2 or if it is a derived T2 through the tone sandhi rule. They also need to know that a T3 does not always surface faithful to its underlying form and that a sandhi tone is a 'disguised T3.' As Clumeck (1980:269) argues that T2 words are always heard as T2, whereas T3 words are heard as T2 or T3. He suggests that this possibly leads to children's overgeneralization of the tones and that it may take some time before they discover that although they are phonologically contrastive, in one environment, two tones alternate. This takes us to the next discussion, the acquisition of T3S.

3.2.2 Children's acquisition of T3S

It has been established in the previous chapter that the T3S rule is more than simply knowing the rule that T3T3→ **T2**T3. What Mandarin-speaking children encounter is an extremely complex rule application of T3S. In addition to the fact that T2 and T3 are more difficult than T1 and T4 in nature—whether perceptually or in terms of production, or both—T3S also requires building prosodic domains and mapping between syntax and prosody. Mandarin-speaking children also have to know the optional application of T3S: (i) in fast speech, and (ii) across prosodic domains. This is not all. T3S variability also presents a great challenge. That is, the one-to-many mapping relationships between underlying tones and surface tones in a sentence with multiple potential cases of T3S are still to be discovered.

Early acquisition of T3S reported in previous studies

Previous studies (Jeng 1979; Jeng 1985; Li & Thompson 1977; Zhu 2002; Zhu & Dodd 2000) suggest early acquisition of T3S. The existing findings regarding children's acquisition of T3S in the literature are typically just a small portion of the studies whose focus is the general phonological acquisition and/or acquisition of individual tones. However limited, these findings do provide useful information and help to better our understanding and to advance our knowledge of T3S acquisition.

When is T3S rule acquired?

In studying children's language acquisition, an important piece of information researchers (and other people including readers, parents, and non-linguists) are interested in learning is: at what age is the grammar under investigation acquired? Some aspects of grammar may be acquired instantaneously, while others may take time to develop, and in that case there is a period from the time of the emergence of the grammar to adult-like competence. If T3S does take some time before it is fully acquired, we ask: when does the acquisition process begin; when is T3S completely acquired; and how long does it take for children to develop adult-like mastery.

Previous T3S studies

The three most often cited papers are the pioneering work of Chao (1951), the first cross-sectional phonological study of 17 Mandarin-speaking children by Li and Thompson (1977), and the first large-scale cross-sectional experiment with 129 Mandarin-speaking children by Zhu and Dodd (2000). We will begin with Chao (1951), a case study of his granddaughter at 2;4, and a study which continued for a month. It is the earliest literature to indicate interest in children's acquisition of T3S. With respect to T3S, Chao (1951) provides the following examples.

(1)	Biao	you	
	watch	existential (there is)	'There is a watch.'
	3	3	UT
	2	3	ST
	*3	3	Child production

(2)	Bi	you	
	pen	exsitential (there is)	'There is a pen.'
	3	3	UT
	2	3	ST
	*3	3	Child (2;4) production (first try)
	2	3	Child (2;4) production (self-correction a few seconds after the first try)

Chao (1951) says that T3S is "only beginning to be learned," and does not discuss it further or offer his interpretation of what the data may indicate. Nor did he claim early acquisition of T3S. In the later literature, we see that the data were interpreted differently by different researchers. Hong (1980:11) reported that this child had acquired sandhi rules. Jeng (1979:157) stated that the child generally had no problem with the tone sandhi phenomena, and in a later paper, he says that this child was just beginning to learn the rule (Jeng 1985:19). Wong and collegues reported only "had some difficulties with the tone sandhi rules" (Wong et al. 2005:1066).

With (1) and (2) being the only pieces of T3S data in the Chao (1951) study, it is difficult to conclude one way or the other. The child, at 2;4, did not apply T3S in (1). She did not apply T3S in (2) at first, but corrected herself a few seconds later. This may indicate that at 2;4, she was aware of the T3S rule, although she may not have been able to apply it in an adult-like fashion. The acquisition of T3S had started and, was possibly in the process of being developed into adult-like "proficiency." Since no additional examples concerning T3S were provided, we do not have enough information to piece together how much of the T3S rule the child had acquired. We now turn to a few other studies that claim early acquisition of T3S.

Li and Thompson (1977) in a study of 17 children age 1;6 – 3;0 report that the tone sandhi rules are acquired, with infrequent errors, as soon as the child's multi-word utterances begin. In the study of his son JW's tonal acquisition from 0;2 – 1;9, Jeng (1979) claims that he had no problem with T3S. In a later study Jeng (1985) reports that Child K (0;9 – 2;6) developed his T2 and T3, and tone sandhi rule from 1;0. He did not begin to apply T3S correctly until he was 1;9 when he had good control of T3 and Jeng (1985) argues that the emergence of T3S implies that T3 is already acquired. Furthermore, he says that without a 90% correct rate of T3, acquisition of T3S is impossible. At 2;3, Child K's acquisition of tone sandhi rules was virtually complete (Jeng 1985:20-22).

Zhu and Dodd (2000) carried out two studies, a cross-sectional experimental study with129 children aged 1;6 to 4;6 and a longitudinal study with four young children under age 2, and reported similar findings on early acquisition of T3S. T3S errors were found occasionally in the two younger age groups (1;6 – 2;0 and 2; 1 – 2) in the experimental study. No T3S errors were found in the free speech study. Acquisition of T3S was reported to have stabilized by 1;9 for all four children. (We will return to the Zhu and Dodd (2000) study for a more detailed discussion.)

Evidence of T3S acquisition in previous studies

We saw that researchers interpret differently the two pieces of evidence provided in Chao (1951). In what follows, the evidence provided in T3S studies will be presented and discussed. Not all these studies include sample sentences, so only those that were available in the literature are presented here. The presentation of the phrases and sentences from different studies are slightly modified from their original presentation for the purpose of consistency, and also to provide information (such as the predicted surface patterns) that can be compared to the patterns produced by the children.

(3)	[You	[xiao	[yu]]]	(Li & Thompson 1977)
	there are (existential)	small	fish	'There are small fish.'
	3	3	2	UT
	2	3	2	ST
	*3	3	2	Child production

(4)	[Hui	[yao	[ni]]]	(Li & Thompson 1977)
	will	bite	you	'will bite you'
	4	3	3	UT
	4	**2**	3	ST
	*4	3	3	Child production

An important point Li and Thompson (1977) made was that if the child correctly produced as **T2**T3 a simple noun such as *xiaoniao* (T3T3→ **T2**T3) ('birdie,' literally 'small bird'), this cannot serve as evidence that the child can actively apply the rule—not until "he is able to make up his own multi-word predictions" (Li & Thompson 1977:195). They excluded cases such as *xiaoniao* (T3T3) 'birdie' as evidence that the child had acquired T3S. Two examples of T3S errors they provided were (3) and (4) where T3S should have been applied, but the child failed to apply the rule. The age of the child/children who produced (3) and (4) is not specified, but we know that the 17 children in this study aged from 1;6 to 3;0. There are no sample sentences of correct application of T3S.

Jeng (1979) reports that his son generally had no problem with T3S, with the data in (5) as supporting evidence.

(5)

a.	[Wo	[ye	[yao	[chu	qu]]]] (Jeng 1979)	
	I	also	want	to go out	directional comp	'I also want to go out.'
	3	3	4	1	4	UT
	2	3	4	1	4	ST
	2	3	4	1	4	Child production (at 21.5 months)

b.	wo	de	(Jeng 1979)
	I	possessive PRT	'Mine.'
	3	0	UT
	3	0	ST
	3	0	Child production (at 21.5 months)

(5a) and (5b) are evidence of T3 surfaced as a T3 in a non-T3 sequence, and a T2 in a T3-sequence. Even though (5a) is clearly an example of T3S application, it is the only piece of evidence in the study. With the sole example above, and no description of other environments where T3S application occurred (e.g. T3S applied at a certain location in a novel sentence), it is not clear if T3S had been acquired completely. In a study of a different child, Jeng (1985) provided phrases/sentences as in (6) – (8), with the number of tokens.

(6)	Hao	yuan	(Jeng 1985:22)
	so	far	'It's so far.'
	3	3	UT
	2	3	ST
	2	3	Child (1;9) production (one token)
	*1	3	Child (1;9) production (one token)

(7)	Gei	wo	(Jeng 1985:22)
	give	me	'Give me.'
	3	3	UT
	2	3	ST
	2	3	Child (1;9) production (two tokens)

(8)	Hao	kongbu	(Jeng 1985:22)
	so	scary	'How terrible! (How scary!)'
	3	34	UT
	2	34	ST
	2	34	Child (1;9) production (one token)

In (6), the child applied T3S correctly at one time, but at another time T3S was not applied and *hao* 'so' was pronounced with a T1, instead of the underlying tone T3, or the sandhi tone T2. In (7) and (8) where there are also two adjacent T3*, the child applied T3S correctly.

In the sample examples from the previous studies presented in (1) – (8), we see that there are cases of correct T3S application in (2) and (5) – (8), cases of non-application of T3S in (1) – (4), a case of self-correction in (2), and a case that involved using a tone other than T2 or T3 in (6). Sample examples in (1) – (8) provide rather helpful information. Notice, however, that in all the examples we see in (1) – (8), there are only two adjacent T3*, with one T3S application. A sequence of two T3*, regardless of word categories or sentential position, is unable to provide the much needed information on how T3S is applied, because by changing the first T3 to a T2 in a T3T3-sequence, correct applications may surface. A child may know to change a T3T3 sequence to a **T2**T3 sequence, but not know about cyclicity in T3S (i.e. cyclic and non-cyclic strategies in T3S application). This argument is not to diminish the value of application of T3S in cases where there are two adjacent T3*, but we should not ignore the fact that T3S occurs in environments with two adjacent T3* as well as others with more than two.

Do children know how to apply T3S when there are three or more adjacent T3* and T3S is applied multiple times? Unfortunately, only some studies (Chao 1951; Jeng 1979; Jeng 1985; Li & Thompson 1977) provide the sample phrase/sentences produced by children, so it is not always clear what kind of evidence other studies were based on in their argument of early acquisition of T3S.

Contrary to the belief that T3S is acquired early, Lee (1996:300) says, “There is fairly good agreement that children approximate the phonetic values of tones fairly early, and articulatory control of tone is completed before segmental acquisition. However, it is less clear that the phonology of tone (including the various tone sandhi rules, for example) is acquired in full any earlier than the segmental system.” I agree with Lee’s (1996) view and believe that more in-depth studies should be carried out before we come to any conclusion.

Chen-Wilson (2003) also points out that children may have learned T3S on the item-by-item basis in her review of Zhu’s (2000) study of Mandarin-speaking children’s acquisiton of Chinese phonology. In other words, the results should be interpreted with caution since it is not clear if an utterance in which T3S applies correctly is indeed an active application, rather than a lexicalized item that is acquired through common expressions in daily life. Researchers should try to avoid using utterances that might be learned as "chunks" in drawing a conclusion for T3S acquisition. The claim is weakened without sufficient evidence of active T3S application, and can be misleading if the conclusion of early acquisition of T3S is based on only a few tokens of data.

In what follows, I will briefly discuss what we can learn for future studies from previous work regarding the acquisition of T3S.

Zhu and Dodd (2000)

The only existing large-scale child acquisition study of Chinese phonology is Zhu and Dodd (2000). Refreshing and different, their study sets a new milestone and offers a rich resource for research on phonological acquisition by Mandarin-speaking children which can greatly enhance our understanding of their phonological development. As the focus of Zhu and Dodd (2000) is on the segmental acquisition, T3S is not studied deeply. Nevertheless, it would be unwise to overlook their findings on the acquisition of tones and T3S. Zhu and Dodd (2000) is a journal article, which later was incorporated into a book chapter in Zhu (2002), where more information was provided. Zhu (2002) concerns both normally-developing children and children with functional speech disorders. In this review, only the data regarding normally-developing children will be discussed.

Zhu and Dodd (2000) contains two studies. In Study 1, Picture naming and picture description tasks included 129 children aged 1;6 to 4;6. They show that (i) errors of four separate lexical tones are rare even in the youngest child group, and (ii) five out of 21 children from the 1;6 to 2;0 age group and three out of 24 from the 2;1 to 2;6 age group occasionally made tone sandhi mistakes. In Study 2, they examine longitudinal natural speech from four children (0;10-2;0, 1; 0-2;0, 1;1-2;0, and 1;2-1;8). Natural speech data were collected in child-parent interactions. Findings were that (i) T1 and T4 emerged earlier than T2, which is followed by T3; (ii) tone sandhi rules stabilize (66.7% accuracy criterion) soon after their first emergence (by 1;9 for all four children); and (iii) T3S errors were not found.

Regarding experimental materials, 44 words/phrases that young children are likely to know were used, including 39 nouns such as *taiyang* (T4T2) 'sun,' *pingguo* (T2T3) 'apple,' *bizi* (T2T0) 'nose'; four phrases/short expressions *xiexie* (T4T0) 'thank you,' *zaijian* (T4T4) 'bye-bye,' *xi lian* (T3T3→**T2**T3) 'wash (your) face', and *shua ya* (T1T2) 'brush (your) teeth'; and one color word *hong* (T2) 'red' (Zhu 2002:201-202; Zhu & Dodd 2000:14).

In the picture-naming task, although the items for testing acquisition of consonants, vowels and individual tones were well-selected, the use of certain items on the list for testing application of T3S poses some problems. For instance, *shouzhi* (T3T3→ **T2**T3) 'finger', and "*xi* (T3) *lian* (T3)→ (**T2**T3)" 'wash (your) face' may have been learned as frozen chunks without further analysis on the child's part, considering these are commonly used vocabulary. Regarding T3S application within a word, Zhu and Dodd (2000) acknowledge that in such case, the word may be produced without a child's knowledge of the T3S rule; furthermore, it appears that they believe that T3S might be acquired in an instantaneous fashion, rather than through an acquisition process that takes time:

> "As Li & Thompson (1977) pointed out, a child who is able to adjust tones in a single word context may not necessarily have acquired the tone sandhi rule. It is likely that s/he manages to learn the single words as adjusted forms without being aware of tone sandhi rule… the scarcity of tone sandhi errors in the study may be an artifact of the cross-sectional design, in that tone sandhi rules may be acquired during a very short period of time and such a study is unable to capture such changes." (Zhu & Dodd 2000:21-22)

In fact, if the items that might have been learned as frozen chunks are excluded, the two nouns composed of two adjacent T3* (as well as the common expressions) in this study should be excluded for testing the acquisition of T3S. No other items from the list of the experimental items provided by Zhu (2000) have a T3-sequence (i.e. at least two adjacent T3*) that will trigger T3S. The additional information on the number of items used for testing T3S provided by Zhu (2002: 204) shows that there are three items used, which could be lexicalized items and had not been excluded despite Zhu and Dodd (2000) having agreed with Li and Thompson (1977) that T3S in a noun does not serve well as evidence of T3S acquisition.

Another source of T3S data in Zhu and Dodd (2000) is the picture-description task. Unfortunately, no sample T3S production data, either correct or incorrect T3S applications, were presented. Therefore, we do not know in what environments T3S was applied correctly in most age groups, as they repot that all age groups except for the two youngest age groups make T3S errors occasionally. We also do not know how the errors were made (e.g. under-application or over-application), and in what kind of environments they occurred. Children's T3S production data (correct applications or incorrect applications including under-application, mis-application or over-application) provide information that would help us learn how children process the T3S rule. It would have been very helpful if some sample phrases/sentences for T3S acquisition had been included by Zhu and Dodd (2000) and Zhu (2002). Although the findings on the acquisiton of T3S presented by Zhu and Dodd (2000) might be flawed, their work makes a significant contribution to our understanding of Mandarin-speaking children's acquisition of phonology as well as their developmental patterns.

3.3 Conclusion

In general, previous studies show that Mandarin-speaking children acquire lexical tones by age 2, with T1 and T4 being acquired before T2 and T3. T3S has been reported to be acquired early. The definition of what counts as mastery of T3S is very fuzzy. It is unclear what was used in those studies as evidence for adult-like use. Without carefully examination of the T3S phenomenon, the arguments can be misleading or overstated. A more in-depth study of children's acquisition of T3S is needed to consider whether or not children can apply T3S in novel contexts; whether they can correctly use a non-cyclic parsing strategy in flat structures and a cyclic parsing strategy in NPs; and whether or not they can integrate the two strategies at the sentence level. Do they know the T3S optional rules and produce different T3S patterns as adults do? These are the questions that have not been answered in previous studies, and these are questions the current work seeks to answer.

CHAPTER 4

NATURAL SPEECH

4.0 Introduction

To understand children's acquisition of T3S, spontaneous speech of child-adult interaction provides valuable information through which we can learn, for instance, how the child and adult apply T3S in various syntactic contexts, the variability in T3S application in adults and children, and the approximate frequency of the T3S input.

Although T3S is the most extensively studied tone sandhi phenomenon in Mandarin, very little is known about T3S in the context of child-parent interactions. This study seeks to fill in some gaps. First, T3S application in the caretakers' speech has not been studied or described in previous research. Second, we do not have detailed reports on children's application of T3S within a word or across words, within constituents or across constituents. Furthermore, we don't know the frequency of T3S in the input. It would be good to have a general idea of how much T3S input a child receives, and the types of T3S application (e.g. cyclic or non-cyclic, application or non-application of optional T3S) and the T3S variability in the input. Finally, do children and adults behave similarly in spontaneous speech with respect to T3S?

The questions we address in this chapter are the following: what is the frequency of T3S application produced in spontaneous speech samples of children and caretakers (the number of T3S applications is compared to total syllables produced by each participant)? How do children and caretakers apply T3S at different levels (within words, within constituents, and across constituents)? Is there T3S variation within and across speakers?

The chapter is organized as follows. Section 4.1 provides additional information on T3S (which was not included in Chapter 2) that is relevant to our discussion in this natural speech study. Section 4.2 briefly discusses T3S in natural speech. Our hypotheses and predictions are in Section 4.3. In Section 4.4, the methodology used in the study is described. Section 4.5 presents the results. Section 4.6 discusses the results and findings. Section 4.8 concludes the chapter with a summary of our findings.

4.1 Additional linguistic background

The Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997), reviewed in Chapter 2, is used in demonstrating and discussing the sample sentences produced in our natural speech study. Before we discuss the natural speech data in our study, a point regarding T3S at the Word level which is relevant to the analysis of the natural speech data will be addressed first. For ease of presentation, I follow Lin's (2007) derivational processes.

According to the *immediate constituents* principle (Shih 1997:98), in the Word-and-Phrase level Model immediate constituents are joined in disyllabic feet, such as in (1) and (2).

(1)	[Gou	[yao	[[hao-xin]	ren]]]	(Shih 1997:97-99)
	dog	bite	good-natured	person	'Dogs bite a good-natured person.'
	3	3	31	2	UT
	3	3	(31)	2	Word: no T3S
	3	3	(31	2)	Word: incorporation, no T3S
	(**2**	3)	(31	2)	Phrase: T3S; ST1
	(2	**2**)	(31	2)	Phrase: T3S across domains; ST2
or	(3)	(2	31	2)	derived by cyclic application; ST3

Shih (1997:98) suggests that the two syllables *hao-xin* 'good-natured' are joined to form a foot because they are immediate constituents. At the Word level, there is no T3S. At the phrase level, the first two syllables are parsed and form a foot, and T3S applies. We have ST1 (**T2**T3)(T3T1T2) (ST1 is not listed in the Shih 1997, but it is included here as the model predicts this pattern as well). If optional T3S applies across the domains, we have ST2 (**T2T2**)(T3T1T2). Shih (1997:97) argues that for the first two monosyllabic syllables, prosodic restructuring occurs as these two syllables form a domain and such operation can ignore a very strong syntactic boundary (subject-predicate boundary in this case). According to Shih (1997:97), the parsing of ST3 is derived by cyclic T3S application in terms of syntactic structure.

(2)	[[ta	[[da	zhong]	shou]]	le]	(Shih 1997:108)
	he	hit	swollen	hand	aspect marker	‘He hit his hand and it became swollen.’
	1	3	3	3	0	UT
	1	(**2**	3)	3	0	Word: T3S
	1	(2	3)	(3	0)	Phrase: no T3S
	(1	2	3)	(3	0)	Phrase: no T3S; ST1
	(1	2	**2**)	(3	0)	Phrase: T3S across domains; ST2
	*(1	3)	(2	3	0)	ungrammatical

In addition to the immediate constituents condition by which an adjective *hao-xin* ‘good-natured’ is parsed first at the Word level, the unit “verb + resultative complement” is also dealt with at the Word level, by the *immediate constituent* condition (Shih 1997:108). Shih suggests that by the *immediate constituent* condition the verb *da* ‘hit’ and the resultative complement *zhong* ‘swollen’ in (2) should be grouped together first because the resultative complement is the complement of verb, the sister of the verb in the syntactic structure.

As we see in (2), although *da zhong* ‘hit-swollen’ (‘it was hit and it became swollen’) is composed of a verb and a resultative complement, it is dealt with at the Word level because of the *immediate constituents* condition. ST1 is not included in Shih (1997), but is listed in (2) as it is a possible pattern, predicted by the model. When T3S applies across domains, we have ST2. In the unacceptable pattern in (2), the verb and its complement are not dealt with first (i.e. they do not form a foot at the Word level). The first two syllables *ta* ‘he’ and *da* ‘hit’ are grouped together from left to right at the Phrase level, requiring in the immediate constituents *da* ‘hit’ and *zhong* ‘swollen’ to be separated, and such parsing is unacceptable. Let us look at one more example in (3).

(3)	[[[xiuli]	hao]	[biao]]	(Chen 2000:395-396)
	repair	fine	watch	'repair the watch so that it works fine now[15] (that the watch works fine is the result of the repair'
	1 3	3	3	UT
	(13)	3	3	Word[16]: no T3S
	(1**2**	3)	3	Word: T3S
	(12	**2**	3)	Phrase: incorporation, T3S, ST

In (3), we see a disyllabic verb, followed by a resultative complement. In this example, parsing of the syllables begins with the lexical item *xiuli* 'repair,' and T3S does not apply. Similar to (2), where the unit of a verb followed by a resultative complement is handled at the Word level, *xiuli* 'fix' + *hao* 'fine' is dealt with at the Word level, and T3S applies. At the Phrase level, *biao* 'watch' is incorporated in the preceding foot, and T3S applies again. The surface pattern is T1**T2T2**T3.

The discussion above is relevant to the analysis and discussion of sentences in the current study. I will follow the immediate constituents condition (Chen 2000; Shih 1986; Shih 1997) in the analysis of the data. For instance, *xizao* (T3T3)→ (**T2**T3) 'bathe, take a shower' is taken as a lexical item and parsed at the Word level, rather than the Phrase level.

4.2 T3S in natural speech

In order to study T3S, adjacent T3* are needed because T3S is triggered only in such environment. If there are two T3-sequences in the same sentence, interrupted by one or more than one non-T3 syllable, T3S operates separately within these two T3-sequences, and never

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[15] Chen (2000:394-395) says that there are two additional interpretations of the meanings of the sentence: (i) *hao* 'fine' modifies the noun 'watch': [[*xiuli*] [*hao* [*biao*]]] 'to repair a fine watch,' and (ii) *hao* as an aspect marker indicating having finished something [[[*xiuli*] *hao*] *biao*] 'finished with fixing the watch.' These two readings are not the intended meaning for his analysis in (3).

[16] Chen (2000:395) uses "Lexical MRU (Minimal Rhythmic Unit)" which corresponds to the foot building at the Word level in Lin (2007).

goes across the non-T3 syllable(s) as illustrated in (4), a sentence of an adult participant in this study.

(4) Two T3- sequences interrupted by a non-T3

[[Wo	[ye	[hao	[xiang	[qu	xizao]]]]]	wo]	(Adult CL)
I	also	really	want	go	take a shower	PRT	‘I also really want to go take a shower!’ (speaking for an animal while playing with the child)
3	3	3	3	4	33	0	UT
3	3	3	3	4	(**2**3)	0	Word: T3S
(**2**	3)	(**2**	3)	4	(23)	0	Phrase: disyllabic feet; T3S
(2	3)	(2	3)	(4	23)	0	Phrase: incorporation
(2	3)	(2	3)	(4	23	0)	Phrase: incorporation; ST

In (4), the non-T3 syllable *qu* ‘go’ interrupts the sequence of T3*, resulting in two separate T3-sequences. T3S applies within each of the two T3-sequences without going across the non-T3 syllable *qu* ‘go.’ T3S in *xizao* ‘take a shower’ is a case of application at the Word level as discussed in Section 4.2. The other two T3S applications in the first two prosodic domains are cases of T3S application at the phrase level. A sentence with many adjacent T3* as we see in (4) does not occur very frequently. On the other hand, cases of two adjacent T3* within words or across words are fairly common as shown in (5) and (6) respectively.

(5) Two adjacent T3* — within a word

[shuimu]	‘jellyfish’
33	UT
(**2**3)	Word: T3S; ST

(6) Two adjacent T3* — across words

[[hao]	[shao]]	
so	little	‘so little’
3	3	UT
3	3	Word: no T3S
(**2**	3)	Phrase: disyllabic foot, T3S; ST

In (5) and (6) where there are two adjacent T3*, the first T3 surfaces as a sandhi tone, T2. For a lexical item that has two underlying T3* as in (5), the surface tones **T2**T3 are always what children hear in the input. In (6), *hao* 'so' when parsed with another T3 in the same prosodic domain surfaces as a **T2**, but in (7) remains as its underlying tone when followed by a non-T3.

(7) No adjacent T3*, no T3S application

[[hao]	[duo]]	
so	much	'so much'
3	1	UT
3	1	Word: no T3S
(3	1)	Phrase: no T3S; ST

Hao 'so' remains as its underlying tone T3 in (7) since there is no T3-sequence to trigger T3S application. (6) and (7) are simple examples that show a short phrase in a T3-sequence and a non-T3 sequence respectively. Contrastive examples like (6) and (7) may be simple, but such examples as well as multiple T3S applications in a more complex context such as in (4) are essential for children to figure out what the underlying tones are and when and how to apply T3S correctly.

By studying what children hear in the input, not only do we learn how adults actually apply the rule, we also have a better understanding of what kind of T3S input children receive and how they apply T3S. We know that T3S is triggered where there are at least two adjacent T3*. Since there are four lexical tones in Mandarin Chinese, the probability of having all syllables in T3 in a sentence is relatively low.

In the current study, all the T3-sequences produced by children and adults in natural speech are extracted to investigate how T3S is applied in various contexts. In the next section, we present hypotheses for investigating T3S in natural speech.

4.3 Hypotheses and predictions

The age range of child participants is 4 to 6 years of age. Since these children are older than those in previous spontaneous speech studies, we expect that these children will have little trouble with T3S application. More specifically, they will have no trouble applying T3S cyclically at the Word level and non-cyclically at the Phrase level.

Because these children are older and presumably are more mature not only in their phonological development but also in their syntactic development, they probably can produce longer and more complex sentences than the younger children in previous studies.

In what follows, “within constituents” refers to syntactic units such as a verb phrase. “Across constituents” refers to units that are not typically grouped together syntactically as in the case of a unit formed by a subject and a verb, even though such a unit is not uncommon in prosodic parsing. We hypothesize that T3S application occurs more frequently within constituents than across constituents. For instance, T3S application in a ‘subject + verb’ unit (i.e. a non-constituent) is expected to be less frequent than T3S application in a ‘verb + object’ unit (i.e. a constituent).

Finally, if adult speech has multiple T3S patterns, we expect that children’s speech will also. Since we cannot compare identical sentences across participants in spontaneous speech, we will observe whether there are identical or very similar sentences across speakers. We hypothesize that there will be T3S variation in identical or similar sentences. Our hypotheses are summarized in (8).

(8) Hypotheses for T3S in spontaneous speech in 4- to 6-year-olds and their caretakers

H_1: Children age 4 – 6 can apply T3S cyclically at the Word level and non-cyclically both in constituents and across constituents at the Sentence level.

H_2: T3S application occurs more frequently within constituents than across constituents.

H_3: Variability in T3S application is expected due to the various strategies that can be used.

4.4 Method

For the recording of the interactions between the caretaker and the child, we provided a set of toy wild animals, farm animals, farm vehicles, and a play mat which had sections of meadows, farmlands, barns, a pond, etc. The child and the caretaker could play with these toys, but were free to play with their own toys and engage in a typical play session if they wish.

4.4.1 Subjects

Seven children age from 4;5 to 6;6 and five caretakers participated in this study (Table 4.1). Three recordings are recordings of one child and one caretaker. One recording is of twin boys (BR 6;6 and ER 6;6) playing with their mother (Adult TT), and one recording is of a boy (CH 4;5) and a girl (LI 4;6) who are cousins playing with the girl's mother (Adult CZ). The children had no known language or hearing deficits at the time of the recording. Three of the adult participants are elementary school teachers.

Table 4.1 Study 1: Distribution of the subjects

Children	Children's age	Caretakers	Time Duration (minutes)
Child CH	4;5	Adult CZ	35
Child LI	4;6	Adult CZ	35
Child IU	4;6	Adult LU	30
Child ES	5;5	Adult CL	30
Child GK	5;9	Adult EE	36
Child BR	6;6	Adult TT	25
Child ER	6;6	Adult TT	25

4.4.2 Data Collection and transcription

The data were collected in Miaoli, Taiwan. The children and the caretakers were audio- and video-recorded at participants' homes for approximately half an hour. After setting up the equipment, the investigator and the research assistant normally left or stayed on the other side of the room to make sure that the interaction between the child and the mother would be as natural as possible. All subjects' responses were recorded on a Marantz PMD660 with an Audio-technica miniature clip-on microphone (AT831B Cardioid Condenser Lavalier microphone).

A research assistant specialized in phonology and phonetics transcribed all the recordings following CHILDES (Child Language Data Exchange System) conventions (MacWhinney 2000). All the sentences were transcribed in Mandarin Chinese, and the surface tones produced were recorded. Since Mandarin Chinese was used in the transcription, the underlying tone of each character is evident as each character has a lexical tone assigned to it. Surface tones provide the information on how the sentences were said.

4.4.3 Coding procedures

For the purpose of examining T3S application in children and adults, all the sentences with T3-sequences were extracted and further analyzed. Children's repetition of the caretakers' utterances was excluded from the analyses.

Sequences of adjacent T3* were considered T3S environments which trigger the application of T3S. The minimal number of adjacent T3* that triggers T3S application is two. However, if the two T3* belong to different prosodic domains, T3S application is optional. There is no upper limit of number of adjacent T3* to be counted as a T3-sequence. Each occurrence of adjacent T3* was regarded as one single T3-sequence. A sentence in spontaneous speech may have no T3-sequence at all, or it could have one or more than one T3-sequence (i.e. only one T3-sequence or more than one T3-sequence, interrupted by one or more than one non-T3 syllable).

For each T3-sequence that triggers T3S, the T3S application by the speaker was categorized at three levels— (i) Word level, (ii) within constituents, and (iii) across constituents. Examples of for these levels are in (9) – (11).

Where there are multiple patterns predicted for the phrases or sentences produced by children and adults, the pattern that was produced will be marked 'used.' For instance, ST1 and ST2 may both be predicted to be grammatical patterns, and if ST2 was used by the speaker, "ST2 (used)" will show. It should be emphasized that this does not mean that ST1 is ungrammatical. It may be used by other speakers, or the same speakers at other times. It only means that it was not used by the speaker at the time of the recording.

(9) Within words

a. [keyi] 'can (auxiliary)' (LI 4;6)
  33 UT
  (**2**3) T3S; ST

b. [nali] 'where' (LI 4;6)
  33 UT
  (**2**3) T3S; ST

c. [suoyi] 'so' (ES 5;5)
  33 UT
  (**2**3) T3S; ST

d. [zhiyou] 'only' (GK 5;9)
  33 UT
  (**2**3) T3S; ST

e. [laohu] 'tiger' (BR 6;6)
  33 UT
  (**2**3) T3S; ST

In (9), T3S applies within the lexical items. Evidence that the data in (9) are not underlyingly T2T3 are *keshi* 'but' (T3T4), *nar* 'where' (T3T0), *suode* 'income' (T3T2), *zhiyao* 'as long as' (T3T4), and *laoshi* 'teacher' (T3T1). In these examples, the first syllable is a T3, and it does not undergo T3S because it is followed by a non-T3. In addition, each character is assigned an underlying tone, so it is clear what the underlying tones of items in (9) are. In (10), T3S applies in syntactic constituents *gei wo* 'let me' and *zhao wo* 'give back (the change; the amount of money) to me', and these are cases of T3S application within constituents at the sentence level.

(10) Within constituents

a.	[[Gei	wo]	kan]	(ER 6;6)
	let/allow	me	see	‘Let me see.’
	3	3	4	UT
	2	3	4	Word: no T3S
	(**2**	3)	4	Phrase: disyllabic foot, T3S
	(2	3	4)	Phrase: incorporation, no T3S; ST

b.	[Ni	[yao	[[zhao	wo]	[shi	kuai]]]]	(GK 5;9)
	you	have to	give back	me	ten	dollar	‘You have to give me ten dollars back.’
	3	4	3	3	2	4	UT
	3	4	2	3	(2	4)	Word: no T3S
	(3	4)	(**2**	3)	(2	4)	Phrase: disyllabic feet, T3S; ST

There are adjacent T3* in both (11a) and (11b). T3S does not apply within words in (11a) and (11b). At the Phrase level, when the subject pronoun *wo* ‘I’ is incorporated into the foot that follows it, T3S applies. In (11a) and (11b), T3S applies across the subject-predicate boundary, and *wo* ‘I’ surfaces as a **T2**.

(11) Across constituents

a.	[Wo	[xiang	wan]]	(LI 4;6)
	I	want	play	‘I want to play.”
	3	3	2	UT
	3	3	2	Word: no T3S
	3	(3	2)	Phrase: disyllabic foot for smallest domain, no T3S
	(**2**	3	2)	Phrase: incorporation, T3S; ST

b.	[Wo	[xihuan	[wanju	che]]]	(IU 4;6)
	I	like	toy	car	‘I like toy cars.”
	3	31	24	1	UT
	3	(31)	(24)	1	Word: no T3S
	3	(31)	(24	1)	Word: incorporation, no T3S
	(**2**	31)	(24	1)	Phrase: incorporation, T3S; ST

c.	[[Nali]	[you	[[rou]	[hao	chi]]]	a]	(ES 5;5)
	where	have	meat	to	eat	PRT	‘Where can I find meat to eat?’
	33	3	4	3	1	0	UT
	(**2**3)	3	4	3	1	0	Word: T3S
	(23)	(3	4)	(3	1)	0	Phrase: disyllabic foot, no T3S
	(23)	(3	4)	(3	1	0)	Phrase: incorporation, no T3S; ST1
	(2**2**)	(3	4)	(3	1	0)	Phrase: T3S across domains; ST2 (used)

In (11c), *you* ‘have,’ *rou* ‘meat’, *hao* ‘good, and ’*chi* ‘eat’ appear with the structure “*you* ‘have’ + noun + *hao* ‘lit. good’ + verb” which is commonly used to express, for instance, ‘there is something to drink/eat/read/say’. There are three adjacent T3* in (11c). At the Word level, T3S applies in the word *nali* ‘where.’ This is a case of T3S application within a word. At the Phrase level, T3S applies across *nali* ‘where’ and *you* ‘there is,’ which is a case T3S application across constituents.

Once all the data had been coded, total T3S applications, total correct applications, and T3S applications at different levels were counted for each participant. Each T3S production was counted as one T3S token, including the same item said multiple times. T3S type counts refer to the number of different phrases or contexts the T3S instances occurred in.

The sentence in (12) illustrates how the number of T3S applications is counted.

(12)	[[Gei	[wo]]	[wu-shi	kuai]]	
	Give	me	five-ten	dollar	‘Give me fifty dollars.’
	3	3	32	4	UT
	3	3	(32)	4	Word: no T3S
	3	3	(32	4)	Word: incorporation, no T3S
	(**2**	3)	(32	4)	Phrase: disyllabic foot, T3S; ST1 (used by GK 5;9)
	(2	**2**)	(32	4)	Phrase: optional T3S across domains; ST2 (used by IU 4;6, Adult LU, Adult EE)

In (12), ST1 has only one sandhi tone (*gei* ‘give’) that undergoes T3S, so ST1 has one T3S application. ST2 has two sandhi tones (*gei* ‘give’ and *wo* ‘I’), so ST2 of Child IU, Adult LU and Adult EE has two T3S applications.

Finally, examples of how T3S is counted at the three levels will be presented. Recall that each case of adjacent T3* is counted as one T3-sequence. Within each T3-sequence, there can be one T3S application as in (13), or there can be more than one T3S application at different levels as we see in (14).

(13) One T3S application *within a word*

[nali]	'where' (LI 4;6)
33	UT
(**2**3)	T3S; ST

(14) Two T3S applications *within constituents* and *across constituents*

[Wo	[xiang(yao)	[xiao	de]]]	(BR 6;6)
I	want	small	one	'I want the small one.'
3	3	3	0	UT
3	3	(3	0)	Word: no T3S
(**2**	3)	(3	0)	Phrase: disyllabic foot, T3S; ST1
(2	**2**)	(3	0)	Phrase: T3S across domains; ST2 (used)

In (13), the first syllable undergoes T3S, and this T3S application occurs within a word. The example in (13) is counted as one T3S-sequence, and one T3S application within words.

There are two surface patterns for (14), and BR (6;6) produced ST2. In (14), T3S is not applicable at the Word level. At the Phrase level, *wo* 'I' and *xiang* 'want' are parsed in one foot, and T3S applies within this foot. ST1 (**T2**T3)(T3T0) is derived. When optional T3S is applied across the two prosodic domains, we have ST2 (**T2T2**)(T3T0). In this case, the first two syllables undergo T3S. T3S applies across the subject-predicate boundary and *wo* 'I' surfaces as the sandhi tone, **T2**. This is a case of T3S application across constituents because *wo xiang* 'I want' is not a syntactic constituent. The second syllable that also surfaces as the sandhi tone **T2** is a case of T3S application within a *constituent* because *xiang xiao de* 'want the small one' is a syntactic constituent (i.e. the VP is a syntactic constituent, as opposed to, for instance, *wo xiang* 'I want' which is not a syntactic constituent). The example in (14) is counted as one token of T3-sequence (that is, adjacent T3*), but two T3S applications.

In (14), ST2 is derived through optional T3S across domains. Alternatively, left-to-right parsing in fast speech will produce (**T2T2**T3T1). However, Child BR (6;6) produced this in a natural speech setting, not the fast speech setting. The fast speech parsing (**T2T2**T3T1) and ST2

(**T2T**2)(T3T1) are both strings of **T2T2**T3T1 when we look only at the sequence of the tones produced without the prosodic domains they are in.

4.5 Results

In this section, we first report the production of T3*, including adjacent and non-adjacent T3* produced by each participant in Table 4.2.

Table 4.2 Study 1: Number of T3 (adjacent and non-adjacent) and total syllables produced

Participants	T3: Non-adj	T3: Adj	T3: total	Total N of σ	% of T3
Adult CZ[17]	753	258	1011	4655	**21.72** (1011/4655)
Adult LU	582	275	857	3301	**25.96** (857/3301)
Adult CL	467	222	689	2912	**23.66** (689/2912)
Adult EE	295	219	514	2131	**24.12** (514/2131)
Adult TT[18]	546	160	706	2589	**27.27** (706/2589)
CH (4;5)	24	12	36	176	**20.45** (36/176)
LI (4;6)	136	39	175	770	**22.73** (175/770)
IU (4;6)	237	106	343	1395	**24.59** (343/1395)
ES (5;5)	323	103	426	1635	**26.06** (426/1635)
GK (5;9)	320	135	455	1817	**25.04** (455/1817)
BR (6;6)	135	57	192	790	**24.30** (192/790)
ER (6;6)	146	39	185	838	**22.08** (185/838)

[17] Adult CZ is the mother of LI (4;6) and the caretaker of CH (4;5). The two children LI and CH are cousins and they play together.
[18] Adult TT is the mother of twin boys BR (6;6) and ER (6;6).

The production of adjacent T3* is further divided into *two, three*, and *four or more*[19] adjacent T3*. Table 4.3 shows the number of tokens of *two, three,* and *four or more* T3* produced by each participant.

Table 4.3 Study 1: Number of T3-sequences: two, three, and four or more T3*

UT	Two T3*: 33				Three T3*: 333				Four or more T3*:3333(3)						% of **T2**
ST	**2**3	3)(3	# T3	# **T2**	**22**3	3**2**3	# T3	# **T2**	**222**3	**2**3**2**3	3)(3**2**3	3**22**3	# T3	# **T2**	(Total **T2/** Total T3*)
Adult CZ	95	8	206	95	9	7	48	25	1	0	0	0	4	3	**47.67** (123/258)
Adult LU	115	3	236	115	9	4	39	22	0	0	0	0	0	0	**49.82** (137/275)
Adult CL[20]	88	2	180	88	5	4	30	15	1	1	1	0	12	6	**49.10** (109/222)
Adult EE[21]	85	3	176	85	6	4	30	16	2	0	0	0	13	6	**48.86** (107/219)
Adult TT	57	2	118	57	5	5	30	15	0	1	0	2	12	6	**48.75** (78/160)
CH (4;5)	3	0	6	3	2	0	6	4	0	0	0	0	0	0	**58.33** (7/12)
LI[22] (4;6)	14	0	30	15	3	0	9	6	0	0	0	0	0	0	**53.85** (21/39)
IU (4;6)	44	0	88	44	3	3	18	9	0	0	0	0	0	0	**50.00** (53/106)
ES (5;5)	40	1	82	40	3	4	21	10	0	0	0	0	0	0	**48.54** (50/103)
GK (5;9)	52	2	108	52	2	3	15	7	1	0	0	2	12	7	**48.89** (66/135)
BR (6;6)	12	0	24	12	7	4	33	18	0	0	0	0	0	0	**52.63** (30/57)
ER (6;6)	14	0	28	14	0	1	3	1	2	0	0	0	8	6	**53.85** (21/39)

(# T3= total number of underlying T3; # **T2**= total number of sandhi tone (i.e. T3 that surfaced as **T2**; "3)(3" or "3)(3**2**3" indicate the two adjacent T3* belong to different prosodic domains.)

[19] There is only one case of five adjacent T3* produced by one adult (Adult EE). There are no cases where the number of adjacent T3* goes beyond five.

[20] For the category of three T3*, Adult CL also produced a sequence of (T2T3)(T3T4)

[21] For the category of "four or more T3*, Adult EE produced two sequences of four adjacent T3* (4 T3* × 2 = 8 T3*) and one sequence of five adjacent T3* (5 T3* ×1 = 5 T3*).

[22] Child Li (4;6) made a T3S error in a two-T3 sequence where she produced *T3**T2** instead of **T2**T3. There are 15 two-T3 sequences, with a total of 30 underlying T3* and 15 sandhi tones. Within the 15 sandhi tones, one is a misapplication.

Table 4.4 shows the T3S frequency (total number of T3S applications divided by total syllables produced) for each participant.

Table 4.4 Study 1: T3S frequency

Caretakers	Total T3S applications	Total syllables produced	T3S (%)	Children	Total T3S applications	Total syllables produced	T3S (%)
Adult CZ	132	4655	**2.84**	CH (4;5)	7	176	**3.98**
				LI (4;6)	20	770	**2.60**
Adult LU	153	3301	**4.63**	IU (4;6)	57	1395	**4.09**
Adult CL	123	2912	**4.22**	ES (5;5)	58	1635	**3.55**
Adult EE	91	2131	**4.27**	GK (5;9)	72	1817	**3.96**
Adult TT	90	2589	**3.48**	BR (6;6)	24	790	**3.04**
				ER (6;6)	20	838	**2.39**

(T3S % = Total T3S applications/Total syllables produced)

The numbers of T3S applications in Table 4.4 are the number of times the T3S rule is applied and an underlying T3 changes to a T2. The first question is whether or not T3S frequency of children and adults are similar. In Table 4.4, we see that the T3S frequency for each child and adult is under 5%. All children except for CH (4;5) have a slightly lower T3S frequency than their caretakers. However, the T3S frequency of children highly resembles that of adults. Next, we turn to how children did when they produced T3S.

Table 4.5 presents all the child and adult participants' overall production of T3S, token counts and correct rates. Each different case of T3S is regarded as a type. Each type may be said one time only, or multiple times. "Token counts" in Table 4.5 refers to total tokens of T3S applications.

Table 4.5 Study 1: T3S correct rates

Caretakers	Type counts	Token counts	Correct tokens	Correct rate (%)	Children	Type counts	Token counts	Correct tokens	Correct rate (%)
Adult CZ	85	132	130	**98.48**	CH (4;5)	4	5	5	**100**
					LI (4;6)	11	18	17	**94.44**
Adult LU	85	142	142	**100**	IU (4;6)	19	53	53	**100**
Adult CL	68	115	115	**100**	ES (5;5)	41	57	57	**100**
Adult EE	52	80	80	**100**	GK (5;9)	41	65	64	**98.46**
Adult TT	61	88	87	**98.86**	BR (6;6)	19	22	21	**95.45**
					ER (6;6)	13	16	16	**100**

(Correct % = Total correct tokens/ Total tokens)

All children and adults have a 100% or near 100% correct rate. Two T3S errors were found in Adult CZ and Adult TT as shown in (15a) and (15b) respectively.

(15) T3S errors in adults

a.	[Ni	[hui	[na	[shenme	dongxi]]	[[gen	tamen]	[yiqi	zhu]]]]	(Adult CZ)
	you	will	take	what	thing	with	hem	together	cook	‘What will you take (out) to cook with them?’
	3	4	2	30	11	1	10	13	3	UT
	3	4	2	(30)	(11)	1	(10)	(13)	3	Word: no T3S
	(3	4)	2	(30)	(11)	1	(10)	(13)	3	Phrase: no T3S
	(3	4	2)	(30)	(11)	(1	10)	(1**2**	3)	Phrase: incorporation; T3S; ST
	*(3	4	2)	(30)	(11)	(1	10)	(13	3)	ST (used; two tokens)

b.	[Zhuan	[hen	yuan]]	(Adult TT)
	spin	very	round	‘(It) spins round and round; (it) spins and it’s round.’
	3	3	2	UT
	3	(3	2)	Word: disyllabic foot for the smallest domain, no T3S
	(**2**	3	2)	Phrase: incorporation, T3S; ST
	*(3	3	2)	ST (used; one token)

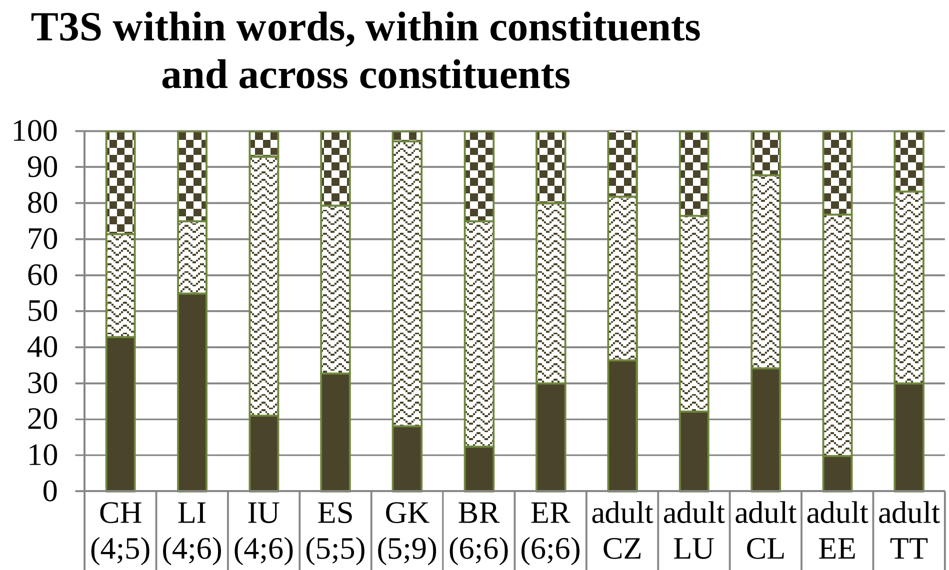
The small number of T3S tokens in some children, such as Child CH (4;5) who had only 5 T3S tokens, may not be very telling. Also, Child IU (4;6) produced a large number of T3S tokens, but many of them were of the same types, so the type counts were much lower. This was the case for three caretaker adults CZ, LU, and CL as well. It is not surprising as repetition of the same sentence is common in child-parent interactions. Sentences such as "…g*ei wo* (give (something) to me)" and "*Wo xiang*… (I want…) are two common sentence types with identical T3 strings that were said multiple times by some of these children and their caretakers. Overall, children appeared to apply T3S without much difficulty.

Let us now look more specifically at T3S application at different levels—*within words, within constituents,* and *across constituents*. Table 4.6 shows the number of T3S applications at the three levels by subjects. The percentage for each level by subjects is presented in Figure 4.1.

Table 4.6 Study 1: Number of T3S applications within words, within constituents, and across constituents

Participants	Application levels: Within Words	Within constituents	Across constituents	T3S applications total
CH (4;5)	3	2	2	7
LI (4;6)	11	4	5	20
IU (4;6)	12	41	4	57
ES (5;5)	19	27	12	58
GK (5;9)	13	57	2	72
BR (6;6)	3	15	6	24
ER (6;6)	6	10	4	20
Adult CZ	48	60	25	132
Adult LU	34	83	36	153
Adult CL	42	66	15	123
Adult EE	9	61	21	91
Adult TT	27	48	15	90

Figure 4.1 Study 1: Percentages of T3S application at three levels by subjects



	CH (4;5)	LI (4;6)	IU (4;6)	ES (5;5)	GK (5;9)	BR (6;6)	ER (6;6)	adult CZ	adult LU	adult CL	adult EE	adult TT
Across constituents	28.57	25	7.02	20.69	2.78	25	20	18.94	23.53	12.20	23.08	16.67
Within constituents	28.57	20	71.93	46.55	79.17	62.50	50	45.45	54.25	53.66	67.03	53.33
Within words	42.86	55	21.05	32.76	18.06	12.50	30	36.36	22.22	34.15	9.89	30

For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.

In Figure 4.1, the number of T3S applications within words is greatest in two four-year-olds CH (4;5) and LI (4;6). As mentioned earlier, the small T3S counts make these results very preliminary. Except for these two children, T3S applications appear to occur most frequently within constituents. T3S applications at all three levels are attested in all the participants. However, there is not a clear trend of increase or decrease of T3S application with age at any particular level.

The second question asked is whether or not children ages 4 – 6 can apply T3S cyclically at the Word level and non-cyclically at the constituent level. Unfortunately, we are unable to conclude whether or not children ages 4 – 6 could apply T3S cyclically within words due to the lack of evidence of multiple T3S applications within a lexical item. In almost all the Word-level lexical items used by the children there were at most only two adjacent T3*, such as *keyi* (T3T3) ‘can,’ *suoyi* (T3T3) ‘so,’ *nali* (T3T3) ‘where,’ *laohu* (T3T3) ‘tiger,’ *xizao* (T3T3) ‘take a shower/bath,’ *yongyuan* (T3T3) ‘forever,’ *buru* (T3T3) *dongwu* (T4T4) ‘mammals (lit. breast-feeding animals).’ All of these underlying T3T3 sequences surface as **T2**T3 sequences. These vocabulary items most likely are learned as frozen chunks[23] (see Appendix A for a complete list of possible frozen chunks). The only example with more than two adjacent T3* at the Word level in children’s data was *Mi-laoshu* ‘Mickey Mouse’ (T3T3T3→ T3**T2**T3) produced by ES (5;5), and as a proper noun (it may be a lexicalized item), it does not serve as a good piece of evidence that the child did apply T3S cyclically. Due to the lack of child spontaneous speech data of cyclic T3S application in multiple-layered morphosyntactic structures, such as compound nouns or NPs where cyclic application is required, we are unable to have a conclusive argument regarding children’s cyclic T3S application within words.

With respect to strategies, they also can apply T3S non-cyclically both within constituents and across constituents. To know whether or not children apply T3S non-cyclically, T3S applications at the Phrase level are examined. Crucially, T3S applications in sequences of three or more T3* must be examined. Correct T3S application in a sequence of two T3* is insufficient because **T2**T3 can be derived from either cyclic or non-cyclic parsing as illustrated in (16) where T1 is used for the first syllable, but T2 or T4, which are also non-T3*, will give the same prediction regarding how T3S is applied.

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[23] Although disyllabic lexical items which have a sequence of T3T3 underlyingly and surface as **T2**T3 are most likely to be learned as frozen chunks, it is not clear whether or not separate monosyllabic T3-lexical items, when combined (such as *wo* ‘I’/ *ni* ‘you’ and *xiang* ‘want’ to form “I/you want…” which are common in child-parent interactions), are also learned as frozen chunks.

(16) [T1 [T3 [T3 …]]]
a. a cyclic parsing strategy (bottom-up)
T1 (**T2** T3)→ (T1T2T3)
b. a non-cyclic parsing strategy (left-to-right)
(T1 T3) T3→ (T1**T2**T3)

In (16), we see that even though derivational processes of cyclic and non-cyclic parsing strategies differ, the surface patterns in (16a) and (16b) are the same. If the two adjacent T3* are the first two syllables, and the third syllable is a non-T3, the surface pattern will be (**T2**T3T1) through both cyclic and non-cyclic parsing strategies.

In what follows, I will show how a sequence of at least three T3* at the Phrase level allows us to see more clearly what parsing strategy is used at this level. Several cases produced by some children will be discussed.

T3S application in three adjacent T3* from three hierarchical layers can offer us some evidence as shown in a simplistic way in (17). Disyllabic T3T3 lexical items (e.g. *xizao* T3T3→ (**T2**T3) 'bathe/take a shower') preceding or following another T3 are excluded from the discussion of (17) because T3S always applies to T3T3 lexical items before it applies to a third T3.

(17) [T3 [T3 [T3 …]]]
a. a cyclic parsing strategy (bottom-up)
T3 (**T2** T3)→ (T3T2T3)
b. a non-cyclic parsing strategy (left-to-right)
(**T2** T3) T3→ (T2**T2**T3)

As we see in (17), a cyclic parsing strategy predicts (T3**T2**T3) while a non-cyclic parsing strategy predicts (**T2T2**T3). A small number of sentences were produced by children in this study that fit the description of the T3-sequence in (17). Sample sentences are in (18) – (20), with the adjacent T3* underlined. The derivational process in (18), (19), and (20) follows the Word-and-Phrase level Model (non-cyclic parsing at the Phrase level).

(18)	[[Mama,]	[wo	[ye	[xiangyao	wan]]]]	(LI 4;6)
	Mommy	I	also	want	play	'Mommy, I also want to play.'
	32[24]	3	3	34	2	UT
	(32)	3	3	(34)	2	Word: no T3S
	(32)	(**2**	3)	(34)	2	Phrase: disyllabic foot, T3S
	(32)	(2	3)	(34	2)	Phrase: incorporation, no T3S; ST1
	(32)	(2	**2**)	(34	2)	Phrase: T3S across domains; ST2 (used)

(19)	[Wo	[yao	[zhao	[wo	[baba]	[mama]]]]]	(ES 5;5)
	I	want	look for	my	daddy	mommy '	I want my mommy and daddy.'
	3	4	3	3	32	32	UT
	3	4	3	3	(32)	(32)	Word: no T3S
	(3	4)	(**2**	3)	(32)	(32)	Phrase: disyllabic feet, T3S; ST1
	(3	4)	(2	**2**)	(32)	(32)	Phrase: T3S across domains, ST2 (used)

(20)	[[Wo	[xiang	[[hen	duo	zhi]	[hen	duo	zhi]]]]ye]		(BR 6;6)
	I	want	very	many	CL	very	many	CL	PRT	'I want many many (of the animals)!'
	3	3	3	1	1	3	1	1	0	UT
	3	3	(3	1	1)[25]	(3	1	1)	0	Word: no T3S
	(**2**	3)	(3	1	1)	(3	1	1)	0	Phrase: disyllabic foot, T3S
	(**2**	3)	(3	1	1)	(3	1	1	0)	Phrase: Incorporation, no T3S, ST1
	(2	**2**)	(3	1	1)	(3	1	1	0)	Phrase: T3S across domains; ST2 (used)

In (18), (19), and (20), non-cyclic parsing at the Phrase level predicts the three-T3 sequence to surface as either (**T2**T3)(T3..) or (**T2T2**)(T3..). The former has two adjacent T3*, but since they belong to two different prosodic domains, it is grammatical. The three children who produced the examples in (18) – (20) used (**T2T2**)(T3..) which does not have any adjacent T3*.

[24] *Mama* 'mommy' is underlyingly T1T0 originally, but it has undergone some change in Taiwan Mandarin speakers, especially in children and in child-directed speech where *mama* 'mommy' is T3T2 underlyingly. Later in the discussion section, I will return to discuss the new forms (new underlying tones) in some vocabulary (mostly kinship terms) which Yeh (2010) investigates. I will also discuss how these new forms relate to this current T3S study.

[25] The parsing of *hen duo zhi* 'very many CL (classifier)' is simplified here, without going through the cyclic parsing for simple nouns, compound nouns, or NPs at the Word level in the Word-and-Phrase level model. Cyclic parsing for [[*hen duo*] [*zhi*] 'very many CL' is (T3T1)T1→(T3T1T1).

Although the sentences in (18) – (20) are evidence that these children know how to apply T3S non-cyclically at the Sentence level, due to the scarcity of similar data in the current study, we cannot claim that children do know to use non-cyclic parsing at the phrase or sentence level.

In order to test our second hypothesis—H_2: T3S application occurs more frequently within constituents than across constituents— the frequency of T3S being applied within constituents and across constituents is compared. Let us take a look at examples in (21) and (22). Application of T3S (ST2) and non-application of T3S (ST1) are both grammatical in these examples. If T3S applies more easily within constituents than across constituents, we should find a higher T3S application rate in the former than in the latter.

(21) Within constituents

[Ta	[you	[wasi	lu]]]	(Adult CZ)
he	has	gas	stove	‘He has a gas stove.’
1	3	31	2	UT
1	3	(31	2)	Word: no T3S
(1	3)	(31	2)	Phrase: no T3S; ST1
	↑ non-application			
(1	**2**)	(31	2)	Phrase: T3S across domains; ST2 (used)
	↑ application			

(22) Across constituents

[[laohu]	[ye	[shi	[liang	zhi]]]	ye]	(Adult CL)
tiger	also	are	two	CL	PRT	‘There are also two tigers!’
33	3	4	3	1	0	UT
(**2**3)	3	4	(3	1)	0	Word: T3S
(23)	(3	4)	(3	1)	0	Phrase: disyllabic foot, no T3S; ST1 (used)
↑ non-application						
(2**2**)	(3	4)	(3	1)	0	Phrase: T3S across domains; ST2
↑ application						

In (21), T3S is not applicable within words. T3S does not apply across the two prosodic domains in ST1. The non-application is grammatical because the two adjacent T3* belong to different prosodic domains. ST1 is a case of non-application within a syntactic constituent *you wasi lu* ‘has a gas stove.’ Adult CZ’s production is ST2, with the application of T3S across the two prosodic domains. This is a case of T3S application within a syntactic constituent.

In (22), T3S applies within a word. At the Phrase level, *ye shi* ‘also are’ form a disyllabic foot and T3S does not apply across the first two prosodic domains. This is ST1 that Adult CL used. ST2 is also a grammatical pattern where T3S applies across the first two prosodic domains. As we see in (21) and (22), application and non-application of T3S can occur within constituents as well as across constituents.

Application and non-application of T3S within constituents and across constituents were examined for each participant. T3S application rates in constituents and across constituents are calculated separately (T3S application % = total application of T3S/(total application of T3S + total non-application of T3S)) for each individual. It should be emphasized that all these tokens used for the calculation of the rate of T3S application are grammatical patterns (i.e. application or non-application of T3S in these contexts are both correct, and T3S errors were not included in such calculation). Table 4.7 shows the T3S application rates within constituents and across constituents by subject.

Table 4.7 Study 1: T3S application rates (%) within constituents and across constituents by subject

Caretakers	Within constituents	Across constituents	Children	Within constituents	Across constituents
Adult CZ	**83.88** (60/72)	**86.21** (25/29)	CH (4;5)	**100** (2/2)	**100** (2/2)
			LI (4;6)	**100** (4/4)	**100** (5/5)
Adult LU	**95.40** (83/87)	**90** (36/40)	IU (4;6)	**100** (41/41)	**66.67** (4/6)
Adult CL	**95.65** (66/69)	**83.33** (15/18)	ES (5;5)	**100** (27/27)	**75** (12/16)
Adult EE	**96.83** (61/63)	**95.45** (21/22)	GK (5;9)	**98.28** (57/58)	**28.57** (2/7)
Adult TT	**94.12** (48/51)	**62.50** (15/24)	BR (6;6)	**100** (15/15)	**66.67** (6/9)
			ER (6;6)	**100** (10/10)	**80** (4/5)
Average (adults)	**92.98** (318/342)	**84.21** (112/133)	Average (children)	**99.36** (156/157)	**70** (35/50)

As seen in Table 4.7, all adults have application and non-application of T3S within constituents and across constituents. Except for Adult CZ, all adults have a higher T3S application rate within constituents than across constituents. Adult TT's T3S application rate for *across constituents* is much lower than that for *within constituents* (within constituents: 94.12%; across constituents: 62.50%), but the difference is not great in other adults.

Almost all children applied T3S all the time within constituents as we see a 100% T3S application rate in all children except GK (5;9) whose T3S application rate within constituents is close to 100%. Children applied T3S across constituents 70% of the time. There was very little T3S data for two 4-year-olds, CH (4;5) and LI (4;6), so that the 100% within constituents and across constituents for them may not be as meaningful as for other participants. In fact, for all children, the data for T3-sequences across constituents are very few; therefore, these percentages of Table 4.7 may not accurately reflect how each of them actually applies T3S across constituents. Children vary greatly regarding application of T3S across constituents (e.g. GK 5;9: 28.57%, ER 6;6: 80%, and LI 4;6 100%).

If we compare adults' and children's average rates of application and non-application of T3S within constituents and across constituents, it appears that while adults do show little tendency of applying T3S more in one case than the other (within constituents: 92.98% vs. across constituents: 84.21%; a 8.77% difference), children appear to apply T3S more within constituents than across constituents (within constituents: 99.36% vs. across constituents: 70%; a 29.36% difference). While adults apply T3S fairly similarly within constituents and across constituents, children seem to distinguish them and almost always apply T3S within constituents, but apply T3S only 70% of the time across constituents. This may indicate that children are still developing to the stage where adults apply T3S within constituents and across constituents rather similarly. Children may not yet apply T3S as freely and automatically as adults would across constituents. Our second hypothesis— H_2: T3S application occurs more frequently within constituents than across constituents— cannot be confirmed for the following reasons.

(i) Adults data: T3S application occurred only slightly more frequently within constituents than across constituents (by a 8.77% difference).

(ii) Children's data: Although T3S application occurred a lot more frequently within constituents than across constituents in children (by a 29.36% difference), due to the relatively small amount of across-constituent data from each child, further investigation will be needed to confirm whether or not children do apply T3S much more frequently within constituents than across constituents.

We now turn to T3S variation attested in the spontaneous speech data. Despite the fact that sentences produced in spontaneous speech are not controlled for the purpose of comparison across subjects, sentences of similar T3S environments were extracted for testing our third hypothesis—H_3: Variability in T3S application is expected due to the various types of strategies that are available. We expect that there will be T3S variation in identical or similar sentences. We begin with one sentence that was produced by four participants.

(23)	[[Gei	[wo]]	[[wu-shi]		kuai]]	
	Give	me	five-ten		dollar	'Give me fifty dollars.'
	3	3	3	2	4	UT
	3	3	(3	2)	4	Word: no T3S
	3	3	(3	2	4)	Word: incorporation, no T3S
	(**2**	3)	(3	2	4)	Phrase: disyllabic foot, T3S; ST1 (used by GK 5;9)
	(2	**2**)	(3	2	4)	Phrase: T3S across domains; ST2 (used by IU 4;6, Adult LU, Adult EE)

In (23), Child GK (5;9) did not apply T3S across the prosodic domains, but Child IU (4;6), Adult LU, and Adult EE all did. Next, we will focus on sentences that begin with a T3-subject pronoun.

Pronouns occur frequently in mother-child interactions, which allow us to compare speakers' parsing strategies. Frequently used T3-subject pronouns *wo* 'I' and *ni* 'you' provide a chance for us to compare across subjects how T3S is applied in sentences with subject pronouns. Furthermore, they allow us to observe and to better understand the cliticization of the pronouns in T3S application. In what follows, we focus on various sentences containing a T3-subject pronoun. The predicted pattern(s) and the attested pattern(s) are both listed for comparison. Where there is more than one surface pattern, the pattern produced by the speaker(s) will be noted (e.g. ST1, ST2 (used), ST3).

(24)

a.	[Ni	[gei	wo]]	(IU 4;6, GK 5;9, Adult LU)
	you	give	me	'You give (something) to me.'
	3	3	3	UT
	3	3	3	Word: no T3S
	3	(**2**	3)	Phrase: disyllabic foot for the smallest domain
	(3	2	3)	Phrase: incorporation; ST1 (used)
	(**2**	**2**	3)	Larger domain in fast speech, T3S; ST2
b.	[Wo	[gei	ni]]	(IU 4;6, GK 5;9)
	I	give	you	'I give (something) to you.'
	3	3	3	UT
	3	3	3	Word: no T3S
	3	(**2**	3)	Phrase: Disyllabic foot for the smallest domain
	(3	2	3)	Phrase: Incorporation; ST1 (used)
	(**2**	**2**	3)	Larger domain in fast speech, T3S; ST2

In (24), based on the Word-and-Phrase level model, a disyllabic smallest domain has to be parsed first at the Phrase level because no foot has been formed at the Word level as there are no nouns, and pronouns are clitics. After the disyllabic smallest domain has been parsed at the Phrase level, the subject pronoun is incorporated. No further T3S application needs to apply at this point since there are no adjacent T3*. ST1 (T3**T2**T3) was the pattern used in three different individuals. According to the Word-and-Phrase level model, one large domain can be formed in fast speech and T3S applies from left to right, so that ST2 (**T2T2**T3) is also possible for (24a) and (24b). Given that a three-syllable sequence is quite short, it should be easy to form a three-syllable domain and apply T3S non-cyclically, but such pattern was not found in our participants although it is a possible pattern. Next, we look (25) which has (24b) inside the longer sentence.

(25)	[[Wo	[[gei	[ni]]	[shi	kuai]]]	[jiu	[haole]]]	(Adult EE)
	I	give	you	ten	dollar	then	sufficient	'I'll give you ten dollars, and that will be enough (that is what I am willing to pay).'
	3	3	3	2	4	4	30	UT
	3	3	3	(2	4)	4	(30)	Word: no T3S
	(**2**	3)	3	(2	4)	4	(30)	Phrase: disyllabic foot, T3S
	(2	**2**	3)	(2	4)	(4	30)	Phrase: incorporation, T3S; ST1
	(3)	(**2**	3)	(2	4)	(4	30)	ST2 (used)

In (25), the first three syllables are the same as (24). Unlike in (24), there are syllables parsed at the Word level in (25), so that at the Phrase level T3S should apply non-cyclically, starting with the first two syllables *wo gei* 'I give,' followed by the incorporation of the third syllable *ni* 'you.' Such procedure predicts (**T2T2**T3) for the first three syllables in (25); however, T3**T2**T3 was produced for the first three syllables, identical to the pattern in (23) and (24).

The surface pattern in (25) indicates that the non-cyclic parsing from left to right at the Phrase level did not occur. One possibility is that because of the strong syntactic boundary, the subject pronoun makes a degenerate foot by itself without being parsed with a neighboring foot, despite the fact that pronouns are prosodically weak and are prone to cliticize. The idea of "strong syntactic boundary" was mentioned in an example of Shih (1997:97-99) that we saw earlier, repeated in (26).

(26)	[Gou	[yao	[[hao-xin]	ren]]]	(Shih 1997:97-99)
	dog	bite	good-natured	person	'Dogs bit a good-natured person.'
	3	3	31	2	UT
	3	3	(31)	2	Word: no T3S
	3	3	(31	2)	Word: incorporation, no T3S
	(**2**	3)	(31	2)	Phrase: T3S, ST1
	(2	**2**)	(31	2)	Optional T3S across domains, ST2
or	(3)	(2	31	2)	derived by cyclic application; ST3

When optional T3S applies across the domains, we have ST2 (**T2T2**)(T3T1T2). Shih (1997:97) argues that the first two syllables, in prosodic restructuring, can ignore a very strong syntactic boundary and form a foot. According to Shih (1997:97), ST3 is derived by cyclic T3S in terms of syntactic structure. Given that there is a strong syntactic boundary, an alternative explanation for ST3 is that it is a subject-predicate parsing.

Non-cliticization of the pronoun was found in children as well, as (27) shows.

(27)	[Ni	[[gei	[wo]]	[liang	kuai]]]	(GK 5;9)
	you	give	me	two	dollar	'Give me two dollars.'
	3	3	3	3	4	UT
	3	3	3	(3	4)	Word: no T3S
	(**2**	3)	3	(3	4)	Phrase: disyllabic foot, T3S
	(2	**2**	3)	(3	4)	Phrase: incorporation, T3S; ST1
	(2	2	**2**)	(3	4)	Phrase: T3S across prosodic domains; ST2
	(3)	(**2**	**2**)	(3	4)	ST3 (used)

In (27), the monosyllabic foot that *ni* 'you' is in cannot be derived from non-cyclic parsing at the Phrase level. Sentences in (25) and (27) provide counter evidence that, at the Phrase level, syllables are parsed from left to right. In ST3 in (27), although prosodically weak, the subject pronoun stands alone in its own monosyllabic domain. As mentioned, the speaker possibly preferred maintaining the subject-predicate boundary and not apply T3S across it. It appears that a monosyllabic foot followed by a disyllabic foot is better than a ternary foot in these cases. For (25) and (27), if we compare the prosodic domains in ST3 which the speakers used with the syntactic constituents, we found that prosody and syntax align rather nicely.

While we found sentences where T3S does not apply across the subject-predicate boundary when it could in (25) and (27), we also found numerous examples of T3S applying across the subject-predicate boundary where the subject is also a pronoun as in (28) – (30).

(28)	[[Wo	[xiang	[[dakai]	lai]]]	ye]	(ES 5;5)
	I	want	open	directional comp	PRT	'I want to open this up!'
	3	3	31	2	0	UT
	3	3	(31)	2	0	Word: no T3S
	(**2**	3)	(31)	(2	0)	Phrase: T3S; ST1
	(**2**	**2**)	(31)	(2	0)	Phrase: T3S across domains; ST2 (used)

(29)	[[Ni	[ye	[xihuan	[wanju	che]]]]	wo]	(Adult LU)
	you	also	like	toy	car	PRT	'You also like toy cars!'
	3	3	31	24	1	0	UT
	3	3	31	(24	1)	0	Word: no T3S
	(**2**	3)	(31)	(24	1	0)	Phrase: T3S; ST1
	(**2**	**2**)	(31)	(24	1	0)	Phrase: T3S across domains; ST2 (used)

(30)	[Na	[[wo	[keyi	[mai	gou]]]	ma]]	(Adult EE)
	then	I	can	buy	dog	question PRT	'Then can I buy dogs?'
	4	3	33	3	3	0	UT
	4	3	(**2**3)	3	3	0	Word: T3S
	(4	3)	(23)	(**2**	3)	0	Phrase: disyllabic foot, T3S
	(4	3)	(23)	(2	3	0)	Phrase: incorporation, no T3S; ST1
	(4	**2**)	(2**2**)	(2	3	0)	Phrase: T3S across domains; ST2[26] (used)

Sentences in (28) – (30) show cases where T3S applies across the subject-predicate boundary. The non-application of T3S across the subject-predicate boundary in (25) and (27) involve three and four adjacent T3* respectively. The application of T3S across the subject-predicate boundary in (28) and (29) involve three adjacent T3*, and in (30) five adjacent T3*. In the very long sequence of T3* in (30), the subject-predicate boundary would have been a good 'break' for the T3-sequence to be divided into domains. That is, T3S not to apply across such boundary so that

[26] For this speaker, optional T3S was applied in both the second syllable and the fourth syllable. If only one optional T3S occurs, namely (T4**T2**)(T2T3)(T2T3T0) or (T4T3)(T2**T2**)(T2T3T0), the patterns are also grammatical.

the sequence of five adjacent T3* is at least down to one T3 to the left of the boundary and four T3* to the right of the boundary. Attested for Adult EE was a **T2T2T2T2**T3 sequence where T3S was applied across three prosodic domains as shown in ST2. An alternative account for this adult speaker's surface pattern is the larger domain parsing strategy. If this is the case, there is only one extremely large domain for the whole sentence, and T3S applies from left to right. It is not clear whether this speaker was using a larger domain parsing and applied T3S from left to right in one step, even though it was not a fast speech setting.

We have just discussed the application and non-application of T3S across the subject-predicate boundary in sentences with a subject pronoun. The grouping of the subject pronoun with the following syllable is not well-formed in terms of syntax because such unit is not a syntactic constituent. However, in terms of prosody, it is preferred that a monosyllabic subject pronoun joins a neighboring syllable to form a larger foot, so it does not stand by itself as a degenerate foot. Violating syntactic well-formedness in the parsing satisfies prosody, whereas violating prosodic well-formedness in the parsing satisfies syntax. Neither choice is perfect. Both "syntax-over-prosody" and "prosody-over-syntax" choices are attested in the participants in this study.

Earlier we saw an example of five adjacent T3* in (30), the greatest number of adjacent T3* and the only case in our data. One question we might ask is: does the number of adjacent T3* the subject pronoun is in affect the cliticization of the subject pronoun? The sentences with T3-subject pronouns followed by at least one T3 are extracted. Except for Child CH (4;5), the rest of the participants had some of such sentences. Table 4.8 shows the frequency of cliticization of the subject pronoun with two, three, and four adjacent T3*.

Table 4.8 Study 1: Frequency (%) and Number of cliticizations of subject pronouns in two, three, and four adjacent T3*

Number of adjacent T3* / Participants	Two (T3-pronoun+ T3)	Three (T3-pronoun + T3T3)	Four (T3-pronoun + T3T3T3)
CH (4;5)	- (Ø)	- (Ø)	- (Ø)
LI (4;6)	100 (3/3)	100 (2/2)	- (Ø)
IU (4;6)	100 (4/4)	33.33 (1/3)	- (Ø)
ES (5;5)	100 (6/6)	33.33(1/3)	- (Ø)
GK (5;9)	100 (2/2)	0 (0/3)	0 (0/1)
BR (6;6)	66.67 (2/3)	80.00 (4/5)	- (Ø)
ER (6;6)	100 (1/1)	0 (0/1)	100 (2/2)
Adult CZ	100 (19/19)	0 (0/4)	- (Ø)
Adult LU	100 (33/33)	66.67 (2/3)	- (Ø)
Adult CL	100 (7/7)	- (Ø)	100 (1/1)
Adult EE	100 (7/7)	0 (0/4)	- (Ø)
Adult TT	100 (7/7)	20.00 (1/5)	33.33(1/3)

When there are only two adjacent T3*, adults always cliticized the subject pronoun, and children behaved very similarly. There was only one case where a child BR (6;6), did not cliticize the subject pronoun. This same child cliticized the subject pronoun in the other two cases where there were two adjacent T3*.

The number of sentences which begin with a T3-subject pronoun followed by two or three T3* (i.e. three or four adjacent T3*) are not very many, as shown in Table 4.8. Despite the small number of three or four adjacent T3* appearing in the child and adult speech we collected, the data seem to indicate that the subject pronoun is much less consistently cliticized where there are three or four adjacent T3* than where only two adjacent T3* occur. Sentences in (31) and (32) are sample sentences with the subject pronoun in three and four adjacent T3* respectively.

(31) Three adjacent T3*

a. Subject pronoun undergoes T3S

[[Wo	[xiang	[liang	zhi]]]	ye]	(LI 4;6)
I	want	two	CL	PRT	'I want two (of the animals)!'
3	3	3	1	0	UT
3	3	(3	1)	0	Word: no T3S
(**2**	3)	(3	1)	0	Phrase: disyllabic foot, T3S
(**2**	3)	(3	1	0)	Phrase: incorporation, no T3S, ST1
(2	**2**)	(3	1	0)	Phrase: T3S across domains; ST2 (used)

b. Subject pronoun does not undergo T3S

[Ni	[hen	chao]]	(GK 5;9)
you	very	noisy	'You are very noisy.'
3	3	3	UT
3	3	3	Word: no T3S
3	(**2**	3)	Phrase: disyllabic foot for smallest domain; T3S
(3	2	3)	Phrase: incorporation, No T3S; ST1 (used)
(**2**	**2**	3)	Larger domain in fast speech; ST2

(32) Four adjacent T3*

a. Subject pronoun undergoes T3S

[Wo	[ye	[xiang	[xuan	[san	zhi]]]]]	(ER 6;6)
I	also	want	choose	three	CL	'I also want to choose three (animals).'
3	3	3	3	1	1	UT
3	3	3	3	(1	1)	Word: no T3S
(**2**	3)	(**2**	3)	(1	1)	Phrase: disyllabic feet, T3S, ST1
(**2**	**2**)	(**2**	3)	(1	1)	Phrase: T3S across domains, ST2 (used)

b. Subject pronoun does not undergo T3S

[Ni	[[gei	[wo]]	[liang	kuai]]]	(GK 5;9)
you	give	me	two	dollar	'Give me two dollars.'
3	3	3	3	4	UT
3	3	3	(3	4)	Word: no T3S
(**2**	3)	3	(3	4)	Phrase: disyllabic foot, T3S
(2	**2**	3)	(3	4)	Phrase: incorporation, T3S; ST1
(2	2	**2**)	(3	4)	Phrase: T3S across domains; ST2
(3)	(**2**	**2**	3	4)	ST3 (used)

The sentences in (31a) and (32a) show that the subject pronoun is cliticized to the following syllable and undergoes T3S whereas the sentences in (31b) and (32b) present cases where the subject pronoun did not undergo T3S. In (31b), the subject pronoun surfacing with its underlying tone can be accounted for because after the subject pronoun has been incorporated into the disyllabic foot that follows it, there are no more adjacent T3*, so T3S needs not apply. Is it possible that only children leave the subject pronoun as a degenerate foot, but not adults? Such parsing was found in adults as in (33).

(33)	[Wo	[qing	nimen]	[dao	[wo	jia]	[he-he		[cha]]]	ba]	(Adult CZ)
	I	invite	you (pl.)	arrive/go	I/my	home	drink-drink		tea	PRT	‘Why don’t you come over to my place for a cup of tea?’
	3	3	30	4	3	1	1	1	2	0	UT
	3	3	(30)	4	(3	1)	1	1	2	0	Word: no T3S
	(**2**	3)	(30)	4	(3	1)	(1	1)	(2	0)	Phrase: disyllabic foot, T3S
	(2	3)	(30)	(4	3	1)	(1	1)	(2	0)	Phrase: incorporation; no T3S; ST1
	(**2**	**2**)	(30)	(4	3	1)	(1	1)	(2	0)	Phrase: T3S across domains; ST2
	(3)	(**2**	30)	(4	3	1)	(1	1)	(2	0)	ST3 (used)

ST3 of (32b) and (33) seems to have a better prosody-syntax alignment, similar to those of (25) and (27).

We hypothesized that there would be variability in T3S application due to different parsing strategies. In various sentences presented in (24) – (33) which involve T3-subject pronouns, we have seen variability regarding how the monosyllabic subject pronoun is parsed. The attested surface patterns indicate that sometimes the subject pronoun is parsed with its following syllable to form a foot, and sometimes it stands alone as a degenerate foot. Leaving the subject pronoun as a degenerate foot is possibly a different parsing strategy (e.g. cyclic parsing or subject-predicate parsing). A subject pronoun is not always cliticized to its following domain, and it appears that it is much less consistently cliticized where there are three or four adjacent T3* than where only two adjacent T3* occur. Although T3S variability is not limited to cases with subject pronouns, the data we see in these sentences with subject pronouns that are available to us reveal

T3S variability exhibited in children and adults. Our third hypothesis—H_3: Variability in T3S application is expected due to the various types of parsing strategies that are available— is confirmed.

Lastly, it is worth looking into application and non-application of T3S in the context of only two adjacent T3*. We know that when two adjacent T3* belong to different prosodic domains, T3S application is optional across the two domains. The number of cases where T3S does not have to apply when there are two adjacent T3* which belong to different prosodic domains is listed in Table 4.9. The application and non-application of T3S in sequence of two T3* are presented in two categories: *within constituents* and *across constituents*.

Table 4.9 Study 1: Two adjacent T3* that belong to different prosodic domains

T3T3 / Participants	Within constituents		Across constituents		Total
	T3S applied T3T3→ **T2**T3	T3S not applied T3T3→ T3T3	T3S applied T3T3→ **T2**T3	T3S not applied T3T3→ T3T3	
CH (4;5)	0	0	2	0	2
LI (4;6)	0	0	0	0	0
IU (4;6)	1	0	0	0	1
ES (5;5)	2	0	1	1	4
GK (5;9)	8	1	0	1	10
BR (6;6)	0	0	2	0	2
ER (6;6)	0	0	0	0	0
Adult CZ	11	7	1	1	20
Adult LU	10	3	0	0	13
Adult CL	8	2	2	0	12
Adult EE	10	2	2	1	15
Adult TT	3	1	3	1	8

(The numbers in the table refer to number of cases of application and non-application within constituents and across constituents.)

As we see in Table 4.9, there are few sentences in the child data that contain two adjacent T3* that belong to different prosodic domains. GK (5;9) and ES (5;5) are the only two children that have more than two such cases. ES (5;5) and GK (5;9) are also the only two children that show evidence of application and non-application of T3S in a sequence of two T3* that belong to different prosodic domains. Without more such T3S environments produced by other children, whether or not they know that T3S application is optional in two T3* that belong to different prosodic domains is unknown.

Each of the adults shows both T3S application and non-application in the environment of two adjacent T3* which belong to different prosodic domains. We found that T3S tends to be applied, rather than not applied, across prosodic domains both within constituents and across constituents. Since children's data were too little, we focus on the adult data now. Table 4.10 shows the percentages of each adult's application and non-application of T3S within constituents and across constituents as well as the average percentage for the adults as a group.

Table 4.10 Study 1: Adjacent T3* that belong to two prosodic domains (%)

Adult participants	Within constituents		Across constituents	
	T3S applied T3T3→ **T2**)(T3	T3S not applied T3T3→ T3)(T3	T3S applied T3T3→ **T2**)(T3	T3S not applied T3T3→ T3)(T3
Adult CZ	**61.11** (11/18)	**38.89** (7/18)	**50** (1/2)	**50** (1/2)
Adult LU	**76.92** (10/13)	**23.08** (3/13)	n/a	n/a
Adult CL	**80** (8/10)	**20** (2/10)	**100** (2/2)	**0** (0/2)
Adult EE	**83.33** (10/12)	**16.67** (2/12)	**66.67** (2/3)	**33.33** (1/3)
Adult TT	**75** (3/4)	**25** (1/4)	**75** (3/4)	**25** (1/4)
Average	**73.68** (42/57)	**26.32** (15/57)	**80** (8/10)	**20** (2/10)

There are a lot more cases of adjacent T3* that belong to different prosodic domains within constituents than across constituents. In a sequence of two adjacent T3* both within (e.g. [(T1<u>T3</u>)(<u>T3</u>T4)]) and across constituents (e.g. [(T1<u>T3</u>)][(<u>T3</u>T4]]), the chance of T3S being applied is much higher than it not being applied.

Within constituents, application of T3S is about three times the non-application of T3S (73.68% vs. 26.32%). This shows that adults prefer to apply T3S in the sequence of two T3* although such application is optional (in T3S across domains). Across constituents, application of T3S is four times the non-application of T3S (80% vs. 20%). This shows that even if the two T3* belong to different prosodic domains, and the two domains are not in the same syntactic constituent, they still prefer to apply T3S than not to apply T3S.

Taken together, in a sequence of two T3* that belong to two prosodic domains, adults prefer to apply T3S both within constituents and across constituents. One out of three to four times on average, the adults did not apply T3S in the context where two adjacent T3* belong to different prosodic domains. Consequently, children receive more of the application of T3S than the non-application in the input for the environment in which two adjacent T3* belong to different prosodic domains. We would expect children's data to reflect adults' preference, but we will need more of children's data in order to learn whether or not this is true.

The investigation of the adult data revealed adults exhibited variability as they did not consistently apply or not apply T3S. Variability that arises from optional T3S across domains as well as from cliticization of pronouns and different parsing strategies in sentences that contain subject pronouns presented earlier gave us a good amount of evidence to support our third hypothesis—H_3: Variability in T3S application is expected due to the various types of strategies that can be used.

4.6 Discussion

In this section, we will discuss our findings in detail in several aspects.

T3S application at different levels

Children age 4 – 6 exhibited a high rate of correct T3S applications in spontaneous speech. Regardless of low counts of T3S instances in some children, T3S application *within words*, *within constituents*, and *across constituents* were all attested in all child and adult participants.

Due to the lack of data of cyclic T3S application within words and insufficient data of non-cyclic T3S application at the Phrase level, no conclusion can be drawn regarding whether or not children indeed know to use cyclic and non-cyclic strategies at the Word level and at the Phrase level respectively. To test cyclicity at the Word level, lexical items which are composed of only two adjacent T3* do not serve as evidence, as these items always surface as **T2**T3 which children hear and produce. Novel NPs or compound nouns that are composed of multilayers are needed. They can give us more informative evidence on how children parse syllables in their T3S application.

As for T3S application at the Phrase level, we found a small number of sentences (see (18), (19) and (20)) that support children's knowledge of the non-cyclic strategy. However, evidence of only several sentences is inadequate to make the claim. More importantly, we found that the surface patterns in some sentences of children and adults did not match the non-cyclic parsing strategy at the Phrase level in the Word-and-Phrase level Model. These are sentences that begin with a subject pronoun which appears to stand alone as a degenerate foot rather than being parsed with its following syllable in forming a larger prosodic domain. A different parsing strategy of subject-predicate parsing or syntax-based parsing may account for these sentences.

Subject pronouns

Chen (2000) discussed object pronouns taken as clitics in T3S application (Chen 2000: 402-403). There is no mention of the status of subject pronouns in the T3S literature. A pronoun cliticizes because of its prosodically weak nature. In such case, we would expect to see a subject pronoun form a foot with its following syllable, but this did not always occur in our spontaneous speech data. This may indicate that a Mandarin subject pronoun may behave as a typical clitic and cliticize, or may act like a regular noun and stand alone in its own domain in the subject position.

One may ask what motivates a pronoun not to join its following syllable in forming a foot, but to be in a degenerate foot by itself. A possibility is that, on the one hand, a prosodically weak element like a pronoun should cliticize, but, on the other hand, there is a strong subject-predicate boundary (see some discussion in §4.2) that the subject pronoun prefers not to cross over. Crossing over to cliticize honors prosody (since a degenerate foot is not preferred), and not crossing over to cliticize and remaining as a degenerate foot honors syntax (maintains the strong subject-predicate boundary). If speakers were in fact maintaining the subject-predicate boundary, then there is an additional parsing for the structure in (34).

(34) Subject pronoun + give + recipient

[ni/wo	[gei	ni/wo]]	
you/me	give	you/me	'I give you/you give me.'
3	3	3	UT
3	3	3	Word: no T3S
3	(**2**	3)	Phrase: disyllabic foot, T3S

Two possible parsings in the next step:

<u>Incorporation of the subject pronoun:</u>

(3	2	3)	Phrase: Incorporation, no T3S; ST1

<u>No incorporation of the subject pronoun:</u>

(3)	(2	3)	Phrase: No incorporation, no T3S; ST2 (an additional possible parsing)
(**2**	**2**	3)	Larger domain in fast speech, T3S; ST3

As we see in (34), the surface pattern ST1 T3**T2**T3 is predicted to be (T3**T2**T3) in one domain, and the other possible parsing suggested is (T3)(**T2**T3) in two domains. Since the surface pattern (T3**T2**T3) and (T3)(**T2**T3) produce the same sequence T3**T2**T3, which parsing was actually used for the production is unclear and might not be easy to know. Although the three-syllable sentence in (34) can be easily parsed in a three-syllable prosodic domain in one step, the absence of ST2 (**T2T2**T3) in our data might reveal other factors (such as the resistance of the subject pronoun to undergo T3S in certain contexts). Speakers might even use T3**T2**T3 if they were asked to speak faster; however, this needs to be tested.

We now look at one of the sentences in our data (presented in (27), repeated here in (35)) which clearly shows the subject pronoun being parsed as a degenerate foot.

(35)	[Ni	[[gei	[wo]]	[liang	kuai]]]	(GK 5;9)
	you	give	me	two	dollar	'Give me two dollars.'
	3	3	3	3	4	UT
	3	3	3	(3	4)	Word: no T3S
	(**2**	3)	3	(3	4)	Phrase: disyllabic foot, T3S
	(2	**2**	3)	(3	4)	Phrase: incorporation, T3S; ST1
	(2	2	**2**)	(3	4)	Phrase: T3S across prosodic domains; ST2
	(3)	(**2**	**2**)	(3	4)	ST3 (used)

According to the Word-and-Phrase level Model, at the Phrase level disyllabic feet are parsed from left to right, so in (35), the initial syllable *ni* 'you' has no choice but to undergo T3S as it would be parsed with its following syllable which is also a T3. The pattern used by GK (5;9) is a subject-predicate pattern. *Wo* 'I' stands alone as a degenerate foot without undergoing T3S. The pattern is possibly a case of cyclic application like the example in (26), or the child prefers to separate the subject from the predicate and produced the subject-predicate pattern. A pattern like this will need to be addressed as it is a phenomenon we found in adults as well as children.

If the subject pronoun can stand alone as a degenerate foot in (35), it should not be very surprising that such parsing can occur in (34) as well. In (34), the parsing (T3)(**T2**T3) may indicate that the alignment of syntactic boundaries and prosodic domains is well attended to (that is, the parsing of the subject pronoun being a degenerate foot in (34) and (35) is a better alignment of both syntactic constituents and prosodic domains).

To summarize, in building the prosodic domains within which T3S applies, syntax-dependency and well-formedness of the foot structure are both crucial, but there is more to how speakers parse the syllables into feet. Based on the data in our study, these speakers seem to attend to the alignment of prosodic domains and syntactic constituents, and sometimes at the cost of leaving the subject pronoun as a degenerate foot. In dealing with subject pronouns, variable strategies (cliticization and non-cliticization) were found in the participants of this study. If a Mandarin subject pronoun does have a dual status (a clitic and cliticizes or a non-clitic and does not cliticize), then it follows that the cliticization or non-cliticization of subject pronouns is one of the sources for T3S variability.

In short, the subject-predicate boundary and the alignment of prosody and syntax may play important roles in how speakers build the prosodic domains and cause subject pronouns to behave inconsistently as a clitic or not. Further investigation will be needed to test this assumption. In future studies we should examine both the frequency of a subject pronoun as a clitic or non-clitic in both child and adult production.

T3S application across the subject-predicate boundary

Regarding T3S variability, for particular sentences, sometimes one surface pattern appears to be stronger than another which was absent in our data, as in the sentence *Wo gei ni* ‘I give you’ or *Ni gei wo* ‘you give me’ (see (24)). In this three-T3 sequence four participants (Child IU 4;6, Child GK 5;9, Adult LU, and Adult EE) produced the pattern T3**T2**T3, and the other possible pattern **T2T2**T3 was absent.

In the environment of more than two adjacent T3*, cases where T3S applies across a subject-predicate boundary often include a subject pronoun followed by an adverb (e.g. *ye* ‘also’) or an auxiliary (e.g. *xiang* ‘want’), both of which, being monosyllabic, form a disyllabic foot with the preceding pronoun. Crucially, this foot is commonly followed by a disyllabic lexical item beginning with a T3 (e.g. *dakai* T3T1 'open,' *xihuan* T3T1 'like,' *keyi* T3T3 'can (aux)'). Given that T3S applies at the Word level first, the lexical items are dealt with before T3S applies at the sentence level. It is understandable why the subject pronoun and the monosyllabic T3-syllable that follows it are parsed as a disyllabic foot. Without this, the two syllables would be left as degenerate feet. Successive degenerate feet are banned when the two syllables can form a perfect disyllabic foot even though such prosodic domain crosses over the subject-predicate boundary. Put differently, if the subject-predicate boundary can be maintained (that is, if there is such option), speakers tend to maintain the boundary. But if maintaining the boundary causes prosodic ungrammaticality, T3S is applied across the boundary.

We have mainly discussed T3S application in cases that contains T3-pronouns in the subject position. Whether or not T3S applies across the subject-predicate boundary appears to depend largely on whether or not the speakers have an option. If the sentence is grammatical, whether speakers apply T3S across the subject-predicate boundary or not, they tend to choose to honor the subject-predicate boundary by not applying T3S across the boundary. If, however, not applying T3S across the boundary will result in an unacceptable T3S output, they will apply T3S across the boundary.

Optional T3S application in two adjacent T3 that belong to two prosodic domains*

When two adjacent T3* belong to different prosodic domains, T3S application is optional. Both application and non-application (See Table 4.10) were found in all adults and two children (ES 5;5 and GK 5;9), with application more frequent than non-application.

On average, for adults, application of T3S is 73.68% and non-application is 26.32% within constituents. Across constituents, the application and non-application of T3S are 80% and 20%

respectively. Application of T3S is preferred both within constituents and across constituents. In any sequence of two T3* that belong to two different domains, approximately one out of three to four times there will be a non-application of T3S. In the input to child language acquisition, the non-application of T3S in the environment of only two adjacent T3* belonging to two prosodic domains can be noise that makes the data less transparent. With T3S variability in adult speech, children do not have unambiguous data.

*Optional T3S across prosodic domains in sequences with multiple T3**

Regarding optional T3S application across prosodic domains when there are more than two adjacent T3*, it was difficult to compare the behavior of children and adults without adequate and systematic data, which cannot be controlled for in natural speech studies. A sentence produced by four participants in (23), repeated in (36), offers some helpful information for comparison.

(36)	[[Gei	[wo]]	[wu-shi		kuai]]	
	Give	me	five-ten		dollar	'Give me fifty dollars.'
	3	3	3	2	4	UT
	3	3	(3	2)	4	Word: no T3S
	3	3	(3	2	4)	Word: incorporation, no T3S
	(**2**	3)	(3	2	4)	Phrase: disyllabic foot, T3S; ST1 (GK 5;9)
	(2	**2**)	(3	2	4)	Phrase: optional T3S across domains; ST2 (IU 4;6, Ault LU, Adult EE)

In (36), both adult speakers applied T3S across two prosodic domains. One child did and one child did not. With few sentences produced by children and adults in our data that are syntactically identical or similar and with multiple adjacent T3* (at least three adjacent T3*), no further comparisons can be made across child and adult participants in this regard. The T3S variants arise in (36) because of optional T3S across prosodic domains.

Application or non-application of T3S within constituents and across constituents

On average, adults apply T3S within constituents and across constituents fairly similarly (within constituents: 92.98% vs. across constituents: 84.21%; a 8.77% difference), but children appear to apply T3S more within constituents than across constituents (within constituents: 99.36% vs. across constituents: 70%; a 29.36% difference). Adults handle these similarly, as the data show that they apply T3S only slightly more frequently within constituents than across constituents.

Unlike adults, children may be more limited to what is in the immediate environment and looking across constituents may not be as easy for them as for adults. That children apply T3S within constituents more than across constituents may indicate that they differentiate the two. Although our child data show that T3S is applied more frequently within constituents than across constituents by approximately 30%, the amount of child data was relatively small, so that whether or not children do distinguish "within constituents" from "across constituents" and apply T3S more in the former than in the latter needs to be confirmed when more child data becomes available.

The new falling-rising (T3-T2) sequence in Taiwan Mandarin (Yeh 2010)

In child-directed speech, reduplications are common. Yeh reports (2010) a new falling-rising (T3-T2) sequence in some vocabulary, mostly kinship terms. This new pattern is relevant to our study of T3S application. I will briefly talk about Yeh's (2010) study and then present examples from our natural speech study to show supporting evidence of this new form as well as the new pattern's interaction with the T3S rule.

Yeh (2010) conducted an experiment to compare the phonetic naturalness of Rising-Falling (T2T3) and Falling-Rising (T3T2) tonal patterns. Participants were asked to read the stimuli created from the base syllables for six kinship terms. An example Yeh (2010) provided was the syllable *jie*, taken from *jie jie* 姊姊 'sister.' In writing, there are different characters for this same syllable: *jie* 姊 (T3) 'sister', *jie* 解 (T3) 'to solve, to untie', *jie* 結 (T2) 'a knot.' These words are used to form disyllabic stimuli. As participants read the stimuli in a carrier sentence, depending on what characters they read the tonal production would differ: (i) *jie jie* 姊姊 'elder sister' T3T3→ T3T0 (the Neutral tone sandhi), (ii) *jie jie* 解解 'to solve' T3T3→ **T2**T3 (Tone 3 sandhi), (iii) *jie jie* 姊姊 'elder sister' T3T3→ T3**T2** (the new form), and (iv) *jie jie* 解結 'to untie a knot' T3T2 (UT=ST). For (iii), where the new form is expected, the participants were reminded to produce it in a childlike manner (as a child would produce it).

Yeh (2010) says that the results of the experimental study show that the new T3T2 pattern, the opposite pitch contour of the T2T3 pattern which is derived from the T3S rule, has significantly fewer pitch changes than the T2T3 pattern, and appears to be more natural phonetically (with 'phonetic naturalness' being defined as fewer pitch changes, longer duration of rising (T2) syllables and shorter duration of falling (T3) syllables).

The new pattern T3T2 is relevant to our current study because it applies to kinship terms frequently used in child-directed speech. As Yeh (2010) points out, in the following examples the "original pattern" changes to "the new pattern"— *mama* 'mother' (T1T0→ T3T2), *shushu* 'uncle' (T2T0 → T3T2), *jiejie* 'sister' (T3T0→ T3T2), *didi* '(younger) brother' (T4T0→ T3T2). Notice that the initial syllable in the new form is T3, regardless of its original underlying tone. Certain non-kinship nominal reduplications, such as *gou* 'dog' (T3), gives *gou-gou* 'dog, doggie' the surface form of T3T2, rather than the T2T3 that T3S would predict. In addition to the T3-T2 sequences which Yeh's (2010) experimental study focuses on, *shenme* 'what' is one of the limited number of lexical items which have undergone tonal changes and surface as T3-T2 sequences. Unlike other vocabulary that has the new form of T3T2 only, *shenme* ‘what’ interestingly also has T3T0 as its new form. Therefore, for Taiwan Mandarin speakers as shown in (37), there are three underlying tones altogether for *shenme* ‘what’: T2T0 (original lexical tone), T3T2 (one new form), and T3T0 (the other new form). The new tonal patterns, T3T2 and T3T0, are double underlined.

(37)	shenme	‘what’
	2 0	UT1 (original form)
	3 2	UT2 (New form 1 in Taiwan Mandarin)
	3 0	UT3 (New form 2 in Taiwan Mandarin)

While the reduplication of kinship terms tends to be more restricted to child-directed speech, the new forms of *shenme* ‘what’ in (37) are widely used across age groups in Taiwan, and both forms were attested in our child and adult data. In (37), the new forms are marked as T3T2 and T3T0 underlyingly rather than as surface patterns because speakers did not use the original underlying tones T2T0 when this lexical item interacts with an adjacent T3. Instead, the new forms T3T0 and T3T2 were used as underlying (i.e., lexical) forms as we see in (38) and (39) respectively. In these cases of *shenme* ‘what’ preceded by a T3 syllable, T3S is triggered.

(38)	[Kan	[ni	[yao	[mai	shenme]]]]	(GK 5;9)
	see	you	want to	buy	what	‘See what you want to buy.’
a.	4	3	4	3	20	UT (*shenme* ‘what’ in original form)
	4	3	4	3	(20)	Word: no T3S
	(4	3)	(4	3)	(20)	Phrase: no T3S; ST1
b.	4	3	4	3	30	UT (*shenme* ‘what’ in new form)
	4	3	4	3	(30)	Word: no T3S
	(4	3)	(4	3)	(30)	Phrase: no T3S
	(4	3)	(4	**2**)	(30)	Phrase: T3S across domains; ST2 (used)

(39)	[Yang	[shenme]]	(Adult TT)
	raise	what	‘Raise what?’
a.	3	20	UT (*shenme* ‘what’ in original form)
	3	(20)	Word: no T3S
	(3	20)	Phrase: incorporation, no T3S; ST1
b.	3	(32)	Word: no T3S
	(**2**	32)	Phrase: incorporation, T3S; ST2 (used)

In (38) and (39), T3S applies because the new forms for *shenme* ‘what’ (T3T0 and T3T2) begin with a T3, and therefore, create a T3-sequence that triggers T3S. Whether or not a Taiwan Mandarin speaker has s*henme* ‘what’ with the new form of T3T2 or T3T0, both forms begin with a T3 and trigger T3S when following an underlying T3. T3S application in these cases cannot be accounted for without assuming the new lexical tones of *shenme* ‘what.’ The majority of current Taiwan Mandarin speakers appear to use T3T2 or T3T0 as their lexical tones for *shenme* ‘what,’ rather than the original lexical tones, T2T0. It should be noted that the predicted surface forms and the attested surface patterns resulting from the distinct new forms of T3T2 or T3T0 are all grammatical.

To summarize, the tonal changes in *shenme* ‘what’ in Taiwan Mandarin speakers explain why T3S is applied in cases where T3S seems to be unnecessary if we simply look at the original lexical tones. T3S application in cases like (38) and (39) are counted as correct. It should be noted that in this current study, all the children and caretakers are native speakers of Taiwan Mandarin. Mandarin speakers of other regions may not have the new forms of certain vocabulary that has been discussed earlier. Mandarin speakers from other regions may also have different grammatical judgments regarding what counts as a grammatical T3S output. The findings of this study apply to Taiwan Mandarin speakers and may not apply to Mandarin speakers of other regions.

4.7 Conclusion

In this section, I summarize the findings of the present study with respect to T3S in spontaneous speech.

Three levels of T3S application were examined— *within words*, *within constituent*, *across constituents*. T3S application at all three levels was attested in all child and adult participants.

Due to the lack of multi-layer structures at the Word level produced by both children and adults, no conclusion can be drawn regarding cyclic T3S application within words. At the Phrase level, we found cyclic and non-cyclic T3S application. But there were also cases that could not be accounted for by the non-cyclic parsing strategy at this level. It appeared that children and adults do not always parse disyllabic feet from left to right at the Phrase level, as we saw in the case of a subject pronoun parsed as a degenerate foot, rather than parsed with the following syllable. We suggest that the subject-predicate boundary and a better alignment of syntactic constituents and prosodic domains are the possible sources of participants' use of the parsing strategy.

The number of adjacent T3* appears to affect the choice of maintaining the subject-predicate boundary or applying T3S across the boundary to form a binary foot. Based on our spontaneous speech data, when a T3-subject pronoun is followed by another T3, the subject pronoun often surfaces as a sandhi tone, **T2**, as the result of being parsed with the following word regardless of the word category (e.g. an adverb, and auxiliary, or a verb). Subject pronouns are much less likely to cliticize in sequences where there are three or four adjacent T3* than in sequences where there are only two.

In a sentence beginning with a monosyllabic T3 pronoun followed by a VP which contains a monosyllabic T3 verb and a monosyllabic T3 pronoun, the attested pattern in both children and adults is T3**T2**T3, even though **T2T2**T3 is a possible pattern as well. Both patterns are predicted by the Word-and-Phrase level Model. The absence of the **T2T2**T3 pattern is interesting because, presumably, in a three-syllable sequence, parsing all three syllables in one domain is relatively easy. In longer sentences which also have a monosyllabic pronoun followed by two or more than two T3*, we found the subject pronoun is sometimes parsed as a degenerate foot, and sometimes it forms a prosodic domain with its following syllable(s). It seems that a monosyllabic subject pronoun has a dual status, behaving like a clitic sometimes, and at other times behaving like a monosyllabic noun that is not prosodically weak and can stand alone as a degenerate foot. In summary, the behavior of a subject pronoun in T3S is intriguing. It does not consistently join other syllable(s) in forming prosodic domains. Its flexibility as to what kind of prosodic domain it is in (whether it stands alone in a monosyllabic foot or joins other syllables in forming a prosodic domain) is still to be examined.

Optionality is one of the sources of T3S variation. Where optional T3S is allowed, variation is attested across two prosodic domains: within and across constituents. Different parsing strategies that result in different T3S surface patterns were attested. For instance, in the context of adjacent T3* belonging to different prosodic domains both within constituents and across constituents, adults apply T3S about three to four times as frequently as not. The shifting between application and non-application of T3S produces variation. Because of insufficient child data for this context in our investigation, it is unknown whether or not children behave similarly to adults in this regard.

It is a great challenge to obtain desired T3S in various syntactic structures across child and adult speakers, although the limited data in this study and the analysis we conducted provide some information on T3S in child-parent interactions to fill in some gaps in the T3S acquisition literature. More mother-child natural speech data can be collected in future studies to confirm the findings of this study as well as to answer certain questions we are unable to answer due to limits of the data we collected.

As T3S data are quite limited in natural speech, we seek also to investigate T3S application in children and adults through a series of experiments. Presented in the next three chapters are T3S experimental studies of non-cyclic T3S application in flat structures, cyclic T3S application in NPs, and cyclic and non-cyclic T3S strategies at the sentence level.

CHAPTER 5

FLAT STRUCTURES

5.0 Introduction

It has been established in previous chapters that T3S heavily depends on syntax. Most utterances people produce, short phrases or long sentences, are in the form of hierarchical syntactic structures. There are times, however, when there is no internal structure, such as a string of digits in phone numbers or a foreign proper noun translated into the target language. "Louisiana," for instance, is translated as "*lùyìxīānnà*" in Mandarin Chinese. No syllable in the sequence of five syllables is in a syntactic position higher than others. We refer to these structures without internal structures as "flat structures."

T3S requires setting up the prosodic domains within which T3S applies. Typically, syntax and prosody both play vital roles in the building of such domains. In a flat structure, all the syllables in the string are in principle at the same level.

A flat structure serves as a perfect opportunity to investigate T3S with the focus on the prosodic facets only. What does T3S depend on when there is "no syntax" for it to refer to? Exactly how T3S application relies on prosody in building the T3S domain is what this study seeks to answer. We focus on three major areas in T3S application in flat structures: (i) binary parsing, (ii) the incorporation of an unparsed syllable, and (iii) directionality of foot building. In addition, we are interested in children's developmental pattern in acquisition of T3S in flat structures and what it tells us about children's way of grouping syllables into larger units.

The organization of this chapter is as follows: In Section 5.1, central issues regarding how T3S is applied in flat structures is discussed in detail, based on what we know from previous theoretical studies. Some findings relevant to flat structures from an experimental study will also be reviewed and discussed. In Section 5.2, we ask our research questions, followed by our hypotheses and predictions. Section 5.3 includes the design of our experiment on flat structures, the results and discussion. Section 5.4 concludes this chapter.

5.1 T3S in Flat structures

We know that both syntax and prosody are crucial elements in T3S application. In a flat structure, with no obvious internal syntactic structure, one solution for T3S application is to depend solely on prosody.

A disyllabic foot is a preferred foot structure in Mandarin Chinese, and such binary foot comprises the basic T3S domain within which T3S must apply (Lin 2007:205-206). Exactly how is the string of syllables grouped to form one or more prosodic domains? We test how children and adults parse syllables into feet in flat structures. We ask the following questions:

(i) Is binary parsing the main foot-building strategy in flat structures?

(ii) Is an unfooted syllable incorporated into a neighboring foot in cases where there is odd number of syllables?

(iii) What is the directionality of foot-building in flat structures?

(iv) Is there a developmental pattern in children’s acquisition of T3S?

5.1.1 Previous theoretical studies on T3S in flat structures

Syllables in flat structures are parsed from left to right in binary feet, and any leftover syllable is then incorporated into the neighboring foot according to the Word-and-phrase level Model (Chen 2000:368; Shih 1986; Shih 1997). The Stress-foot Model has the same view: in polysyllabic names and digits, disyllabic feet are built from left to right (Duanmu 2000/2007; Duanmu 2004:70). There is no mention of incorporation of an unfooted syllable in Duanmu

(2000/2007). (1) - (2) are examples of T3S application in flat structures from Chen (2000) and Lin (2007).

(1) Flat structure: translation of ‘Somalia’ (Chen 2000:369)

Suo	ma	li	ya	‘Somalia’
3	3	3	3	UT
(**2**	3)	(**2**	3)	ST
*(3)	(**2**	**2**	3)	
*(**2**	**2**	3)	(3)	
*(2	3)	(3)	(3)	

(2) Flat structure: four T3-digits (Lin 2007:206)

jiu	jiu	jiu	jiu	‘9999’
3	3	3	3	UT
(**2**	3)	(**2**	3)	ST

In (1), the binary parsing from left to right predicts the surface pattern (**2**3)(**2**3). It is not clear whether or not the large domain parsing of (**222**3) is regarded as a possible surface pattern by Chen (2000). In (2), we see that the sequence of four digits have the same prediction of two binary feet as the four-syllable translation of ‘Somalia.’ In the context of parsing syllables into feet in fast speech, a larger domain can be created (Chen 2000; Lin 2007; Shih 1986; Shih 1997). Therefore, (**222**3) is also a possible output. In (3), we see that the two adjacent T3-digits belong to different domains.

(3) Flat structure: two T3-digits that belong to two different domains (Duanmu 2000/2007:239)

qi	wu	wu	qi	‘7557’	
1	3	3	1	UT	
(1	3)	(3	1)	ST1	(No T3S application across domains)
(1	**2**)	(3	1)	ST2	(T3S applies across domains)

In (3), there are two possible surface patterns ST1 and ST2 because the two T3-digits belong to different prosodic domains, and T3S does not have to apply, though it can (Duanmu 2000/2007:239). Next, let us look at how the surface pattern is derived in a five-digit sequence. In (4), we see a case with odd number of syllables where binary parsing will leave one syllable unparsed.

(4) Flat structure: five digits (Lin 2007:206)

jiu	jiu	jiu	jiu	jiu	'99999'
3	3	3	3	3	UT
(**2**	3)	(**2**	3)	3	Disyllabic feet, T3S
(2	3)	(2	**2**	3)	Incorporation, T3S; ST

In (4), binary feet are built from left to right, followed by incorporation of the unfooted syllable to its neighboring foot. The prediction is (**2**3)(**22**3), a binary foot followed by a ternary foot. Lin (2007) points out that if the directionality is from right to left, then the unfooted syllable would have been on the left edge (Lin 2007:206). In Chen's (2000) OT (Optimality Theory, Prince & Smolensky 1993/2004) analysis of a flat structure composed of five consecutive digits *wu* 'five', (**2**3)(**22**3) is the optimal output, while (**22**3)(**2**3), (3)(**2**3)(**2**3), and (**2**3)(**2**3)(3) are not (Chen 2000:368). Notice that the right-to-left binary parsing followed by incorporation, which results in (**22**3)(**2**3), is one of the non-optimal outputs. Even a seemingly good output (3)(**2**3)(**2**3) which does not violate two adjacent T3* is ungrammatical due to violation of left-to-right parsing.

Shih (1997) also regards (**22**3)(**2**3) as an ungrammatical pattern (Shih 1997:98). She suggests, "In the absence of any existing structure, such as a list of digits or nonsense syllables, prosodic reconstructing proceeds from left to right. The directionality is shown in domains containing odd number syllables: it is the last foot that accommodates an extra member" (Shih 1997:98). In other words, for Shih (1997), the ternary foot in the flat structure signifies that an unfooted syllable is accommodated.

According to the Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997), fast speech have larger domains, so that (**2222**3) is potentially a grammatical surface pattern. Our experiment investigates how T3S is applied in normal speech rather than in fast speech. Nevertheless, this larger domain parsing (**2222**3) will be considered as a possible output as well.

Table 5.1 summarizes what are grammatical and ungrammatical patterns in sample flat structures with some examples that were presented earlier in this section. The predictions are based on the Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997).

Table 5.1 List of grammatical and ungrammatical patterns in flat structures

Flat structures	jiu jiu jiu '999'	Suo ma li ya 'Somalia'	jiu jiu jiu jiu '9999'	qi wu wu qi '7557'	jiu jiu jiu jiu jiu '99999'
UT	333	3333	3333	1331	33333
Surface pattern(s)	(**22**3)	(**2**3)(**2**3)	(**2**3)(**2**3) (**222**3)	(13)(31) (1**2**)(31)	(**2**3)(**22**3) (**2222**3)
Ungrammatical pattern(s)	*(**2**3)(3) *(3)(**2**3)	*(3)(**22**3) *(**22**3)(3) *(**2**3)(3)(3)	*(3)(**22**3) *(**22**3)(3) *(**2**3)(3)(3)	*(1**22**1)	*(**22**3)(**2**3) *(3)(**2**3)(**2**3) *(**2**3)(**2**3)(**2**) *(**2**3)(**2**3)(3) *(3)(**22**3)(3)

In the next section, I will review an experimental study that tested how T3S is applied in flat structures.

5.1.2 Kuo et al.'s (2007) study

Kuo et al. (2007) present an acoustic experimental study where the participants were asked to produce the sentences at three speech rates, *slow*, *normal*, and *fast*. Two-, three-, and four-digits are embedded sentence-initially in carrier sentences which are question and answer pairs. An example of a question and answer pair is given in (5). According to Kuo et al. (2007: 231), T3S applies in the digits first, and then, T3S applies across the syntactic boundary, which is reflected in the derivations in (5). I provide a more detailed word-for-word gloss for the sentences for the purpose of clarity and illustration of relevant information on T3S involved here. All the possible patterns that are derived through the Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997) are added for comparing the attested patterns to the predicted patterns.

(5) Four-syllable flat structures in carrier sentences (Kuo et al. 2007:214-217)

a.

Q: Liang	liang	liang	liang	you	mei	you	
two	two	two	two	there is	there is not[27]		'Is there two-two-two-two?'[28]
3	3	3	3	3	2	3	UT
(**2**	3)	(**2**	3)	(3	2	3)[29]	Disyllabic feet, T3S; ST1
(2	**2**)	(2	3)	(3	2	3)	T3S across domains, T3S; ST2
(2	**2**)	(2	**2**)	(3	2	3)	T3S across domains, T3S; ST3
(**2**	**2**	**2**	**2**	3	2	3)	Larger domain in fast speech, T3S; ST4

b.

A: Liang	liang	liang	liang	you	
two	two	two	two	there is	'There is two-two-two-two.'
3	3	3	3	3	UT
(**2**	3)	(**2**	3)	3	Disyllabic feet, T3S
(2	3)	(2	**2**	3)	Incorporation, T3S; ST1
(2	**2**)	(2	2	3)	T3S across domains, T3S; ST2
(**2**	**2**	**2**	**2**	3)	Larger domain in fast speech, T3S; ST3

Notice that the last two syllables in (5a) are irrelevant for T3S application because the negation particle *mei* 'not' is a T2. Upon reaching this syllable, the series of multiple consecutive

[27] Presentation of these experimental sentences is different from the Kuo et al. (2007) paper in order to provide the relevant information for the discussion in this section. An example of the original presentation of the testing sentence of five T3-digits embedded in the carrier sentence is below, where "L" indicates the low tone (T3) and "R" indicates the Rising tone (T2):

LiangL liangL liangL liangL youL meiR youL?

'Is there X (X= number sequence, which is '2' in this case)?' Kuo et al. (2007: 214).

The tones are indicated by letters such as L (Low, T3) or R (Rising, T2). For consistency in this dissertation, numerals are used instead. In addition, prosodic domains for the attested surface forms have been added, so that we can see the speakers' parsing strategies more easily.

[28] "Is there X (X range from 2 – 4 digits)?" is the translation provided by the authors in the Kuo et al. (2007) study. I personally think that the structure tested in this study corresponds to a topicalized structure, with the "X" is being moved from the sentence-final position to the sentence-initial position. If this is correct, "X, is there (it)?" may be a more appropriate translation. The structure is relevant and potentially affects how the sentence is parsed in a sentence that is topicalized. Nevertheless, the original translation is reported as is.

[29] "Y*ou mei you (you* 'there is' + *mei you* 'there is not') 'Is there…?' is parsed in a prosodic domain in one step here for simplification. The derivational steps are [T3 [T2T3]]→ T3 (**T2**T3)→ (T3T2T3).

T3* discontinues. Since the last two syllables in (5a) are irrelevant, they were excluded from the reports of the findings.

Within the sequence of adjacent T3*, all syllables except for the final syllable (*you* 'there is') were extracted for phonetic analysis (*you* 'there is' is the final syllable in the T3-sequence and always surfaced as a T3, so this syllable was not included in the phonetic analysis) (Kuo et al. 2007). In their report of the surface patterns of T3-sequences, *you* 'there is' is presented as L (Low tone) in parentheses to distinguish it from the digit-sequence preceding it (e.g. RRRR(L)) for indicating **T2T2T2T2**T3, with the first four syllables being digits and the final syllable being a non-digit.

It should be emphasized that the underlined portions (indicating consecutive T3*) in the question and answer pair in (5a) and (5b) are identical (i.e. the syllables of the whole sentence in (5b) are identical to the first five syllables in (5a)). Kuo et al. (2007) reported that most subjects broke the sequence of five T3* into two spans (**T2**T3)(**T2T2**T3)[30], indicating the strong binarity effect. In addition, speakers who had the parsing of (T**2T**3)(T**2T2**T3) for (5) at the slow speed consistently used the same parsing at the fast speed. One speaker had a large domain parsing of (**T2T2T2T2**T3) in both slow and fast speech rate (Kuo et al. 2007:215-218).

The sample example from (Kuo et al. 2007), shown in (5), has a sequence of four digits, but a sequence of two and three digits were also tested in the same carrier sentences. In those cases where there are two and three digits, followed by *you* 'there is,' Kuo et al. (2007) reported that starting with the low speed, all subjects show "left-to-right sweep," resulting in all digits' underlying T3* changing to the sandhi tone (**T2**) and *you* 'there is' stays intact as it is the last

[30] The boxed sequence of tones indicates the sequence of digits, followed by an unboxed T3, which is an existential verb *you* 'there is.'

syllable with a T3 in the sequence (2007:215). That is, in a sequence of three adjacent T3* and four adjacent T3*, (**T2T2**T3) and (**T2T2T2**T3) are the attested patterns.

In addition, one of the robust findings of this study is that the derived T2 and the underlying T2 differ in that the former is slightly lower in pitch though they have the same shape, and therefore, these two are acoustically distinct (Kuo et al. 2007:222). There are some points worth mentioning.

First, the results show that both (T**2T**3)(T**2T2**T3) and (**T2T2T2T2**T3) are attested in slow and fast speech rate in the first five syllables in (5), with the former being the dominant pattern. This challenges a widely accepted view that one large domain only occurs at fast speech rate, and multiple domains occurring at normal or slower speech rate. Although a prosodic domain can grow larger as the speech rate increases, it does not have to. The relation between size of prosodic domains and the speech rate is not one of cause and effect.

Second, for a sequence of three T3* (two T3-digits followed by *you* 'there is'), after the two-digits are parsed, it is relatively easy for adults to incorporate a third T3 into a binary foot that has been formed. Potentially, under the interpretation of the structure as a topicalized sentence (see footnote 28), a major syntactic boundary between the two digits and *you* 'there is' should be considered, and in that case, T3S does not have to apply. The fact that most participants of the study did apply T3S indicates that for a three-T3 sequence, to apply T3S across the domains is preferred, either because the sentences are too short, or because there is an effect of constantly repeating the same carrier string.

Third, two syllables constitutes a binary foot. For a slightly larger foot, a three-syllable foot, it is referred as a super foot (Chen 2000; Lin 2007; Shih 1986; Shih 1997). As such a foot is only a little larger than a typical binary foot, it is not surprising that for a sequence of three T3* (two

T3-digits followed by *you* 'there is,' a T3), all the syllables are grouped together to form one foot, or the prosodic domain. The prosodic domain appears to be stretched further to four syllables in a three-digit sequence followed by *you* 'there is,' a T3, since (Kuo et al. 2007) reported the patterns to be **T2T2T2**T3. In (Kuo et al. 2007), a four-syllable domain appears to be an upper limit beyond which syllables are divided into multiple domains, as we see in (5). For a sentence with very many consecutive T3* (five and beyond), although theoretically possible, speakers may not necessarily use the "left-to-right sweep" fashion of changing all the T3* into sandhi tone except for the last one in the sequence. Rather, dividing the longer sequence of T3* into more than one domain appears to be preferred by the participants in this experiment (by breaking the sequence of five T3* into two spans (**T2**T3)(**T2T2**T3) where the boxed tones refer to a flat structure followed by a T3 verb *you* 'there is').

Lastly, Kuo et al. (2007) acknowledge in the endnotes that in the five-T3 sequence in (5), the first four T3* are in an unstructured environment, and the last T3 *you* 'is there' is outside this environment; therefore, Kuo and colleagues suggest a two-step derivation with the first step dealing with digits only; in the second step, T3S applies across a syntactic boundary (Kuo et al. 2007:231): [[3333][323]]→[(**222**3)][(323)]→[[(222**2)][(**323)]]. Given that the first four syllables are digits, and can potentially be divided into two binary feet, followed by *you mei you* (T3T2T3) 'is there?" it is possible to have two binary feet in [four T3-digits], followed by [*you mei you* 'is there?' (T3T2T3)]. It would be interesting to see whether or not this possible pattern, [(**2**3)(**2**3)][(323)] for (5a), is acceptable or produced by other speakers, although it is not attested in the seven subjects in Kuo et al. (2007).

5.1.3 Re-thinking the linguistic environment for investigating flat structures

In the Kuo et al. (2007) study, two, three, and four digits are embedded in the sentence-initial position of carrier sentences which are question and answer pairs. In other words, the flat structure— the adjacent digits — is part of a sentence, which is not a flat structure. Would parsing of the flat structure be affected by the carrier sentences? Depending on what follows the flat structure, we see different number of possible surface patterns in (5), repeated in (6) below for convenience.

(6)

a.	Q: Liang	liang	liang	liang	you	mei	you	
	two	two	two	two	there is	there is not		‘Is there two-two-two-two?’
	3	3	3	3	3	2	3	UT
	(**2**	3)	(**2**	3)	(3	2	3)	Disyllabic feet, T3S; ST1
	(2	**2**)	(2	3)	(3	2	3)	T3S across domains, T3S; ST2
	(2	**2**)	(2	**2**)	(3	2	3)	T3S across domains, T3S; ST3
	(**2**	**2**	**2**	**2**	3	2	3)	Larger domain in fast speech, T3S; ST4
b.	A: Liang	liang	liang	liang	you			
	two	two	two	two	there is			‘There is two-two-two-two.’
	3	3	3	3	3			UT
	(**2**	3)	(**2**	3)	3			Disyllabic feet, T3S
	(2	3)	(2	**2**	3)			Incorporation, T3S; ST1
	(2	**2**)	(2	2	3)			T3S across domains, T3S; ST2
	(**2**	**2**	**2**	**2**	3)			Larger domain in fast speech, T3S; ST3

There are more possible surface patterns in (6a) than in (6b). This is mainly because that in the question, *you mei you* ‘Is there …?’ is a three-syllable unit that could be a foot by itself, whereas in the answer, *you* ‘there is’ is monosyllabic and may be too light to form a foot itself, and consequently, it is incorporated into the preceding foot formed by digits. In short, in the identical T3-sequences in (6a) and (6b), the last T3 in the sequence (*you* ‘there is’) must join its preceding foot in (6b), but not in (6a) because the carrier sentences differ in the number of syllables.

There is no mention of whether or not there are parsing differences between the T3-sequences extracted from the question and from the answer. Without considering the effect of two different carrier sentences types, the tendency of speakers' parsing of one way or the other may be biased. Although it may not be as relevant to the question asked by Kuo et al. (2007), how speakers parse the T3-sequence in (6a) and (6b) would provide valuable information for those interested in larger domain parsing. To sum up, despite the fact that the T3-sequences extracted from question and answer pairs are identical, how the sentence-initial sequence of digits is parsed is potentially affected by what follows it.

5.2 Research questions, hypotheses, and predictions

Our study investigates how T3S is applied in pure flat structures of two, three, and five digits. Our purpose is to learn how flat structures are parsed in children and adults. Since a flat structure has no internal structure, is left-to-right binary parsing strategy used in building T3S domains? We test three major factors in T3S application in flat structures—binary parsing, incorporation of an unfooted syllable, and directionality of foot-building.

5.2.1 Research questions and hypotheses

Our three main research questions are repeated below in (7) for convenience, followed by four hypotheses our experimental study tests.

(7) Research questions:

a. Is binary parsing the main foot-building strategy in flat structures?

b. Is an unfooted syllable incorporated into a neighboring foot in cases where there is odd number of syllables?

c. What is the directionality of foot-building in flat structures?

d. Is there a developmental pattern in children's acquisition of T3S? Is T3S acquired at an early age? When is T3S acquisition completed?

As mentioned earlier, in Mandarin, a disyllabic foot is a preferred foot structure, and such binary foot comprises the basic T3S domain within which T3S obligatorily applies (Lin 2007:205), so a disyllabic foot makes a perfect foot structure. We hypothesize that syllables are grouped according to the binary parsing strategy, and test the hypothesis in two-, three-, and five-syllable flat structures. Based on the Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997), we hypothesize that if there is an unparsed syllable at the end, it is incorporated into a neighboring foot. In addition, following the existing T3S models, it is hypothesized that the directionality is from left-to-right.

Regarding children's acquisition of T3S, no existing T3S studies investigate children's T3S acquisition in flat structures. Various T3S acquisition studies were reviewed in the previous chapter. Contrary to the findings of these studies, we found in our pilot study (Wang 2008) that children can change a T3 to a T2 when it is followed by another T3 early on, but it takes time for children's to perform in an adult-like way. We hypothesize that T3S acquisition begins early, but develops with age. Our four major hypotheses are summarized in (8).

(8) Four hypotheses

Binary parsing (H_1): Binary parsing precedes other parsing strategies. Binary feet are built iteratively until no more binary foot can be built (i.e. zero or one syllable left at the end).

Incorporation (H_2): If there is an unparsed syllable, it is incorporated into a neighboring foot.

Directionality L to R (H_3): Binary feet are formed from left to right. That is, every two syllables form a binary foot, going from left to right.

Developmental Hypothesis (H_4): Mastery of T3S develops with age. It is not acquired instantaneously at an early age.

5.2.2 Predictions of T3S application in flat structures

With binary parsing, even number of syllables can be evenly divided into disyllabic feet, but not odd number of syllables. Directionality of foot building is crucial since left-to-right parsing and right-to-left parsing strategies predict different surface patterns in odd number of syllables in flat structures. Shih (1986; 1997) proposes left-to-right prosodic parsing in flat structures, and such view is supported in later studies (Chen 2000:368; Duanmu 2000/2007:238; Lin 2007:206). In the subsections that follow, the predictions are made for flat structures that are composed of two, three, and five syllables.

5.2.2.1 A two-syllable flat structure

For a structure that consists of two T3-digits such as "five-five," the prediction for T3S application is in (9).

(9) A two-syllable flat structure

σσ
(σσ)   Binary parsing

Prediction of T3S application:

wu	wu	
five	five	'five-five'
3	3	UT
(**2**	3)	ST

Two syllables form a perfect binary foot within which T3S applies. Non-application of T3S will result in ungrammatical surface form.

5.2.2.2 A three-syllable flat structure

In cases where there are three syllables, according to the Word-and-Phrase level model (Chen 2000; Shih 1986; Shih 1997), after a disyllabic foot has been parsed from left to right, the leftover syllable is predicted to be incorporated into the disyllabic foot as we see in (10a). According to the Word-and-Phrase level model, the derived output (3**2**3) in (10b) is ungrammatical because binary parsing should be from left to right, not from right to left.

(10) A three-syllable flat structure

a. σσσ

(σσ)σ	Binary parsing from left to right
(σσσ)	Incorporation

Prediction of T3S application:

wu	wu	wu	
five	five	five	'five-five-five'
3	3	3	UT
(**2**	3)	3	T3S
(2	**2**	3)	T3S; ST

b. σσσ

σ(σσ)	Binary parsing from right to left
(σσσ)	Incorporation

Prediction of T3S application:

wu	wu	wu	
five	five	five	'five-five-five'
3	3	3	UT
3	(**2**	3)	T3S
*(3	2	3)	No T3S; ST

c. σσσ

(σσσ)	a three-syllable foot built in one step (larger domain in fast speech)

Prediction of T3S application:

wu	wu	wu	
five	five	five	'five-five-five'
3	3	3	UT
(**2**	**2**	3)	T3S; ST

If a three-syllable foot is built in one step as we see in (10c) without the step of incorporation, a three-syllable foot is formed and T3S applies from left to right. The surface pattern in (10c) is the same as that of (10a). That is to say, (**T2T2**T3) can surface from either source. Therefore, a three-syllable sequence will not allow us to disambiguate by which parsing strategy the surface pattern (**T2T2**T3) is obtained. Given that three-syllable is fairly short, and might be easily parsed in a three-syllable foot in one step, a surface form of (**T2T2**T3) may in fact be generated through such parsing.

To summarize, we expect that in a flat structure that consists of three syllables, a three-syllable prosodic domain will be built. If the surface pattern is **T2T2**T3, it could be derived through left-to-right parsing followed by incorporation, or it could be by way of setting up one domain in one step. If the surface pattern is T3**T2**T3, then it is derived from right-to-left binary parsing followed by incorporation. In order to test directionality, it is necessary that we extend the number of syllables.

5.2.2.3 A five-syllable flat structure

How do we know when and how an unfooted syllable is incorporated into a neighboring foot? As previously mentioned, the binary foot that the unparsed syllable is incorporated into signifies the directionality (Chen 2000; Lin 2007; Shih 1986; Shih 1997). A four-syllable flat structure does not allow us to test directionality since binary parsing from either direction will predict the same surface output (**T2**T3)(**T2**T3). A five-syllable flat structure, much like the three-syllable structure, is ideal for testing directionality. For now, let us assume that binary parsing strategy is used, and when there is a leftover syllable as in the case of odd number of syllables, it is incorporated into a neighboring foot. For odd number of syllables, there should be multiple binary feet plus one ternary feet, which is the result of incorporation, at either edge as illustrated in (11).

(11) Odd number of syllables composed of multiple binary feet and one ternary foot

a. Left-to-right parsing

σσσσσσ………………………………………………σσσ

(Binary foot)(Binary foot)(Binary foot) … (**Ternary foot**)

b. Right-to-left parsing

σσσ……………………………………………σσσσσσ

(**Ternary foot**)… (Binary foot)(Binary foot)(Binary foot)

The derivations for a left-to-right parsing strategy and a right-to-left parsing strategy are in (11a) and (11b) respectively. The ternary foot is on the right edge in left-to-right parsing, and on the left edge in the right-to-left parsing. We now turn to a five-syllable flat structure.

(12) A five-syllable flat structure

a. σσσσσ

(σσ)(σσ)σ	Binary parsing from left to right
(σσ)(σσσ)	Incorporation

Prediction of T3S application:

(**T2**T3)(**T2**T3)T3	T3S
(T2T3)(T2**T2**T3)	T3S; ST

b. σσσσσ

σ(σσ)(σσ)	Binary parsing from right to left
(σσσ)(σσ)	Incorporation

Prediction of T3S application:

T3(**T2**T3)(**T2**T3)	T3S
*(T3T2T3)(T2T3)	No T3S; ST

c. σσσσσ

(σσσσσ)	five-syllable foot built in one step (larger domain in fast speech)

Prediction of T3S application:

T3T3T3T3T3	UT
(**T2T2T2T2**T3)	T3S; ST

If foot-building is from left to right, the leftover syllable should be on the right edge, and then it is incorporated into a neighboring foot to form a ternary foot as in (12a). Hypothesis H_3 Direction L to R will be supported in this case. However, if foot-building is from right to left, the leftover syllable should be on the left edge, and subsequently it is incorporated into the neighboring foot to form a ternary foot as in (12b). Since at this point, there are no adjacent T3*, T3S does not apply. If this is the case, Hypothesis H_3 Direction L to R will be rejected. It should be noted that (**T2T2**T3)(**T2**T3), the reversal of two feet in the predicted surface pattern (**T2**T3)(**T2T2**T3), is ungrammatical according to the Word-and-Phrase level model.

As an unparsed syllable should be incorporated into a neighboring foot, the surface pattern (**T2**T3)(**T2T2**T3) implies a left-to-right binary parsing, and the surface pattern (T3**T2**T3)(**T2**T3) implies a right-to-left binary parsing. A five-syllable flat structure reveals the directionality when there are two domains.

An additional surface pattern (**T2T2T2T2**T3) is possible. It shows that all the five syllables are parsed in one step as in (12c). This output does not support or reject Hypothesis H_3 *Directionality L to R* because the hypothesis concerns the directionality of parsing binary feet. One large domain parsing in this case, therefore, does not qualify to test this hypothesis. However, whether or not there is a bias of using this larger domain parsing among different age groups can be compared. We expect that it is easier for adults than children to have the larger domain parsing since adults can process a larger amount of information at one time. Among children, we expect that older children have more of the larger domain parsing than younger children.

5.3 Study 2: Flat structures

5.3.1 Method

5.3.1.1 Subjects

Sixty-six subjects were recruited in Taichung, Taiwan for this study. There are three age groups: three-year-olds, five-year-olds, and adults. Table 5.2 shows the distribution of the participants.

Table 5.2 Study 2: Distribution of the subjects

Age groups	N	Age range	Mean	Standard deviation
3-year-olds	19	3;4 – 3;11	4;4	2.42 (mo.)
5-year-olds	27	5;1 – 5;11	6;3	3.05 (mo.)
adults	20			

5.3.1.2 Procedure

All children were tested individually in a quiet classroom in the kindergarten or in the home of the child. Adult subjects were also tested individually in a quiet room. The elicited production task lasted approximately 12 minutes for children, and 6 minutes for adults.

Children were told that they were going to play a game. Some stuffed animals were introduced to the children in the beginning in order to create a more friendly game-like setting. The stuffed animals then were set aside on the table as if they were watching the child and the experimenter play the game they were about to play. Each subject sat in front of a laptop computer which displayed a large colored digit. As the digit showed on the screen, the experimenter asked the child what it was. This was to make sure that the child knew the digit and could say it with the underlying tone correctly. The task was to say a digit two times, three times, and then five times. As simple as it may sound for adults, for 3-year-olds, or even 5-year-olds, it may not be necessarily easy, especially in repeating a digit five times. Keeping track of how many times the digit has been said and how many times it still needs to be said may give them extra burden. The procedure below is followed in order to remove such burden for children.

Figure 5.1 Flat structures: A child's hand, (a) – (c) for two, three, and five digits respectively

a. for two digits | b. for three digits | c. for five digits

The experimenter said, “What’s this? (pointing to the digit on the screen)” After the child gave the answer, she was told to hold out one hand just like the experimenter showed her, with five fingers up straight. Then the experimenter gently bent down three of her fingers, leaving two up (See Figure 5.1 (a)) and said, “You say it (pointing to the digit on the screen) when I tap your fingers, okay?” As two fingers were up, the child said the digit upon each of the two fingers was tapped by the experimenter’s index finger.

After completing saying the digits two times, the experimenter held out one hand again, with five fingers up straight, and asked the child to do the same. She now gently bent down two of the child’s fingers, leaving three fingers up (See Figure 5.1 (b)). The child was told to say the same digit, which was still on the computer screen, when the experimenter tapped her fingers. As three fingers were up, the child said the digit when each of the three fingers was tapped.

Finally, the experiment once again held out one hand, with five fingers up straight. The child followed. There was no need to bend down the child’s fingers this time. With her five little fingers up straight (See Figure 5.1 (c)), the experimenter asked, “Are you ready? I am going to tap (your fingers) now.” The experimenter proceeded when the child was ready. The child said the digit five times in this final round. Each child was familiarized with the task in a practice session before proceeding to the experiment. (See Appendix B for Mandarin experimental prompts and materials.)

For adults, it could be easily understood that the task was to say the digit shown on the screen two, three, and five times. Adults saw the digit on the computer screen as well, but they were instructed to say the digit two times, then three times, and then finally, five times. There was no need to hold out a hand, and saying the digit as their fingers were tapped by the experimenter as it was done with children. All subjects’ responses were recorded on a Marantz PMD660 with an

Audio-technica miniature clip-on microphone (AT831B Cardioid Condenser Lavalier microphone). (A second digital recorder, a Sony ICD-P530F, was used in case of technical problems.)

5.3.1.3 Design

An elicited repetition task (Crain & Thornton 2000; McDaniel et al. 1998) is used in this experiment. Digits are used in the task. Digits from 0 to 9 are all single syllables in Mandarin. Except for “5” and “9” which are in Tone 3, all the rest of the digits are in Tone 1, Tone 2, or Tone 4 (i.e. non-T3*). T3-digits “5” and “9” were used as the test items, and non-T3 digits were used as the control items and in the practice session.

In the control items, the surface tones and the underlying tones are the same because non-T3* are not affected by T3S. In the test items, T3S will apply according to how the string of syllables is parsed. Surface tones will differ from underlying tones due to T3S application. In (13) below, we keep only the parsing information and predicted outputs, which is based on the Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997). Detailed derivations of the predicted patterns have been presented and discussed in Section 5.2.2.

(13) Flat Structures in two, three, and five syllables

a. two syllables

σσ
(σσ) Binary parsing from L to R

T3T3→ (**T2**T3)

b. three syllables

σσσ
(σσ)σ Binary parsing from L to R
(σσσ) Incorporation

T3T3T3→ (**T2**T3)T3→ (T2**T2**T3)
Or T3T3T3→ (**T2T2**T3)

c. five syllables
σσσσσ
(σσ)(σσ)σ Binary parsing from L to R
(σσ)(σσσ) Incorporation

(**T2**T3)(**T2**T3**)**T3→(T2T3)(T2**T2**T3)
Or (**T2T2T2T2**T3)

For two-syllable items, the surface pattern (**T2**T3) derived through disyllabic foot-building and through larger domain parsing in fast speech are the same. For three-syllable items, the surface pattern **(T2T2**T3) can result from disyllabic parsing followed by incorporation, or from the larger domain parsing. In the five-syllable item, however, the predicted larger domain parsing, (**T2T2T2T2**T3), differs from the pattern derived from the step-by-step binary parsing from left to right followed by incorporation of the unfooted syllable as we see in (13c).

5.3.1.4 Materials

A sample control item and a sample test item are in Figure 5.2 (a) and (b) respectively. A complete list of the experimental materials as well as the instructions in Mandarin is in Appendix B.

Figure 5.2 Study 2: Saying a digit two, three, and five times

a. Sample control item: a non-T3 digit “3” (Tone 1)	
3	**(i) two times** san san three three ‘three-three’ **(ii) three times** san san san three three three ‘three-three-three’ **(iii) five times** san san san san san three three three three three ‘three-three-three-three-three’
b. Sample test item: a T3-digit “9”	
9	**(i) two times** jiu jiu nine nine ‘nine-nine’ **(ii) three times** jiu jiu jiu nine nine nine ‘nine-nine-nine’ **(iii) five times** jiu jiu jiu jiu jiu nine nine nine nine nine ‘nine-nine-nine-nine-nine’

5.3.1.5 Coding

Two native speakers transcribed the data and coded the answers. Numbers 1, 2, 3 and 4 were used in transcribing the four lexical tones, T1, T2, T3, and T4, respectively. Data were coded in a way to preserve the most available information in subjects’ responses. The coding categories are in (14).

(14) Coding categories for data analysis:

a. Included in the analysis:

i. Correct application of T3S without missing any syllables (missing syllables are indicated by underscores in the coding).

ii. Incorrect application of T3S without missing any syllables

b. Excluded in the analysis:

i. No answer: Saying ‘I don’t know’ or being silent without giving an answer.

ii. Non-target answers: Not saying the digit with the targeted number of times (e.g. saying the digit four times when it should be said three times).

iii. Pauses: Pauses between two T3*.

Answers with pauses between T3* were excluded from the analysis because a pause destroys the T3S environments created. For the control items, since T3S does not apply in non-T3 digits, the surface tones are the same as underlying tones. T3S application is irrelevant in the control items. Sample answers for a T3-digit “9” and how they fit in the coding categories are listed in Table 5.3.

Table 5.3 Study 2: Sample answers and their coding categories for data analysis

A T3-digit "9"		Sample answers (only tonal information is included here)		Included in the analysis?	Correct ✓ or incorrect ✗
a. **Two times**		i.	(23)	✓	✓
jiu jiu		ii.	(33)	✓	✗
nine nine	'nine-nine'	iii.	(22)	✓	✗
3 3	UT	iv.	(32)	✓	✗
		v.	(34)	✓	✗
b. **Three times**		i.	(223)	✓	✓
jiu jiu jiu		ii.	(323)	✓	✗
nine nine nine	'nine-nine-nine'	iii.	(333)	✓	✗
3 3 3	UT	iv.	(233)	✓	✗
		v.	(222)	✓	✗
		vi.	(232)	✓	✗
c. **Five times**		i.	(23)(223)	✓	✓
jiu jiu jiu jiu jiu		ii.	(22223)	✓	✓
nine nine nine nine nine	'nine-nine-nine-nine-nine'	iii.	(223)(23)[31]	✓	✓
		iv.	(33333)	✓	✗
3 3 3 3 3	UT	v.	(23)(333)	✓	✗
		vi.	(22222)	✓	✗
		vii.	(223)(22)	✓	✗
		viii.	(23)(23)(2)	✓	✗
		ix.	(23)(23)(3)	✓	✗
		x.	(3)(23)(33)	✓	✗
		xi.	(23)p(23)p(23)p(23)p(23) (p = pause)	✗	n/a

For statistical analysis, various error patterns were further coded and placed under two basic error categories, with the first category overriding the second one: (i) Over-application: over-application of T3S at the right edge of the domain, resulting in a T2 in the final-digit in the sequence, and (ii) Under-application: under-application of T3S include non-application of T3S as well as under-application of T3S in one or more syllables. To know T3S is to know when to apply the rule as well as when not to apply it. The first category "Over-application" captures the

[31] Although this pattern is not predicted by the Word-and-Phrase level Model, it was treated as a correct pattern because the pattern was attested in adults.

T3S errors made by subjects when they failed to “stop applying T3S” at the rightmost digit in the prosodic domain when the preceding digit(s) had undergone T3S. Errors of this type include *(**T2T2**), *(**T2T2T2**), and *(**T2T2T2T2T2**), but are not limited to these.

Another common T3S error is under-application, namely, T3S is not applied when it should. Examples of under-application errors include *(T3T3), *(**T2**T3T3), *(**T2**T3)(**T2**T3T3). Among all the errors, there was a single error (*T3T3)(**T2**T3**T2**) produced by a 3-year-old that fit the descriptions of both error categories. As it was decided that “Over-application” overrides “under-application” in our coding for error types, it was coded as an over-application error, rather than creating a third error category of this single “mixed” error type.

It is worth emphasizing that of all the errors made by the participants, there was only one error *(T3T4) (for a sequence of two T3-digits) that involves another tone that is not T2 or T3. This error is treated as “under-application” as it is a case of not applying T3S when it should. Incorrect answers in Table 5.3 are used in Table 5.4 for presenting how errors were categorized in the two error types for our error analyses.

Table 5.4 Study 2: Sample T3S errors and their coding categories for error analysis

A T3-digit "9"		Sample errors (only tonal information is included here)		Over-application (O) or Under-application (U)
a. **Two times**		i.	(33)	U
jiu jiu		ii.	(22)	O
nine nine	'nine-nine'	iii.	(32)	O
3 3	UT	iv.	(34)	U
b. **Three times**		i.	(323)	U
jiu jiu jiu		ii.	(333)	U
nine nine nine	'nine-nine-nine'	iii.	(233)	U
3 3 3	UT	iv.	(222)	O
		v.	(232)	O
c. **Five times**		i.	(33333)	U
jiu jiu jiu jiu jiu		ii.	(23)(333)	U
nine nine nine nine nine	'nine-nine-nine-nine-nine'	iii.	(22222)	O
		iv.	(223)(22)	O
3 3 3 3 3	UT	v.	(23)(23)(2)	O
		vi.	(23)(23)(3)	U
		vii.	(3)(23)(33)	U

5.3.2 Results

In this section, we first report the answers that were excluded from the analysis. There were no items excluded from 6-year-olds and adults. For 3-year-olds, numbers of excluded control items and test items are summarized in Table 5.5 and Table 5.6 respectively.

Table 5.5 Study 2: Control items— 3-year-olds' data excluded from the analysis

σσ	σσσ	σσσσσ	Excluded total
No answer: 5	No answer: 5	No answer: 1	11
Non-target: 0	Non-target: 0	Non-target: 0	
Pauses: 0	Pauses: 0	Pauses: 0	

Table 5.6 Study 2: Test items— 3-year-olds' data excluded from the analysis

σσ	σσσ	σσσσσ	Excluded total
No answer: 2	No answer: 1	No answer: 1	6
Non-target: 1	Non-target: 0	Non-target: 0	
Pauses: 0	Pauses: 0	Pauses: 1	

Next, we turn to the results. We found that both child groups did well in the control items. Unlike adults, however, children's correct rates dropped dramatically in the test items. In what follows, the results for the control items and the test items are presented and discussed.

5.3.2.1 Overall correct rates in control items and test items

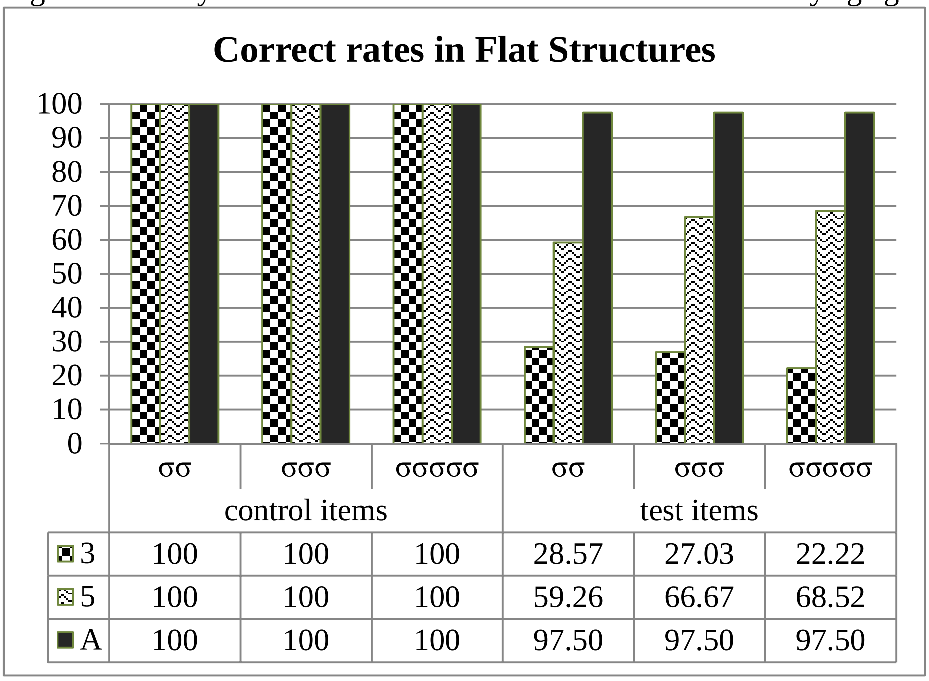
All the subjects did perfectly in the control items with two, three, and five syllables.

Table 5.7 Study 2: Control items (non-T3 digits)

Number of Syllables / Age	σσ % (N)	σσσ % (N)	σσσσσ % (N)
3	100 (33/33)	100 (33/33)	100 (37/37)
5	100 (54/54)	100 (54/54)	100 (54/54)
A	100 (40/40)	100 (40/40)	100 (40/40)

The fact that even the 3-year-olds did not have any difficulties in the control items suggest that the task itself was not beyond what 3- and 5-year-olds could accomplish. More specifically, even saying the non-T3 digit for the maximal times, five times, in the experiment, appeared to be easy for children. For T3-digits, while adults did well in the test items (97.50% correct in two, three, and five syllables), children's correct rates dropped dramatically as we see in Figure 5.3.

Figure 5.3 Study 2: Total correct rates in control and test items by age groups



Since children did perfectly in the control items, T3S is the source of difficulties which caused the dropping of correct rates in both child groups. There is only one acceptable surface pattern, (**T2**T3) and (**T2T2**T3) for two-syllable and three-syllable test items respectively. These predicted patterns match what adults produced, and are attested in children as well.

For five-syllable items, two predicted patterns are (**T2**T3)(**T2T2**T3) and (**T2T2T2T2**T3), with the former pattern attested in adults only, and the latter pattern attested in both child groups and adults. An additional pattern (**T2T2**T3)(**T2**T3) was found in adults as well as children. Even though it is not a predicted pattern, it is considered as a grammatical pattern in our analysis mainly because it was attested in adults. Total correct rates for each age group are calculated by adding up the correct rates of all possible correct patterns within each age group. The information on the frequency of individual correct patterns by age group is in Table 5.8. Figure 5.4 – Figure 5.6 in the next section present the same information in bar charts.

Table 5.8 Study 2: Test items (T3 digits)

Syllable / Age	σσ	σσσ	σσσσσ			
	(**2**3)	(**22**3)	(**2222**3)	(**2**3)(**22**3)	(**22**3)(**2**3)	Total
3	28.57% (10/35)	27.03% (10/37)	16.67% (6/36)	0% (0/36)	5.56% (2/36)	22.22%
5	59.26% (32/54)	66.67% (36/54)	61.11% (33/54)	0% (0/54)	7.41% (4/54)	68.52%
Adults	97.50% (38/40)	97.50% (39/40)	70.00% (28/40)	22.50% (9/40)	5.00% (2/40)	97.50%

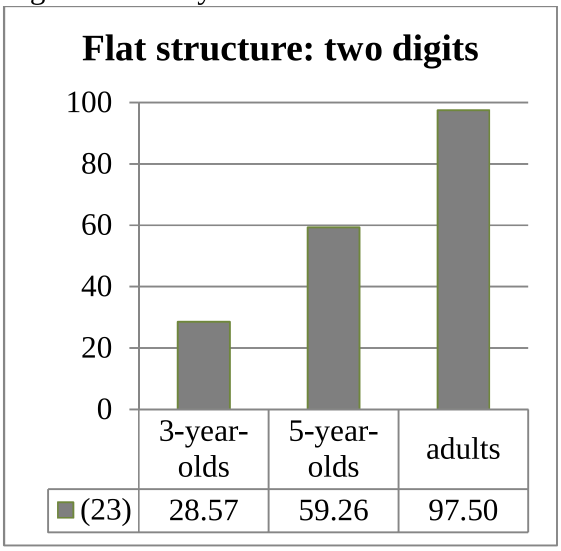
5.3.2.2 Surface patterns in flat structures

Two T3-digits

Logistic regression analyses (see Appendix H) were conducted for correct responses as well as incorrect responses in flat structures. In what follows, the results for two-, three-, and five-digits will be presented separately.

The results show that *age* is significant (*chi square* = 46.067, $p < .001$ with $df = 2$). For correct surface pattern **T2**T3 relative to errors, both 3-year-olds and 5-year-olds are significantly different from adults in T3S application in two T3-digits and they are less likely than adults to have the correct surface pattern of **T2**T3 (3-year-olds: *Odds Ratio* (*OR*) = .010, $p < .001$; 5-year-olds: *OR* = .037, $p = .002$). There is a significant difference between 3-year-olds and 5-year-olds (*OR* = .275, $p = .006$).

Figure 5.4 Study 2: Correct rates of two T3-digits by age group

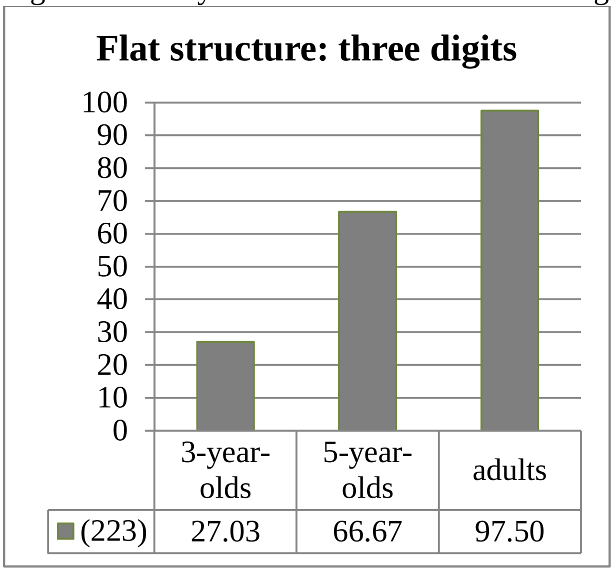


Even though it is a small domain with only two digits, 3-year-olds had a lot of difficulties. Even 5-year-olds had a correct rate of only about 60%. For the adults, the only one error that was produced by one adult was *T2T2, a case of over-application.

Three T3-digits

The results show that *age* is significant (*chi square* = 48.539, $p < .001$ with $df = 2$). For correct surface pattern **T2T2**T3 relative to errors, both 3-year-old and 5-year-olds are significantly different from adults in T3S application in three T3-digits (3-year-olds: *OR* = .009, $p < .001$; 5-year-olds: *OR* = .051, $p = .005$). There is a significant difference between 3-year-olds and 5-year-olds (*OR* = .185, $p < .001$).

Figure 5.5 Study 2: Correct rates of three T3-digits by age group



For the three-digit sequence, 3-year-olds had a lot of difficulties. Five-year-olds had a correct rate below 70%. For the adults, the only one error that was produced by one adult was *T2T2T2, a case of over-application.

Five T3-digits

The results show that *age* is significant (*chi square* = 71.132, *p < .001* with *df* = 6). For five T3-digits, three surface patterns were attested in adults — larger domain parsing (**2222**3), Binary-Ternary parsing (**2**3)(**22**3), and Ternary-Binary parsing (**22**3)(**2**3). The last pattern, Ternary-Binary parsing, is not predicted by the Word-and-Phrase level model, but was attested in all age groups with a low frequency (3-year-olds: 5.56%, 5-year-olds: 7.41%, and adults: 5%).

For both 3-year-olds and 5-year-olds, two surface patterns were attested — larger domain parsing (**2222**3), and Ternary-Binary parsing (**22**3)(**2**3). The Word-and-Phrase level model predicts left-to-right Binary parsing followed by incorporation of unfooted syllable, which results in Binary-Ternary parsing (**2**3)(**22**3). Interestingly, this is the surface pattern that is missing in both child groups. The only error in the adult group, *T2T2T2T2T2, was produced by the same individual who had over-application errors in the two- and three-digit items.

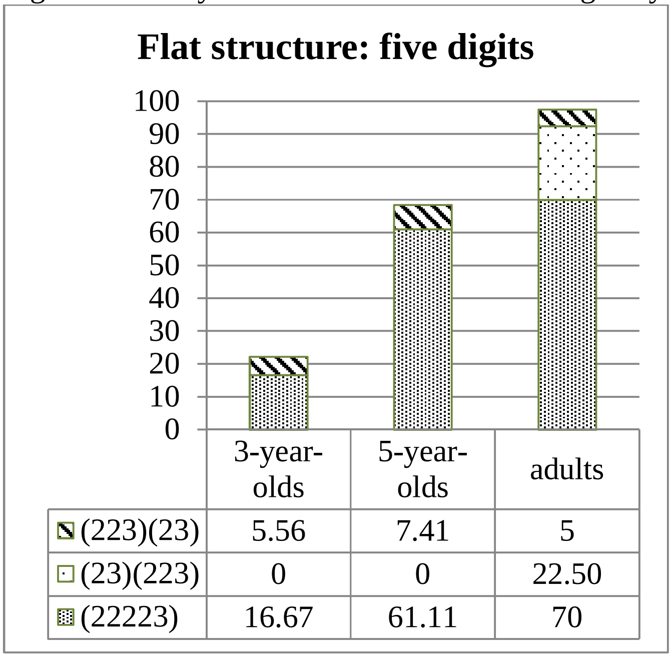
*Larger domain parsing—(**2222**3)*

For larger domain parsing (**2222**3) relative to errors, 3-year-olds and 5-year-olds are found to be significantly different from adults, and both child groups are less likely than adults to have larger domain parsing (3-year-olds: *OR* = .008, $p < .001$; 5-year-olds: *OR* = .069, $p = .012$). Three-year-olds and 5-year-olds are significantly different (*OR* = .110, $p < .001$).

*Ternary-Binary parsing—(**22**3)(**2**3)*

For Ternary-Binary parsing—(**22**3)(**2**3) relative to errors, 3-year-olds are found to be significantly different from adults (*OR* = .036, $p = .020$) while 5-year-olds are not (*OR* = .118, $p = .112$). The two child groups are not significantly different from each other (*OR* = .304, $p = .195$). Figure 5.6 shows the distribution of surface patterns in the five-syllable item by age.

Figure 5.6 Study 2: Correct rates of five T3-digits by age group



The most common surface pattern in all age groups is the larger domain parsing. Five-year-olds' correct rates are below 70% and they are far from adult-like. The correct rate of about 20% shows that 3-year-olds had a lot of difficulties with T3S in the test items. The Binary-Ternary parsing is missing in both child groups.

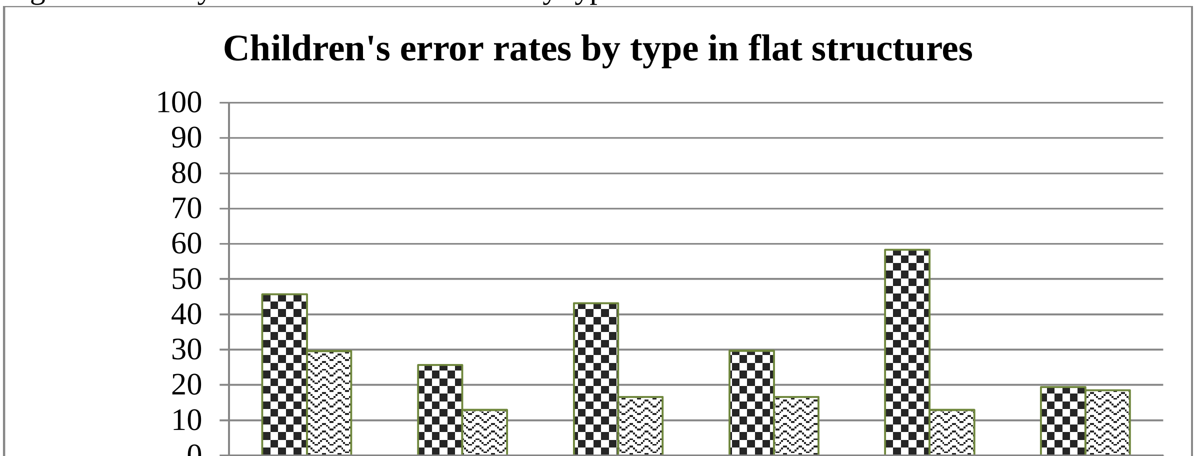
5.3.2.3 Errors in children

Since the adult correct rates for the two-, three-, and five-syllable flat structures are 97.50% (39/40), the T3S error analysis is focused on children's errors by comparing 3-year-olds' errors to 5-year-olds'.

Children's T3S errors were categorized under "over-application" or "under-application" as stated earlier. Do younger children and older children's errors tend to be one way or another? Or does one error type occur more frequently than the other type in children? Figure 5.7 shows children's error rates by type.

Children's error rates by type

Figure 5.7 Study 2: Children's error rates by type in flat structures



	σσ		σσσ		σσσσσ	
	over-application	under-application	over-application	under-application	over-application	under-application
3-year-olds	45.71	25.71	43.24	29.73	58.33	19.44
5-year-olds	29.63	12.96	16.67	16.67	12.96	18.52

In Figure 5.7, a developmental trend can be clear seen. The error rates decrease by age, regardless of the error types. Three-year-olds are prone to make over-application errors. Five-year-olds' T3S errors do not show a strong tendency of either over- or under-application in three- and five-syllable items. In the two-syllable item, however, they tend to over-apply the T3S rule.

Logistic regression analyses were conducted for children's error types in flat structures. The results for two-, three-, and five-digits are as follows.

Two T3-digits

The independent variable *age* is significant (*chi square* = 7.447, *p* = .024 with *df* = 2). For both error types relative to correct surface pattern (**T2**T3), 3-year-olds are significantly different from 5-year-olds (Over-application: *OR* = 3.100, *p* = .026; Under-application: *OR* = 3.986, *p* = .026). The *Odds Ratio* value indicates that 3-year-olds are about three times more likely than 5-year-olds to over-apply T3S rule. They also are four times more likely than 5-year-olds to under-apply T3S rule.

Three T3-digits

Age is still significant in three T3-digits (*chi square* = 14.592, *p* = .001 with *df* = 2).). For both error types relative to correct surface pattern (**T2T2**T3), 3-year-olds are significantly different from 5-year-olds (Over-application: *OR* = 6.400, *p* = .001; Under-application: *OR* = 4.400, *p* = .010). The *Odds Ratio* value indicates that 3-year-olds are roughly 6.5 times more likely than 5-year-olds to over-apply T3S rule, and they are 4.5 times more likely than 5-year-olds to under-apply T3S rule.

Five T3-digits

The results show that *age* is significant (*chi square* = 24.496, *p < .001* with *df* = 2). For the error type *Over-application*, 3-year-olds are significantly different from 5-year-olds (*OR* =

13.875, $p < .001$). The *Odds Ratio* value indicates that 3-year-olds are roughly 14 times more likely than 5-year-olds to over-apply T3S rule. The two child groups are not significantly different in the other error type, *Under-application* (OR = 3.237, p = .062).

5.3.3 Checking hypotheses

The adult grammar is ultimately what children will arrive at. The adult T3S patterns attested in this study are compared against the surface patterns predicted by the Word-and-Phrase level model. The *Binary parsing hypothesis* (H_1) and *Incorporation Hypothesis* (H_2) are supported by adults' answers of (**T2**T3) and (**T2T2**T3) in the two and three T3-digit items respectively, just as predicted. No adults produced two T3* in the two-syllable items. The fact that (**T2**T3) was the only response in the adult group indicates that a binary foot is formed for two syllables. For three-syllable items, if we had the answer type (**T2**T3)(T3), it would be evidence against our *Incorporation Hypothesis* (H_2) which states an unfooted syllable should be incorporated into a neighboring foot, but it was not attested in adults. As mentioned previously, (**T2T2**T3) pattern have two sources—(i) larger domain parsing or (ii) the step-by-step parsing (binary parsing followed by incorporation of unfooted syllable). We cannot be completely certain that the pattern (**T2T2**T3) here is a result of incorporation. Nevertheless, the Incorporation Hypothesis (H_2) was also tested in the five-syllable items, where there was no ambiguity. We will return to this in the later discussion.

For testing H_3, *Directionality L to R*, five T3-digits were used. Even though we cannot use three T3-digits to test directionality partially because we were unable to disambiguate the sources of (**T2T2**T3), the unattested pattern (T3**T2**T3) in adults sheds some light. (T3**T2**T3) is a pattern that results from right-to-left parsing, followed by incorporation of the first syllable that is unfooted. As (T3**T2**T3) never surfaced in the adult data, at this point, we do not see any evidence of right-to-left parsing. To confirm whether or not right-to-left parsing is indeed never used in adults, we now turn to the results of five-digit items.

In five T3-digits, the larger domain parsing (**T2T2T2T2**T3) is the dominant pattern across age groups (adults: 70.00%, 5-year-olds: 31.11%, and 3-year-olds: 16.67%). The non-fast speech pattern (**T2**T3)(**T2T2**T3) that the Word-and-Phrase level model predicts was attested only in the adult group, at 22.50%. Not a single child produced this pattern. The fact that (**T2**T3)(**T2T2**T3) was attested, but not (T3**T2**T3)(**T2**T3), gives strong evidence that it was left-to-right parsing, rather than right-to-left parsing. Hypothesis H_3 *Directionality L to R* is supported by the adult data. In addition, (**T2**T3)(**T2T2**T3) confirms *Incorporation Hypothesis* (H_2) that an unfooted syllable is incorporated into a neighboring foot.

Interestingly, an unpredicted pattern (**T2T2**T3)(**T2**T3) was attested across all age groups, with a small percentage (between 5% - 8%) in each age group. We will return to discuss this pattern in more detail in Section 5.3.4.

Lastly, even though there were a lot of T3S errors in children, it was clear that 3-year-olds can change a T3 to a T2 when followed by another T3, and they had correct rates between 20% - 30% for two, three, and five T3-digits. Five-year-olds had correct rates at about 60% - 70% for the two, three and five T3-digits. The results roughly translate to an increase in the correct rate by 40% in children's T3S application in flat structures in two years' time, from age 3 to age 5. Five-year-olds are still in the process of mastering the use of the T3S rule and still do not have adult-like performance. Hypothesis H_4 *Developmental Hypothesis* is supported by our experimental results.

5.3.4 Discussion

This section is divided into three subsections. First, observations of correct patterns attested will be discussed in detail. Next, we turn our attention to T3S errors in children. Both attested and unattested errors will be looked into in order to identify any existing patterns in children's errors. Discussion on what can be learned from the Kuo et al. (2007) study as well as our current study will conclude this section.

5.3.4.1 Correct surface patterns

(**T2**T3) and (**T2T2**T3) are the predicted and attested patterns in two T3-digits and three T3-digits respectively. For five T3-digits, both child groups have two patterns, the larger domain parsing (**T2T2T2T2**T3) and an unpredicted pattern (**T2T2**T3)(**T2**T3) which was also attested in adults. The predicted pattern (**T2**T3)(**T2T2**T3) was attested in adults, but not in children. A summary table of the discrepancies is in Table 5.9.

Table 5.9 Summary of discrepancies between attested and predicted patterns in a 5-syllable flat structure

σσσσσ	Predicted patterns		Unpredicted patterns
	ST1	ST2	ST3
T3T3T3T3T3 UT	(**T2**T3)(**T2T2**T3)	(**T2T2T2T2**T3)	(**T2T2**T3)(**T2**T3)
3-year-olds	×	√	√
5-year-olds	×	√	√
adults	√	√	√

(Attested: √, unattested: ×; shaded cells show the discrepancies between predicted patterns and attested items.)

ST1 (**T2**T3)(**T2T2**T3): Children do not have the predicted pattern and this is not the most frequent pattern.

ST2 (**T2T2T2T2**T3): It is a fast speech pattern according to the Word-and-Phrase level model, but in our experimental setting where fast speech was not required, it was the most commonly used pattern across age groups. Such results suggest that ST2 does not necessarily occur only in fast speech. The claim is supported by the results in the Kuo et al. (2007) study where larger domain parsing was attested in slow, normal, and fast speech rates.

ST3 (**T2T2**T3)(**T2**T3): Neither left-to-right nor right-to-left parsing can account for this pattern For the Word-and-Phrase level model to account for this pattern, modifications will be needed to accommodate this pattern unless such pattern is regarded as ungrammatical. A possible explanation may be that both binary and ternary feet are available in flat structures. In other words, upon knowing that the total number of syllables is five, in the subject's mind, the string is divided into a binary foot and a ternary foot, and both of which are available before the first syllable is produced. If a binary foot is picked first, the pattern (**T2**T3)(**T2T2**T3) surfaces. If a ternary foot is picked first, the pattern (**T2T2**T3)(**T2**T3) surfaces. The ability of dividing a string of five syllables into a binary foot and a ternary foot may be intuitive and automatic as "five" is not that great a number. As the number grows, speakers probably depend on some orderly way of parsing the string of syllables. We explore some other possibilities of parsing odd number of syllables in flat structures beyond the standard view of left-to-right binary parsing in flat structures as shown in Table 5.10.

Table 5.10 Possible parsing of odd number of syllables if left-to-right parsing is not the only option

Number of syllables	five σσσσσ	seven σσσσσσσ	nine σσσσσσσσσ	eleven σσσσσσσσσσσ
a. Left-to-right parsing (predicted)	(σσ)<u>(σσσ)</u>	(σσ)(σσ)<u>(σσσ)</u>	(σσ)(σσ)(σσ)<u>(σσσ)</u>	(σσ)(σσ)(σσ)(σσ)<u>(σσσ)</u>
b. Right-to-left parsing (not predicted)	<u>(σσσ)</u>(σσ)	<u>(σσσ)</u>(σσ)(σσ)	<u>(σσσ)</u>(σσ)(σσ)(σσ)	<u>(σσσ)</u>(σσ)(σσ)(σσ)(σσ)
c. Ternary parsing when it is possible	n/a	n/a	(σσσ)(σσσ)(σσσ)	n/a
d. Bi-directional parsing	n/a	(σσ)<u>(σσσ)</u>(σσ)	(σσ)(σσ)<u>(σσσ)</u>(σσ) (σσ)<u>(σσσ)</u>(σσ)(σσ)	(σσ) (σσ)(σσ)<u>(σσσ)</u>(σσ) (σσ)(σσ)<u>(σσσ)</u>(σσ)(σσ) (σσ)<u>(σσσ)</u>(σσ)(σσ)(σσ)

In (a) and (b) in Table 5.8, a ternary foot is on the right edge for left-to-right parsing, and on the left edge for right-to-left parsing. In (c), a string of nine syllables is potentially good for ternary parsing, with three evenly divided ternary feet. It is not clear if the bi-directional parsing in (d) does happen as it requires the parsing to go the opposite way at the same time.

Even though binary parsing gives a perfect foot structure, it may not necessarily always precede other types of feet. In our daily life, we sometimes have a string of digits to read out, as in the case of phone numbers, social security numbers, and credit card numbers. In these cases, hyphens to break up the string are placed in the written form. For a seven-digit phone number, it is normally in the form of XXX-XXXX. For social security numbers, it is XXX-XX-XXXX. And for credit cards, we commonly see XXXX-XXXX-XXXX-XXXX. Notice that each chunk of the digits in these examples is composed of two, three, or four digits. This may indicate that for five digits and beyond, dividing the sequence into multiple units helps us process the information more easily. Is it possible that a three-digit unit and a four-digit unit are as accessible as a two-digit unit? I believe the answer is, “very likely” as we survey additional supporting evidence as follows.

First, Cowan et al. (2007) also points out the presentation of phone numbers in the form of ### - ####, and suggests that there exists some rapid grouping process to help retrieve the digits by reducing the number of chunks (Cowan et al. 2007). Cowan et al. (2007) reported that in the (Ericcson et al. 1980) study where an individual was trained to increase his digit span up to 80 digits within a year, the person learned to repeat about 20 digits in months, which was said to be learned through grouping 3 or 4 digits into new chunks, and later the chunks are further grouped into super-chunks (Cowan et al. 2007). This provides supporting evidence that a three- or four-digit chunk is a legitimate chunk. It is robust and active in the initial digit-grouping.

Second, consider again the case of phone numbers and social security numbers. In these series of digits, a three-digit unit precedes the rest of the units composed by two and/or four digits. A three-digit chunk may precede chunks formed by two or four digits, which is contrary to the notion of incorporation of the unfooted syllable on the right edge when the left-to-right parsing is followed. One may argue that foot-building has to do with syllables, and not all digits are of the same number of syllables. Such argument is reasonable. “Zero” and “seven” are the only two digits that are disyllabic among digits 0 – 9 in English. Without any hyphens in digits that are in the written form, number of syllables may have an effect on how the digits are parsed. However, in Mandarin, digits 0 – 9 are all monosyllabic, so there is no such concern. The surface pattern (**T2T2**T3)(**T2**T3) which was attested in our data was not as unusual as some might have thought if we take into consideration that grouping digits in units of two or three is common. The ternary foot in this case then is possibly the result of a digit-parsing strategy, rather than a product of a binary foot followed by incorporation of an unfooted syllable.

While binary parsing works very well in even-number syllables such as two or four syllables, ternary parsing will not be very useful in such environment. However, if the even number happens to be a multiple of “three,” then ternary parsing is available as binary parsing is available. Take a six-syllable string for example, it may be parsed in three binary feet ((σσ)(σσ)(σσ)) or in two ternary feet ((σσσ)(σσσ)). This does not mean that any parsing strategy can happen randomly. There should be a certain order, such as honoring the directionality “left-to-right” or using binary foot or ternary foot only when the context allows.

Before we close this section, it should be pointed out that it is possible that the Ternary-Binary parsing (**T2T2**T3)(**T2**T3) is a pattern used only by Taiwan speakers, including children and adults. Only when such parsing strategies are found in Mandarin speakers from other regions could we be more certain that ternary feet indeed are available for parsing digits. Future studies can test whether this pattern is also found in adults in Mandarin speakers in other regions where Mandarin is spoken.

5.3.4.2 T3S Errors

T3S rule involves T2 and T3 only, and the other two lexical tones, T1 and T4 are irrelevant. Among all the adults, there were three error tokens of over-application from the same individual (***T2T2**, ***T2T2T2**, ***T2T2T2T2T2**). When children make T3S mistakes, what is the nature of the mistakes they make? We found in children's answers a great variety of T3S errors, which is a rich source through which we can have a peek into what they do when they parse and produce flat structures.

Of all the responses in the test items, only one error was found to be involved with a non-T3— *T3T4, which was produced by a 3-year-old for saying two T3-digits (target answer: **T2**T3). One possibility is that the child knew that T3T3 was ungrammatical after the first syllable had been produced. In order to meet the requirement of "no adjacent T3*" in the T3S rule, one thing that could be done was to change the tone of the second syllable because it was too late to change the first syllable. If this was what happened, it actually indicates that the child knew that two T3* standing next to each other is bad, and he used his own repair strategy. Except for this single error made by one child, all the T3S errors children made involve T2 and/or T3. We now turn to these errors in the context of two, three and five digits.

Two T3-digits

If we assume that children know that only T2 and T3 are involved in their T3S application, then for a sequence of two T3-digits, there are four (two slots with two possible tones $=2^2$ combinations) different combinations with only T2 or T3 in each slot as shown in (15).

(15) Four possible combinations of T2 and T3 in two T3-digits

***T2T2**	*T3**T2**
T2T3	*T3T3

Only one surface pattern is grammatical, **T2**T3. All the other three combinations (***T2T2**, *T3T3, and *T3**T2**) were found in our child data. For comparison of the frequency of each error type, the number of tokens of each error type is divided by total tokens of errors. The frequency of the error types are calculated separately for 3-year-olds and for 5-year-olds. We found that ***T2T2** is the most common (3-year-olds: 61.54%; 5-year-olds: 60.87%), followed by T3T3 (3-year-olds: 34.62%; 5-year-olds: 30.43%) in both child groups. *T3**T2** is less common (8.70%) and was attested in the 5-year-olds only. It appears that for both age groups, in a two-syllable flat structure, they are prone to over-apply T3S rule rather than under-apply it.

***T2T2** and *T3**T2** both meet the requirement of "No adjacent T3*," and in this regard, this type of errors show that the child has certain knowledge about T3S, though it may not be complete knowledge, namely, they know that there are alternations between T2 and T3, but they do not know the right time to use one tone or the other. For *T3**T2**, it may be that the child realized that T3S should have been applied after the first syllable had been produced in the underlying tone, T3. To avoid two adjacent T3*, the second syllable is changed to a T2. This is possibly a repair strategy used by the child.

*T3T3 violates T3S, and children who had this type of errors may or may not be aware of it. It is possible that the grammar was in place, but the child did not produce it correctly, and did not attempt to repair the error after it was produced.

Three T3-digits

For three T3-digits, there are eight (three slots with two possible tones =2^3 combinations) different combinations of T2 and T3 in the sequence as in (16).

(16) Eight possible combinations of T2 and T3 in three T3-digits

***T2T2T2**	*T3**T2T2**
T2T2T3	*T3**T2**T3
***T2**T3**T2**	*T3T3**T2** (not attested)
***T2**T3T3	*T3T3T3

Except for *T3T3**T2**, all patterns were attested in this study. The predicted surface pattern **T2T2**T3 is attested in all age groups. Children have the pattern of T3**T2**T3, but not adults.

The pattern T3**T2**T3 does not violate what T3S prohibits, two adjacent T3* in the domain. If binary feet are built from left to right, followed by incorporation of unfooted syllable, T3**T2**T3 should not have surfaced. Two possible explanations for T3**T2**T3 are the following:

(i) Syllables are parsed from right to left, followed by incorporation of the unfooted syllable.

T3T3T3→ T3 (**T2**T3)→ (T3T2T3)

(ii) The directionality is from left to right, but first, the leftmost syllable is somehow parsed as a degenerate foot, and then the other two syllables are parsed as a binary foot.

T3T3T3→ (T3)T3T3→ (T3)(**T2**T3)

For 3-year-olds, ***T2T2T2** is the most common (55.56%), followed by *T3T3T3 (25.93%) and the other error types are much less common (below 6%). For 5-year-olds, *T3T3T3 is the most common (31.58%), followed by ***T2T2T2** (21.05%) and ***T2**T3**T2** (21.05%), and the other types of errors are less common (below 6%).

The error type ***T2**T3**T2** is as common as ***T2T2T2** in 5-year-olds. As previously suggested in errors of *T3**T2** and *T3T4 for two T3-digits, ***T2**T3**T2** may be a child's repair strategy for three T3-digits in order to avoid two adjacent T3* after the second syllable had been produced in T3. It was one way out, even though it was not perfect. To the child, it could be a better choice than ***T2**T3T3. Another possibility of the source of ***T2**T3**T2** may be due to child's expectation of alternations between T2 and T3. Children may be familiar with binary foot building, and a string of multiple binary feet such as (**T2**T3)(**T2**T3)(**T2**T3)(**T2**T3) has a good rhythm in the alternation of the tones. In a three-digit sequence, the child had to end it (probably unexpectedly) at the third digit as she realized there were no more digits after that. Later in the five-digit items, we will again examine the error type of alternations between T2 and T3.

Five T3-digits

For five-digit items, the Binary-Ternary parsing, (**T2**T3)(**T2T2**T3), is missing in both child groups. Predicated by the Word-and-Phrase level model, the pattern is obtained by binary parsing from left to right followed by incorporation of the unfooted syllable on the right edge. In adults, 22.50% of the correct answers are of this pattern, with the larger domain parsing (**T2T2T2T2**T3) being the dominant pattern. Ternary-Binary parsing, (**T2T2**T3)(**T2**T3), is the least common, with only 5%, in adults. As adult speech is the language input for children, and if frequency of each surface pattern plays a role, it is intriguing that children have the most and the least frequent patterns attested in adults, but not the second common pattern.

For five T3-digits, there are 32 (five slots with two possible tones $=2^5$ combinations) different combinations of T2 and T3 in the sequence. Without any knowledge of how to parse feet and how to incorporate an unparsed syllable, the chance is 1/32 (3.125%) to correctly choose a particular surface pattern that is desired. The fact that children did much better than 3.125% show that they had some knowledge of T3S. It was not just by chance that they applied T3S correctly when they did. Even when they did not apply T3S correctly, their errors reveal a substantial amount of information. We now take a closer look at what we can learn from children's errors.

We know that there are 32 combinations of T2 and T3 in a 5-syllable sequence. With three correct surface patterns, we have 29 patterns left, and all of these are errors. In our study, only 11 error patterns were attested. To better understand why some error patterns surface, while others do not, let us remember what T3S requires, and what the consequences are if the requirements were not met. Simply put, what makes a bad pattern bad? Following what T3S requires, the result should meet each point listed in (17), regardless of how many feet are parsed in a flat structure.

(17) Summary of characteristics of expected surface patterns when T3S is correctly applied

a. Initial syllable is a T2.

b. The final syllable is a T3.

c. No adjacent T3* within the same domain

Not correctly applying T3S naturally will not generate the expected result listed in (17). A summary of what is helpful in categorizing possible error types is in (18), which is the opposite of (17).

(18) Summary of characteristics of ungrammatical patterns when T3S is not correctly applied

a. *Initial syllable is a T3

b. *Final syllable is a T2

c. *Adjacent T3* within the same domain

Notice that an ungrammatical pattern does not have to have all of (18a), (18b), and (18c). With just one of them, the pattern is ungrammatical. If some error patterns surface, while others do not, maybe some errors are better than others. A convenient way to help us better understand the attested and unattested error patterns is to use the concept of violation in Optimality Theory (Prince & Smolensky 1993/2004), and regard (18a), (18b), and (18c) each as one violation of T3S. We assume that an error pattern with one violation is better than another error pattern with two violations, which in turn is better than yet another error pattern with three violations. Without further complicating the picture, violations in (18a) – (18c) are treated as equally bad (they are neither ranked nor weighted.)

Table 5.11 lists all 32 combinations of T2 and T3 in a five-syllable structure. The patterns are further divided into grammatical and ungrammatical patterns, attested and unattested patterns, and other sub-categories. The digits in Table 5.11 indicate the surface tones (e.g. **T2T2T2T2**T3 is represented as 22223.)

Table 5.11 Study 2: 32 combinations of T2 and T3 in a five-digit sequence

<table>
<tr><th colspan="2">Attested (14 patterns)</th><th>Unattested (18 patterns)</th></tr>
<tr><td>Grammatical (3 patterns)</td><td>Ungrammatical (11 patterns)</td><td>Ungrammatical (18 patterns)</td></tr>
<tr><td rowspan="2">In children and adults:
22223
22323

Only in adults:
23223</td><td colspan="2">Characteristics of ungrammatical patterns:
a. *Initial syllable in T3 (*Initial T3)
b. *Final syllable in T2 (*Final T2)
c. *Adjacent T3* (*T3T3)</td></tr>
<tr><td>In children and adults:
*22222 (one violation)

Only in children:
<u>In both child groups</u>:
*22322 (one violation)
*22333 (one violation)
*33333 (one violation)

<u>In 3-year-olds only</u>:
*22232 (one violation)
*23333 (one violation)
*33233 (two violations)
*33232 (three violations)

<u>In 5-year-olds only</u>:
*23232 (one violation)
*23233 (one violation)
*32333 (two violations)</td><td>Not in children or adults:

Three violations (4 patterns):
<u>*Initial T3, *Final T2, *T3T3:</u>
*32332
*33222
*33322
*33332

Two violations (9 patterns):
<u>*Initial T3 and *Final T2:</u>
*32222
*32322
*32232

<u>*Final T2 and *T3T3:</u>
*23322
*22332
*23332

<u>*Initial T3 and *T3T3:</u>
*33223
*33323
*32233

One violation (5 patterns):
<u>*Final T2:</u>
*23222

<u>*Initial T3:</u>
*32223
*32323

<u>Adjacent T3*:</u>
*23323
*22233</td></tr>
</table>

From Table 5.11, we know that the errors 3-year-olds made include one, two, and three violations. For 5-year-olds, their errors include one violation and two violations. For the only adult that made the error *T2T2T2T2T2, it was an error of one violation. It shows that the younger the age, the higher number of violations appears to be tolerated.

An interesting discovery is that, our child subjects knew what kinds of errors are "better errors" to make. That is, when they made a T3S error, errors of fewer violations had a better chance to be picked than errors of more violations. This point is demonstrated by the percentage of an error to actually surface in our participants in Table 5.12. The numbers of possible patterns and attested patterns for calculating the "survival rate of error patterns" is obtained from Table 5.11.

Table 5.12 Study 2: Percentages of attested and unattested error patterns in children

Errors by number of T3S violations	Number of attested error patterns	Number of unattested error patterns	Total number of possible error patterns	Percentage of attested patterns ("survival rate")	Percentage of unattested patterns	Total
Calculation	(A)	(B)	(C = A + B)	(D = A/C)	(E = B/C)	(D + E)
Three violations	1	4	5	20.00%	**80.00%**	100%
Two violations	2	9	11	18.18%	**81.82%**	100%
One violation	8	5	13	**61.54%**	38.46%	100%
Total	11	18	29	n/a	n/a	n/a

Of all of the 13 possible error patterns of one violation, eight of them surfaced (61.54%). Errors of two or three violations surfaced at a much lower rate, with 18.18% and 20.00% respectively. In other words, the higher the number of violations, the less likely it is to be attested. This indicates that even though children made T3S mistakes, the mistakes were not just random mistakes.

Are there particular error types that children are prone to make? For 3-year-olds, the most common error type is ***T2T2T2T2T2** (60.71%), followed by *T3T3T3T3T3 (14.29%). All the other error types are of low frequency (0% - 7.14%). For 5-year-olds, the most common error types is *T3T3T3T3T3 (41.18%), followed by ***T2T2T2T2T2** (17.65%) and ***T2**T3**T2**T3**T2** (17.65%). The results echo what we had seen previously in the three-digit items. Based on frequency of children's error types, the profiles we have for 3-year-olds and 5-year-olds can be summarized in (19) and (20) respectively.

(19) Three-year-olds

Using sandhi tone for all syllables (60.71%) is a better strategy than using underlying tones for all the syllables (14.29%).

(20) Five-year-olds

a. Using underlying tones for all the syllables (41.18%) is a better strategy than using sandhi tone for all the syllables (17.65%).

b. Alternation strategy (alternating between T2 and T3 in a string of syllables, 17.65%) is as good as using sandhi tone for all the syllables (17.65%).

While ***T2**T3**T2**T3**T2** was one of the favored strategies in 5-year-olds, such pattern is non-existent in 3-year-olds. At age 3, they might not have noticed the alternation strategy that 5-year-olds have noticed. At this young age, they also might be better at maintaining the same tone in a sequence (e.g. ***T2T2T2T2T2** or *T3T3T3T3T3). At age 5, children not only have noticed the option of alternation strategy (***T2**T3**T2**T3**T2**), they are more mature in terms of articulatory development and can manage alternations better than younger children could. ***T2**T3**T2**T3**T2** is not the only error pattern of alternations. *T3**T2**T3**T2**T3 is also a pattern that alternates between T2 and T3. However, it never surfaces. The absence of this pattern provides indirect evidence that the parsing is from left-to-right, rather than from right-to-left.

Of the eleven attested error patterns, 72.73% (8/11) are the result of one violation, 18.18% is a result of two violations (2/11), and only 9.09% (1/11) is a result of three violations (occurred in

3-year-olds only). It is evident that children’s error patterns were attended to, rather than produced carelessly. Their production of T3S in flat structures, even when the attempts did not succeed, was governed by the grammar of T3S that was still maturing.

In all unattested error patterns, about 80% of the errors of two and three violations did not appear in children’s production. That means these children were aware of the degree of “badness.” Their errors of one violation may be bad, but errors of one violation are closer to the target than other errors that are relatively worse.

5.3.4.3 General discussion

This current study as well as the Kuo et al. (2007) study provide much needed empirical data for us to better understand T3S in flat structures. Both studies support the areas where predictions made by T3S theories match the empirical evidence. In a number of areas where predictions did not perfectly match the experimental data, the findings raise issues that need to be addressed in future work. The findings of the Kuo et al. (2007) study and the current study are checked against predications made by the Word-and-Phrase level model. The summary is in Table 5.13.

Table 5.13 Checking empirical data against theoretical predictions

T3S application in flat structures predicted by the Word-and-Phrase level Model	(Kuo et al. 2007) Flat structure (2, 3, and 4 digits) embedded sentence-initially, followed a T3 *you* 'there is') in a carrier sentence	This current study Flat structures (2, 3, and 5 digits)
a. Binary parsing	Evident in sequences of five adjacent T3*, but not very clear in three and four adjacent T3*	Yes
b. Incorporation of the unfooted syllable	Yes	Yes
c. Directionality: from left to right	Yes	Yes, but there was an extra pattern in five-syllable items that could not be accounted for by left-to-right binary parsing.
d. Larger domain parsing in fast speech	Larger domain parsing occurred in slow, normal, and fast speech rates.	Larger domain parsing occurred in normal speech (the experimental setting).

One may wonder whether or not the experimental design affects the results in Table 5.12. In the next two subsections, this possibility is briefly discussed.

T3S in flat structures in the Kuo et al. (2007) study

Two main areas the Kuo et al. (2007) study investigates are (i) the phonetic nature of the derived T2 and a true T2, and (ii) how T3S is applied in flat structures. Embedding a flat structure in a carrier sentence does not have an effect on (i), but may have an effect on (ii). When the number of adjacent T3* is small, the string of T3* may be prone to be parsed in one domain. However, as the number of adjacent T3* grows, separating the syllables into multiple prosodic domains is inevitable.

Schematically, the sentence in (21) represents a flat structure composed of an odd number of syllables (digits) being embedded sentence-initially.

(21) Odd number of syllables in a flat structure embedded in a sentence

	Liang	liang	….	liang	liang	liang	you	mei you?		
	Two	two	…	two	two	two	there is there is not			'Is there two-two-… -two-two-two?'
	3	3	…	3	3	3	3	2	3	UT
a.	(**2**	3)	…	(**2**	**2**	3)	(3	2	3)	ST1
b.	(**2**	3)	…	**(2**	**2**	**2)**	(3	2	3)	ST2
c.	*(**2**	3)	…	<u>(**2**</u>	<u>3)</u>	<u>(**2**</u>	<u>3)</u>	(2	3)	ungrammatical

In the flat structure, syllables are parsed in disyllabic feet from left to right, leaving the last digit unparsed. Then this unparsed syllable is incorporated into the disyllabic foot that precedes it. The result is ST1. In (21b), when T3S applies across the last two prosodic domains, ST2 results.

In (21c), it appears that disyllabic feet are formed nicely; however, the right-most digit in the sequence is "detached" from the rest of the digits when it joins the following syllable in the non-flat structure to form a disyllabic foot. The extraction of this syllable out of the flat structure is most likely to be responsible for the ungrammaticality of the potentially perfect binary parsing. The dangling unfooted digit at the edge of the sequence should join the members of its own kind (i.e. digits), rather than being "given away" to a syllable in the non-flat structure, even if that allows the formation of a perfect binary foot. The ungrammaticality of (21c) strongly indicate that T3S is dependent on syntax even in this case where both structure-less flat structure and structured carrier sentence are present.

To eliminate the effect a carrier sentence may have on the T3S application in a flat structure, the syllable(s) immediately preceding and/or following the flat structure may be restricted to non-T3* (T1, T2, or T4). In that case, the T3S application in the flat structure will not be affected by a neighboring T3 in the carrier sentence.

How does T3S apply in a flat structure that is in a sentence when one or more T3* are on either side, or even both sides (of the flat structure)? The location of the flat structure can be at the sentence-initial, sentence-medial, or sentence-final position, so shifting the location of the flat structure will allow us to learn how the flat structure interacts with neighboring syllable(s) from outside the flat structure. By manipulating the location of the flat structure, as well as the number of adjacent T3* within and outside the flat structure, it may help us understand more of the nature of T3S application. In the literature, discussion on flat structures are generally restricted to pure flat structures, so the (Kuo et al. 2007) study initiates an area in T3S that had not been previously explored.

T3S in flat structures in the current study

Our experimental work focuses on flat structures of two, three, and five digits. Existing T3S literature on flat structures commonly agree on the left-to-right binary parsing, followed by incorporation (Chen 2000; Lin 2007; Shih 1986; Shih 1997). We provide data from both children and adults in their application of T3S. While the surface patterns for two- and three-digit flat structure matched the predicted patterns, in the five-digit flat structure, in addition to the two predicted patterns (**T2T2T2T2**T3 and **T2**T3**T2T2**T3) predicted by the Word-and-Phrase level model, a third pattern was attested (**T2T2**T3**T2**T3). For future studies, the number of digits can be expanded to test whether or not there is indeed an alternative parsing besides the conventional parsing predicted by the T3S models.

In our study, 5-year-olds are not yet adult-like. Future studies can study children of a wider age range, preferably including children beyond five years old. This will allow us to learn approximately at what age children become adult-like. In addition, the tasks were purposefully kept simple in our study for the youngest age group was three years of age. For future studies, if it is appropriate for the participants' ages, the series of digits can be made longer, or more complicated with different digits in the same string (e.g. instead of 555555, use 595959 or 555999). T3S in odd number of digits (e.g. 3, 5, 7, 9 digits) and even number of digits (e.g. 2, 4, 6, 8 digits) can be compared. Do subjects consistently use the same strategy for odd number of digits, or even number of digits? For example, is binary parsing used consistently in even number of digits? In cases where incorporation is predicted in odd number of digits, is it found true in speakers' production? In the number of syllables where both binary parsing and ternary parsing are possible as in a 6-digit sequence, is it that only binary parsing is used? These are some appealing questions future research on T3S in flat structures can ask.

For the unexpected pattern (**T2T2**T3)(**T2**T3) attested in the experiment, without further evidence, we could only offer a plausible explanation that both binary feet and ternary feet are robust. In the case of five syllables, to divide the string into two domains, it is either "2 + 3" or "3 + 2," and since "five" is not a large number, the calculation could happen in the speakers mind instantly or automatically. It would be very interesting to see what speakers do in a seven-syllable flat structure, which is ideal for testing whether binary parsing goes before ternary parsing in the beginning. A study using seven-digit sequence may have to minimize the possible bias of phone-number reading. A bias that comes from a habitual way of grouping 3 digits followed by 4 digits in such case may not be very easy to eliminate.

A nine-digit sequence potentially has even more possibilities of how syllables can be chunked. The pattern predicted by the Word-and-Phrase level model is three binary feet followed by a ternary foot (2+2+2+3), with a total number of four feet. Is it possible that the sequence is divided into three ternary feet (3+3+3)? An even number of digits can be equally interesting and it does not have to be always divided into binary feet. An example is the 10-digit cell phone numbers in Taiwan, and the sequence is typically broken down as XXXX-XXX-XXX, which has three feet only. With a long string of digits, it is reasonable to maximize the number of digits a domain can accommodate, and yet for each domain, the load has to be manageable for the speaker. This may in fact be a better option than following binary parsing and have five small feet identical in size. Linking T3S in flat structures and how short and longer sequence of digits are divided is an area still to be explored.

5.4 Conclusions

For the control items, 3-year-olds, 5-year-olds, and adults all did perfectly (100% correct rate) showing they all understood the task. In the test items, adults had a 97.50% correct in two-, three-, and five-digit flat structures. Binary parsing and incorporation of the unfooted syllable were supported by our data. Nevertheless, in the five-syllable item, an unpredicted pattern was attested in all age groups.

We found also in the five-syllable item the larger domain parsing pattern was the dominant pattern in all age groups. This suggests that larger domain parsing is not restricted in fast speech only.

In our study, 3-year-olds' correct rates in the test items in two, three, and five syllables were between 20% and 30%, while 5-year-olds' were between 60% and 70%. A developmental pattern is clear. At age 3, children have the knowledge of changing a T3 to a T2 when followed by another T3 in flat structures, but at age 5, children still are not adult-like. An investigation of carefully sorting out children's T3S errors proved very interesting. It is true that children had difficulties with T3S application, especially the 3-year-olds, but they were not just making errors randomly. Even when they made errors, those errors were the "better" kind of errors. The correct patterns they produced and the errors they made were governed by certain principles or restricted by a range of constraints.

CHAPTER 6

NPS AND EVIDENCE FOR A SYNTACTIC PARSING

6.0 Introduction

In the previous chapter, we examined contexts without internal structures that require non-cyclic T3S application. As most utterances humans produce have internal structures, when T3S is applied, most likely, it is a case of T3S application in a structured phrase or sentence. In this chapter, we focus specifically on short NPs, a context in which T3S should be applied cyclically. In the next chapter, we will look at sentences where a mixture of cyclic and non-cyclic strategies is needed.

At the level of NPs, prosodic domains for T3S have to be built from the innermost constituents outwards. T3S outputs depend on the syntactic structures because the prosodic parsing is built based on it. Within NPs, a speaker's T3S surface patterns reflect how the T3S structure was built. The rest of the chapter is organized as follows. I begin in section 6.1 with some linguistic background on cyclic T3S applications at the Word level, and then I show how it works in various noun compounds and NPs. Section 6.2 presents research questions, hypotheses, and predictions. Our experimental study on NPs is in Section 6.3, the major section of this chapter. The results and detailed discussions are also included in this section. Finally, Section 6.4 concludes this chapter with a summary of the findings.

6.1 Linguistic background

6.1.1 Cyclic T3S application at the Word Level

According to the Word-and-Phrase level model (Chen 2000; Shih 1986; Shih 1997), T3S is cyclic at the Word level, which includes simple nouns, compound nouns and complex nouns. Complex nouns refer to 'modifier + noun,' such as *xiao laoshu* 'small mouse' (Lin 2007:207).

Lin further clarifies that, although a noun with a modifier is often treated as a noun phrase syntactically, in this T3S model, compound nouns, complex nouns [modifier + noun], along with simple nouns are treated as words, instead of phrases (Lin 2007:207). 'Modifier + noun' and 'verb + resultative complement[32]' constructions are taken as lexical, instead of phrasal constructions, because they behave like integral lexical items[33] phonologically (Chen 2000:387). Verbs are typically treated at the phrase level except for the verb compounds (e.g. *xizao* 'take a bath/shower' and *xunzhao* 'to look for') and 'verb + resultative complement' construction mentioned earlier. We restrict the contexts of testing cyclic T3S application only to NPs in order to keep the experimental task simple for children. In the rest of the chapter, we investigate cyclic T3S application in NPs only (including compound nouns) and compound verbs will not be discussed further. It should be noted that all the examples in this chapter are examples of T3S applications at the Word level. Therefore, in the presentation of the examples, the distinction between the Word level and the Phrase level will not be included. In the next chapter where examples at the sentence levels are presented, such distinction will be made for clarity.

6.1.2 Compound Nouns and NPs

In this section, cyclic T3S application in compounds and NPs of various structures and length are exemplified in (1) – (7). Focus will be placed on the cyclic foot-building, and the possibility of larger domain parsing in fast speech is not our focus here. Thus, the fast speech pattern is not

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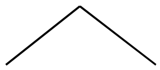
[32] An example of the structure of "verb + resultative complement" is as follows where *wan* 'finish' is a resultative complement to indicate the state/result of the action.

[chi wan]
eat finish 'done eating'

[33] Chen (2000:387) indicates that "modifier + noun" and "verb + resultative" constructions behave like integral lexical items. This means the two elements of each of the structures above are grouped together. The two elements will be parsed in the same prosodic domain in T3S application.

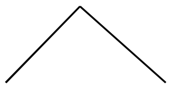
included in the following examples, predicted by the Word-and-Phrase level Model. Cyclic application in (1) and (2) gives different surface patterns.

(1)



σσ		σ	
[[laohu]		wei]	
tiger		tail	‘tiger tail’
3	3	3	UT
(**2**	3)	3	T3S
(2	**2**	3)	Incorporation; T3S, ST
*(3	2	3)	

(2)

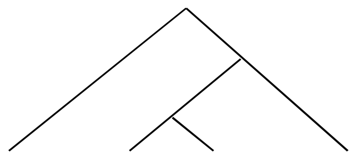


σ	σσ		
[paper	[laohu]]		
paper	tiger		‘a tiger made of paper; paper tiger’
3	3	3	UT
3	**(2**	3)	T3S
(3	**2**	3)	Incorporation; No T3S, ST
?(**2**	**2**	3)	

In (1) and (2), we see two three-syllable noun-noun compounds. In (1), we see a disyllable noun followed by a monosyllabic noun. T3S first applies in the innermost constituent, the disyllabic noun. In the second cycle when the monosyllabic noun is incorporated, T3S applies again, resulting in the **T2T2**T3 surface pattern. In (2), it is a monosyllabic noun followed by a disyllabic noun. Again, T3S applies to the innermost constituent, the disyllabic noun. When the monosyllabic noun preceding it is incorporated in the next cycle, T3S does not apply because there are no adjacent T3* now. The pattern (**T2T2**T3) in (2) may be grammatical to some native speakers, but not others, though such pattern can be derived in the Word-and-Phrase level model through larger parsing in fast speech. The results of the current study will provide some answers to this question.

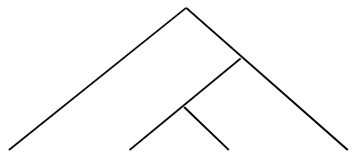
Next, let us look at phrases in (3) – (6) which are all composed of four syllables. Their internal structures differ, however. We will see that T3S starts in the innermost constituents in these NPs consistently.

(3)



[xiao	[[lao-hu]	wei]]	
small	tiger	tail	'small tiger tail'
3	33	3	UT
3	(**2**3)	3	T3S
3	(2**2**	3)	Incorporation; T3S
(3	22	3)	Incorporation; No T3S, ST
*(2	3)(2	3)	

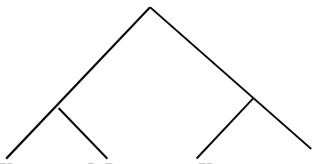
(4)



[xiao	[[duan	tui]	gou]]	
small	short	leg	dog	'(a) small short-legged dog'
3	3	3	3	UT
3	(**2**	3)	3	T3S
3	(2	**2**	3)	Incorporation; T3S
(3	2	2	3)	Incorporation; No T3S, ST
*(2	3)	(2	3)	

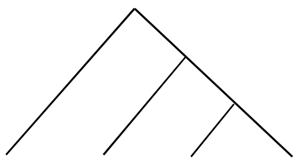
In (3), the innermost constituent is *laohu* 'tiger' which is in the phrase-medial position. Two subsequent steps produce the surface pattern of T3**T2T2**T3. The NP in (4) is a case of mixed-branching NP, a structure that is less talked about in the T3S literature. Typically, left-branching and right-branching structures are used for the contrast in cyclicity in previous T3S studies. In (4), the second and the third syllables form a foot *duan tui* 'short-legged' which modifies *gou* 'dog.' A ternary foot for '*duan tui gou* 'short-legged dog' forms in the next cycle where T3S applies to *tui* 'leg' when the rightmost syllable *gou* 'dog' is incorporated. The final step is to incorporate the initial syllable *xiao* 'small' and T3S does not apply in this cycle. The NPs in (3) and (4) have the same surface pattern though they are slightly different in their internal structures in that *laohu* ‘tiger’ is disyllabic lexical item whereas *duan tui* ‘short-legged’ are two monosyllabic lexical items. The following examples illustrate different patterns.

(5)



[[hai	di]	[hai	cao]]	
sea	bottom	sea	grass	‘sea-bottom seaweed’
3	3	3	3	UT
(**2**	3)	(**2**	3)	T3S, ST
*(3	2	2	3)	

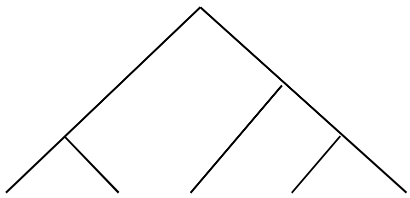
(6)



[xiao	[zi	[hai	cao]]]	
small	purple	sea	grass	‘small purple seaweed’
3	3	3	3	UT
3	3	(**2**	3)	T3S
3	(3	2	3)	Incorporation; No T3S
(**2**	3	2	3)	Incorporation; T3S, ST
*(3	2	2	3)	

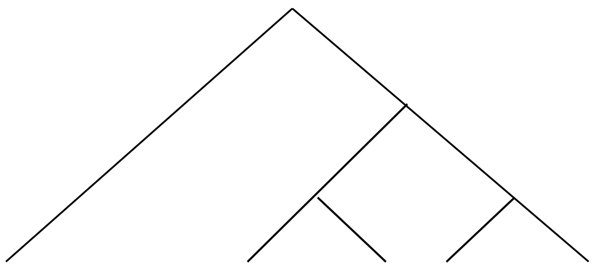
In (5), the embeddedness of the two constituents is the same. Two binary feet are parsed at the same time, and T3S applies simultaneously within these two feet, producing the surface pattern of **T2**T3**T2**T3. In (6), notice that the surface pattern is also **T2**T3**T2**T3, yet it is not derived through the same way. As the phrase in (6) is a right-branching structure, T3S applies first in the innermost constituent *haicao* ‘seaweed’, and then proceeds to a layer higher to incorporate the second syllable *zi* ‘purple’ where T3S does not apply since there are no adjacent T3* at this point. Finally, *xiao* ‘small,’ the topmost layer, is incorporated. T3S applies again. Here we see that though the same surface pattern may come from different syntactic structures, we know the surface pattern for (3) and (4) cannot be used in (5) and (6), and vice versa. In this experiment, two types of structures ((4) and (6)) were tested. We now turn to two more examples of 5-syllable phrases in (7) and (8). Although the patterns in (7) and (8) are not tested, they also are used to demonstrate cyclic T3S in the NPs which have different internal structures.

(7)



[[Bei	hai]	[xiao	[hai	gou]]]	
north	sea	small	sea	dog	‘small North Sea fur seals’
3	3	3	3	3	UT
(**2**	3)	3	(**2**	3)	T3S
(2	3)	(3	2	3)	Incorporation, No T3S, ST1
(2	**2**)	(3	2	3)	Optional T3S across domains, ST2
*(3	2	3)	(2	3)	

(8)



[ai	[[duan	pao]	[xuan	shou]]]	
short (height)	short (length)	run	select	hand (a trained athlete)	
					‘(a) short sprinter’
3	3	3	3	3	UT
3	(**2**	3)	(**2**	3)	T3S
(3	2	3)	(2	3)	Incorporation; No T3S, ST
*(2	3)	(3	2	3)	
*(2	2)	(3	2	3)	

In (7), the five-syllable NP is composed of a two-syllable and a three-syllable constituents, with the latter having one more layer than the former. T3S applies cyclically in *bei hai* ‘North Sea’ and *xiao hai gou* ‘small fur seal,’ resulting in (**T2**T3)(T3**T2**T3) in the surface. Notice that the second and the third syllable both surface as a T3, but the two adjacent T3* belong to different prosodic domains and the surface pattern is grammatical. When optional T3S applies across the domains, another pattern (**T2T2**)(T3**T2**T3) surfaces. The two grammatical patterns in (7) are ungrammatical in (8) which also have five syllables. In (8), *duan pao* 'short race' modifies *xuanshou* '(a) trained athlete,' and T3S applies separately in these two disyllabic feet first. *Ai* 'short (in height)' modifies *duan pao xuan shou* 'sprinter' and when it is incorporated into the following foot, no T3S applies. The surface pattern is (T3**T2**T3)(**T2**T3) for the NP in (8). The structural difference between (7) and (8) explains why a surface pattern is grammatical in one is ungrammatical in the other. Their T3S patterns reflect their syntactic structures.

To sum up, (1) – (8) clearly show that cyclicity is strictly followed in T3S applications in compounds and NPs because if that were not true, we would have found those NPs of three, four, and five syllables in (1) – (8) to exhibit the same surface pattern for the same number of syllables. In other words, (**T2T2**T3), (**T2**T3)(**T2**T3), and (**T2**T3)(**T2T2**T3) would have been found consistently in three-, four-, and five-syllable structures respectively, regardless of the internal structural differences. In short, T3S in NPs is sensitive to morpho-syntax. Prosody-based left-to-right parsing that works in flat structures is out of the picture in structured NPs. In the next section, based on what we know about cyclic T3S application in NPs, research questions are raised, followed by hypotheses and predictions for the experimental study on NPs.

6.2 Research questions, hypotheses, and predictions

These experiments are designed to investigate children's and adults' T3S application in NPs. Three-syllable compound nouns and four-syllable NPs which have different internal structures are used to test children's parsing strategies.

6.2.1 Research questions and Hypotheses

Our major research questions are as follows.

(9) Research questions

a. Do children know to apply T3S cyclically in NPs?

b. Does structural complexity affect parsing strategies they use?

Whether or not children refer to syntax when they build T3S domains can be inferred from the surface patterns they produce. Responses reflecting cyclic parsing provide evidence that syntax is referred to. On the contrary, responses reflecting non-cyclic parsing, even when the branching of the NPs differs, will be counter evidence that syntax is referred to. We assume that R-branching (right-branching) is less complicated than the M-branching (mixed-branching) structure (i.e. branching of one direction is easier than branching of more than one direction). Our hypotheses are in (10).

(10) Two hypotheses

NP Cyclic Parsing Hypothesis (H_1): Children know how to use cyclic bottom-up parsing strategy in NPs.

Strategy Shift Hypothesis (H_2): When structures increase in complexity they may default to a prosodic parsing and ignore syntax.

6.2.2 Predictions of T3S application in NPs

In this section, the predictions of three-syllable compound nouns and four-syllable NPs are presented. Our focus is placed on the cyclic parsing process, and the fast speech pattern obtained through a larger domain within which T3S applies from left to right is excluded from the predictions because our experimental setting does not require fast speech, and as normal speech is used, we expect the normal cyclic parsing.

6.2.2.1 Three-syllable compound nouns

The surface patterns in (11) and (12) below differ because of their morphosyntactic differences. In (11), T3S applies in the innermost unit, the first noun, which has two syllables. When the second noun is incorporated in the next cycle, T3S applies again. The surface pattern is (**T2T2**T3). In (12), T3S applies first to the innermost unit, the second noun, which has two syllables. When the first noun is incorporated in the next cycle, T3S is inapplicable.

(11) A three-syllable [[σσ] σ] compound noun

[[laoshu]		bi]	
mouse		pen	'mouse-pen' (a pen that looks/shapes like a mouse)
3	3	3	UT
(**2**	3)	3	T3S
(2	**2**	3)	Incorporation, T3S; ST

(12) A three-syllable [σ [σσ]] compound noun

[zhi	[haima]]		
paper	seahorse		'paper seahorse' (a seahorse that is made of paper)
3	3	3	UT
3	(**2**	3)	T3S
(3	2	3)	Incorporation, No T3S; ST

If children make no reference to syntactic properties of the novel compound nouns, we expect to see (**T2T2**T3) for both structures ([[σσ] σ] and [σ [σσ]]). However, if children use syntactic properties in building feet, then the two different structures [[σσ] σ] and [σ [σσ]] should have (**T2T2**T3) and (T3**T2**T3) respectively through the cyclic parsing strategy.

6.2.2.2 Four-syllable noun phrases

Now we look at predictions for four-syllable NPs. Right-branching and left-branching structures are commonly used for contrasting the different T3S surface patterns in the two structures. Mixed-branching structures, however, are less talked about. In (13) - (15), all three structures are presented. Due to the relatively low occurrence of left-branching NPs in Mandarin and difficulties in finding suitable left-branching examples for children, right-branching and mixed-branching structures are used for testing cyclic T3S applications in NPs. Our purpose in this experiment is to test whether or not children are sensitive to syntax in applying T3S in NPs, so using two different structures will sufficiently meet our needs.

(13) A four-syllable right-branching ([σ [σ [σσ]]]) NP

[xiao	[zi	[haima]]]	
small	purple	seahorse	'(a) purple seahorse'
3	3	33	UT
3	3	(**2**3)	T3S
3	(3	23)	Incorporation, No T3S
(**2**	3	23)	Incorporation, No T3S; ST

(14) A four-syllable left-branching ([[[σσ] σ] σ]) NP

[[[zhanlan]	guan]	zhang]	(Chen 2000:383)
exhibition	hall	director	'exhibition hall director'
33	3	3	UT
(**2**3)	3	3	T3S
(2**2**	3)	3	Incorporation, T3S
(2**2**	**2**	3)	Incorporation, T3S; ST

(15) A four-syllable mixed-branching ([σ [[σσ] σ]]) NP

[xiao	[[duan	tui]	ma]]	
small	short	leg	horse	'(a) small short-legged horse'
3	3	3	3	UT
3	(**2**	3)	3	T3S
3	(2	**2**	3)	Incorporation, T3S
(3	2	2	3)	Incorporation, No T3S; ST

In (13) – (15), T3S always begins with the innermost constituent, and then proceeds outwards cyclically, taking one layer at a time when a syllable is incorporated into the foot that has been built. A right-branching structure in (13) results in the "alternating pattern," (**T2**T3)(**T2**T3), which alternates between T2 and T3. A left-branching structure in (14) begins T3S at the left edge of the structure. One syllable is incorporated at a time and T3S applies each time since there are adjacent T3* upon each incorporation. The surface pattern is (**T2T2T2**T3). In (15), the innermost constituent is in the middle. When the final syllable is incorporated into the binary foot, T3S applies, but when the initial syllable is incorporated into the ternary foot, T3S does not apply since there are no adjacent T3*. The surface pattern is (T3**T2T2**T3).

To summarize, different surface patterns are expected depending on internal structures of the compounds or NPs. For a three-syllable noun-noun compound whose first noun is disyllabic, (**T2T2**T3) is expected. If it is the second noun that is disyllabic, (T3**T2**T3) is expected. If children do not refer to structural differences, then the left-to-right prosodic parsing which result in (**T2T2**T3) will surface for both structures. For four syllable NPs, (**T2**T3**T2**T3) and (T3**T2T2**T3) is expected for a right-branching NP and a mixed-branching NP respectively through the cyclic bottom-up parsing strategy. If no reference is made to syntax, (**T2**T3**T2**T3) obtained by the left-to-right binary parsing will surface for both structures. A summary of the predicted patterns for the structures tested is in Table 6.1.

Table 6.1 Study 3: Predicted patterns for the structures tested

Structures	Three-syllable compound nouns		Four-syllable NPs	
	[[σσ]σ] N-N compound	[σ[σσ]] N-N compound	[σ[σ[σσ]]] R-branching NP	[σ[[σσ]σ]] M-branching NP
UT	333	333	3333	3333
ST	**22**3	3**2**3	**2**3**2**3	3**22**3

6.3 Experiment 2: NPs

Experiment 2 consists of elicitation of novel three-syllable compound nouns and four-syllable NPs, shown in (16) and (17) respectively. T3S applies cyclically in both structures.

(16) Two structures tested in three-syllable compound nouns

a.	[[σ σ] σ]		b. [σ [σ σ]]	
	3 3 3	UT	3 3 3	UT
	(**2** 3) 3		3 (**2** 3)	
	(**2** **2** 3)	ST	(3 2 3)	ST

(17) Two structures tested in four-syllable NPs

a.	[σ [σ [σ σ]]]		b.	[σ [[σ σ] σ]]	
	3 3 3 3	UT		3 3 3 3	UT
	3 3 (**2** 3)			3 (**2** 3) 3	
	2 (3 2 3)			3 (2 **2** 3)	
	(**2** 3 2 3)	ST		(3 2 2 3)	ST

6.3.1 Method

6.3.1.1 Subjects

One hundred fourteen subjects were recruited in Taichung, Taiwan for this study. There are five age groups: three-, four-, five-, and six-year-olds, and adults. Table 6.2 shows the distribution of the participants.

Table 6.2 Study 3: Distribution of the subjects

Age groups	N	Age range	Mean	Standard deviation
3-year-olds	24	3;1 – 3;11	3;7	2.49 (mo.)
4-year-olds	20	4;1 – 4;9	4;3	2.40 (mo.)
5-year-olds	27	5;0 – 5;11	5;3	3.05 (mo.)
6-year-olds	23	6;0 – 6;11	6;6	3.04 (mo.)
adults	20			

6.3.1.2 Procedure

All child subjects were tested in a quiet classroom in the kindergarten or in the home of the child. Adult subjects were tested in a quiet room. The elicited production task lasted approximately 15-20 minutes for children, and 10 minutes for adults. Children were told that they were going to look at pictures on the computer and play a game. Each subject sat in front of a laptop computer which displayed slides of pictures. All data was recorded by a Marantz PMD 660 with an Audio-technica miniature clip-on microphone.

6.3.1.3 Design

An elicited repetition task (Crain & Thornton 2000; McDaniel et al. 1998) is used in this experiment. The procedure used to elicit three-syllable compound nouns and four-syllable NPs are similar, with the latter more complicated than the former. Comparing to the three-syllable compound nouns which requires putting two nouns together, four-syllable items have more ‘building blocks’ and more layers to be attended to in building the novel NPs. As a result, more pictures were used to elicit four-syllable NPs than three-syllable compound nouns.

T3S does not apply in the control items which have no adjacent T3* underlyingly; therefore, the surface tones are the same as the underlying tones. In the test items, T3S will apply through the building of prosodic domains based on the morphosyntactic structure of the compound nouns or NPs. Surface tones should reflect the internal structure of the compound noun or NP. The structures tested and their derivations of T3S application are presented separately below. A list of controls and tests is in Appendix C.

Three-syllable compound nouns

Two three-syllable structures tested are in (18). We keep only the parsing information and predicted outputs, which is based on the Word-and-Phrase level Model (Chen 2000; Shih 1986; Shih 1997).

(18) Two structures in three-syllable compound nouns

a. noun-noun compound

σσ	σ	
33	3	UT
(**23**)	3	T3S
(2**2**	3)	Incorporation, T3S; ST

b. noun-noun compound

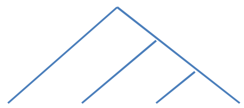
σ	σσ	
3	33	UT
3	(**23**)	T3S
(3	23)	Incorporation, No T3S; ST

Four-syllable NPs

Two four-syllable structures tested are in (19).

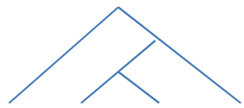
(19) Two structures in four-syllable NPs

a. Right-branching NP



σ	σ	σ	σ	
3	3	3	3	UT
3	3	(**2**	3)	T3S
3	(3	2	3)	Incorporation, No T3S
(**2**	3	2	3)	Incorporation, T3S; ST

b. Mixed-branching NP

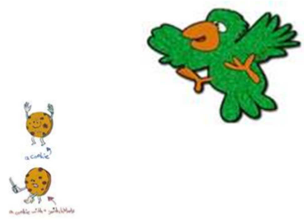
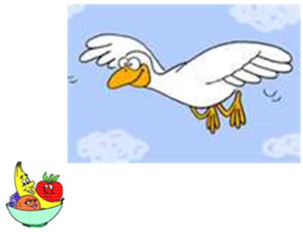


σ	σ	σ	σ	
3	3	3	3	UT
3	(**2**	3)	3	T3S
3	(2	**2**	3)	Incorporation, T3S
(3	2	2	3)	Incorporation, No T3S; ST

6.3.1.4 Materials

We showed each child pictures of animals and objects in order to elicit novel compound nouns. Animals or objects that are typically known to children were used, but the combinations of the nouns in the compounds are novel. Each picture is shown individually, one at a time on different Powerpoint slides. Sample experimental materials are provided for three-syllable compound nouns and four-syllable NPs in Figure 6.1 and Figure 6.2 respectively. Both figures include a sample control item and a test item for both structures tested. A complete list of the experimental material as well as the instructions in Mandarin is in Appendix D.

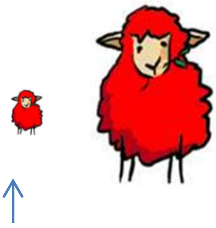
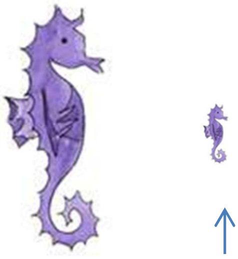
Figure 6.1 Study 3: Sample materials in three-syllable compound nouns

Control or Test / Structures	Control	Test
[[σσ]σ]	a.  [[binggan] niao] cookie bird ‘cookie-bird’ 3 1 3 UT 3 1 3 ST	b.  [[shuiguo] niao] fruit bird ‘fruit-bird’ 3 3 3 UT **2** **2** 3 ST
[σ[σσ]]	c.  [shui [daxiang]] water elephant ‘water- elephant’ 3 4 4 UT 3 4 4 ST	d.  [shui [laohu]] water tiger ‘water-tiger’ 3 3 3 UT 3 **2** 3 ST

For instance, to elicit a novel compound that has the structure of [[σσ]σ] (Figure 6.1 (b)) and with all three syllables in T3, [[T3T3] T3]: [[*shuiguo*] *niao*] ‘fruit-bird,’ the experimenter first showed a picture of a bird that looks very happy when seeing cookies (Figure 6.1 (a)). As this picture was shown to the child, the experimenter told the child, “Look at this bird. He’s so happy to see the cookies. He loves eating cookies. Let’s call it a *cookie-bird*.” This was to model how the compound noun was to be built. Then the experimenter showed another picture that also had a bird in it ((Figure 6.1 (b)): A different bird which looks very happy when he sees fruits.) The experimenter asked (pointing at the fruits), "What are these?" to make sure the child knew the name of the item (*shuiguo* 'fruit'). She continued to say (pointing to the bird), "He loves fruits, so we call it …" The child is expected to build a compound noun for this test item. The procedure is used for all the test items and the control items.

As done in three-syllable compound nouns, we showed each child pictures of animals and objects in order to elicit novel four-syllable NPs. Similarly, the animals, objects, and adjectives used are typically known to children. Novel four-syllable NPs with right-branching and mixed-branching structures were created with adjectives (size, color, etc.) and nouns. The experimenter made sure that the child knew how to say the individual items before the intended NP was built. In order to elicit the intended adjectives to be used, a pair of contrasting ideas was presented (e.g., a *big* elephant vs. a *small* elephant, a *green* frog vs. a *white* frog, and a *tall* bird vs. a *short* bird). The procedure used for eliciting novel four-syllable NPs is similar to that for three-syllable compounds. What is different is that there are more layers in the four-syllable NPs, and one layer is elicited at a time, starting with the innermost unit. So for the right-branching structure [σ[σ[σσ]]], we began with the last two syllables, followed by the second syllable, and finally, adding the outermost layer, which is the first syllable. For a mixed-branching structure [σ[[σσ]σ]], we began with the two middle syllables, followed by the last syllable, and finally, adding the outermost layer, which is the first syllable. Sample materials used for four-syllable NPs are in Figure 6.2.

Figure 6.2 Study 3: Sample materials in four-syllable NPs

Control or Test Structure	Control	Test
[σ [σ [σσ]]]	a. 	b. 
	[xiao [hong [mianyang]]] small red sheep ‘(a) small red sheep’ small red sheep 3 2 22 UT 3 2 22 ST	[xiao [zi [haima]]] small purple seahorse ‘(a) small purple seahorse’ small purple seahorse 3 3 33 UT **2** 3 **2**3 ST
[σ [[σσ] σ]]	c. 	d. 
	[xiao [[chang bi] xiang]] small long trunk elephant ‘(a) small long-trunked elephant’ small long trunk elephant 3 2 2 4 UT 3 2 2 4 ST	[xiao [[duan tui] ma]] small short leg horse ‘(a) small short-legged horse’ small short leg horse 3 3 3 3 UT 3 **2** **2** 3 ST

6.3.1.5 Coding

Two native speakers transcribed the data and coded the answers. After the transcriptions were completed, the test items were coded for statistical analysis. Numbers 1, 2, 3 and 4 were used in transcribing the four lexical tones, T1, T2, T3, and T4, respectively. Data were coded in a way to preserve the most available information in subjects' responses. Our target answers in this study are three or four syllables in compound nouns and NPs respectively. Children do not always give the desired answers— they may miss a syllable or give an extra syllable, for example. An underscore is used to indicate a missing syllable in the subject's response. For extra words, they were transcribed as said. The coding categories are in (20).

(20) Coding categories for data analysis:

a. Included in the analysis: Correct or incorrect application of T3S without missing any syllables and with syllables in the correct word order.

b. Excluded in the analysis:

i. No answer: Saying 'I don't know' or being silent without giving an answer.

ii. Non-target answers: Saying something else, such as adding additional word(s) or missing word(s), which result in non-target answers.

iii. Word order: Scrambling word orders, which did not fit the intended template of the N-N compound or NPs.

iv. Pauses: Pauses between two T3*.

For the analysis of children's T3S application, the data were used only if the responses fit the exact number of target words and in the desired order. Responses with additional words, insufficient words, or wrong word orders were excluded from the analysis. This was because the environment that was created to trigger T3S was altered, and the condition for T3S application changed as a result. In short, all the data used for analyzing T3S were 100% correct in terms of syntax.

T3S does not apply in the control items, so T3S application is irrelevant in the control items. Sample answers for the test items in three-syllable compound nouns and four-syllable NPs and how they fit in the coding categories are listed in Table 6.3.

Table 6.3 Study 3: Sample answers and their coding categories for analysis of T3S application

Three-syllable compound nouns (a – b) and four-syllable NPs (c – d)	Sample answers (surface tones)	Included in the analysis?	Correct ✓ or incorrect ✗
a. [[shuiguo] niao] fruit bird 'fruit-bird' 3 3 3 UT **2** **2** 3 ST	i. (223) ii. (233) iii. (232) iv. (222) v. (323) vi. (23_) vii. nouns reversed	✓ ✓ ✓ ✓ ✓ ✗ ✗	✓ ✗ ✗ ✗ ✗ n/a n/a
b. [shui [laohu]] water tiger 'water-tiger' 3 3 3 UT 3 **2** 3 ST	i. (323) ii. (223)[34] iii. (_23) iv. nouns reversed	✓ ✓ ✗ ✗	✓ ✗ n/a n/a
c. [xiao [zi [haima]]] small purple seahorse '(a) small purple seahorse' small purple seahorse 3 3 33 UT **2** 3 **2**3 ST	i. (2323) ii. (3223) iii. (3323) iv. (3123) v. (3_23) vi. (_323) vii. (3)p(3)p(23) (p = pause) viii. Scrambling errors	✓ ✓ ✓ ✓ ✗ ✗ ✗ ✗	✓ ✗ ✗ ✗ n/a n/a n/a n/a
d. [xiao [[duan tui] ma]] small short leg horse '(a) small short-legged horse' small short leg horse 3 3 3 3 UT 3 **2** **2** 3 ST	i. (3223) ii. (2223) iii. (3323) iv. (2323) v. (3_23) vi. (32_3) vii. (_2_3) viii. (3)p(323) ix. Scrambling errors	✓ ✓ ✓ ✓ ✗ ✗ ✗ ✗ ✗	✓ ✓ ✗ ✗ n/a n/a n/a n/a n/a

(Note: Underscores refers to missing syllables. Correct or incorrect are based on the surface patterns predicted by existing T3S models as well as whether or not such pattern is attested in adults.)

[34] Briefly mentioned in Section 2.3.1, the pattern (**T2T2**T3) may be grammatical to some native speakers, but not others, though such pattern can be derived in the Word-and-Phrase level model. This pattern was regarded as incorrect, mainly based on the adult production in this study. Adults never produced this pattern.

For statistical analysis, various error patterns were further coded and placed under three basic error categories in (21).

(21) Error categories

a. Under-application (U): Not applying T3S to one or more syllable when needed. An example for a response in the structure [T3 [[T3T3] T3]] is (*T3T3T2T3).

b. Mis-application (M): This category includes ”over-application” and “wrong applications.” Over-application refers to applying T3S to a syllable when not needed in the final syllable position, such as the answer (*T2T2T2) for [[T3T3] T3]. Mis-application refers to applying T3S to two adjacent syllables wrongly as we see in a response (*T2T3T2T3) for the structure [T3 [[T3T3] T3]]. In this case, even though there are no adjacent T3*, it is an ungrammatical pattern.

c. Other (O): Errors that do not fit the descriptions of the previous two categories are placed under the “Other” category. An example is *T4T2T3 for [T3 [T3T3]].

The first category “Under-application” captures the T3S errors made by subjects when they failed to apply T3S when necessary. Unlike in flat structures, we found a pure “over-application” error very rare. More specifically, over-application in the final syllable was very rare in compound nouns and NPs. Therefore, such type of error was combined with the “Mis-application” category which is a common error type in children across age groups. Errors categorized as “Mis-application” errors most often involved two syllables, with the application reversed (apply T3S to the syllable that should not undergo T3S or not apply T3S to the syllable that should undergo T3S.) The “Other” category is to categorize all other errors, such as producing a tone other than T2 or T3 in the response. Incorrect answers in Table 6.3 are extracted and used in Table 6.4 for presenting how errors were categorized in the three error types for our error analyses.

Table 6.4 Study 3: Sample T3S errors and their coding categories for error analysis

Three-syllable compound nouns (a – b) and four-syllable NPs (c – d)	Sample errors (only tonal information is included here)	Under-application (U) Mis-application (M) Other (O)
a. [[shuiguo] niao] fruit bird 'fruit-bird' 3 3 3 UT **2** **2** 3 ST	i. (233) ii. (232) iii. (222) iv. (323)	U M M M
b. [shui [laohu]] water tiger 'water-tiger' 3 3 3 UT 3 **2** 3 ST	i. (333) ii. (223)	U M
c. [xiao [zi [haima]]] small purple seahorse '(a) small purple seahorse' small purple seahorse 3 3 33 UT **2** 3 **2**3 ST	i. (3223) ii. (3323) iii. (3123)	M U O
d. [xiao [[duan tui] ma]] small short leg horse '(a) small short-legged horse' small short leg horse 3 3 3 3 UT 3 **2** **2** 3 ST	i. (3323) ii. (2323)	U M

6.3.2 Results

In this section, we first report the answers that were excluded from the analysis. Numbers of excluded control items and test items in three-syllable compound nouns and four syllable NPs are in Table 6.5 – Table 6.8.

Table 6.5 Study 3: Three-syllable compound nouns (Control items)— data excluded from the analysis

	[σ [σσ]]					[[σσ] σ]				
	No answer	Non-target	Diff. word order	Pauses	Excluded total	No answer	Non-target	Diff. word order	Pauses	Excluded total
3	7	7	4	0	18	2	5	0	0	7
4	2	7	11	0	20	1	3	0	0	4
5	1	6	4	0	11	1	5	0	0	6
6	1	7	1	0	9	0	1	0	0	1
A	0	2	0	0	2	0	0	0	0	0

Table 6.6 Study 3: Three-syllable compound nouns (Test items)— data excluded from the analysis

	[σ [σσ]]					[[σσ] σ]				
	No answer	Non-target	Diff. word order	Pauses	Excluded total	No answer	Non-target	Diff. word order	Pauses	Excluded total
3	7	12	5	0	24	1	7	0	0	8
4	0	4	12	0	16	1	5	0	0	6
5	2	6	3	0	11	0	2	0	0	2
6	0	5	1	0	6	0	0	1	0	1
A	0	0	0	0	0	0	0	0	0	0

Table 6.7 Study 3: Four-syllable compound nouns (Control items)— data excluded from the analysis

	Right-branching					Mixed-branching				
	No answer	Non-target	Diff. word order	Pauses	Excluded total	No answer	Non-target	Diff. word order	Pauses	Excluded total
3	3	11	0	0	14	6	25	0	0	31
4	0	9	0	0	9	4	15	0	0	19
5	4	1	0	0	5	3	9	2	0	14
6	1	0	0	0	1	0	4	2	0	6
A	0	0	0	0	0	0	0	0	0	0

Table 6.8 Study 3: Four-syllable compound nouns (Test items)— data excluded from the analysis

	Right-branching					Mixed-branching				
	No answer	Non-target	Diff. word order	Pauses	Excluded total	No answer	Non-target	Diff. word order	Pauses	Excluded total
3	3	9	0	2	14	6	24	1	2	33
4	0	5	0	0	5	2	20	1	0	23
5	1	2	0	2	5	1	15	1	6	23
6	0	1	0	0	1	0	12	2	1	15
A	0	0	0	0	0	0	0	0	0	0

Next, we turn to the results. We found that children across age groups did make reference to syntax when applying T3S to compounds and NPs. Unlike adults, however, children showed less consistency in cyclic T3S applications at the Word level. In what follows, the results for three-syllable compound nouns and four-syllable NPs are presented and discussed in separate subsections.

6.3.2.1 Three-syllable compound nouns

The task for three-syllable compound nouns involves placing two nouns together to create a novel compound noun. NP Cyclic Parsing Hypothesis (H_1) was tested to see whether or not children know to use cyclic bottom-up parsing strategy in compound nouns.

In the three-syllable compound nouns, adults and children across age groups had a 100% correct rate in the control items (Table 6.9). This indicates that the task of building a noun-noun compound by placing two nouns together was an easy task for children across age groups. For the test items, adults still had a 100% correct rate.

Table 6.9 Study 3: Correct rate (%) in three-syllable compound nouns— Control items (no T3S)

Structure	[σ [σσ]]	[[σσ] σ]
3-year-olds	100 (30/30)	100 (41/41)
4-year-olds	100 (20/20)	100 (36/36)
5-year-olds	100 (43/43)	100 (48/48)
6-year-olds	100 (37/37)	100 (45/45)
adults	100 (38/38)	100 (40/40)

We know that children did well in the control items which were without T3S applications. Did they do as well in the test items which required T3S applications? Now we turn to the test items in three-syllable compound nouns.

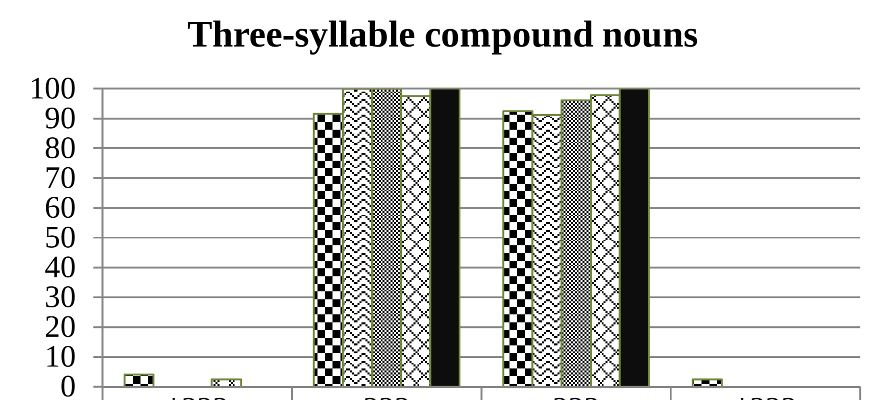
Table 6.10 Study 3: Correct rate (%) in three-syllable compound nouns— Test items (with T3S)

Structure	[σ [σσ]]		[[σσ] σ]	
	*(**22**3)	(3**2**3)	(**22**3)	*(323)
3-year-olds	**4.17** (1/24)	**91.67** (22/24)	**92.50** (37/40)	**5.56** (1/40)
4-year-olds	**0** (0/24)	**100** (24/24)	**91.18** (31/34)	**0** (0/34)
5-year-olds	**0** (0/43)	**100** (43/43)	**96.15** (50/52)	**0** (0/52)
6-year-olds	**2.50** (1/40)	**97.50** (39/40)	**97.78** (44/45)	**0** (0/45)
adults	**0** (0/40)	**100** (40/40)	**100** (40/40)	**0** (0/40)

In Table 6.10, the ungrammatical pattern *(T3**T2**T3) for the [[σσ] σ] is uncontroversial. As mentioned earlier, some native speakers may find the surface pattern (**T2T2**T3) in the [σ [σσ]] structure grammatical or acceptable, while others may consider it ungrammatical. This pattern never surfaced in our adult data. For now, we treat this pattern as ungrammatical, mainly based on the adult data. The pattern was rarely produced by children, and that may support the possibility of children's judgment of this pattern being ungrammatical.

Will the decision of treating (**T2T2**T3) as ungrammatical affect later analysis? There were only two tokens of (**T2T2**T3) in the [σ [σσ]], occurred once in one 3-year-old and once in one 6-year-old, so the effect of treating such pattern as grammatical or ungrammatical was minimal. Either way, these two ago groups were adult-like and were not different from adults.

Figure 6.3 Study 3: Correct rates in three-syllable compound nouns by age



	*223	323	223	*323
	[σ[σσ]]: [water [tiger]]		[[σσ]σ]: [[fruit] bird]	
3	4.17	91.67	92.50	2.50
4	0	100	91.18	0
5	0	100	96.15	0
6	2.50	97.50	97.78	0
A	0	100	100	0

As described in Section 6.3.1.5, errors fall under three categories: *Under-application*, *Mis-application*, and *Other*. As children did very well in three-syllable compound nouns, there were few errors. All three error types, *Under-application*, *Mis-application*, and *Other*, were attested, with *Under-application* being the most common (one token in the 3-year-old group, three tokens in the 4-year-old group, one token each in 5- and 6-year-old groups), followed by *Mis-application*. The error type *Other* is rare. This error type *Other* is when a tone other than T2 or T3 (so either T1 or T4) is used in the surface pattern.

Two-proportion *z-test* (α = .05, two-tailed) was conducted to determine if there is a significant difference between any two age groups. The Null hypothesis is that there is no difference between any two age groups. The results show that none of any two age groups are significantly different from each other in the test items in the three-syllable compound nouns. Since the *p*-values are greater than the significant level (0.05), the Null hypothesis that no significant difference exist between any two age groups is confirmed ([[σσ] σ] compound noun— 3 (3-year-olds) & A (adults): p = 0.0767, 4 (4-year-olds) & A: p = 0.1848, 5 (5-year-olds) & A: p = 0.5933, 6 (6-year-olds) & A: p = 0.9522, 3 & 4: p = 0.8259, 3 & 5: p =0.7627, 3 & 6: p = 0.5261, 4 & 5: p = 0.6227, 4 & 6: p = 0.4197, 5 & 6: p = 0.8997; [σ [σσ]] compound noun— 3 & A: p = 0.2661, 6 & A: p = 1.000, 3 & 4: p = 0.4703, 3 & 5: p = 0.2412, 3 & 6: p = 0.6477, 4 & 6: p = 0.7949, 5 & 6: p = 0.9713).

NP Cyclic Parsing Hypothesis (H_1) is confirmed by the results. Children across age groups and adults did differentiate the structural differences ([[σσ] σ] vs. [σ [σσ]]) and did apply T3S cyclically. None of the child groups are significantly different from adults in their T3S application in the three-syllable compounds with different internal structures. In Figure 6.3, we see that children clearly are sensitive to the internal structure of the compound nouns and apply T3S accordingly.

To summarize, children's application of T3S in the three-syllable compound nouns was not found to be significantly different from adults'. They referred to the internal structure when they applied T3S.

6.3.2.2 Four-syllable NPs

Four-syllable R-branching NP ([σ[σ[σσ]]]) and M-branching NP ([σ[[σσ]σ]]) predict different (**T2**T3**T2**T3) and (T3**T2T2**T3) respectively. Presumably, M-branching (more than one branching direction) is more complicated than R-branching (one branching direction). First, we tested the NP Cyclic Parsing Hypothesis (H_1) to see whether or not children know to use cyclic bottom-up parsing strategy in building novel NPs. Secondly, we tested the Strategy Shift Hypothesis (H_2) and see if children always use cyclic bottom-up parsing strategy, or if they may ignore syntax and shift to the non-cyclic left-to-right parsing when the structure becomes more complicated.

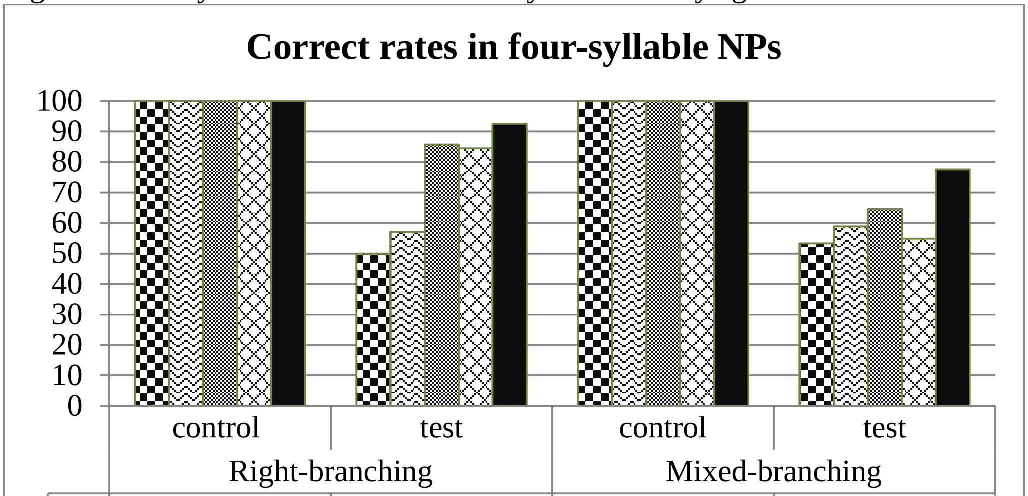
In four-syllable NPs, all age groups had a 100% correct rate in the control items in both right-branching (R-branching) and mixed-branching (M-branching) structures (Table 6.11). The fact that children did perfectly in the control items shows that they could build the structure and produce the novel NPs effortlessly when T3S was not involved.

Table 6.11 Study 3: Correct rate (%) in four-syllable NPs— Control items (no T3S)

Structure	Right-branching	Mixed-branching
3-year-olds	100 (34/34)	100 (17/17)
4-year-olds	100 (31/31)	100 (21/21)
5-year-olds	100 (49/49)	100 (40/40)
6-year-olds	100 (45/45)	100 (40/40)
adults	100 (40/40)	100 (40/40)

Figure 6.4 shows that when T3S is required, we see a very different picture. In the test items, which have T3S, the correct rates dropped slightly in the R-branching structure, and more dramatically in the M-branching structure. Even adults did not reach the 100% correct rate. The distribution of different T3S patterns in subjects' responses is in Table 6.12, with the primary pattern in bold type.

Figure 6.4 Study 3: Correct rates in four-syllable NPs by age



	Right-branching control	Right-branching test	Mixed-branching control	Mixed-branching test
3	100	50	100	53.33
4	100	57.14	100	58.82
5	100	85.71	100	64.52
6	100	84.44	100	54.84
A	100	92.50	100	77.50

Table 6.12 Study 3: Correct rate (%) in four-syllable NPs— Test items (with T3S)

Structure	Right-branching			Mixed-branching		
	(2323)	*(3223)	(2223)	*(2323)	(3223)	(2223)
3-year-olds	**50.00**	11.76	0	20	**46.67**	6.67
	(17/34)	(4/34)	(0/34)	(3/15)	(7/15)	(1/15)
4-year-olds	**57.14**	5.71	0	23.53	**52.94**	5.88
	(20/35)	(2/35)	(0/35)	(4/17)	(9/17)	(1/17)
5-year-olds	**85.71**	0	0	25.81	**41.94**	22.58
	(42/49)	(0/49)	(0/49)	(8/31)	(13/31)	(7/31)
6-year-olds	**84.44**	6.67	0	38.71	**48.39**	6.45
	(38/45)	(3/45)	(0/45)	(12/31)	(15/31)	(2/31)
adults	**92.50**	0	0	12.50	**77.50**	0
	(37/40)	(0/40)	(0/40)	(5/40)	(31/40)	(0/40)

Logistic regression analyses were conducted for the responses in four-syllable test items. The results show that the independent variables *age* as well as *structural branching* as a set are significant (*chi square* = 202.819, $p < .001$ with $df = 15$).

*Pattern (**2**3**2**3)*: Grammatical for R-branching, ungrammatical for M-branching

The use of pattern (**2**3**2**3) relative to errors in R-branching NPs and that in M-branching NPs is significantly different (*Odds Ratio* (*OR*) = 2.567, *p* = .013). The OR value indicates that an R-branching NP is about 2.5 times more likely to have this pattern than an M-branching structure.

For the surface pattern (***2**3**2**3*) relative to errors, both 3- and 4-year-olds (3-year-olds: *OR* = .168, *p* = .001; 4-year-olds: *OR* = .222, *p* = .005) are significantly different from adults, but 5- and 6-year-olds are not (5-year-olds: *OR* = .802, *p* = .684; 6-year-olds: *OR* = 1.382, *p* = .590).

*Pattern (3**22**3)*: Grammatical for M-branching, ungrammatical for R-branching

The use of pattern (3**22**3) relative to errors in R-branching NPs and that in M-branching NPs is also significantly different (*OR* = .058, *p < .001*). The OR value indicates that an M-branching NP is about 17 times more likely to have this pattern than an R-branching structure.

For the surface pattern **(*3**22**3*)** relative to errors, again both 3- and 4-year-olds (3-year-olds: *OR* = .261, *p* = .037; 4-year-olds: *OR* = .233, *p* = .023) are significantly different from adults, but 5- and 6-year-olds are not (5-year-olds: *OR* = .328, *p* = .080; 6-year-olds: *OR* = .687, *p* = .575).

*Pattern (**222**3)*: Grammatical for M-branching and R-branching

The use of pattern (**222**3) relative to errors in R-branching NPs and that in M-branching NPs are not significantly different (*OR* = 8.728E-10, *p* = .998). This pattern surfaced only in M-branching NPs, and only in children.

For the surface pattern **(*222*3)** relative to errors, 3-, 4-, and 5-year-olds (3-year-olds: *OR* = 1.214E8, *p < .001*; 4-year-olds: *OR* = 1.032E8, *p < .001*; 5-year-olds: *OR* = 8.100E8, *p < .001*) are significantly different from adults.

One of our research questions was whether or not children are sensitive to structural differences in their T3S application. Both 5- and 6-year-olds are adult-like in distinguishing two surface patterns (**2**3**2**3) and (3**22**3) according to the internal structures, but 3- and 4-year-olds are not. For four-syllable NPs, Cyclic Parsing in NPs Hypotheses (H_1) is confirmed in older children (5- and 6-year-olds), but rejected in younger children (3- and 4-year-olds).

Error types in four-syllable NPs

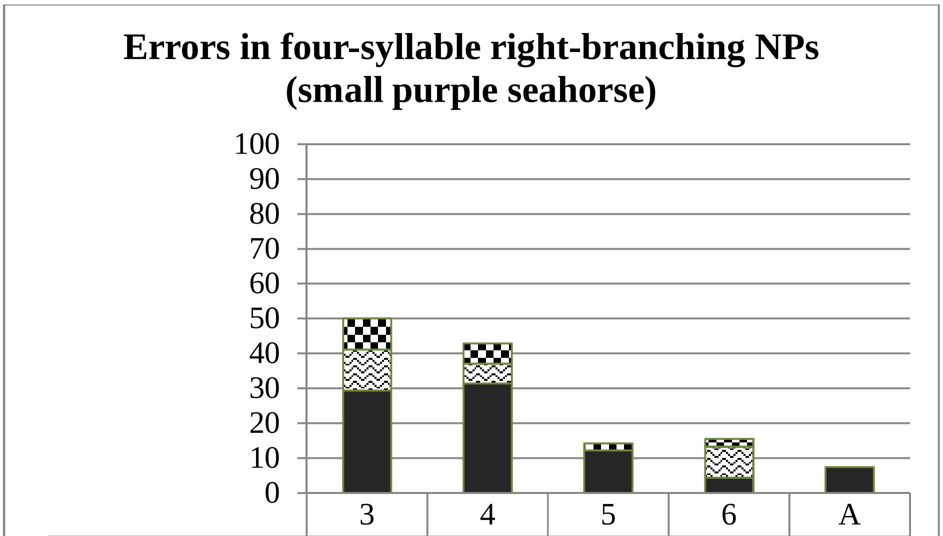
We now turn to the T3S errors. As shown in Table 6.13, the most common error type is *Under-application* in the R-branching and *Mis-application* in the M-branching NPs.

Table 6.13 Study 3: Error types (%) in four-syllable NPs

Structure	Right-branching			Mixed-branching		
	Under-application	Mis-application	Other	Under-application	Mis-application	Other
3-year-olds	**29.41** (10/34)	11.76 (4/34)	8.82 (3/34)	**26.67** (4/15)	20 (3/15)	0 (0/15)
4-year-olds	**31.43** (11/35)	5.71 (2/35)	5.71 (2/35)	17.65 (3/17)	**23.53** (4/17)	0 (0/17)
5-year-olds	**12.24** (6/49)	0 (0/49)	2.04 (1/49)	9.68 (3/31)	**25.81** (8/31)	0 (0/31)
6-year-olds	4.44 (2/45)	**8.89** (4/45)	2.22 (1/45)	6.45 (2/31)	**38.71** (12/31)	0 (0/31)
adults	**7.50** (3/40)	0 (0/40)	0 (0/40)	10 (4/40)	**12.50** (5/40)	0 (0/40)

For R-branching NPs, all three error types, *Under-application*, *Mis-application*, and *Others* were attested in children whereas only *Under-application* was found in adults (Figure 6.5).

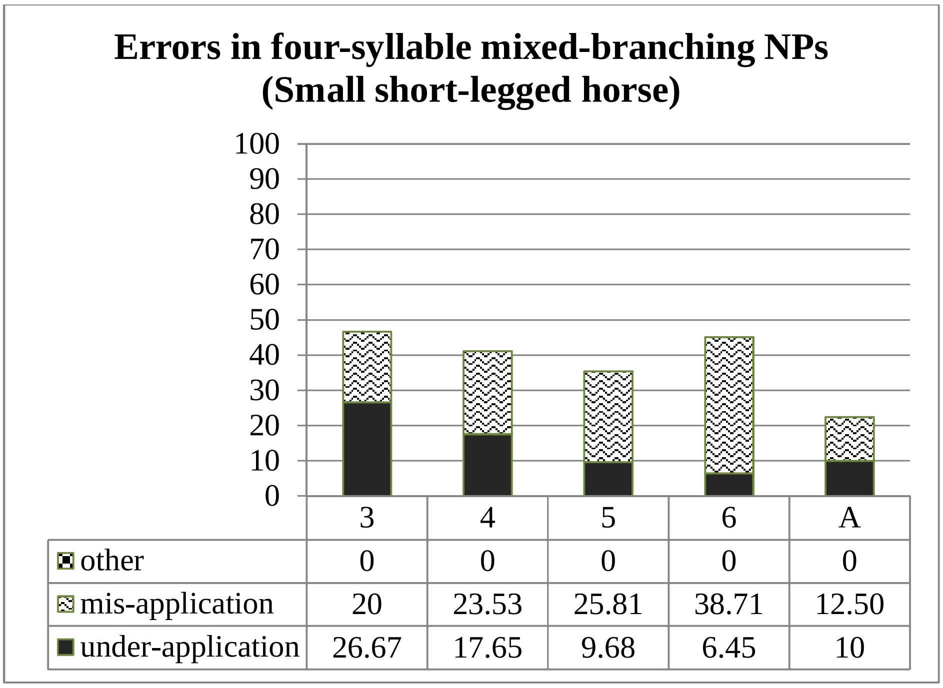
Figure 6.5 Study 3: Errors in four-syllable right-branching NPs by age



	3	4	5	6	A
other	8.82	5.71	2.04	2.22	0
mis-application	11.76	5.71	0	8.89	0
under-application	29.41	31.43	12.24	4.44	7.50

The error rates decrease by age, and even adults had under-application errors. While 3- and 4-year-olds' error rates are high between 40% and 50%, by age five or six, they drop to about 15%. The error type *Other* is attested in all child groups in the R-branching NPs, but not in the M-branching NPs. For M-branching NPs, only the *Under-application* and *Mis-application* error types were attested in all children and adults (Figure 6.6).

Figure 6.6 Study 3: Errors in four-syllable mixed-branching NPs by age



The overall error rates are higher in the M-branching than the R-branching NPs across age groups. Children's under-application errors decrease by age. Mis-application errors, however, increase by age. All the mis-application errors were the (**T2**T3**T2**T3) pattern. Unlike children, adults have about the same proportion for both error types.

A logistic regression analysis was performed for the errors found in four-syllable test items. The results show that the independent variables *age* and *branching structure* as a set are statistically significant (*chi square* = 73.794, $p < .001$ with $df = 15$). This shows that the independent variables as a set reliably distinguished among the error patterns.

Under-application errors

For the error type *Under-application* relative to correct responses in the four-syllable NPs, the branching structure of the NP was not found to be significant ($OR = .926$, $p = .827$). This indicates that Under-application errors did not occur more because of one or the other structural branching type. The *OR* value indicates that such error type occur with about the same frequency in R-branching and in M-branching NPs.

For the error type *Under-application* relative to correct responses, both 3- and 4-year-olds (3-year-olds: *OR* = 5.534, *p* = .001; 4-year-olds: *OR* = 4.602, *p* = .003) are significantly different from adults, but 5- and 6-year-olds are not (5-year-olds: *OR* = 1.424, *p* = .509; 6-year-olds: *OR* = .715, *p* = .609).

Mis-application errors

For the error type *Mis-application* relative to correct responses in the four-syllable NPs, the branching structure of the NP was found to be significant (*OR* = .147, *p* < *.001*) . The *OR* value indicates that such error type is roughly seven times more likely to occur in the M-branching NP than in the R-branching NP.

For the error type *Under-application* relative to correct responses, 3-, 4-, and 6-year-olds (3-year-olds: *OR* = 5.780, *p* = .008; 4-year-olds: *OR* = 3.872, *p* = .043; 6-year-olds: *OR* = 5.219, *p* = .003) are significantly different from adults, but 5-year-olds are not (5-year-olds: *OR* = 2.189, *p* = .202).

Other errors

The error type that is categorized as *Other* refers to using a tone other than T2 or T3 in the surface pattern. For the error type *Other* relative to correct responses in the four-syllable NPs, there were only seven tokens in the R-branching NPs and none in the M-branching NPs. The frequency of this error type found in children are extremely low, and none of the child groups are found to be significantly different from adults (3-year-olds: *OR* = 1.817E8, *p* = .997; 4-year-olds: *OR* = 1.049E8, *p* = .997; 5-year-olds: *OR* = 2.788E7, *p* = .998; 6-year-olds: *OR* = 3.013E7, *p* = .998).

One of the two hypotheses was the Strategy Shift Hypothesis (H_2), testing whether children always used the cyclic bottom-up parsing strategy regardless of structural complexity, or if they may shift to the non-cyclic left-to-right parsing when the structure becomes more complex. Simply put, do children make T3S errors which are based on the non-cyclic left-to-right parsing in the M-branching NP ([σ[[σσ]σ]])? We found that mis-application errors occurred more in M-branching NPs than in R-branching NPs, indicating that the more complicated structure is the source of the shift of strategies. In addition, all the mis-application errors in the M-branching NPs were of the (**T2**T3**T2**T3) pattern, a left-to-right non-cyclic parsing strategy. The Strategy Shift Hypothesis (H_2) is confirmed in all children except for the 5-year-olds who were not statistically different from adults. In terms of under-application, both 5- and 6-year-olds are adult-like, but 3- and 4-year-olds are not.

6.3.3 Discussion

In this section, T3S applications in three-syllable compound nouns and four-syllable NPs will be discussed separately.

6.3.3.1 Three-syllable compound nouns

All child groups were adult-like in [σ [σσ]] and [[σσ]σ] compound nouns. Children do refer to the morphosyntactic structure of the novel compound nouns in their T3S application. They apply T3S cyclically in the three-syllable compound nouns.

For the pattern (**T2T2**T3) in the [σ [σσ]] compound noun, we know that it could be derived in the Word-and-Phrase level model and that some speakers find it acceptable while others do not. If such pattern is derived through the larger domain parsing, we would expect to find the pattern in some adults, given that they are more likely to process a larger load of information at a time, hence, parse all three syllables in one domain. In fact, not only did adults never use the pattern, almost all children did not, either. The only two tokens of the (**T2T2**T3) pattern were found in a 3-year-old and a 6-year-old. The fact that children and adults in this study rarely used the larger domain parsing, even in a relatively small domain of three syllables, may suggest that the optional larger domain parsing does not apply in certain contexts, such as in the case of [σ [σσ]]. It appears that for the [T3 [T3T3]] structure, once the inner constituent has undergo T3S, no further T3S needs to apply in the first syllable, situated in the outer layer of the structure. Future studies can further investigate this issue.

6.3.3.2 Four-syllable NPs

First of all, children across age groups all had 100% rate in the control items (which are without T3S) in the R-branching and in the M-branching NPs. The overall error rates in the test items are higher for the M-branching than the R-branching NPs, indicating that T3S was more difficult for them in the M-branching structure.

Children's under-application errors decrease with age in both R-branching and in M-branching, showing a developmental trend. The decrease in under-application points to more awareness of applying T3S when necessary, and therefore, less under-application errors.

Mis-application errors did not show a clear trend in the R-branching NP, but such errors increase with age in the M-branching NP. All the mis-application errors in M-branching NPs were the *(**T2**T3**T2**T3) pattern, which was the result of the prosodic left-to-right binary parsing. Such a strategy possibly was used because the cyclic parsing in the M-branching NP had become a little too complicated for the children. In other words, when faced with complicated structures, children's ability to apply T3S cyclically in the NP may be weakened and they may ignore the internal structure and default to the non-cyclic prosodic parsing from left to right. Their choice of switching to the default binary parse, comparing to not applying T3S at all, may suggest that they would rather apply T3S wrong than not apply it at all. Namely, in their grammar, non-cyclic T3S application (even if it is incorrect) is better than not applying T3S at all. Interestingly, some adults had this incorrect binary parsing (12.50%) in the M-branching NP as well. It is not clear why adults did that. One possibility is that, the M-Branching NP items were items at the end of the experiment, so that they might have been tired and did not pay much attention, which could be true for children as well.

For NPs that are different in the internal structure but the same in syllable number, the non-cyclic parsing strategy results in the same surface patterns, while the cyclic parsing strategy results in different surface patterns. The fact that (**T2**T3**T2**T3) and (T3**T2T2**T3), the predicted patterns for the R-branching and the M-branching NPs respectively, were the most frequent patterns for the two structures within each age group indicates that they did refer to syntax and apply T3S cyclically, although they are still maturing in consistent cyclic T3S application in NPs. A majority T3S errors in the M-branching items were *(**T2**T3**T2**T3), a non-cyclic left to right parsing in the structure when the structure [σ[]σσ]σ]] predicts (T3**T2T2**T3). This indicates that even though children have the cyclic parsing strategy, they may shift to the non-cyclic parsing strategy when the syntactic structure becomes more complicated.

The larger domain parsing (**T2T2T2**T3) was predicted for the M-branching and the R-branching NPs, and in our experimental data, while the pattern was found in the M-branching NPs, it was not found in the R-branching NPs. In addition, in the M-branching NPs, all child groups have the (**T2T2T2**T3) pattern, but not adults, though adults were presumably better in processing a larger domain. The larger domain parsing (**T2T2**T3) in the [σ[σσ]] compound nouns was not attested in adults (and only found in two children out of 94 children). The disfavored larger domain parsing in the three-syllable [σ[σσ]] compound noun and the four-syllable M-branching NP [σ[]σσ]σ]] may suggest that for compound nouns and NPs, speakers prefer the cyclic pattern which in a way preserves the internal structure of the compound nouns or NPs.

6.4 Conclusions

Our research questions for this experiment were:

1. Do children know to apply T3S cyclically in NPs?
2. Does structural complexity affect parsing strategies they use?

Cyclic T3S application in three-syllable compound nouns ([σ[σσ]] and [[σσ]σ]) and four-syllable NPs (R-branching [σ[σ[σσ]]] and M-branching [σ[[σσ]σ]]) were used to test two hypotheses, the NP Cyclic Parsing Hypothesis and the Strategy Shift Hypothesis. Our results show that children refer to syntax in building prosodic domains and apply T3S cyclically. NP Cyclic Parsing Hypothesis is confirmed.

We also found that when the structure became more complicated as in the M-branching structure, children sometimes shifted to the non-cyclic binary parsing from left to right without referring to the syntactic structure. R-branching NPs were not difficult for children, but many of the children had trouble in the M-branching NPs. All the mis-application errors in the M-branching NPs ([σ[[σσ]σ]]) were ***T2**T3**T2**T3, resulting from a non-cyclic parsing strategy. We know that cyclic application would give T3**T2T2**T3. This confirms the Strategy Shift Hypothesis.

Children across age groups were adult-like in their T3S application in the three-syllable compound nouns. In the four-syllable NPs, R-branching was easier than M-branching. T3S application in four-syllable M-branching structure was the most challenging task across age groups. In short, although children show evidence of cyclic parsing in compound nouns and NPs, they might shift to the non-cyclic parsing when the structure increases in complexity.

CHAPTER 7

T3S IN SENTENCES

7.0 Introduction

Previous studies suggest early acquisition of T3S (Jeng 1979; Jeng 1985; Li & Thompson 1977; Zhu 2002; Zhu & Dodd 2000). The previous three chapters present a Natural Speech study as well as two experimental studies which tested non-cyclic and cyclic parsing strategies in flat structures and in NPs respectively. In this chapter, we test T3S application at the sentence level where an integration of cyclic and non-cyclic strategies is required. We test specifically the factors that potentially affect the application of T3S, including the length of the sentence, the number of adjacent T3* embedded in the sentence, the noun-pronoun distinction, and the syntactic differences in the sentences. How the participants, children and adults, parse syllables into prosodic domains for T3S application in sentences will provide valuable information on children's acquisition of T3S and T3S theories. In this chapter, two repetition studies are presented.

Both Study 4 and Study 5 are elicited production studies. The composition of the experimental sentences in Study 4 and that in Study 5 are identical. The only difference is in the audio recordings of the stimuli, one with tonal manipulation and one without. In Study 4 Natural Speech Repetition (henceforth NSR), the audio recordings were of natural speech (one of the surface patterns was used for the recordings) whereas in Study 5 Robot Talk Repetition (henceforth RTR), manipulated speech which had the T3S effect removed was used (more detail will be presented in Section 7.3.2.4). Simply put, NSR is with T3S and RTR is without T3S. In what follows, research questions, hypotheses and predictions for both studies will be presented.

7.1 Research questions, hypotheses and predictions for both studies

7.1.1 Research questions

In Study 4 NSR and Study 5 RTR, specific research questions regarding T3S application at the sentence level take into consideration the complexity of sentences, the matches and mismatches between syntax and prosody and properties of the subject.

Complexity: Does complexity—the number of adjacent T3*, the length of sentences (total number of syllables)— play a role in T3S application?

The mapping of syntax and prosody: Even though foot-building in T3S application depends heavily on syntax, we know that T3S domains are not isomorphic to syntactic domains. What role does the alignment of syntax and prosody play in T3S application? How does mapping between syntax and prosody affect T3S application in children and adults?

The distinction between subject pronoun (pro) and subject NP: Do pronouns behave differently from NPs in T3S application, and more specifically, in the subject position? Previous studies suggest that functional words, including prepositions, object pronouns, classifiers, are prosodically weak and can cliticize to a preceding syllable (Chen 2000:400-403; Lin 2007:216; Shih 1986; Shih 1997; Zhang 1997:307-308).

7.1.2 Hypotheses and predictions for both studies

Two experiments were designed in a way that the following two questions can be answered.

1. Are children able to repeat[35] when they hear a sentence where T3S has been applied?
2. Are children able to actively apply T3S when they hear a sentence where T3S has not

[35] There is always the possibility that older children especially repeat without knowing the rule as a frozen chunk. However, most studies (e.g. Brown and Bellugi, 1964, McDaniel et al., 1998) show that it is very hard to repeat without using grammar.

been applied?

Study 4 NSR tests the repetition of sentences where T3S is correctly applied. Study 5 RTR tests application of T3S in the repetition of sentences where the T3S effect was removed. In other words, Study 4 NSR tests "passive" repetition and Study 5 RTR tests "active" application of T3S. Both studies used elicited production data. As we can expect, the task in Study 4 will be easier than that in Study 5 because the "work" of T3S application is done in the former, but not the latter. Participants hear natural speech (with T3S) in Study 4 NSR, but unnatural speech (without T3S) in Study 5 RTR where they need to work on the T3S application themselves.

We now turn to the specific hypotheses. First, applying T3S to two, five, or six consecutive T3*, for instance, naturally requires a different workload. The same goes for the length of sentences. The more consecutive T3* and/or the longer the sentence, the more complex the task of T3S application. In H_1, we define complexity in terms of number of adjacent T3* and total number of syllables in the sentence. Our Null Hypothesis (H_0) is that the number of T3* and number of syllables will not affect T3S application.

(1) Complexity Hypothesis (H_1):

a. Number of adjacent T3*: The more adjacent T3*, the more complex the task.

b. Length of sentences: The more the syllables, the more complex the task.

Predictions:

a. Everything else held constant, a sentence with *no* adjacent T3* (therefore, no T3S is required) is easier than a sentence with *some* adjacent T3*, which in turn is easier than a sentence with *all* the syllables in T3.

b. A sentence with fewer syllables is easier than a sentence with more syllables.

Secondly, based on the Word-and-Phrase level Model, T3S domains are built with partial reference to syntax (cyclic application at the Word level and non-cyclic application at the Phrase level), and the T3S domains and the syntactic domains are not isomorphic (Chen 2000: Ch 9; Shih 1986; Shih 1997). If there is only one prosodic domain for the whole sentence, there is no issue with the syntax-prosody misalignment because the left and right edges of the syntactic domain map perfectly to the left and right edges of the prosodic domain. However, if there are more than two prosodic domains, they may or may not align with syntactic boundaries. Since T3S partially depends on syntax, let us focus on the major syntactic boundary, the subject-predicate boundary. Except for very short sentences, a typical sentence is broken into more than one prosodic domain. We hypothesize that prosodic boundaries are prone to match the major syntactic boundary, namely, the subject-predicate boundary. Our Null Hypothesis (H_0) is that there is no clear relationship between syntactic domains and prosodic domains (i.e. T3S domains). We test not only whether or not a relationship between syntax and prosody exists in T3S application, but also whether or not the alignment of syntax and prosody respects syntactic boundaries.

(2) Syntax-prosody Alignment Hypothesis (H_2): Prosodic boundaries tend to match the major syntactic boundaries.

Prediction: A parsing which results in a good match between syntax and prosody will occur more frequently than a mismatch between syntax and prosody.

7.2 Study 4: NSR = Natural Speech (with Sandhi) Repetition

In this experiment, we test children in their repetition of structurally different sentences where T3S have been applied. The goal is to see not only if children are able to repeat sentences where T3S has been correctly applied, but also to find out whether or not they use the pattern they hear. This is because there are multiple surface patterns, and they may hear a pattern, but choose to repeat with their own pattern.

7.2.1 Method

7.2.1.1 Subjects

Thirty-two subjects participated in this study. Twenty-one children, age 4;0 – 6;8, were recruited in Taichung, Taiwan. They were divided into two age groups, four-year-olds and six-year-olds. In the six-year-old group, only two children (5;9 and 5;10 respectively) were under 6;0. Eleven adults[36] participated in the study. All of them were native speakers of Mandarin Chinese from Taiwan, studying at Michigan State University. Table 7.1 shows the distribution of the subjects.

Table 7.1 Study 4: Distribution of the subjects

Age groups	N	Age range	Mean	Standard deviation
4-year-olds	11	4;0 – 4;10	4;4	3.68 (mo.)
6-year-olds	10	5;9 – 6;8	6;3	3.68 (mo.)
adults	10			

7.2.1.2 Procedure

All children were tested in a quiet classroom in the kindergarten or in the home of the child. The adult subjects were tested at their homes or in a quiet room. The elicited production task lasted approximately 10 minutes for adults, and 15 – 20 minutes for children. Each child was presented a Robot and a beanie bear *Xiaoli*. The experimenter told the child that they were about to play a game. She said, “Look, this is a Robot, and this is Bear *Xiaoli*. Robot says something to

[36] An adult subject, after completing the experiment, mentioned to the experimenter that her friends often commented that she “talked weird.” The data of this adult subject was excluded in order to ensure, the best way we could, that adult data reflect the norm of adult speech. Her scores in 4w4σ and 4w6σ control and test items were 100% correct. In the Pro-5w6σ and NP-5w6σ control items, the answers were also 100% correct. Her scores for the Pro-5w6σ and NP-5w6σ test items were 50% correct and 0% correct respectively.

Bear *Xiaoli*, but Bear *Xiaoli* cannot hear her. Could you help her by listening to what the Robot is saying? After you hear it, you tell *Xiaoli*, okay? Do you want to play the game?" (See Appendix E for Mandarin experimental prompts and materials.) The subjects heard the audio recordings through headphones (Philips SHP2000) and saw accompanying pictures from a laptop computer, and then, repeated what they heard.

Each PowerPoint slide consisted of the images of the Robot, Bear *Xiaoli* and/or other animals doing various activities. The purpose of showing the images along with the audio recordings is to assist children in their understanding of the recordings. All the images were obtained from Google images (http://www.google.com/imghp?hl=en&tab=wi) and by photographing real objects (Robot and Bear *Xiaoli*). All subjects' responses were recorded on a Marantz PMD660 with an Audio-technica miniature clip-on microphone (AT831B Cardioid Condenser Lavalier microphone). (A second digital recorder, a Sony ICD-P530F, was used in case of technical problems.)

7.2.1.3 Design

An elicited repetition task (Crain & Thornton 2000; McDaniel et al. 1998) is used in this experiment. The four structures tested in the study are in (1). Throughout the chapter, sentences will be identified by the following labels for the four structures: 4w4σ (four words, four syllables), 4w6σ (four words, 6 syllables), PRO-5w6σ (subject pronoun, 5 words, 6 syllables) and NP-5w6σ (subject NP, 5 words, 6 syllables). Based on the Word-and-Phrase level Model, the predicted patterns for each structure are listed in (3) (see Appendix G for derivations for test items). In general, at the Word level (including simple nouns, compound nouns and NPs), T3S applies cyclically, and at the Phrase level, T3S applies non-cyclically.

(3) The four structures in the experimental sentences and T3S patterns expected

a. 4w4σ:

[Wo	[xiang	[mai	[bi]]]]	
I	want	buy	pen	‘I want to buy pens.’
3	3	3	3	UT
3	3	3	3	Word: no T3S
3	3	(**2**	3)	Phrase: disyllabic foot for the smallest domain, T3S
(**2**	3)	(2	3)	Phrase: Disyllabic foot for the remaining syllables, T3S; ST1
(**2**	**2**	**2**	3)	Larger domain in fast speech; ST2

b. 4w6σ:

[[haima]	[xiang	[zhao	[shuimu]]]]	
seahorse	want	look for	jellyfish	‘Seahorse wants to look for Jellyfish.’
33	3	3	33	UT
(**2**3)	3	3	(**2**3)	Word: two disyllabic feet, T3S
(23)	(**2**	3)	(23)	Phrase: disyllabic foot, T3S; ST1
(**22**	**2**	3)	(23)	Larger domain in fast speech; ST2

c. Pro-5w6σ:

[Ni	[xiang	[yang	[xiao	[laohu]]]]]	
you	want	raise	small	tiger	‘You want to have/raise (a) small tiger.’
3	3	3	3	33	UT
3	3	3	3	(**2**3)	Word: T3S
3	3	3	(3	23)	Word: Incorporation, no T3S
(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2

ii. Rightward incorporation:

(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3

d. NP-5w6σ:

[Ma	[xiang	[zhao	[xiao	[haigou]]]]]	
horse	want	look for	small	fur-seal	'Horse wants to look for the small fur-seal.'
3	3	3	3	33	UT
3	3	3	3	(**2**3)	Word: T3S
3	3	3	(3	23)	Word: Incorporation, no T3S
(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2

ii. Rightward incorporation:

(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3

4w4σ in (3a) and 4w6σ in (3b) are both composed of four words, but they differ in the total number of syllables. We test whether or not the length of sentences has an effect by comparing these two sentence groups. In addition, Syntax-Prosody Alignment hypothesis H_2 will be tested as well.

Pro-5w6σ and NP-5w6σ are used to test all the hypotheses except for H_{1b} which concerns the effect of sentence length (PRO-5w6σ and NP-5w6σ are of the same length (6 syllables long), so this hypothesis cannot be tested). PRO-5w6σ in (3c) and NP-5w6σ in (3d) differ only in whether or not it is a subject pronoun (henceforth subject pro) or a subject NP. We test whether or not there is a difference in T3S application when the subject is an NP and when it is a pronoun.

As mentioned earlier, previous studies suggest that an object pronoun cliticizes leftwards to the preceding syllable (Chen 2000; Lin 2007; Shih 1986; Shih 1997; Zhang 1997). What was left unexplored in previous studies was whether or not subject pros behave similarly in cliticization. There is a problem, however. Being in the initial position of the sentence, a subject pro cannot cliticize leftwards to the preceding syllable since nothing precedes it. It will be interesting to know whether the subject pro stays as a degenerate foot in its own prosodic domain, or that it joins the following syllable(s) in forming a prosodic domain even though there is a major syntactic boundary between subject and predicate. Positioning pronouns in the subject position in Study 4 and Study 5 allows us to test not only a pronoun's well-known property of being prosodically weak, but also its directionality of the cliticization which has not received much attention.

What we also are interested in is the directionality of incorporation of an unparsed syllable. An example in (3c) is repeated in (4).

(4)	PRO-5w6σ:					
	[Ni	[xiang	[yang	[xiao	[laohu]]]]]	
	you	want	raise	small	tiger	'You want to have/raise (a) small tiger.'
	3	3	3	3	33	UT
	3	3	3	3	(**2**3)	Word: T3S
	3	3	3	(3	23)	Word: Incorporation, no T3S
	(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S
	Directionality for the Incorporation in the next step:					
i.	Leftward incorporation:					
	(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
	(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2
ii.	Rightward incorporation:					
	(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3

In (4), at the Word level, the innermost constituent *laohu* 'tiger' is parsed, and T3S applies. *Xiao* 'small' is then incorporated, and T3S does not apply. At the Phrase level, a disyllabic foot is formed from left to right, and T3S applies. Now we have one remaining syllable that we need to incorporate into a neighboring domain. We are faced with two choices: Incorporating rightwards or incorporating leftwards. There is no specification of the directionality in the Word-and-Phrase Model, so let us take a closer look at the two options we have at this point.

a. *Incorporating leftwards*: The unparsed syllable is incorporated into the disyllabic domain obtained at the Phrase level (i.e. the first two syllables). There is no reference to syntax.

b. *Incorporating rightwards*: The unparsed syllable is incorporated into the ternary domain obtained at the Word level. There is reference to syntax.

If *Option a Incorporating leftwards* is taken, the remaining unparsed syllable is incorporated into the preceding domain, and T3S applies within it. We have ST1 (**T2T2**T3)(T3**T2**T3). If Optional T3S across domain applies, we have ST2 (**T2T2T2**)(T3**T2**T3).

If *Option b Incorporating rightwards* is taken, the remaining unparsed syllable is incorporated into the following domain, and T3S applies within it. We have ST3 (**T2**T3)(**T2**T3**T2**T3).

It should be noted that the subject-predicate pattern is also a possible T3S pattern. Let us look at a sentence shown earlier in (3d), repeated here in (5).

(5) NP-5w6σ:

[Ma	[xiang	[zhao	[xiao	[haigou]]]]]	
horse	want	look for	small	fur-seal	'Horse want to look for the small fur-seal.'
3	3	3	3	33	UT
3	3	3	3	(**2**3)	Word: T3S
3	3	3	(3	23)	Word: Incorporation, no T3S
(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2

ii. Rightward incorporation:

(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3

Alternative parsing:

(3) %	(2	3)	(3	23)	ST4

↑ intonational break

In (5), at the Word level, the innermost constituents are parsed. T3S applies in the object noun, but T3S is not applicable in the subject noun. Next, still at the Word level, the adjective *xiao* ‘small’ is incorporated into its following domain, and T3S applies. At the Phrase level, a disyllabic foot is formed from left to right for the first two syllables, and T3S applies, followed by the incorporation of the unparsed syllable *deng* ‘wait for,’ and T3S applies again.

The additional pattern (T3)(**T2**T3)(T3**T2**T3) occurs when there is an intonational break (the convention is to indicate it with “%”) and/or there is an emphasis/focus on the subject (Chen 2000: 379-380, 411-413). It is not clear whether or not there is an intonational break and/or if there is an emphasis or focus on the subject in the data collected for Study 4 and Study 5. It is also not clear if this additional pattern is specific to Taiwan Mandarin speakers. Future investigation will be needed to answer the questions in this regard.

For a T3S application to occur, there has to be a T3S environment to trigger it. Whenever there are adjacent T3*, the environment for triggering T3S application is potentially created. Therefore, such environment plays a crucial role in our experimental design. The levels of difficulty can vary depending on how many adjacent T3* there are in a sentence. Zero T3S applications when there are no adjacent T3* is expected to be the easiest since it is without any T3S workload. These are the control items which require no T3S applications. It should be noted that control items sometimes contain a T3; however, it is not preceded or followed by another T3, so T3S is never triggered.

For the test items, there are two conditions. The first condition is the T3S environment of three adjacent T3*. The second condition is the T3S environment of maximal adjacent T3* allowed for that sentence. The maximal number of T3* that is allowed for (3a) is four because the sentence is four syllables long. Sentences (3b) – (3d) each has six syllables, so the maximal number of T3* allowed for them is six.

For easy reference to the conditions in the test items (three T3* and maximal T3*) and as well as the condition of "no adjacent T3*" the control items, we use the simplified terms in (6). These labels will be used in the rest of the chapter.

(6) Three conditions: No adjacent T3*, three T3*, and all T3*

a. **No adjacent T3***: No adjacent T3*, and therefore T3S is not applicable (the control items).

b. **Three T3***: Three adjacent T3* embedded in the sentences.

c. **All T3***: Maximal adjacent T3* allowed for that sentence (four adjacent T3* for (3a) and six adjacent T3* for (3b) – (3d)).

Not only is the number of adjacent T3* important, the location of the T3-sequence needs to be specified as well. For the control items, no specification is required as there are no adjacent T3*. For the "maximal T3*" test items, we know that each syllable in that sentence bears a T3 underlyingly. In this case, all the syllables are in T3, so specification of where the T3-sequence is located is unnecessary. In short, there is no confusion of the location of the T3-sequence in the control items and in the test items where each syllable is in T3.

The specification of the location of T3* is necessary in cases where three T3* are embedded in the sentence. We specify the location of T3* with bold type in (7).

(7) Location of adjacent T3* for the three-T3 condition (shown in **bold type**)

a. 4w4σ:

$[\boldsymbol{\sigma}_{pronoun}[\boldsymbol{\sigma}_{want}[\boldsymbol{\sigma}_{verb}[\sigma NP]]]]$

[Ni	[xiang	[mai	[hua]]]]	
you	want	buy	flower	‘You want to buy flowers.’
3	3	3	1	UT
3	3	3	1	Word: no T3S
3	3	(3	1)	Phrase: disyllabic foot for the smallest domain, no T3S
(**2**	3)	(3	1)	Phrase: Disyllabic foot for the remaining syllables, T3S; ST1
(**2**	**2**	3	1)	Larger domain in fast speech, ST2

b. 4w6σ:

$[\sigma\boldsymbol{\sigma}NP\ [\boldsymbol{\sigma}_{want}\ [\boldsymbol{\sigma}_{verb}\ [\sigma\sigma NP]]]]$

[[banma]	[xiang	[zhao	[xiongmao]]]]	
zebra	want	look for	panda bear	‘Zebra wants to look for Panda bear.’
13	3	3	21	UT
(13)	3	3	(21)	Word: two disyllabic feet, T3S
(13)	(**2**	3)	(21)	Phrase: disyllabic foot, T3S; ST1
(1**2**	**2**	3)	(21)	Larger domain in fast speech, T3S; ST2

c. PRO-5w6σ:

$[\boldsymbol{\sigma}_{pronoun}\ [\boldsymbol{\sigma}_{want}[\boldsymbol{\sigma}_{verb}\ [\sigma_{adj}[\sigma\sigma NP]]]]]$

[Wo	[xiang	[zhao	da	[hema]]]]]	
I want	look for	big	hippo		‘I want to look for (a) big hippo.’
3	3	3	4	23	UT
3	3	3	4	(23)	Word: T3S
3	3	3	(4	23)	Word: Incorporation, no T3S
(**2**	3)	3	(4	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(4	23)	Phrase: Incorporation, T3S; ST1

ii. Rightward incorporation:

(2	3)	(3	4	23)	Phrase: Incorporation, T3S; ST2
(2	**2**)	(3	4	23)	Optional: T3S across domains; ST3

d. NP-5w6σ:

[**σ**NP	[$\boldsymbol{\sigma}_{want}$	[$\boldsymbol{\sigma}_{verb}$	[σ_{adj}	[σσNP]]]]]	
[Gou	[xiang	[zhao	[da	[xingxing]]]]]	
Dog	want	look for	big	gorilla	'Dog wants to look for Gorilla.'
3	3	3	4	11	UT
3	3	3	4	(11)	Word: T3S
3	3	3	(4	11)	Word: Incorporation, no T3S
(**2**	3)	3	(4	11)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(4	11)	Phrase: Incorporation, T3S; ST1

ii. Rightward incorporation:

(2	3)	(3	4	11)	Phrase: Incorporation, T3S; ST2
(2	**2**)	(3	4	11)	Optional: T3S across domains; ST3

To summarize the experimental design, the control items are those that need no T3S applications (no adjacent T3*). The test items have two conditions—three T3* and all T3*. Table 7.2 lists the number of tokens of controls and tests for each sentence type.

Table 7.2 Study 4: Tokens for test and control items

Control items/test items	Control	Test		
Conditions	No adjacent T3*	Three T3*	All T3*	
			4 T3*	6 T3*
4-syllable sentences:				
4w4σ: [$\sigma_{pronoun}$[σ_{want}[σ_{verb}[σ_{NP}]]]]	2	2	2	n/a
6-syllable sentences:				
4w6σ: [$\sigma\sigma_{NP}$[σ_{want}[σ_{verb}[[$\sigma\sigma_{NP}$]]]]	2	2	n/a	2
PRO-5w6σ: [$\sigma_{pronoun}$[σ_{want}[σ_{verb}[σ_{Adj}[$\sigma\sigma_{NP}$]]]]]	2	2	n/a	2
NP-5w6σ: [σ_{NP}[σ_{want}[σ_{verb}[σ_{Adj}[$\sigma\sigma_{NP}$]]]]]	2	2	n/a	2

From Table 7.2, we can see that for each sentence structure, there are six tokens, with two each for No adjacent T3*, Three-T3* and All T3*. There are 24 tokens in all (4 sentence types × 6 tokens each sentence type).

In this experiment, we test whether or not children are able to repeat correctly the sentences that have various numbers of T3S applications. Due to the T3S variability, more than one T3S pattern is possible. Upon hearing a sentence in natural speech, are they able to repeat it? If so, will they repeat the T3S pattern that they hear or will they repeat with a different surface pattern?

For the audio recording of these experimental sentences, we selected the pattern where more T3* undergo T3S. By using the pattern that has more derived T2's, rather than fewer derived T2's, we are testing to what extend children can retain the pattern that may or may not have been acquired. We are more interested in how much the children can do (that is, their potential), rather than how little children can do. For instance, in (8) below, we see various possibilities in the surface form.

(8)	[Ma	[xiang	[zhao	[xiao	[haigou]]]]]	
	horse	want	look for	small	fur-seal	'Horse want to look for the small fur-seal.'
	3	3	3	3	33	UT
	3	3	3	3	(**2**3)	Word: T3S
	3	3	3	(3	23)	Word: Incorporation, no T3S
	(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S
	Directionality for the Incorporation in the next step:					
i.	Leftward incorporation:					
	(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
	(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2
ii.	Rightward incorporation:					
	(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3
	Alternative parsing:					
	(3) % (2		3)	(3	23)	ST4
	↑ intonational break					

In (8), ST1 is the pattern derived first. Although both ST1 and ST2 are possible patterns, the level of difficulty in producing them varies. Our reasoning is that, the more derived T2's, the more work (the higher demand). It follows that ST2 which has four derived T2s is more difficult than ST1 and ST3 which has three derived T2s. ST4 which has two derived T2s is assumed to be the least difficult. A female native speaker recorded the selected surface pattern for each sentence with a professional digital recorder Marantz PMD660. These recorded sentences were put on the PowerPoint slides where children will hear the sentences with accompanying pictures.

7.2.1.4 Materials

In the 24 experimental sentences, 16 are test items, and 8 are control items. A sample sentence each for the control items (no adjacent T3*), three-T3 test items, and all-T3 test items are in Figure 7.1 (a) - (c) respectively. The underlying tones and the surface pattern selected for the audio recording are included in these sample sentences. (See the Appendix E for the full set of 18 test items and 6 control items.)

Figure 7.1 Study 4: Sample materials

a. Sample control item— no adjacent T3*	
	Audio recording: [Zhu [xiang [bian [lan [jingyu]]]]] pig want become blue whale 'Pig wants to become (a) blue whale.' pig want become blue whale 1 3 4 2 12 UT 1 3 4 2 12 ST used
b. Sample test item— three T3*	
	Audio recording: [Gou [xiang[zhao [da [xingxing]]]]] dog want look for big gorilla 'Dog wants to look for (the) big gorilla.' dog want look for big gorilla 3 3 3 4 11 UT **2** **2** 3 4 11 ST used
c. Sample test item— all T3*	
	Audio recording: [Ma [xiang [zhao [xiao [haigou]]]]] horse want look for small fur-seal 'Horse wants to look for (the) small fur-seal.' horse want look for small fur-seal 3 3 3 3 33 UT **2** **2** **2** 3 **2**3 ST used

7.2.1.5 Coding

One native speaker transcribed the data and coded the answers. Numbers 1, 2, 3 and 4 were used for the four lexical tones, T1, T2, T3, and T4 respectively. Data were coded in a way to preserve the most available information in subjects' responses. The coding categories are in (9).

(9) Coding categories for data analysis:

a. Included in the analysis:

i. Correct application of T3S without missing any syllables (missing syllables are indicated by underscores in the coding).

ii. Incorrect application of T3* without missing any syllables

iii. Answers with one or two missing syllables

b. Excluded in the analysis:

i. No answer: Saying “I don’t know” or being silent without giving an answer.

ii. Non-target answers: Saying something else, such as adding additional words to the sentences, replacing the name of an animal, which result in non-target answers.

iii. Pauses: Pauses between two T3*.

iv. Other: Missing three or more syllables.

When there are missing syllables in the subjects’ answers, it is often one or two syllables in the medial position that are left out. Only when the number of missing syllables does not go beyond two syllables are the answers included in the analysis. Answers with pauses between T3* are excluded from the analysis because a pause destroys the T3S environments created. Sample answers and how they fit in the coding categories are in Table 7.3.

Table 7.3 Study 4: Sample answers and their coding categories for data analysis

Sample sentence:

[Wo	[xiang	[mai	bi]]]		
I	want	buy	pen	‘I want to buy pens.’	
3	3	3	3	UT	
(**2**	3)	(**2**	3)	ST1	
(**2**	**2**	**2**	3)	ST2	→ The pattern the subjects heard.

Sample answers (Only tones are listed.)	Include in the analysis?	Correct ✓ or incorrect ✗
2 3 2 3 2 2 2 3	Yes Yes	✓ ✓
3 3 2 3 2 3 3 3	Yes Yes	✗ ✗
2 _ 2 3 _ _ 2 3 _ _ _ 3	Yes Yes No	✗ ✗ n/a
3 pause 3 2 3	No	n/a
Silence or saying “I don’t know.”	No	n/a
Saying something else: [ta [mai [zhege]]] he buy this ‘He buys this.” 1 3 45	No	n/a

After the responses were coded as shown in Table 7.3, a second step of coding was needed for all the correct answers. We know that when a participant’s answer is correct, there are different ways for it to be correct since there are multiple surface patterns. For the purpose of analyzing correct patterns produced by the participants, all the correct responses were further categorized.

It should be noted that we categorize the correct responses in terms of the type of feet shown in the surface patterns. For instance, for a six-T3 sequence, the pattern (**T2**T3)(**T2**T3**T2**T3) (see rightward incorporation in (3c) and (3d)) is identified as an alternating pattern (alternating between T2 and T3), and (**T2T2**T3)(T3**T2**T3) a ternary pattern. Since a pure non-cyclic strategy that produces (**T2**T3)(**T2**T3)(**T2**T3) is the same as the predicted pattern (**T2**T3)(**T2**T3**T2**T3) through rightward incorporation, and we do not know which parsing the speakers use, such sequence alternating between T2 and T3 will be labeled as the "alternating pattern." It should be emphasized that the "alternating' and 'ternary' patterns here do not mean that the string of syllables are parsed non-cyclically from left to right in two-syllable or three-syllable domains. The definition of the categories used is in (10), followed by sample correct responses and their corresponding coding categories in Table 7.4.

(10) Categories for correct responses and their definitions:

a. The alternating pattern: The syllables alternate between T2 and T3, or are parsed in binary feet.

b. The ternary pattern: The pattern is composed of ternary feet.

c. The opt rule pattern (the optional rule pattern): The pattern is derived through one of the optional rules in the Word-and-Phrase level Model. That is, either through optional T3S across prosodic domains, or through the larger domain parsing in fast speech.

d. The subject-predicate pattern: The parsing of the subject is separated from the predicate.

For (10a), in the four-syllable sentences, the alternating pattern is **T2**T3**T2**T3, and in the six-syllable sentences, it is **T2**T3**T2**T3**T2**T3. For (10b), the ternary pattern, it is relevant in the 6-syllable sentences, but not in the 4-syllable sentence. In our 6-syllable sentences with a monosyllabic NP or a monosyllabic pronoun (see the structure in (3c) and (3d)), the ternary pattern always separates the verb and the object. The opt rule pattern in (10c) is derived when T3S applies across two domains or through larger domain parsing in fast speech. The subject-predicate pattern in (6d) is derived where there is an intonational break and/or there is an emphasis or focus on the subject, according to Chen (2000:379-380, 411-413). Sample correct answers and how they fit in each category in (10) are summarized in Table 7.4.

Table 7.4 Study 4: Sample correct responses and their coding categories

	[Ni	[xiang	[yang	[xiao	[laoshu]]]]]		
	you	want	raise/have	small	mouse		
	‘You want to raise/have (a) small fur-seal.’						
	you	want	raise/have	small	mouse		
	3	3	3	3	33	UT	Categories for correct responses
	2	**2**	**2**	3	**2**3	ST used	
a.	(**2**	3)	(**2**	3	**2**3)	ST1	The alternating pattern
b.	(**2**	**2**	3)	(3	**2**3)	ST2	The ternary pattern
c.	(**2**	**2**	**2**)	(3	**2**3)	ST3	The opt rule pattern
d.	(3)	(**2**	3)	(3	**2**3)	ST4	The subject-predicate pattern
e.	(3)	(**2**	**2**)	(3	**2**3)	ST5	The subject-predicate pattern

7.2.2 Results and discussion for control items in NSR

Table 7.5 shows the number of items included and excluded in control items. Table 7.6 shows the number of the excluded control items by coding categories (see §7.2.1.5).

Table 7.5 Study 4: Number of items included (I) and excluded (E) in control items

	4w4σ			**4w6σ**			**PRO-5w6σ**			**NP-5w6σ**		
Number of items	I	E	total	I	E	total	I	E	total	I	E	total
4-year-olds	20	2	22	19	3	22	17	5	22	16	6	22
6-year-olds	20	0	20	20	0	20	19	1	20	20	0	20
adults	20	0	20	20	0	20	19	1	20	20	0	20

Table 7.6 Study 4: Control items— data excluded from the analysis

	4w4σ					**4w6σ**				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	2	0	0	2	0	3	0	0	3
6	0	0	0	0	0	0	0	0	0	0
A	0	0	0	0	0	0	0	0	0	0

	PRO-5w6σ					**NP-5w6σ**				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	5	0	0	5	0	6	0	0	6
6	0	1	0	0	1	0	0	0	0	0
A	0	1	0	0	1	0	0	0	0	0

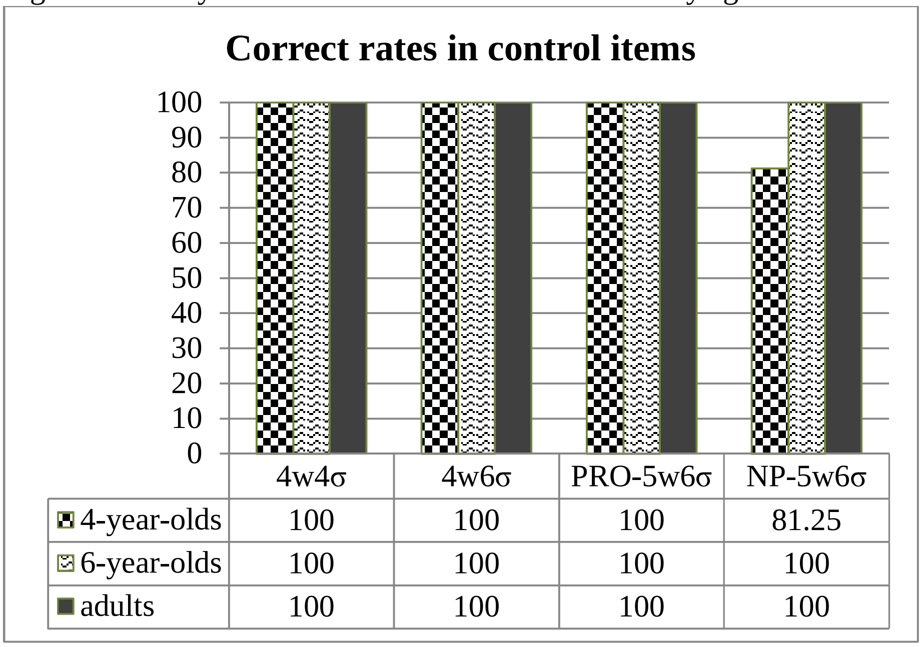
Table 7.7 shows the correct rates for control items.

Table 7.7 Study 4: Correct rates (%) in control items

	4w4σ	**4w6σ**	**PRO-5w6σ**	**NP-5w6σ**
4-year-olds	100 (20/20)	100 (19/19)	100 (17/17)	81.25 (13/16)
6-year-olds	100 (20/20)	100 (20/20)	100 (19/19)	100 (20/20)
adults	100 (20/20)	100 (20/20)	100 (19/19)	100 (20/20)

Figure 7.2 shows the correct rates in the control items by age.

Figure 7.2 Study 4: Correct rates in the control items by age



Recall that for the control items, there are no adjacent T3*, so no T3S is required. That is, surface tones are the same as underlying tones. Unlike correct answers in the test items where there are multiple T3S surface patterns, in the control items, it is simple. The mapping of the underlying tones and the surface tones is one to one, rather than on to many.

The correct rates for four sentence types (4w4σ, 4w6σ, PRO-5w6σ, and NP-5w6σ) by age group (4-year-olds, 6-year-olds, and adults) were calculated. Our Null hypothesis is that there is no difference between any two age groups (i.e. 4-year-olds = 6-year-olds, 4-year-olds = adults, and 6-year-olds = adults).

Overall, the correct rates for all the age groups in the controls of all sentence types (4w4σ, 4w6σ, PRO-5w6σ, and NP-5w6σ) are very high. Even the youngest group, 4-year-olds, did very well except for a lower correct rate at 81.25% in NP-5w6σ items. Six-year-olds are adult-like in having a 100% correct rate in all four sentence types. These results suggest that the length of the sentences, the structures of the sentences were not beyond their capability.

The results show that all age groups did perfectly (100% correct) in three sentence types (4w4σ, 4w6σ, and PRO-5w6σ). Adults and 6-year-olds did perfectly in NP-5w6σ, but 4-year-olds had a correct rate of 81.25%. Two-proportion *z-test* ($\alpha = .05$, two-tailed) was used to determine whether or not the difference was significant. Four-year-olds are not significantly different from 6-year-olds ($p = .156$), and they are not significantly different from adults, either ($p = .156$).

The task of repetition of these sentences in natural speech was an easy task for children. We will see in the next section how children did in the test items where there is T3S effect.

7.2.3 Results and discussion for test items in NSR

Table 7.8 and Table 7.9 summarize by coding categories (see §7.2.1.5) the number of excluded data from "4w4σ and 4w6σ test items" and "PRO-5w6σ and NP-5w6σ test items" respectively.

Table 7.8 Study 4: Test items (4w4σ and 4w6σ)— data excluded from the analysis

	4w4σ: three T3*					**4w4σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	4	0	0	4	0	6	0	0	6
6	0	0	0	0	0	0	0	0	0	0
A	0	0	0	0	0	0	0	0	0	0
	4w6σ: three T3*					**4w6σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	4	1	0	5	0	5	0	0	5
6	0	0	1	0	1	0	0	0	0	0
A	0	0	0	0	0	0	1	0	0	1

Table 7.9 Study 4: Test items (PRO-5w6σ and NP-5w6σ)— data excluded from the analysis

	PRO-5w6σ: three T3*					**PRO-5w6σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	4	0	0	4	0	5	0	0	5
6	0	1	0	0	1	0	0	0	0	0
A	0	0	0	0	0	0	0	0	0	0
	NP-5w6σ: three T3*					**NP-5w6σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	2	0	0	2	0	5	0	0	5
6	0	0	0	0	0	0	0	0	0	0
A	0	1	0	0	1	0	1	0	0	1

In the next subsections, the statistical results and discussion for two sentence pairs, *4w4σ and 4w6σ* and *PRO-5w6σ and NP-5w6σ,* will be presented separately.

7.2.3.1 Results for 4w4σ and 4w6σ items

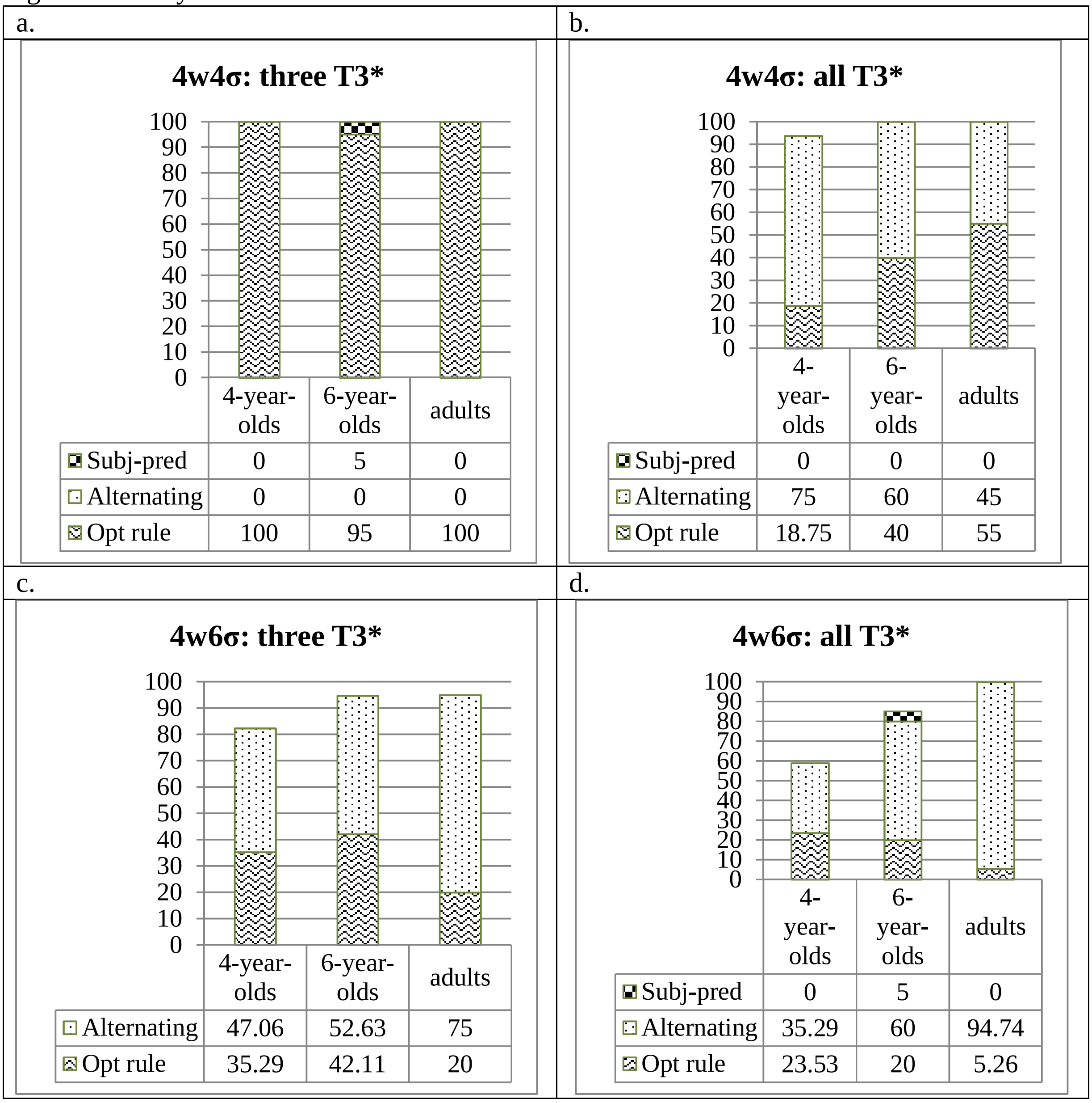
Table 7.10 shows number of items by pattern in 4w4σ and 4w6σ test items and Figure 7.3 shows the correct rates and the distribution of T3S patterns in *4w4σ* and *4w6σ* sentences by age.

Table 7.10 Study 4: Number of items by pattern in 4w4σ and 4w6σ test items

	4w4σ: three T3*				**4w4σ: all T3***			
	Subject-predicate pattern	Alternating pattern	Opt Rule pattern	total	Subject-predicate pattern	Alternating pattern	Opt Rule pattern	total
4	0	0	18	18	0	12	3	16
6	1	0	19	20	0	12	8	20
adults	0	0	20	20	0	9	11	20
	4w6σ: three T3*				**4w6σ: all T3***			
	Subject-predicate pattern	Alternating pattern	Opt Rule pattern	total	Subject-predicate pattern	Alternating pattern	Opt Rule pattern	total
4	0	8	6	17	0	6	4	17
6	0	10	8	19	1	12	4	20
adults	0	15	4	20	0	18	1	19

(4= 4-year-olds, 6= 6-year-olds; the numbers of individual patterns + number of errors = total)

Figure 7.3 Study 4: Correct rates in *4w4σ* and *4w6σ* sentences



a. 4w4σ: three T3*

	4-year-olds	6-year-olds	adults
Subj-pred	0	5	0
Alternating	0	0	0
Opt rule	100	95	100

b. 4w4σ: all T3*

	4-year-olds	6-year-olds	adults
Subj-pred	0	0	0
Alternating	75	60	45
Opt rule	18.75	40	55

c. 4w6σ: three T3*

	4-year-olds	6-year-olds	adults
Alternating	47.06	52.63	75
Opt rule	35.29	42.11	20

d. 4w6σ: all T3*

	4-year-olds	6-year-olds	adults
Subj-pred	0	5	0
Alternating	35.29	60	94.74
Opt rule	23.53	20	5.26

For the opt rule pattern, the number of syllables matters. The frequency of the opt rule pattern is higher in four-syllable sentences than in six-syllable sentences.

Interestingly, the alternating pattern was not attested in three-T3 *4w4σ* items (Figure 7.3 (a)) though it was attested in all-T3 *4w4σ* and three-T3 *4w6σ* and all-T3 *4w6σ* items (Figure 7.3 (b) – (d)). The alternating pattern decreases with age in all-T3 *4w4σ* items (Figure 7.3 (b)), but increases with age in all-T3 *4w6σ* items (Figure 7.3 (d)). The subject-predicate pattern was rarely used in all three age groups. The ternary pattern was never used.

A logistic regression analysis was performed. The results show that the independent variables (age, number of adjacent T3*, and number of syllables) as a set are statistically significant (*chi square* = 120.288, $p < .001$ with df = 15). This indicates that the independent variables as a set reliably distinguished among the response patterns.

The opt rule pattern

The Wald criterion shows that the number of T3* and the number of syllables are found to be statistically significant ($p < .001$ for both) for the opt rule pattern relative to errors. Everything else held constant, three-T3 items are more likely than all-T3 items (*Odds Ratio* (*OR*) = 14.180, $p < .001$), and 4-syllable items more likely than 6-syllable items (*OR* = 99.982, $p < .001$) to have the opt rule pattern. Four-year-olds are significantly different from adults (*OR* = .064, $p = .015$), but 6-year-olds are not (*OR* = .311, p =.325). The OR values indicate that adults are roughly 16 times more likely than 4-year-olds and 3 times more likely than 6-year-olds to use the opt rule pattern.

The alternating pattern

For the alternating pattern relative to errors, the number of syllables is statistically significant (*OR* = 8.873, $p = .044$), and the *OR* value indicates that a four-syllable sentence is more likely to have the alternating pattern than a six-syllable sentence. For the alternating pattern, 4-year-olds are significantly different from adults (*OR* = .052, $p = .006$), and 6-year-olds are not significantly different from adults (*OR* = .210, $p = .174$).

The subject-predicate pattern

For the subject-predicate pattern relative to errors, the number of T3* is not statistically significant (*OR* = .338, p = 4.672), and neither is the number of syllables (*OR* = 27.412, p = .072).

7.2.3.2 Discussion for 4w4σ and 4w6σ items

First of all, regarding the number of T3*, in the 4w4σ sentences, children did equally well in the three-T3 and all-T3 items. In the 4w6σ items, however, while children did fairly well in the three-T3 items (4-year-olds: 82.35% and 6-year-olds: 97.74%), their correct rates dropped in the all-T3 items (4-year-olds: 58.82% and 6-year-olds: 85%). Complexity Hypothesis (H_{1a}) Number of adjacent T3*— the more adjacent T3*, the more complex the task— is supported.

Regarding the length of sentences, both 4-year-olds and 6-year-olds did better in the 4-syllable sentences than in the 6-syllable sentences. Complexity Hypothesis (H_{1b}) Length of sentences— the more the syllables, the more complex the task, is supported.

Regarding syntax-prosody alignment, it was predicted that parsing which results in a good match between syntax and prosody will occur more frequently than a mismatch between syntax and prosody. In the 4w4σ sentences, the use of the alternating pattern decreases with age. In the 4w6σ sentences, its use increases with age. It should be noted that in the latter, the alternating pattern gives a good syntax-prosody mapping. The results support the Syntax-prosody Alignment Hypothesis (H_2)— Prosodic boundaries tend to match the major syntactic boundaries.

Participants did not always use the pattern they heard. The opt rule pattern was what the participants heard in these test sentences. The percentage of the opt rule pattern was very likely to be boosted to some extent by what they heard since participants could simply hear a pattern and repeat it back. However, we also see that participants did not always use the pattern that they heard. In fact, their own preference for a particular pattern was so strong in some test items that the pattern they heard was produced by only a small percentage of people.

Since the subject-predicate pattern was rarely used (with only 5% in three-T3 4w4σ items in 6-year-olds and 5% in all-T3 4w6σ items in 6-year-olds), we will focus on the alternating pattern, which was produced by some participants in all age groups in replacing the opt rule pattern that they heard. Let us first look at the alternating pattern for three-T3 4w4σ and three-T3 4w6σ sentences shown in (11). A T3 is indicated by "*3*" and a non-T3 is indicated by an *X*. In the following derivations, all the patterns derived are possible. The boxed pattern is the pattern used in the stimuli.

(11) The alternating pattern in 4w4σ and 4w6σ sentences— three T3*

a. 4w4σ: $[\sigma_{pronoun}[\sigma_{want}[\sigma_{verb}[\sigma_{NP}]]]]$

3	3	3	X	UT
3	3	3	X	Word: not applicable
2	3	(3	X)	Phrase: disyllabic foot for the smallest domain, no T3S
(2	3)	(3	X)	Phrase: disyllabic foot, T3S; ST1
(**2**	**2**	3	X)	Larger domain in fast speech; ST2

b. 4w6σ: $[\sigma\sigma_{NP}[\sigma_{want}[\sigma_{verb}[[\sigma\sigma_{NP}]]]]$

X3	3	3	XX	UT
(X3)	3	3	(XX)	Word: not applicable
(X3)	(**2**	3)	(XX)	Phrase: disyllabic foot, T3S; ST1
(X**2**	2	3)	(XX)	Larger domain in fast speech; ST2

In (11a), no foot has been formed at the Word level, so at the Phrase level, a disyllabic foot is formed for the smallest domain, and T3S does not apply. At the Phrase level, the subject pro forms a binary foot with the following syllable. This prosodic domain crosses the subject-predicate boundary. Notice that the prosodic constituent (first two syllables) is a non-constituent syntactically. In addition, the alternating pattern[37] (**T2**<u>T3</u>)(<u>T3</u>Tx) has two adjacent T3*, although it is a grammatical because the two T3* belong to different feet. Despite the first foot in the alternating pattern being acceptable, when there is another option, speakers seemed to prefer a pattern without any adjacent T3* over a pattern with adjacent T3* belonging to two domains. ST2 is derived through larger domain parsing in fast speech. This pattern does not have any adjacent T3* and participants favored it.

Now consider (11b), the subject NP and the object NP are parsed at the Word level, and the auxiliary verb and the verb are parsed non-cyclically at the Phrase level. In this case, no prosodic domain crosses over the subject-predicate boundary. There is no mismatch between syntax and prosody at the major syntactic boundary. This may account for the fact that across three age groups, the alternating pattern was used more than the opt rule pattern that they heard. Adults' preference for the alternating pattern is evident (the alternating pattern: 75%, the opt rule pattern: 20%). The two child groups, 4- and 6-year-olds used the opt rule pattern more (4-year-olds: 35.29% and 6-year-olds: 42.11%) than adults. It is possible that children were more willingly repeat something as heard, and adults subconsciously worked out the pattern that was "faithful" to the pattern that they would normally use.

We now turn to the all-T3 items. In all-T3 4w4σ items, while the use of the alternating pattern decreases with age (4-year-olds: 75%, 6-year-olds: 60%, and adults: 45%), the use of the opt rule pattern increases with age (4-year-olds: 18.75%, 6-year-olds: 40%, and adults: 55%). The alternating pattern has two evenly divided disyllabic feet, and is particularly favored by the 4-year-olds. On the other hand, adults used the opt rule pattern (55%) slightly more than the

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[37] The alternating pattern includes the pattern that alternates between **T2** and T3 as well as the pattern that consists of the bracketing of binary feet.

alternating pattern (45%). Six-year-olds' use of the opt rule pattern (40%) and the alternating pattern (60%) clearly show the trend of becoming less like 4-year-olds and more like adults.

In all-T3 *4w6σ* items, however, the use of the alternating pattern increases with age (4-year-olds: 35.29%, 6-year-olds: 60%, and adults: 94.74%). Only 5.26% of the adults repeated the sentence with the opt rule pattern they heard, and the rest (94.74%) of the adults all used the alternating pattern. Six-year-olds also showed a preference for the alternating parsing (60%), compared to the two other patterns (the subject-predicate pattern: 5%, and the opt rule pattern: 20%). The bias toward the alternating pattern in 6-year-olds and adults in this case is very strong. Six-year-olds and adults used fewer opt rule patterns in all-T3 4w6σ items than in all-T3 4w4σ items (there is no clear difference in 3-year-olds). As the sentence grew longer, it was harder to use the opt rule pattern.

7.2.3.3 Results for PRO-5w6σ and NP-5w6σ items

Table 7.11 shows number of items by pattern in PRO-5w6σ and NP-5w6σ test items.

Table 7.11 Study 4: Number of items by pattern in PRO-5w6σ and NP-5w6σ test items

	PRO-5w6σ: three T3*					**PRO-5w6σ: all T3***				
	Subj-pred pattern	Alternating pattern	Ternary pattern	Opt Rule pattern	total	Subj-pred pattern	Alternating pattern	Ternary pattern	Opt Rule pattern	total
4	0	17	0	0	18	0	3	4	10	17
6	0	19	0	0	19	0	6	5	6	20
adults	0	19	0	0	20	0	5	5	7	20

	NP-5w6σ: three T3*					**NP-5w6σ: all T3***				
	Subj-pred pattern	Alternating pattern	Ternary pattern	Opt Rule pattern	total	Subj-pred pattern	Alternating pattern	Ternary pattern	Opt Rule pattern	total
4	0	0	20	0	20	0	0	6	10	17
6	2	0	17	0	20	2	0	6	10	20
adults	3	0	16	0	19	5	0	9	5	19

(4= 4-year-olds, 6= 6-year-olds; the numbers of individual patterns + number of errors = total.)

Figure 7.4 Study 4: Correct rates in *PRO-5w6σ* and *NP-5w6σ* sentences

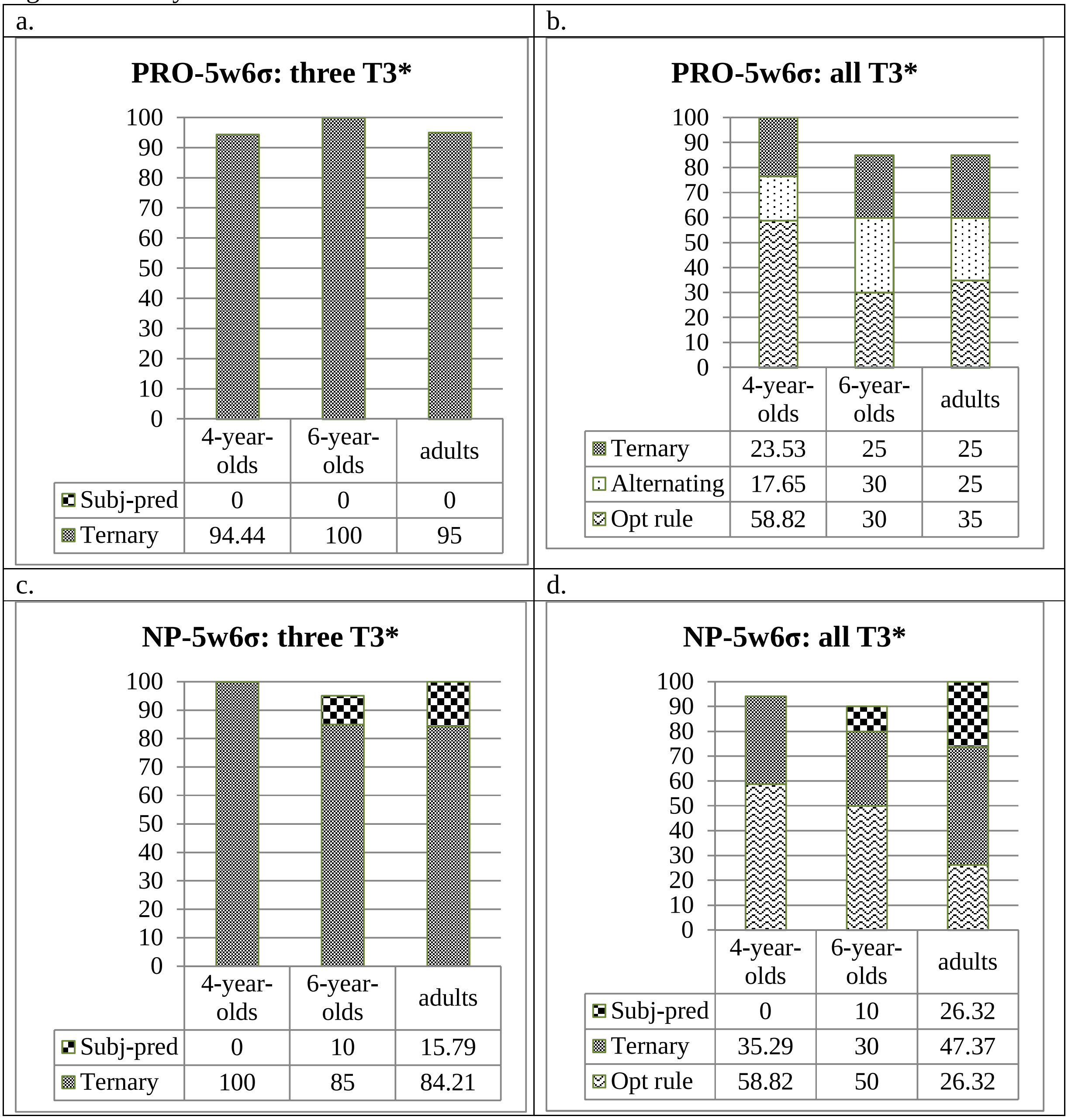


Figure 7.4 shows the correct rates and the distribution of T3S patterns for *PRO-5w6σ* and *NP-5w6σ* sentences by age. The subject-predicate pattern was used in *NP-5w6σ* sentences (Figure 7.4 (c) and (d)), but not in *PRO-5w6σ* sentences (Figure 7.4 (a) and (b)). Also, 6-year-olds and adults used this pattern, but 4-year-olds did not. The subject-predicate pattern is used by adults in all-T3 *NP-5w6σ* 26.32% of the time, compared to 0% in all-T3 *PRO-5w6σ* items. This

shows that that although the subject noun can stand alone in its domain, subject pro does not. Notice also that 6-year-olds have 10% in all-T3 *NP-5w6σ* items. Although the percentage is fairly low, their use of the subject-predicate pattern in *NP-5w6σ* items, but not in *PRO-5w6σ* items, indicates that they are aware of the distinction between subject NPs and subject pros.

The alternating pattern surfaced only in all-T3 *PRO-5w6σ* sentences (Figure 7.4 (b)), and all three age groups used this pattern. The ternary pattern occurred more in the three-T3 items (Figure 7.4 (a) and (c)) than in all-T3 items (Figure 7.4 (b) and (d)). For the all-T3 items, regardless of *PRO-5w6σ* or *NP-5w6σ* sentences, the younger the children, the more likely they were to use the pattern they heard, the opt rule pattern.

A logistic regression analysis was conducted. The results show that the independent variables (age, number of adjacent T3*, and subject NP vs. subject pronoun) as a set are statistically significant (*chi square* = 180.806, $p < .001$ with $df = 20$).

The opt rule pattern

For the opt rule pattern relative to errors, the number of T3* is not statistically significant (*OR* = 2.199E-9, $p = .997$), and neither is the noun-pronoun distinction (*OR* = .390, $p = .211$). Four-year-olds and 6-year-olds are not significantly different from adults (4-year-olds: *OR* = 3.527, $p = .187$; 6-year-olds: *OR* = .942, $p = 1.059$).

The alternating pattern

For the alternating pattern relative to errors, the number of T3* is not statistically significant (*OR* = 2.824E-9, $p = .998$), and neither is the noun-pronoun distinction (*OR* = 5.990, $p = .150$). Four-year-olds and 6-year-olds are not significantly different from adults (4-year-olds: *OR* = 1.422, $p = .760$; 6-year-olds: *OR* = 1.326, $p = .758$).

The ternary pattern

For the ternary pattern relative to errors, the number of T3* is statistically significant (*OR* = 9.174, p = .002). The OR value indicates that, everything held constant, a three-T3 sentence is roughly 9 times more likely to have the ternary pattern than a six-T3 sentence. Four-year-olds and 6-year-olds are not significantly different from adults (4-year-olds: *OR* = 1.416, p = .708; 6-year-olds: *OR* = .613, p = .510). The noun-pronoun distinction is not significant (*OR* = .282, p = .084).

The subject-predicate pattern

For the subject-predicate pattern relative to errors, the number of T3* is not statistically significant (*OR* = 2.997, p = .255), and neither is the noun-pronoun distinction (*OR* = 3.208E-10, p = .998).

7.2.3.4 Discussion for PRO-5w6σ and NP-5w6σ items

For PRO-5w6σ and NP-5w6σ items, the number of T3* did not have much effect on children's correct rates (approximately 5% - 15% difference). Although overall, the correct rates are slightly higher in three-T3 items than in all-T3 items, the difference is minimal and 4-year-olds actually did better in all-T3 PRO-5w6σ items than in three-T3 PRO-5w6σ. These results do not provide strong evidence to support H_{1a}— Number of adjacent T3*: The more adjacent T3*, the more complex the task.

The use of the subject-predicate pattern in NP-5w6σ items in 6-year-olds and adults lends support to the Syntax-prosody Alignment Hypothesis (H_2)— Prosodic boundaries tend to match the major syntactic boundaries. The subject-predicate pattern gives a pattern that have a good mapping between syntax and prosody. However, it should be noted that the ternary pattern where the prosodic domain crosses the subject-predicate boundary was used more frequently than the subject-predicate pattern. Although a monosyllabic subject NP can stand alone, 6-year-olds and adults prefer the ternary pattern to the subject-predicate pattern. While 6-year-olds used the subject-predicate pattern, 4-year-olds never did. This may indicate that 6-year-olds are more aware of the syntactic properties of the NP and/or that they are more sensitive to the subject-predicate boundary than 4-year-olds.

Speakers did not always repeat the surface pattern they heard. In fact, a lot of time, children and adults used another surface pattern. In all sentences except for three-T3 PRO-5w6σ items, at least two surface patterns surfaced in speakers' repetition. The variability in all-T3 PRO-5w6σ and all-T3 NP-5w6σ are especially interesting. A sharp contrast exists in the use of the alternating pattern for PRO-5w6σ (Figure 7.4 (b)), but the subject-predicate pattern for NP-5w6σ (Figure 7.4 (d)).

The subject-predicate pattern

The subject-predicate pattern was used in NP-5w6σ items, but not in PRO-5w6σ items. Since a subject NP can stand alone in its own domain, the subject-predicate pattern surfaced as a result. In addition, 6-year-olds and adults used the subject-predicate pattern, but not 4-year-olds (three T3*: 4-year-olds: 0%, 6-year-olds: 10%, and adults: 15.79%; all T3*: 4-year-olds: 0%, 6-year-olds: 10%, and adults: 26.32%). This may indicate that at age 4, the subject-predicate pattern for sentences with subject NPs is still being acquired, or yet to be acquired. Six-year-olds used this pattern only 10%. Comparing to the absence of this pattern in 4-year-olds, 6-year-olds seemed to starting to acquire this pattern. A difference of 26.32% in adults' use of patterns between the NP-5w6σ items and the PRO-5w6σ items reveals that adults differentiate the prosodic difference between monosyllabic nouns and pronouns, and therefore, produced the subject-predicate pattern in sentences with a subject noun, but not a subject pronoun.

The alternating pattern

In PRO-5w6σ all-T3 items, the alternating pattern was attested in all three age groups. Four-year-olds had this pattern in place, though they did not use it as much as 6-year-olds and adults (4-year-olds: 17.65%, 6-year-olds: 30%, and adults: 25%). The two child groups were aware of the noun-pronoun distinction. They also were fairly close to how frequently adults used the alternating pattern, with 4-year-olds using it slightly less than adults, and 6-year-olds using it slightly more than adults.

The ternary pattern

The ternary pattern occurred more in the three-T3 items than in all-T3 items, possibly because there are other strategies (the alternating pattern and the opt rule pattern) available in the latter. Across age groups, the ternary pattern occurs more in the NP-5w6σ all-T3 items (4-year-olds: 35.29%, 6-year-olds: 30%, and adults: 47.37%) than in the PRO-5w6σ all-T3 items (4-year-olds: 23.53%, 6-year-olds: 25%, and adults: 25%). This is probably because that in the latter, children and adults also used the alternating pattern, but not in the former.

The opt rule pattern

Echoing the finding of younger children perhaps were more willing to repeat the pattern they heard, again, 4-year-olds were the ones who produced the opt rule pattern the most frequently. This also shows that children did not have trouble repeating the sentences when the T3S is applied correctly.

For the all-T3 items (both subject pro and subject NP)

Now if we shift our focus to 6-year-olds in their production in the all-T3 items, they were moving towards the adult-like distribution of different T3S patterns. In all-T3 PRO-5w6σ items, the distribution of three patterns in 6-year-olds is strikingly similar to that of adults (Figure 7.4

(b)). For all-T3 NP-5w6σ items, the developmental patterns is quite clear, showing that the opt rule pattern decreases with age, but the subject-predicate pattern increases with age (Figure 7.4 (d)). Recall that the subject-predicate pattern was only attested in subject NP items, but not subject pro items. Combine this fact with the fact that only 6-year-olds and adults had the subject-predicate pattern, and that 6-year-olds' use of this pattern was less than adults (and none of the 4-year-olds used it), it may indicate that 6-year-olds were starting to restrict syntactically the use of T3S across the major syntactic boundary in subject NP items (6-year-olds: 10% vs. adults: 26.32%), but not in subject pro items.

To conclude, in Study 4 NSR, children generally did fairly well. Upon hearing a particular pattern for a sentence, children and adults did not always use the pattern they heard. T3S variability was evident in the results. This leads us to the next study, Study 5, where participants had to apply T3S on their own— the underlying tones of the sentences are available, but not the surface tones. We now turn to our final study, the most complicated and yet, the most attractive and informative, in the series.

7.3 Study 5: RTR = Robot Talk (without sandhi) Repetition

7.3.1 Background

In Study 4 NSR where there were no tonal manipulations, we found that children, both 4-year-olds and 6-year-olds, were able to repeat the sentences without too much difficulty. For both children and adults, they did not always repeat the sentences with the same T3S pattern they heard. Keeping this in mind, we ask the following question: what do children do when there is no T3S at all in the input and they have to do the T3S applications themselves? What about adults? Will the distribution of the T3S patterns in Study 5 RTR be similar to that in Study 4 NSR?

We are departing from mere repetition in Study 4, and now will take a closer look into children's T3S application in Study 5 from a source that only has underlying tones. All the sentences in Study 5 were identical to those in Study 4. However, the T3S effect was removed in Study 5. Although the speech without T3S effect can be understood,[38] it might sound unnatural or even rather strange, like the unnaturalness found in how robots talk. That was why this experiment was named "Robot Talk Repetition." The tonal manipulation in RTR was to change all the sandhi tones (derived T2s from T3* because of T3S rule) to their underlying tone, T3. One way to think of it is that, we gave "processed" (T3S applied) sentences in Study 4, but "unprocessed" (T3S never applied, as if T3S rule did not exist in the language) sentences in Study 5. Will the children still be able to repeat the sentences? If they can still repeat the sentences, will they use the T3S patterns attested in Study 4? What surface patterns will they use?

7.3.2 Method

An elicited repetition task (McDaniel et al. 1998; Crain and Thornton 2000) was used in Study 5. All the sentences used in Study 4 were the same, except that in Study 5, there were tonal manipulations (Detailed examples will be given in Section 7.3.2.4).

7.3.2.1 Subjects

Fifty-seven subjects participated in this study. Forty-three children, age 4;1 – 6;11, were recruited in Taichung, Taiwan. They were divided into two age groups, four-year-olds and six-year-olds. Fourteen adult subjects participated in the study. All of them were native speakers of

[38] In my informal inquiry of friends' experiences of acquiring T3S, a response I received from a person who is currently an elementary school teacher shared that when teaching her pupils about T3S, she sometimes removes T3S from her speech intentionally and had her students correct her speech. That is, to have them apply T3S for her.

Mandarin Chinese from Taiwan. The participants in this study were different from those in Study 4. Table 7.12 shows the distribution of the participants.

Table 7.12 Study 5: Distribution of the subjects

Age group	N	Age range	Mean	Standard deviation
4-year-olds	20	4;1 – 4;9	4;6	2.40 (mo.)
6-year-olds	23	6;0 – 6;11	6;6	3.04 (mo.)
Adults	14			

7.3.2.2 Procedure

All children were tested in a quiet classroom in the kindergarten or in the home of the child. All the adult participants were tested in a quiet room or the home of the participant. The elicited production task lasted approximately 10 minutes for adults, and 15 – 20 minutes for children. Each child was presented a Robot and a beanie bear *Xiaoli*. The experimenter told the child that they were about to play a game called "Robot Talk." She said, "Look at this Robot. She talks funny, and the bear doesn't understand a word she says. The bear *Xiaoli* understands Child Talk only, not the Robot Talk. Can you help her? Listen to the Robot Talk, and then tell *Xiaoli* what she says, okay? Do you want to play the game?" The subjects heard recordings and saw accompanying pictures from a laptop computer, and then, repeated what they heard.

The recording device and the headphone used in this experiment are the same as those in Study 4. The images and pictures used in this experiment are identical to those in Study 4.

7.3.2.3 Design

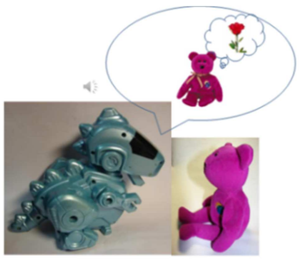
The design of Study 5 is the same as that of Study 4 (See Section 7.2.1.3), except that the T3S effect was removed in Study 5. The removal of the T3S effect is the only difference between the two studies. All the underlying T3* surface as T3* without undergoing the T3S rule in Study 5. The manipulation of the tones will be presented in the following section.

7.3.2.4 Materials

There were 24 sentences, 16 test items and 8 control items. Sample sentences are in Figure 7.5. (See the Appendix F for the full set of 18 test items and 6 control items.)

Figure 7.5 Study 5: Sample materials

a. Sample control item—no adjacent T3*

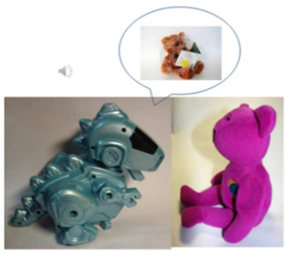


[Ni	[xiang	[mai	hua.]]]	
you	want	buy	flower	'You want to buy flowers.'
3	3	3	1	UT
3	3	3	1	Robot Talk

b. Sample test item—three adjacent T3*

[Wo	[xiang	[mai	bi.]]]	
I	want	buy	pens	'I want to buy pens.'
3	3	3	3	UT
3	3	3	3	Robot Talk

c. Sample test item—six adjacent T3*

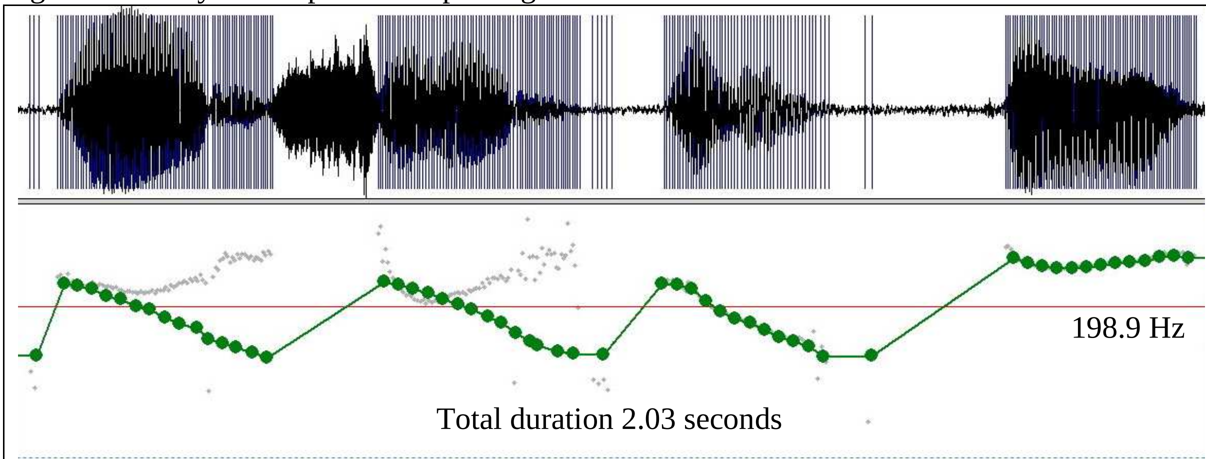


[Ta	[xiang	[kan	shu.]]]	
he	want	read	book	'He wants to read books.'
1	3	4	1	UT
[39] *1*	3	*1*	*1*	Robot Talk

[39] The tones in *italics* indicate the moderate manipulation on the tone (slight changes in shape and/or height), rather than changing the original tone categorically as in the test items where a derived T2 is completely changed to the underlying T3.

Since all the sandhi tones (derived T2 from T3 because of T3S rule) were changed to the underlying T3, the Robot Talk was essentially a speech without the T3S rule. A female native speaker's natural speech of all 24 sentences was recorded on a professional digital recorder Marantz PMD660. The software PRAAT (Boersma & Weenink 2009) was subsequently used in the manipulation of the tones. The manipulation was to *undo* all the T2's that are derived from T3* because of the T3S rule. These derived T2's are changed to their underlying tones, T3*. Examples of two test items and a control item are in Figure 7.6, Figure 7.7 and Figure 7.8.

Figure 7.6 Study 5: Sample Praat Spectrogram for a test item— three T3*



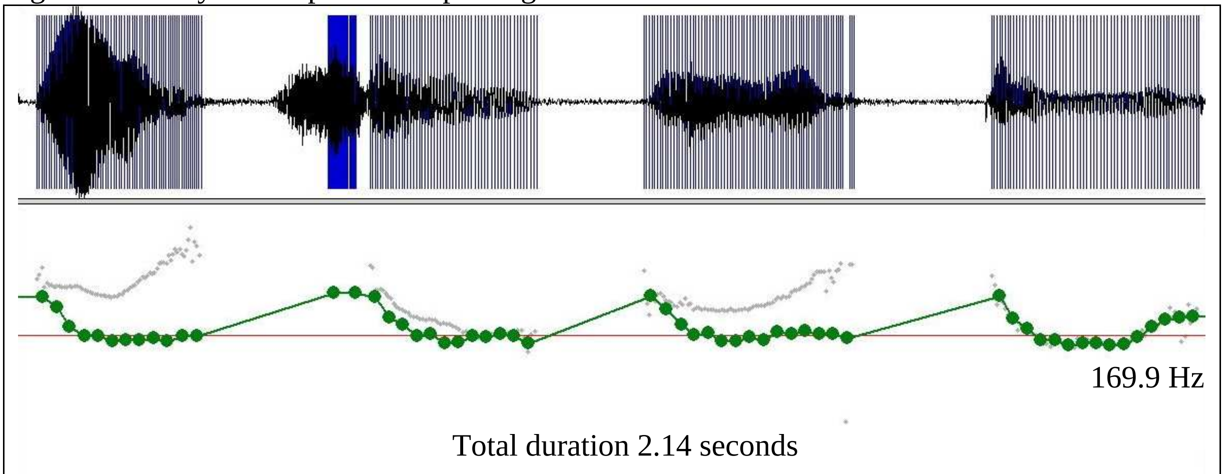
[Ni	[xiang	[mai	hua]]]
you	want	buy	flower

'You want to buy flowers.'

you	want	buy	flower	
T3	T3	T3	T1	UT
T2	**T2**	T3	T1	ST
T3	T3	T3	T1	Robot Talk

In Figure 7.6, the last syllable in T1 is intact. The third syllable also remained intact and served as the baseline T3 for the preceding two T3*. The bold dots were drawn to various positions in order to change the shape and pitch of the tones, and in our case, from T2 (a high rising tone) to T3 (a low dipping tone). The first two syllables were manually manipulated by drawing the bold dots. The original thin dots situated higher were the surface tones, derived T2's, in the original recordings. The pitch height and shape were altered to conform to the baseline T3, the third T3 in the three-T3 sequence. After the tonal manipulation, the original recording no longer had the T3S effect (no more derived T2s). The manipulated speech became our Robot Talk, a talk with all underlying tones (Robot Talk = UT), a talk without T3S rule.

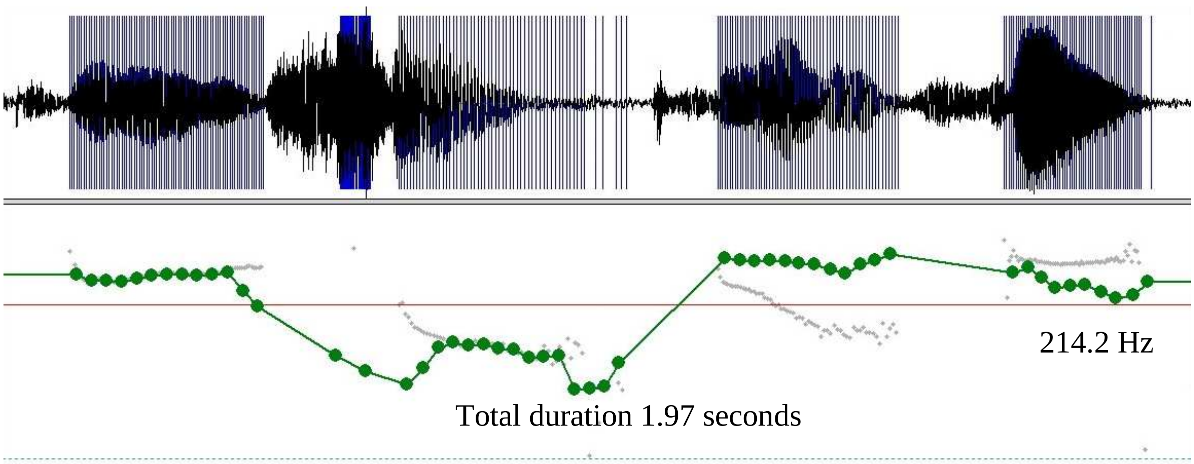
Figure 7.7 Study 5: Sample Praat Spectrogram for a test item— all T3*



[Wo	[xiang	[mai	bi]]]	
I	want	buy	pen	
'I want to buy pens.'				
I	want	buy	pen	
T3	T3	T3	T3	UT
T2	T3	**T2**	T3	ST
T3	T3	T3	T3	Robot Talk

In Figure 7.7, the last syllable remains intact, and served as the baseline T3 to its preceding three T3*. In the original recording, the first and the third syllables surfaced as a T2, a rising tone, because of the T3S rule. These two syllables were changed to T3, the low dipping tone. The second syllable actually did not change to T2 in the original recording—(**T2**T3)(**T2**T3), which is one of the surface patterns of the sentence. As the last syllable was used as the baseline T3, the height of the second T3 was also lowered very slightly to match the height of the fourth syllable, the baseline T3.

Figure 7.8 Study 5: Sample Praat Spectrogram for a control item



[Ta	[xiang	[kan	shu]]]	
he	want	read	book	
‘He wants to read books.’				
he	want	read	book	
T1	T3	T4	T1	UT
T1	T3	T4	T1	ST
T1[40]	*T3*	T1	*T1*	Robot Talk

In order to maintain the consistency of the “weirdness” of Robot Talk, some tones in the control items were manipulated slightly. There was one concern, however. For the control items, since there were no adjacent T3*, there was no T3S rule applied in the first place. Unlike the test items, the tonal manipulation for the control items was not changing the derived T2 to its underlying tone, T3. Although tonal manipulations in the test items did not cause a change in the meaning (i.e. a sentence with or without T3S application carry the same meaning), a categorical

40 The tones in italics indicate minor change (in shapes and/or pitch height) in the tones that cannot be categorized in any of the four lexical tones.

change in tones in the control items was not the best option because tones are contrastive in Mandarin, so a change in the tone often leads to a change in the meaning. For the control items, we minimized the possibility of alteration of the meaning of the words by slightly changing the shape and/or height of the tones, although a change of one tone to another tone is not completely prohibited in the manipulation if it would not lead to confusion and would not change the meaning of the sentence. For instance, the third syllable in Figure 7.8 was changed from T4, a falling tone, to T1, a high level tone, and the intended meaning can easily be retrieved because *kan* 'to read, to watch' can be read as T1 in *kan jia* 'to watch the house, to house-sit.' If this syllable had been changed from T4 to T3 instead, the meaning of the sentence would have totally changed. In tone 3, *kan* means to chop (e.g. a tree), so *kan* in T3, followed by *shu* 'book' would mean 'to chop the book.' This kind of tonal manipulation that leads to change in meaning was avoided.

As seen in Figure 7.8, besides the third syllable being changed from T4 to T1, the first, second and the last syllables were altered slightly in height or in shape. This is for the weirdness effect of the Robot Talk, and yet at the same time, not sacrificing the preservation of the intended meanings of the sentences. The accompanying picture cues also helped the subjects to identify the intended meaning of the Robot Talk.

7.3.2.5 Coding

All the coding procedure was the same as that in Study 4. (See Section 7.2.1.5.)

7.3.3 Results and discussion for control items in RTR

Table 7.13 shows the number of items included and excluded in control items. Table 7.14 shows the number of excluded control items by coding categories.

Table 7.13 Study 5: Number of items included (I) and excluded (E) in control items

	4w4σ			**4w6σ**			**PRO-5w6σ**			**NP-5w6σ**		
Number of items	I	E	total	I	E	total	I	E	total	I	E	total
4-year-olds	38	2	40	23	17	40	29	11	40	26	14	40
6-year-olds	46	0	46	43	3	46	43	3	46	41	5	46
adults	27	1	28	26	2	28	28	0	28	28	0	28

Table 7.14 Study 5: Control items— data excluded from the analysis

	4w4σ					**4w6σ**				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	2	0	0	2	0	17	0	0	17
6	0	0	0	0	0	0	3	0	0	3
A	0	1	0	0	1	0	2	0	0	2
	PRO-5w6σ					**NP-5w6σ**				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	11	0	0	11	0	14	0	0	14
6	0	3	0	0	3	0	5	0	0	5
A	0	0	0	0	0	0	0	0	0	0

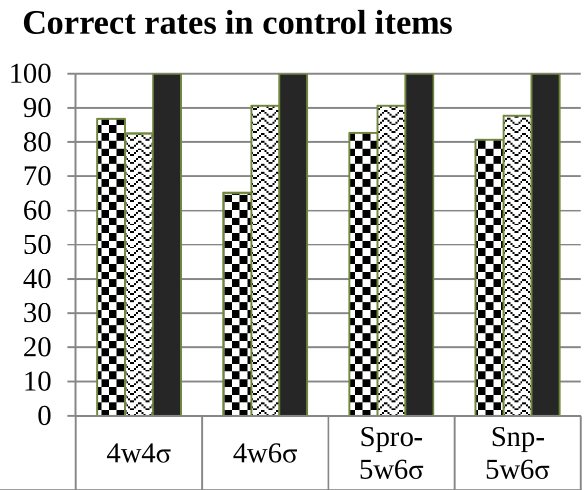
Table 7.15 shows the correct rates for control items.

Table 7.15 Study 5: Correct rates (%) in control items

	4w4σ	**4w6σ**	**PRO-5w6σ**	**NP-5w6σ**
4-year-olds	86.84 (33/38)	65.22 (15/23)	82.76 (24/29)	80.77 (21/26)
6-year-olds	82.61 (38/46)	90.70 (39/43)	90.70 (39/43)	87.80 (36/41)
adults	100 (27/27)	100 (26/26)	100 (28/28)	100 (28/28)

Figure 7.9 shows the correct rates for the control items by age in Study 5 RTR. Adult consistently had a 100% correct rate for all four sentence types as they did in Study 4 NSR. Their performance was not affect by the manipulation of the tones in the control items. The correct rates of the control items for both child groups dropped, however.

Figure 7.9 Study 5: Correct rates in control items by age



	4w4σ	4w6σ	Spro-5w6σ	Snp-5w6σ
4-year-olds	86.84	65.22	82.76	80.77
6-year-olds	82.61	90.70	90.70	87.80
adults	100	100	100	100

The two-proportion *z-test* (α = .05, two-tailed) was used to test whether there was a significant difference between any two age groups. The Null hypothesis is that there is no significant difference between any of the two age groups in 4w4σ, 4w6σ, PRO-5w6σ, and NP-5w6σ sentences.

4w4σ

No two age groups are significantly different: 4-year-olds and 6-year-olds (p = .818), 4-year-olds and adults (p = .136), 6-year-olds = adults are not statistically different (p = .056).

4w6σ

Four-year-olds are significantly differently from 6-year-olds (p = .026) and adults (p = .004). Six-year-olds and adults are not statistically different (p = .284).

PRO-5w6σ

No two age groups are found to differ significantly: 4-year-olds and 6-year-olds (p = .524), 4-year-olds and adults (p = .080), 6-year-olds and adults (p = .284).

NP-5w6σ

Four-year-olds are significantly differently from 6-year-olds (*p* = .664) and adults (*p* = .049). Six-year-olds and adults are not statistically different (*p* = .148).

7.3.4 Results and discussion for test items in RTR

Table 7.16 and Table 7.17 summarize by coding categories the number of excluded data from "4w4σ and 4w6σ test items" and "PRO-5w6σ and NP-5w6σ test items" respectively.

Table 7.16 Study 5: Test items (4w4σ and 4w6σ)— data excluded from the analysis

	4w4σ: three T3*					**4w4σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	0	7	0	0	7	0	6	0	0	6
6	0	7	0	0	7	0	3	0	0	3
A	0	1	0	0	1	0	1	0	0	1
	4w6σ: three T3*					**4w6σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	1	20	0	0	21	1	15	0	0	16
6	0	13	0	0	13	0	5	0	0	5
A	0	1	0	0	1	0	2	0	0	2

Table 7.17 Study 5: Test items (PRO-5w6σ and NP-5w6σ)— data excluded from the analysis

	PRO-5w6σ: three T3*					**PRO-5w6σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	1	19	0	0	20	1	24	1	0	26
6	1	3	0	0	4	1	7	2	0	10
A	0	1	0	0	1	0	0	0	0	0
	NP-5w6σ: three T3*					**NP-5w6σ: all T3***				
	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total	No answer	Non-target	Pauses	Missing sylla-bles	Exclu-ded total
4	1	10	0	1	12	3	11	0	2	16
6	0	5	1	0	6	3	4	0	0	7
A	0	0	0	0	0	0	0	0	0	0

The next subsections present the statistical results and discussion for two sentence pairs, *4w4σ and 4w6σ* and *PRO-5w6σ and NP-5w6σ.*

7.3.4.1 Results for 4w4σ and 4w6σ items

Table 7.18 shows number of items by pattern in 4w4σ and 4w6σ test items.

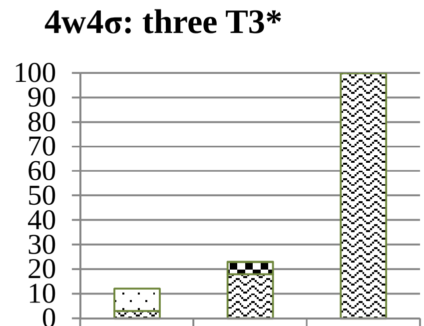
Table 7.18 Study 5: Number of items by pattern in 4w4σ and 4w6σ test items

	4w4σ: three T3*				**4w4σ: all T3***			
	Subject-predicate pattern	Alter-nating pattern	Opt Rule pattern	total	Subject-predicate pattern	Alter-nating pattern	Opt Rule pattern	total
4	0	3	1	33	0	4	0	34
6	2	0	7	39	2	11	0	43
adults	0	0	27	27	0	24	3	27
	4w6σ: three T3*				**4w6σ: all T3***			
	Subject-predicate pattern	Alter-nating pattern	Opt Rule pattern	total	Subject-predicate pattern	Alter-nating pattern	Opt Rule pattern	total
4	0	1	1	19	0	4	0	24
6	0	12	3	33	0	15	2	41
adults	0	22	4	27	0	26	0	26

(4= 4-year-olds, 6= 6-year-olds; the number of individual patterns + number of errors = total.)

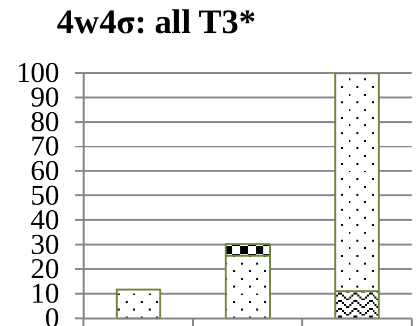
Figure 7.10 Study 5: Correct rates in *4w4σ* and *4w6σ* sentences

a.



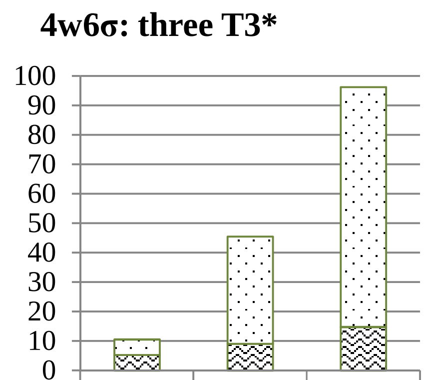
	4-year-olds	6-year-olds	adults
Subj-pred	0	5.13	0
Alternating	9.09	0	0
Opt rule	3.03	17.95	100

b.



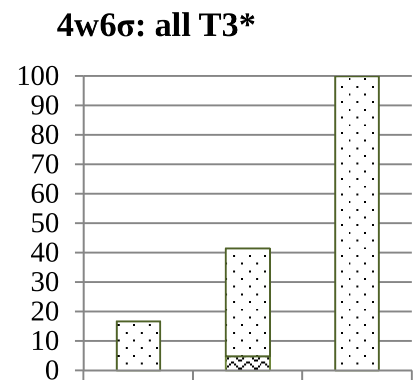
	4-year-olds	6-year-olds	adults
Subj-pred	0	4.65	0
Alternating	11.76	25.58	88.89
Opt rule	0	0	11.11

c.



	4-year-olds	6-year-olds	adults
Alternating	5.26	36.36	81.48
Opt rule	5.26	9.09	14.81

d.



	4-year-olds	6-year-olds	adults
Alternating	16.67	36.59	100
Opt rule	0	4.88	0

Figure 7.10 shows the correct rates and distribution of the T3S patterns in 4w4σ and 4w6σ by age. For the 4-syllable items, the opt rule pattern is the preferred pattern in the three-T3 items, whereas the alternating pattern is the preferred pattern in the all-T3 items. For the 4w6σ items, both three T3* and all T3*, the alternating pattern is the dominant pattern in all age groups. Even though 4-year-olds and 6-year-olds are far from adult-like, a developmental pattern shows.

A logistic regression analysis was performed. The results show that the independent variables (age, number of adjacent T3*, and number of syllables) as a set are statistically significant (*chi square* = 332.374, $p < .001$ with $df = 15$). This indicates that the independent variables as a set reliably distinguished among the response patterns.

The opt rule pattern

The Wald criterion shows the number of T3* (*OR* = 15.267, $p < .001$) and the number of syllables (*OR* = 4.308, $p = .006$) are statistically significant for the opt rule pattern relative to errors. The OR values show that, everything else held constant, three-T3 items are roughly 15 times more likely than all-T3 items, and 4w4σ items are 4 times more likely than 4w6σ items to have the opt rule pattern. Both 4-year-olds and 6-year-olds are significantly different from adults (4-year-olds: *OR* = .000, $p < .001$, 6-year-olds: *OR* = .003, $p < .001$).

The alternating pattern

The number of T3* (*OR* = .429, $p = .014$) and the number of syllables (*OR* = .296, $p < .001$) are statistically significant for the alternating pattern relative to errors. The OR values show that, everything else held constant, all-T3 items are roughly two times more likely than three-T3 items to have the alternating pattern, and 4w6σ items are three times more likely than 4w4σ items to have the alternating pattern. Both 4-year-olds and 6-year-olds are significantly different from adults (4-year-olds: *OR* = .002, $p < .001$, 6-year-olds: *OR* = .005, $p < .001$).

The subject-predicate pattern

For the subject-predicate pattern relative to errors, no independent variables, including the number of T3* (*OR* = .1.217, $p = .850$), number of syllables (*OR* = 2.173E7, $p = .995$), and age (*OR* = .015, $p = .999$), are found to be statistically significant.

7.3.4.2 Discussion for 4w4σ and 4w6σ

Both 4-year-olds and 6-year-olds did not show very much difference in the 4w4σ items and 4w6σ items. The number of T3* and the length of sentences did not have an effect. The results do not support the complexity Hypothesis (H_{1a}) Number of adjacent T3* and (H_{1b}) Length of sentences.

Both 4-year-olds' and 6-year-olds' correct rates were very low, although the patterns the 6-year-olds favor reflect those of the adults. In the 4w6σ sentences, the alternating pattern which gives a good syntax-prosody mapping, is used by most adults. Most 6-year-olds used the alternating pattern as well. The results support the hypothesis Syntax-prosody Alignment Hypothesis (H_2)— Prosodic boundaries tend to match the major syntactic boundaries.

A lot of errors in children were due to the misperception of the auxiliary verb *xiang* 'want' as a T4, instead of a T3. *Xiang* in T4 can be "is like," and when put in our experimental sentences, they make sense, too. For instance, the original intended meaning of "You want to buy flowers" is changed to "It's like you are buying flowers." The children's correct rates might have been understated because of this error due to the misperception (4-year-olds: 63.63% (21/33) and 6-year-olds: 43.59% (17/39).) However, no such errors were found in adults.

For three-T3 4w4σ items, all adults used the opt rule pattern, whereas both child groups had another pattern in addition to the opt rule pattern (4-year-olds: the alternating pattern and 6-year-olds: the subject-predicate pattern.)

For all-T3 4w4σ items in RTR, the dominant pattern across all groups is the alternating pattern. In adults' responses the alternating pattern is used 88.89% of the time while the large domain pattern was used only 11.11% of the time. Compare this with all-T3 4w4σ items in NSR where adults used 45% of the alternating pattern and 55% of the opt rule pattern, it shows that adults favor the alternating pattern when they were not provided any pattern for the repetition. The lower percentage of the use of the alternating pattern in NSR was due to the fact that about half of the adults repeated with the pattern they heard. Since in Study 5, participants were provided with the underlying tones, not one of the surface patterns, the distribution of surface patterns in this study supposedly reflects more truthfully the T3S patterns the participants would use in reality. If this is true, in all-T3 4w4σ items, adults tend to use the alternating pattern far more than the opt rule pattern. Given that a 4-syllable domain is not very large and should be relatively easy for adults, adults' preference for two disyllabic feet for the sentence is actually very interesting. When we also looked at all-T3 4w6σ items, the alternating pattern was used by adults 100% of the time. In addition, it is also the dominant pattern in 4-year-olds and 6-year-olds. The alternating parsing strategy appears to be a robust parsing strategy. Furthermore, the use of alternating parsing in the 4w6σ items gives a good mapping between syntax and prosody as in (8), which supports our syntax-prosody alignment hypothesis.

(12)	[[haima]	[xiang	[zhao	[shuimu]]]]	
	seahorse	want	look for	jellyfish	'Seahorse wants to look for Jellyfish.'
	33	3	3	33	UT
	(**2**3)	3	3	(**2**3)	Word: two disyllabic feet, T3S
	(23)	(**2**	3)	(23)	Phrase: disyllabic foot, T3S; ST1
	(2**2**	**2**	3)	(23)	larger domain in fast speech; ST2

7.3.4.3 Results for PRO-5w6σ and NP-5w6σ items

Table 7.19 shows number of items by pattern in PRO-5w6σ and NP-5w6σ test items, and Figure 7.11 shows correct rates in *PRO-5w6σ* and *NP-5w6σ* sentences.

Table 7.19 Study 5: Number of items by pattern in PRO-5w6σ and NP-5w6σ test items

	PRO-5w6σ: three T3*					**PRO-5w6σ: all T3***				
	Subj-pred pattern	Alter-nating pattern	Ternary pattern	Opt rule pattern	to-tal	Subj-pred pattern	Alter-nating pattern	Ternary pattern	Opt rule pattern	to-tal
4	1	0	0	0	20	0	1	0	0	14
6	1	0	20	0	42	3	8	7	0	36
adults	1	0	25	0	27	2	6	11	5	28
	NP-*5w6σ*: three T3*					**NP-*5w6σ*: all T3***				
	Subj-pred pattern	Alter-nating pattern	Ternary pattern	Opt rule pattern	to-tal	Subj-pred pattern	Alter-nating pattern	Ternary pattern	Opt rule pattern	to-tal
4	1	0	1	0	28	2	0	1	0	24
6	8	0	21	0	40	9	2	11	3	39
adults	10	0	18	0	28	7	0	16	5	28

(4= 4-year-olds, 6= 6-year-olds; the numbers of individual patterns + number of errors = total.)

Figure 7.11 Study 5: Correct rates in *PRO-5w6σ* and *NP-5w6σ* sentences

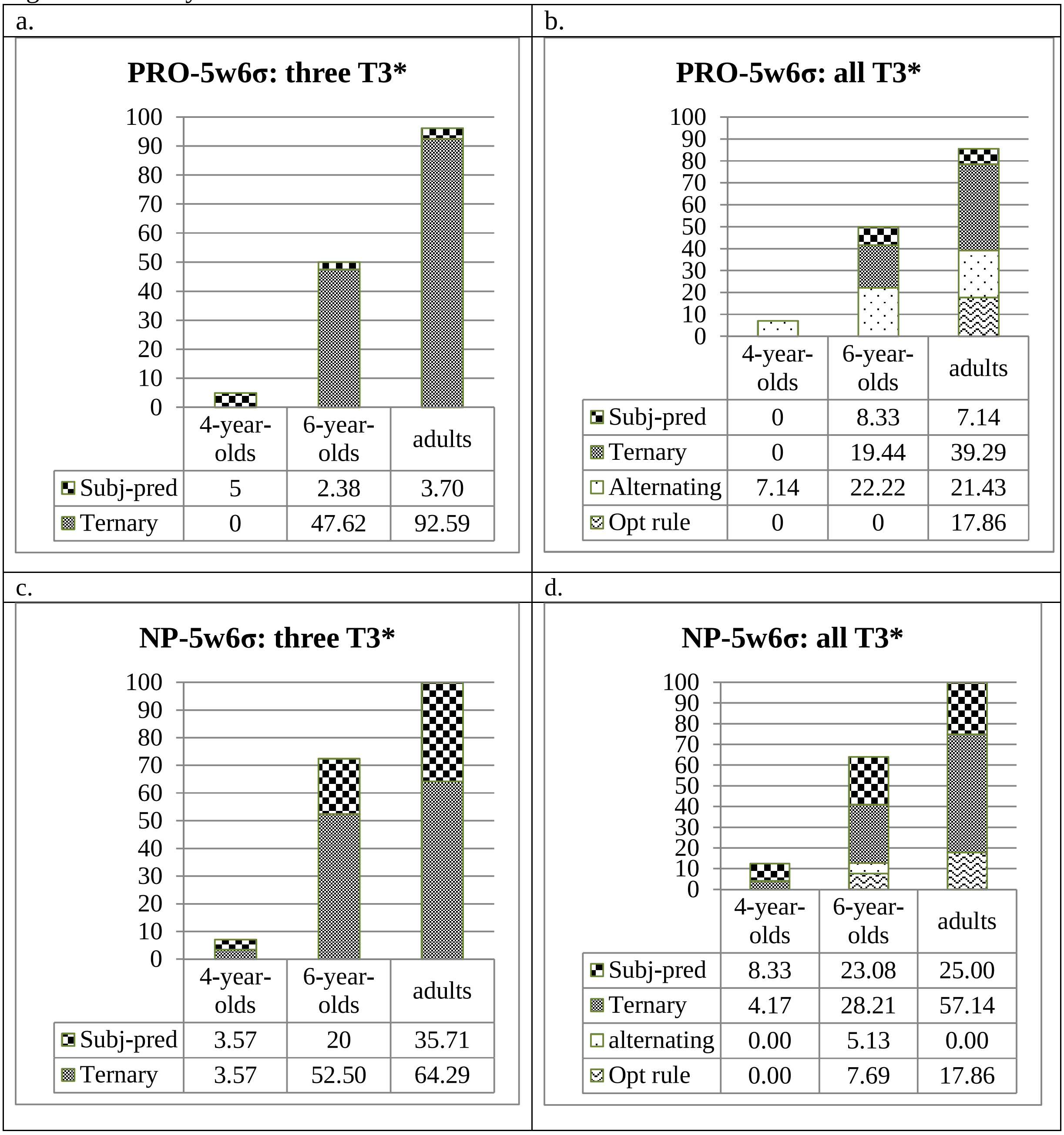


Figure 7.11 (a) – (d) show the correct rates and distribution of T3S patterns in the PRO-5w6σ and the NP-5w6σ items by age. We can see that the subject-predicate pattern is higher in frequency in the NP-5w6σ items than in the PRO-5w6σ items. In the PRO-5w6σ items and the NP-5w6σ items, while 6-year-olds had the patterns attested in adults (except for the opt rule

pattern in all-T3 PRO-5w6σ items), 4-year-olds did not. They also had extremely low correct rates.

Both 6-year-olds and adults did better in the NP-5w6σ items than in the PRO-5w6σ items. The difference is minimal for 4-year-olds, however. Adults did perfectly in the NP-5w6σ items (three-T3 and all-T3), but had a slightly lower correct rate of 96.29% in three-T3 PRO-5w6σ items and a 85.72% correct rate in all-T3 PRO-5w6σ items. For 6-year-olds, the correct rates for the NP-5w6σ items were about 70% and 60% for three-T3 and all-T3 conditions respectively, and the correct rate was about 50% for the PRO-5w6σ items.

A logistic regression analysis was performed. The results show that the independent variables (age, number of adjacent T3*, and subject NP vs. subject pronoun) as a set are statistically significant (*chi square* = 291.799, $p < .001$ with $df = 20$). This indicates that the independent variables as a set reliably distinguished among the response patterns.

The opt rule pattern

The Wald criterion shows the number of T3* (*OR* = 1.746E-9, $p = .998$) and the noun-pronoun distinction (*OR* = .272, $p = .058$) are not found to be statistically significant for the opt rule pattern relative to errors. Six-year-olds are significantly different from adults, but 4-year-olds are not (4-year-olds: *OR* = 9.749E-11, $p =.998$, 6-year-olds: *OR* = .021, $p < .001$).

The alternating pattern

For the alternating pattern relative to errors, the noun-pronoun distinction (*OR* = 5.021, $P = .045$) is statistically significant, but not the number of T3* (*OR* = 1.312E-9, $P = .998$). Both 4-year-olds and 6-year-olds are significantly different from adults (4-year-olds: *OR* = .024, $P = .002$, 6-year-olds: *OR* = .184, $P = .021$).

The ternary pattern

For the ternary pattern relative to errors, both the number of T3* and the noun-pronoun distinction are found to be statistically significant (*OR* = 2.361, *p* = .010 and *OR* = .419, *p* = .010 respectively). Both 4-year-olds and 6-year-olds are significantly different from adults (4-year-olds: *OR* = .001, *p < .001*, 6-year-olds: *OR* = .056, *p < .001*).

The subject-predicate pattern

For the subject-predicate pattern relative to errors, the noun-pronoun distinction (*OR* = .108, *p < .001*) is statistically significant, but the number of T3* is not (*OR* = 1.247, *p* = .586). Both 4-year-olds and 6-year-olds are significantly different from adults (4-year-olds: *OR* = .006, *p < .001*, 6-year-olds: *OR* = .063, *p < .001*).

7.3.4.4 Discussion for PRO-5w6σ and NP-5w6σ

Level of difficulty

In PRO-5w6σ and NP-5w6σ sentences, 4-year-olds' correct rates are under 15%. Three-T3* or all-T3* in these items did not make a difference to them. For 6-year-olds, all-T3 items were more difficult than three-T3 items in NP-5w6σ sentences; nevertheless, the effect of the number of T3* did not show in the PRO-5w6σ sentences. H_{1a}— Number of adjacent T3*: The more adjacent T3*, the more complex the task— cannot be confirmed or rejected.

Regarding syntax-prosody alignment, the use of the subject-predicate pattern in the NP-5w6σ items are between 25% - 35% in 6-year-olds and adults, but only under 10% in the PRO-5w6σ items. The results lend support to the Syntax-prosody Alignment Hypothesis (H_2)— Prosodic boundaries tend to match the major syntactic boundaries. Similar to the results in Study NSR, the ternary pattern was used more frequently than the subject-predicate pattern.

The observation that the subject pro appeared to be more difficult than subject NP was a somewhat surprising result. Even though we expected the sentences with subject pro and subject NP to have different parsing patterns because of their prosodic differences, we did not expect one to be more difficult than the other.

The patterns attested in PRO-5w6σ and NP-5w6σ items in Study 5 RTR echo those attested in Study NSR. A sharp contrast between the use of the alternating pattern for PRO-5w6σ (Figure 7.11 (b)) and the use of the subject-predicate pattern for NP-5w6σ (Figure 7.11 (d)) is not unfamiliar— we have seen that in Study 4. Although the correct rates dropped dramatically in Study 5, the T3S variability remained the same in participants' responses.

The subject-predicate pattern

T3S cannot be done without syntax, and T3S cannot be done without prosody, either. The only minor difference between PRO-5w6σ and NP-5w6σ is the distinction between pro and NP in the subject position, which was the source of the shift in the distribution of the parsing patterns. The subject-predicate pattern occurred much more frequently in the NP-5w6σ items than in the PRO-5w6σ items. Again, since a subject NP, being a full noun, can stand alone better in the subject-predicate pattern.

Unlike in Study 4 where the subject-predicate pattern was not attested in the PRO-5w6σ (both three-T3 and all-T3) items, we found a small portion of responses with this pattern in Study 5 RTR. In these cases where children and adults used the subject-predicate pattern in PRO-5w6σ sentences, it indicates that for these speakers, the subject pronoun could stand as a degenerate foot despite its weak prosodic nature. For them, perhaps maintaining the subject-predicate boundary was more important, even when the subject was a monosyllabic pronoun.

We see that 6-year-olds' patterns reflect those of adults, although they were still far from adult-like accuracy in T3S application. All age groups did better in the NP-5w6σ items than in the PRO-5w6σ items.

The alternating pattern

The alternating pattern was attested in all-T3 PRO-5w6σ items in three age groups, the same as the finding in Study 4. Nevertheless, the alternating pattern showed up in 6-year-olds' production in the NP-5w6σ items, though it was only at a very low frequency, 5.13%.

The ternary pattern

The ternary pattern was attested in the PRO-5w6σ and the NP-5w6σ (both three-T3 and all-T3) items. Six-year-olds and adults have a fairly high proportion of this pattern. Four-year-olds were very limited in the use of patterns seen in 6-year-olds and adults. A 6-syllable sentence with three T3* or six T3* was probably too heavy the workload for 4-year-olds. Even though the length of six syllables is manageable at their age (since they did well in the control items), adding the processing load of T3S clearly add to the workload.

The opt rule pattern

The opt rule pattern was used by the adults only in all-T3 PRO-5w6σ items, (4- and 6-year-olds: 0%, adults: 17.86%) and by both 6-year-olds and adults in all-T3 NP-5w6σ items (4-year-olds: 0%, 6-year-olds: 7.69%, and adults: 17.86%). Overall, this pattern is lower in frequency comparing to other patterns. If we compare these results to the results we obtained in Study 4 NSR, the picture was very different, with all three age groups using the opt rule pattern, and with the 4-year-olds using it the most (all-T3 PRO-5w6σ items: 4-year-olds: 58.82%, 6-year-olds: 30%, and adults: 35%; all-T3 NP-5w6σ items: 4-year-olds: 58.82%, 6-year-olds: 50%, and adults: 26.32%). The comparison reveals the following:

It was not that 4-year-olds were unable to produce the opt rule pattern. We saw in Study 4 NSR that they were the most "willing" group to repeat the sentence with this opt rule pattern they heard. The fact that such pattern was not attested in 4-year-olds in Study 5 may indicate that the high percentage of the larger domain parsing was mere imitated repetition of what they heard.

For 6-year-olds, the much higher percentage of the larger domain parsing in NSR than in RTR may be, too, imitated repetition. However, the very small percentage of 7.69% that showed in all-T3 NP-5w6σ items in RTR provides some evidence that at least some 6-year-olds had the opt rule pattern in place. As they heard underlying tones and could actively applied T3S, the presence of the pattern in these children's production was a piece of evidence that the pattern is in place. Also, like adults, this pattern was the least frequent pattern in 6-year-olds.

In all-T3 PRO-5w6σ and all-T3 NP-5w6σ items, adults showed consistency in what patterns they favored or disfavored. In RTR, the opt rule pattern was the least used (all-T3 PRO-5w6σ: 17.86%, all-T3 NP-5w6σ: 17.86%), and in NSR where they heard this pattern, adults repeat with it 35% and 26.32% of the time in all-T3 PRO-5w6σ and all-T3 NP-5w6σ items respectively. Not surprisingly, the use of the pattern is higher in frequency when they heard this exact pattern in NSR. Taken the results in NSR and in RTR, we see that, in these 6-syllable all-T3 sentences, regardless of the subject being an NP or a pro, adults chose other patterns over the opt rule pattern.

7.4 General Discussion

Two experiments: NSR and RTR

It may be tempting to think that since the participants heard something totally strange in RTR, there is a chance that their responses in RTR are not normal. We found that the patterns that were attested in NSR were also attested in RTR. Even though the designs differ in terms of whether or not T3S is present, the T3S variability remains the same in subjects' responses, children and adults. T3S patterns in NSR and RTR were very fairly consistent, although it was not surprising that there was less variability in NSR than in RTR, given that participants heard one surface pattern, and they could simply repeat with the same pattern, without working out a different pattern themselves. Another way to look at this is that, the subjects were less constrained in giving whatever T3S pattern they had in RTR, whereas in NSR they might have been "more constrained" to the pattern they heard, instead of using their own preferred pattern.

Development in the acquisition of T3S

Between the two experiments, NSR and RTR, we had expected that NSR would be easier. As expected, subjects did better in NSR than in RTR since the former did not require T3S applications, but the latter did. The fact that both child groups performed well in the control items in both studies shows that the length of the sentences did not present a challenge to them, nor did the structures of the sentences. Both child groups also did well in the test items in NSR, which shows that they had no problem repeating a sentence where T3S had been applied correctly. The dramatic drop in children's correct rates in RTR was because of the T3S application that was required. Four-year-olds had a lot of difficulties in the RTR items and were far from adult-like. Six-year-olds differ from 4-year-olds not only in the much higher correct rates in T3S applications, but also in their increasing awareness and use of multiple T3S surface patterns and how the distribution of T3S patterns reflect those of adults. The percentages of the use of the correct T3S patterns in 6-year-olds strongly indicate that they are moving toward to be more like what adults do in T3S application. This supports that T3S develops over a period of time, rather than being acquired instantaneously.

The complexity issue: Number of adjacent T3 and the length of sentence*

In NSR, the length of sentences (4w4σ and 4w6σ) had an effect on 4-year-olds' and 6-year-olds' correct rates. They did better in the 4w4σ sentence than in the 4w6σ sentences. However, in RTR, such contrast did not exist. It could be that the T3S workload was so heavy in RTR that whether children were to apply T3S in a 4w4σ sentence or in a 4w6σ sentence did not make very much difference.

Regarding the number of adjacent T3* in a sentence, overall both child groups did better in the three-T3 items than in the all-T3 items in NSR. The contrast did not exist in RTR, just as what we saw in the case with the number of syllables. Fewer adjacent T3* and fewer syllables in the sentence did not result in higher correct rates in children's responses in RTR, though they did in NSR.

Adults correct rates remain consistently high (100% or close to 100% in most items in both NSR and RTR), indicating that the differences in the number of adjacent T3* and the length of sentence did not have an effect on their responses in both studies.

The alternating pattern and the subject-predicate pattern

The alternating pattern in the NP-5w6σ sentences and the subject-predicate pattern in the PRO-5w6σ sentences may be grammatical to some people, but marginal/ungrammatical to other people. Whether or not the intonational break and/or emphasis/focus plays a role in the subject predicate pattern requires further investigation. In addition, the directionality of leftward or rightward incorporation of an unparsed syllable at the phrase level will need to be examined. Whether or not these patterns are specific to Mandarin speakers in Taiwan is unknown. Data from Mandarin speakers of other regions, when collected, will enable us to examine whether or not some T3S patterns are used across the regions or if they are typically used by Taiwan Mandarin speakers.

The distinction between subject pronoun and subject NP

While a subject NP can stand alone in its own domain, a subject pronoun does not tend to. As a clitic, it is prone to cliticize to a host to form a foot. Because a subject NP can stand alone, we see higher frequency of the subject-predicate pattern in the subject-NP sentences than in the subject-pro sentences. This shows that the prosodic properties of the two are very different; otherwise, we would not have seen the shifts in the percentages of the T3S surface patterns.

Adults' relatively lower correct rate at approximately 85% in all-T3 PRO-5w6σ items in both NSR and RTR is quite telling. Note that adults did perfectly (100% correct) in all-T3 NP-5w6σ items in both NSR and RTR, and these items differ only in the subject being an NP, rather than a pro. The pronoun is clearly the source contributing to the lower correct rate in adults in all-T3 PRO-5w6σ items. There is only one error pattern in adults *(T2T3T3) (T3T2T3), although in children in addition to this error pattern, a common error is *(T3T4T3)(T3T2T3) as well as missing one or two of the syllables.

It is intriguing that 6-year-olds' correct rates in all-T3 PRO-5w6σ items were lower than those in all-T3 NP-5w6σ items in both NSR and RTR. Not only do the surface patterns 6-year-olds produced mirror those adults produced, in the proportion of each pattern and in the comparison between all-T3 NP-5w6σ and all-T3 PRO-5w6σ items as mentioned above, we see 6-year-olds' behavior of T3S application approximating that of adults.

7.5 Conclusions

In this chapter, two experimental studies of T3S at the sentence level, NSR and RTR, were presented. As expected, participants did better in NSR (natural speech without tonal manipulations) than in RTR (with tonal manipulations) because of the lesser workload in the former. We conclude this chapter with a summary of the findings of the two studies.

In Study 4 NSR, the results show an effect of number of adjacent T3* in children's correct rates. Complexity Hypothesis (H_{1a})— Number of adjacent T3*— is supported. Regarding the length of sentences, both 4-year-olds and 6-year-olds did better in 4w4σ sentences than in the 4w6σ sentences. Complexity Hypothesis (H_{1b})— Length of sentences—is supported.

For the PRO-5w6σ and NP-5w6σ items, the number of T3* did not have much effect, and the results do not provide strong evidence to support (H_{1a})— Number of adjacent T3*.

The use of the alternating pattern which gives a good mapping between syntax and prosody in 4w6σ sentences increases with age. The subject-predicate pattern was used by 6-year-olds and adults in the NP-5w6σ items, but not in the PRO-5w6σ items. Taken together, the use of these patterns produces a good mapping between syntax and prosody, supporting the Syntax-prosody Alignment Hypothesis (H_2).

In Study 5 RTR, the Complexity Hypothesis cannot be confirmed or rejected because 4-year-olds' correct rates did not show a difference in the number of T3* and number of syllables and although 6-year-olds did better in three-T3 items than in all-T3 items in NP-5w6σ sentences, the opposite was found in the PRO-5w6σ sentences. Similar to what was found in Study 4 NSR, both adults and 6-year-olds use the subject-predicate pattern in the NP-5w6σ items (25% - 35%), but only under 10% in the PRO-5w6σ items. These results lend support to the Syntax-prosody Alignment Hypothesis (H_2).

In the beginning of the chapter, research questions posed include the following:

1. Does complexity—the number of adjacent T3*, the length of sentences (total number of syllables)— play a role in T3S application?

In some cases, complexity appears to have an effect (especially in NSR), but in other cases, the effect does not exist as in RTR. This could be due to the difficulty of the task in RTR.

2. How does mapping between syntax and prosody affect T3S application in children and adults?

There is no clear evidence that shows that 4-year-olds were aware of the mapping between syntax and prosody. However, 6-year-olds show awareness of the mapping of syntax and prosody. Like adults, they used the alternating pattern in 4w6σ sentences and the subject-predicate pattern in the NP-5w6σ items which give a good mapping between syntax and prosody. Although 6-year-olds do not yet have adult-like accuracy, they mirror what adults do in producing a variety of T3S patterns, and often with similar frequency.

Development of T3S acquisition

Regarding development of T3S acquisition, the findings obtained are summarized as follows:

Overall, the correct rates in 6-year-olds are higher than 4-year-olds. Though their performance was not always adult-like, the developmental trend was evident.

Six-year-olds have more T3S variability than 4-year-olds. Unlike 4-year-olds, they had all the surface patterns that are attested in the adults. This suggests that for 6-year-olds, all the T3S patterns were in place, though the frequency of the patterns might differ from those in adults.

A very crucial piece of information that should not be overlooked is that the increase or decrease in the usage of particular patterns (comparing to 4-year-olds) tells us that 6-year-olds are on the right track— moving toward the adult-like preference in the T3S surface pattern. In many cases, the proportions of the T3S surface patterns in 6-year-olds and in adults were strikingly similar. We have also seen that what appears to be more difficult for adults (in the case of all-T3 PRO-5w6σ items) was also more difficult for the 6-year-olds.

Distinction between subject NP and subject pronoun

In the beginning of the chapter, one of the research questions posed was, do pronouns behave differently from NPs in T3S application? The results of the two studies show that the prosodic difference between a pro and an NP affects speakers' preferences in how they set up the domains for T3S application, and consequently, the surface patterns used for the sentences containing a subject NP or a subject pro exhibit some very interesting distinction. While a subject NP can stand alone and give a subject-predicate pattern, it is far less frequent that a subject pronoun also does the same. As a clitic, a pronoun is weak prosodically, and is prone to form a prosodic domain with another syllable(s), and therefore, is less likely to give a subject-predicate pattern.

Lastly, application of T3S is highly complicated. Syntactic and prosodic factors, the number of adjacent T3*, the length of sentence, the interface of syntax and prosody—alignment between syntax and prosody—all play a role in how prosodic domains are parsed. There is still a lot to be discovered. The experiments presented in this chapter did not support the findings of earlier studies that T3S is mastered early and is almost error-free (Jeng 1979; Jeng 1985; Li & Thompson 1977; Zhu & Dodd 2000). At age 4, children do not have all the T3S patterns that adults have. At age six, children have all the T3S surface patterns attested in the adults, and the frequency of the surface patterns in 6-year-olds is becoming more like that of adults. However, they do not yet have adult-like accuracy. Future studies can investigate even older children and find out at what age children become adult-like in their application of T3S in a more complicated task such as that in RTR.

CHAPTER 8

CONCLUSION

8.0 Introduction

The purpose of the dissertation was to examine how children acquire the syntax-dependent phonological rule Tone 3 Sandhi. The whole process of setting up prosodic domains within which T3S applies is complicated because cyclic and non-cyclic parsing strategies are used at different levels, and the integration of the two strategies is necessary at the sentence level. In addition, there are optional rules, which create T3S variation. Specifically, we ask if T3S is mastered early in children's acquisition. One of the challenges was that there was no previous work targeting T3S we could learn from and compare our findings to. There was also not much experimental data on T3S in adults, which is relevant and crucial to acquisition studies of T3S as adult speech is the language input children receive. Different parsing strategies as well as optional T3S (i.e. T3S is optional across domains and the fast speech rule) result in T3S variants whose frequency is still largely unknown. Given what we know from the existing T3S theories and what needs to be learned in children's acquisition of T3S, a series of five studies were conducted, targeting to answer specific research questions.

The overall primary goal of the dissertation was to investigate children's acquisition of T3S in various contexts. More specifically, we examined children's ability of using a non-cyclic strategy in flat structures and a cyclic strategy in NPs as well as the integration of cyclic and non-cyclic strategies in sentences.

In the beginning of the dissertation, questions posed include the following. The results of the studies answer some, but not all of the questions.

1. Do children know both cyclic and non-cyclic strategies?

   The results of the studies show that they do. They could apply T3S non-cyclically in flat structures and cyclically in NPs.

2. Can children integrate the subject and the VP into a domain where T3S applies?

   Yes, they do. In Study 4 and Study 5, a monosyllabic subject form a domain with the following syllables, creating the alternating pattern or the ternary pattern.

3. In contexts where there are internal structures, are children aware of syntax and refer to syntax in their application of T3S? What do they do in their application of T3S in the more complex structures?

   Although they are aware of syntax and are able to apply T3S bottom up, when the structure becomes more complex (such as in the mixed-branching NPs), they sometimes default to the prosody-based strategy and apply T3S from left to right.

4. When the cyclic parse and the non-cyclic parse mismatch, what do children do?

   In the mixed-branching NPs [σ[[σσ]σ]] where the cyclic parse and the non-cyclic parse mismatch, they sometimes used the non-cyclic strategy without referring to syntax. Therefore, they sometimes produced the non-cyclic parsing (σσ)(σσ), instead of the cyclic parsing σ(σσ)σ→ σ(σσσ)→ (σσσσ). The former gives the surface pattern of (**T2**T3)(**T2**T3) whereas the latter gives the surface pattern of (T3**T2T2**T3). In short, in the more complex structures, such as the mixed-branching structure, children sometimes ignored syntax and used a prosodic parsing strategy, although a syntactic parsing strategy is required in this case.

5. How do children go from zero T3S to adult-like T3S, and whether or not T3S is acquired early as indicated in the literature? If not, what does the developmental pattern look like?

The results in the studies do not support that all the "ingredients" in T3S are mastered early. Children may have the knowledge of the rule T3T3→ **T2**T3 at an early age; however, applying T3S in an adult-like fashion takes years. They have to learn to use the cyclic and non-cyclic strategies, to integrate them, to know how to incorporate an unparsed syllable, to learn the optional rules, and to know the distinction of NPs and pronouns, etc. Younger children have difficulties, and even the oldest age group, 6-year-olds, did not have adult-like mastery of T3S. A clear pattern does show that they were aware of the aspect such as the distinction between an NP and a pronoun in building prosodic domains. A very interesting finding is that even the frequency of the T3S patterns 6-year-olds produce resembles the frequency of T3S patterns produced by adults.

6. Do younger children and older children behave the same or different?

   In some ways, they behave alike, such as they both under-apply and over-apply T3S in some cases. In other ways, older children appear to make a distinction between NP and pronoun that younger children are unable to do. In Study 2, flat structures, a common error pattern that was found in 5-year-olds was not found in 3-year-olds. The error pattern results from alternating between T2 and T3 (***T2**T3**T2**T3**T2**). This may indicate that 5-year-olds is acquiring the rhythm (grouping two syllables into a disyllabic foot).

7. Does children's variability in T3S reflect adults'?

   Older children's variability reflects adults' but younger children's variability is quite limited.

I summarize the hypotheses in Section 8.1. Section 8.2 sums up the findings of each study. Section 8.3 suggests what can be done in future research.

8.1 Hypotheses

Regarding the cyclic and non-cyclic strategies, we asked whether or not children can use the two strategies separately, and whether or not they can integrate the two in sentences. In addition, we asked what children do when a prosody-based non-cyclic parse does not match with a syntax-based cyclic parse. Can children integrate the subject and the VP into a domain where T3S applies? When a cyclic parse and a non-cyclic parse mismatch, what do children do? What do children do in in their application of T3S in the more complex structures?

Regarding development in T3S acquisition, we asked how children go from zero T3S to adult-like T3S, and whether or not T3S is acquired early as indicated in the literature. If not, what does the developmental pattern look like? Do younger children and older children behave the same or differently? Does children's variability in T3S reflect adults' variability? We put forward the following hypotheses.

(1) *Syntax-Prosody Alignment Hypothesis* (Gerken 1996)

T3S cases where a left-to-right parse and the phrase structure dependent parse produce the same results will cause less trouble than cases in which left to right foot building produces a different result than foot building based on the syntax. T3S cases where prosody and syntax mismatch should be more difficult than T3S cases where prosodic domains and syntactic domains align well.

(2) *Structural complexity Hypothesis*

T3S at the clausal level requires the integration of DPs and compounds into a larger prosodic unit. We hypothesize that children will take longer to perform at adult-level T3S at the sentence level than at the phrasal level. Particularly it may be difficult for children to integrate the subject and the VP into a domain where T3S can apply.

(3) *Variational Hypothesis* (Miller 2007; Pearl 2007; Yang 2002)

If there is more variation in particular types of structures in the input, these structures will provide evidence for more than one possible analysis, generating a certain amount of noise in the input. If the input is noisier we expect that children will require more data to converge into the adult language because certain outputs may not unambiguously support one or the other hypothesis.

In what follows, I evaluate how the overall findings obtained across these five studies confirm, reject, or are unable to confirm or reject the hypotheses.

We hypothesized that T3S cases whose prosodic parsing aligns with syntactic parsing is easier than T3S cases whose prosodic parsing and syntactic parsing do not align (the Syntax - Prosody Alignment Hypotheses). This is confirmed with the evidence from four-syllable R-branching NPs (**T2**T3**T2**T3) and M-branching NPs (T3**T2T2**T3). The former whose syntax and prosody align has overall higher correct rates than the latter whose syntax and prosody do not align. Furthermore, in Study 4 and Study 5, a monosyllabic NP is more easily parsed as a degenerate foot than a monosyllabic pronoun, appearing to be motivated by maintaining the subject-predicate boundary. Both adults and children (mostly 6-year-olds) used the subject-predicate pattern, which surfaced as a result of a better alignment between syntax and prosody. In addition, in the 4w6σ sentences, the alternating pattern was used most frequently across age groups, and this pattern matches the syntactic and prosodic parsing. These results lend support to the Syntax-Prosody Alignment Hypothesis.

Regarding structure complexity, in Study 4 NSR and Study 5 RTR, number of adjacent T3* and number of syllables in the sentences had an effect in Study 4 NSR, but the effect did not exist in Study 5 RTR which required children to actively apply T3S. Children did not perform very well in T3S in the sentences in Study 5 RTR. It is not clear if it was due to the structural complexity, variability of the input, or if the task was too hard for children. Children, however, were able to integrate the subject and the VP into a domain where T3S can apply. In Study 3 NPs, children did well in the three-syllable compound nouns. Although in general, children also did well 4-syllable right-branching NPs, they had a lot of difficulties in the mixed-branching NPs. Taken together, the Structural complexity Hypothesis cannot be confirmed or rejected at this point.

There is variability in children and adult production. The longer the string, the more possibilities of variation. Clearly, there is variability and this may cause delays in acquisition. Unfortunately we cannot determine if children's behavior in Study 5 RTR was due to the variability of the input or the complexity of the task and experimental sentences. It is clear that children (a) shift strategies, (b) do not have all the adult patterns, and (c) have non-adult patterns. These observations lead us to conclude that acquisition of T3S is a slow process.

Although T3S variability was found in children and adults and variability may delay children's acquisition of T3S, whether or not variability indeed cause the delay will require further investigation. The task in Study 5 RTR might have been too difficult for children. Study 3 where children were asked to build NPs might also have been beyond some children's capability, especially 3- and 4- year-olds. *Variational Hypothesis* cannot be confirmed at this time.

T3S variability creates ambiguity and although children have the knowledge of cyclic and non-cyclic strategies, and also know to integrate the two strategies at the sentence level, their accuracy is clearly not adult-like. Six-year-olds showed that they are on the right track and approximate to adult-like mastery of T3S in: (i) T3S variability and (ii) frequency of the T3S surface patterns. In short, T3S develops gradually, rather than instantaneously. For children to master T3S at the adult-like level, it takes years.

In the next section, major findings of these studies are summarized.

8.2 Summary and discussion of findings

The studies presented in this dissertation collected natural speech data, elicited production data, and repetition data from children and adults in Taiwan. The findings do not support that mastery of T3S is easy and perfect very early. The results of these studies indicate that although children know to change a T3 to a T2 (the youngest age group: 3-year-olds), children across age groups did not have adult-like accuracy. In what follows, I will summarize and briefly discuss the major findings of each study.

Study 1: Natural Speech

Variability of T3S was attested (resulting from application or non-application of T3S across prosodic domains). Examples of children's T3S application were provided.

We found that in children and adults, T3S applies more frequently within constituents than across constituents. While there is only a 8.77% difference in adults, there is a 29.36% difference in children. This may indicate that while adults can apply T3S in a fairly similar manner within constituents and across constituents, children differentiate the two more (applying T3S within constituents a lot more freely than across constituents).

Although T3S variability was attested in this study, the cases of two adjacent T3* is far greater than three, four, and five adjacent T3*. The number of cases where there were multiple T3* was very small; therefore, a more systematic analysis of T3S application in various syntactic contexts in children and adults could not be carried out.

Study 2: Flat structures

We tested production of two-, three-, and five-digits. While children did perfectly in the control items, 3-year-olds'correct rates in the test items are between 20% and 30%, and 5-year-olds, approximately between 60% and 70% in the test items, indicating that children still do not have adult-like mastery in flat structures (adults: 100% correct in controls and 97.50% in the test items). Under-application and over-application of T3S were attested in both child groups.

In two-, three-, and five-digit sequences, we saw binary parsing strategy and incorporation of the unparsed syllables (when applicable). An interesting finding was that in the sequence of five T3-digits, two patterns were predicted: (i) binary parsing followed by incorporation: (**T2T**3)(**T2T2**T3), and (ii) larger domain parsing: (**T2T2T2T2**T3), but an additional unpredicted pattern (**T2T2**T3)(**T2**T3) was attested in both child group as well as adults. Although low in percentage (below 10%), it is mysterious that children actually used this pattern, but they never used the predicted pattern (**T2**T3)(**T2T2**T3) which was attested only in adults (22.50%). In addition, the major pattern (**T2T2T2T2**T3), assumed to occur in fast speech by many studies, was produced in a normal speech setting.

Regarding children's errors, most common errors for 3-year-olds is over-application (***T2T2**, ***T2T2T2**, ***T2T2T2T2T2**), indicating that although they have the knowledge of changing a T3 to a T2 when followed by another T3, they have difficulty maintaining the underlying tone for the rightmost digit. Five-year-olds had a relatively smaller proportion of such error, and meanwhile another common error type emerged— (***T2**T3**T2** and ***T2**T3**T2**T3**T2**). This is a rather attractive finding which indicates a binary process. The tendency of the alternation of **T2**T3 in iterative binary feet is found in 5-year-olds, but not in 3-year-olds.

With respect to directionality, (**T2**T3)(**T2T2**T3) gives supporting evidence for a left-to-right parsing strategy. On the other hand, (**T2T2**T3)(**T2**T3) gives counter evidence. An explanation is that in flat structures, groupings of two or three, or even four digits, is robust (e.g. phone number reading), and since a three-syllable foot is only slightly larger than a disyllabic foot, these two types of parsing may both be accessible. In other words, children group two or three digits together at one time, rather than going through the process of binary parsing followed by incorporation of the unparsed syllable. Suggestions of how future work can further test parsing strategies are given in Section 8.4.

Study 3: NPs

The major goal in this study was to test the cyclic parsing strategy in three-syllable compound nouns ([σ[σσ]] and [[σσ]σ]) and four-syllable NPs (R-branching [σ[σ[σσ]]] and M-branching [σ[[σσ]σ]]). The findings confirm that children and adults refer to morphosyntax in building prosodic domains and T3S applies cyclically. While children did very well in three-syllable compounds their correct rates dropped in four-syllable NPs. R-branching NPs appeared easier to them than M-branching NPs, and crucially, all the mis-application errors in the M-branching NPs were *T2T3T2T3 (cyclic parsing predicts T3**T2T2**T3). Such error results from a left-to-right binary parsing. In other words, there is no reference to syntax in this pattern. The parsing strategy might have been shifted to the default prosodic parsing without reference to syntax in structurally complex cases. In fact, this error type was not only attested in both child groups, but also in adults.

Study 4: Natural Speech Repetition (NSR) and Study 5: Robot Talk Repetition (RTR)

In these two studies identical sentences were used, with the only difference that in NSR, one of the surface patterns served as the model, and in the RTR, the underlying tones served as the model. T3S variability was attested in both studies. Moreover, the patterns that appeared in NSR were also attested in RTR. More patterns were attested in RTR, which was not surprising as participants were in a sense "freer" to apply T3S rather than being affected by the model surface form. As the participants of the two studies were different, and the tasks were different, the fact that certain patterns were consistently used provides strong evidence that the surface patterns attested in the studies were legitimate, rather than accidental (as it might be tempting to think that may be the case in RTR due to the "unnaturalness or weirdness of the speech").

Overall, 4-year-olds did not perform well in the RTR where they were required to apply T3S in the RTR, and even 6-year-olds were not adult-like. The developmental patterns were clear. Unlike 4-year-olds, 6-year-olds have all the T3S patterns adults have, although their frequency of the T3S patterns sometimes differed from that of adults. By comparing the frequency of T3S patterns across age groups, a clear trend shows that 6-year-olds are approximating their preference of T3S patterns to that of adults. In fact, we found that the frequency of multiple T3S patterns of 6-year-olds and adults was strikingly similar.

In NSR, the length of sentence (4w4σ vs. 4w6σ) had an effect on 4- and 6-year-olds, but in RTR, such effect no longer existed. Regarding complexity that involves the number of adjacent T3*, again, we see an effect (both child groups did better in the three-T3 items than in the six-T3 items) in NSR, but not in RTR. An interpretation is that it is due to the task— the task in the RTR is much harder than in NSR.

Although the ternary pattern appears in both the subject-NP and the subject-pro sentences, we found a distinction between them— a monosyllabic subject NP tends to be parsed in its own domain, that is, being a degenerate foot, and maintain the subject-predicate boundary whereas a subject pro does not tend to. This provides a strong piece of evidence that a monosyllabic NP and a monosyllabic pronoun are prosodically different, hence, are dealt with differently in the foot-building process. The patterns and the frequency of the patterns that 6-year-olds produced mirror those of adults, indicating that they were aware of the distinction in the subject NP and subject pro, which 4-year-olds did not seem to be aware of.

Finally, the ternary pattern used in the 6-syllable experimental sentences always separate the verb and the object as shown in ST1 and ST2 in (4).

(4)	[Ma	[xiang	[deng	[xiao	[mayi]]]]]	
	horse	want	wait for	small	ant	'Horse wants to wait for Small Ant.'
	3	3	3	3	33	UT
	3	3	3	3	(**2**3)	Word: T3S
	3	3	3	(3	23)	Word: Incorporation, no T3S
	(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S
	(2	**2**	3)	(3	23)	Phrase: incorporation, T3S; ST1
	(2	2	**2**)	(3	23)	Phrase: optional T3S across domains; ST2
	Additional patterns attested:					
	(3)	(2	3)	(3	23)	subject-predicate pattern; ST3
	(3)	(2	**2**)	(3	23)	subject-predicate pattern, optional T3S across domains; ST4

In (4), T3S first applies to the NP cyclically at the Word level, which did not appear to be difficult for children. Then, at the Phrase level, T3S applies non-cyclically, followed by incorporation of the unparsed syllable. Such normal derivations give ST1, and if T3S applies across domains, we have ST2. In both cases, the verb and the object are kept separated. The verb and the object are in a syntactic constituent, but in ST1 and ST2, the verb and the object are in two different prosodic domains.

For (4), ST3 and ST4 were attested in children and adults (approximately 25% in adults and 6-year-olds, and below 10% in 4-year-olds) in RTR. It was very telling that while the percentage of the subject-predicate pattern is fairly high in adults in the subject-NP sentences, the same pattern was used at a low frequency in the subject-pro sentences in adults and 6-year-olds (and it was never used by children or adults in NSR.) The contrast in the prosodic property of monosyllabic NPs and monosyllabic pronouns is apparent. While a monosyllabic NP can stand alone, a monosyllabic pronoun does not tend to stand alone easily because as a clitic, it has to cliticize to a host. Although the distinction of subject NPs and subject pronouns has not been directly addressed in the T3S literature, in the results from this study, 6-year-olds were aware of the prosodic differences between NPs and pronouns. The distinction of NPs and pronouns in the application of T3S shown in Study 4 and Study 5 demonstrates a previously unnoticed area that children attend to in their acquisition of T3S.

The results from these experimental studies (Study 2 – Study 5) strongly indicate that although children have some ability to use T3S early on and know to change a T3 to a T2 when followed by another T3, the intricacies of the T3S application develop with time and even the oldest age group, 6-year-olds, are not adult-like.

8.3 Future research

In Study 4 Natural Speech, in spite of its reduced scope and few instances of spontaneous contexts for T3S application, sentences with a subject pronoun produced by children and adults that show a subject-predicate pattern deserves a more careful study.

With respect to the prediction made for flat structures (binary parsing, followed by incorporation of an unparsed syllable, if applicable; directionality is left to right), a longer sequence of digits can be tested in the future if it is appropriate to the age range of the participants. To test directionality, longer odd-number sequences could be used (such as 7, 9, or 11 digits). To test whether or not grouping of three or even four syllables are indeed the alternatives (i.e. binary parsing is not the only strategy), testing multiples of three or four which are also multiples of two will be crucial. For instance, a sequence of six is two feet if groups of three is used (XXX)(XXX) and three feet if grouping of two is used (XX)(XX)(XX). Caution should be made as to what digits are used. In Study 2 Flat Structure, we used identical digits in the same sequence. The "formation" of digits will most likely affect how the digits are parsed, such as 595959 is possibly more likely to be parsed as (59)(59)(59) than (595)(959), and for the same reason, 555999 can be easily parsed as (555)(999) instead of (55)(59)(99).

Another area of interest is how flat structures interact with non-flat structures. By manipulation where flat structures are embedded in sentences, we can further test that.

With respect to compound nouns, we tested four-syllable NPs in the R-branching and M-branching structures. Future work can investigate, for instance, five-syllable NPs with various structures such as [σ[σ[σ[σσ]]]], [[σσ][[σσ]σ]] and [[[σσ]σ][σσ]] (predicting T3**T2**T3**T2**T3, **T2**T3**T2T2**T3, and **T2T2**T3**T2**T3 respectively). Nevertheless, structures with such complexity are very likely to be beyond children's (under age six) capacity as we saw that the four-syllable M-branching NPs were already very difficult for children (age 3-6) in this study.

In the two studies NSR and RTR, we tested four- and six-syllable sentences, and in a limited number of structures with more experimental items per condition. Future research can extend the length of sentence, and also test other syntactic structures. We tested the sentences with different number of adjacent T3*— zero, three, and all (four or six). Future studies can manipulate the number of adjacent T3*. If it is age appropriate, embedding flat structures in sentences will be interesting as we know very little about how T3S in flat structures interact with the neighboring syllables in sentences. The structures and the degree of complexity is less constrained if the experiments are intended for adult participants, but with child participants, factors such as length of sentence and structural complexity need to be carefully considered.

All the studies presented in this dissertation were carried out in Taiwan; future studies can replicate and investigate to see whether or not the results are similar in other regions where Mandarin is spoken. If not, cross-regional results can be compared and the factors that may account for regional difference can be further investigated.

Finally, although both T3S models (see Chapter 2) basically have the same coverage for T3S patterns, there are patterns that were used by participants of these five studies that require further investigation. It is not clear whether the Word-and-Phrase level Model or the Stress-foot Model can better account for the empirical data. In accounting for T3S variation, both models have two optional rules. In the Word-and-Phrase level Model, T3S is optional between domains, and in fast speech, a larger domain is formed within which T3S applies. In the Stress-foot Model, T3S is optional between cyclic branches, and T3S is optional before a T2 that is derived from a T3. A crucial question to ask is, will the optional rules in both models over-generate T3S patterns? T3S theories can be worked toward how to formalize T3S variability as well as variability due to regional or social difference if there is any. An initial attempt of an Optimality Theory (Prince & Smolensky 1993/2004) analysis of T3S variability by adopting Coetzee's (2006) model has been made (Wang & Lin 2011), which hopefully will arouse the interest in analyzing T3S variation in the OT framework. It is my hope that the dissertation of children's acquisition of T3S will inspire many more researchers to conduct studies on children's acquisition of T3S.

Appendix A

Study 1 Possible frozen chucks (The lexical items which have a sequence of T3T3.)

Table 4.11 List of possible frozen chucks and number of tokens produced by each participant

Lexical items	Adult CZ	CH 4;5	LI 4;6	Adult LU	IU 4;6	Adult CL	ES 5;5	Adult EE	GK 5;9	Adult TT	BR 6;6	ER 6;6
biaoyan 'perform'	0	0	0	0	0	0	0	0	0	4	0	0
bu-ru[41] 'breast-feeding'	0	0	0	0	0	0	0	0	0	6	0	2
keyi 'can' (aux)	20	2	4	9	1	9	3	6	10	11	3	2
laoban 'boss; store owner'	0	0	0	1	0	0	0	2	0	0	0	0
laohu 'tiger'	2	0	1	7	4	6	1	0	0	2	2	2
laoshu 'mouse'	0	0	0	0	0	0	1	0	0	0	0	0
liaojie 'realize'	0	0	0	0	0	0	0	1	0	0	0	0
nali 'where'	13	1	4	12	9	6	4	18	0	5	0	2
Qiaohu 'name of a tiger'	0	0	0	0	0	0	1	0	0	0	0	0
suoyi 'so'	4	0	1	0	0	1	3	1	1	1	0	0
suoyou 'all'	0	0	0	0	0	4	0	0	0	1	0	0

[41] *Buru* (T3T3) 'breast-feeding' and *dongwu* (T4T4) 'animals' (lit. breast-feeding animals) together mean 'mammals.'

Table 4.11 (cont'd)

Lexical items	Adult CZ	CH 4;5	LI 4;6	Adult LU	IU 4;6	Adult CL	ES 5;5	Adult EE	GK 5;9	Adult TT	BR 6;6	ER 6;6
xizao 'bathe; take a shower'	0	0	0	0	0	1	2	0	0	0	0	0
xiaogou 'doggie'	1	0	0	0	0	1	0	0	0	0	0	0
yongyuan 'forever'	0	0	0	0	0	0	1	0	0	0	0	0
zhiyou 'only'	2	0	0	0	0	0	0	0	0	0	0	0

Appendix B

Study 2 Experimental materials

Narration: 我們要玩一個遊戲。“這是什麼(指著電腦螢幕上的數字)?”（小孩回答後，繼續說）“你可以把手手伸出來，跟我一樣嗎(示範把一隻手伸出來,五指伸直)?”（輕輕地慢慢地幫小孩把三根手指彎下去,剩下兩根手指伸直）然後說，“我點你的手指的時候，你就說這個數字(指著電腦螢幕上的數字)，好不好？”

The experimenter: We are going to play a game. “What’s this? (pointing to the digit on the screen)” After the child gives the answer, ask the child, “Could you hold out one hand just like me? (The experimenter shows the child by holding out a hand, with five fingers up straight)” (Then the experimenter slowly and gently bends down three of the child’s fingers, leaving two up. “You say the digit (pointing to the digit on the screen) when I tap your fingers, okay?”

“你可以把手手伸出來，跟我一樣嗎(示範把一隻手伸出來)?”（幫小孩把兩根手指彎下去）然後說，“我點你的手指的時候，你就說這個數字，好不好？”

“Could you hold out one hand just like me? (The experimenter shows the child by holding out a hand, with five fingers up straight)” (Then the experimenter slowly and gently bends down two of the child’s fingers, leaving three up. “You say the digit (pointing to the digit on the screen) when I tap your fingers, okay?”

“你可以把手手伸出來，跟我一樣嗎(示範把一隻手伸出來)?”然後說，“我點你的手指的時候，你就說這個數字，準備好了嗎？”

“Could you hold out one hand just like me? (The experimenter shows the child by holding out a hand, with five fingers up straight). You say the digit (pointing to the digit on the screen) when I tap your fingers. Are you ready?”

(Repeated) Figure 5.1 Flat structures: A child’s hand, (a) – (c) for two, three, and five digits respectively

a. for two digits	b. for three digits	c. for five digits
		

Figure 5.8 Study 2: List of materials

a. practice: a non-T3 digit “4” (Tone 4)							
4	**i) two times**						
		si	si				
		four	four				‘four-four’
	ii) three times						
		si	si	si			
		four	four	four			‘four-four-four’
	iii) five times						
		si	si	si	si	si	
		four	four	four	four	four	‘four-four-four-four-four’
b. control item: a non-T3 digit “2” (Tone 4)							
2	**i) two times**						
		er	er				
		two	two				‘two-two’
	ii) three times						
		er	er	er			
		two	two	two			‘two-two-two’
	iii) five times						
		er	er	er	er	er	
		two	two	two	two	two	‘two-two-two-two-two’
c. test item: a T3 digit “5”							
5	**i) two times**						
		wu	wu				
		five	five				‘five-five’
	ii) three times						
		wu	wu	wu			
		five	five	five			‘five-five-five’
	iii) five times						
		wu	wu	wu	wu	wu	
		five	five	five	five	five	‘five-five-five-five-five’

Figure 5.8 (cont’d)

d. control item: a non-T3 digit “3” (Tone 1)	
3	**i) two times** san san three three ‘three-three’ **ii) three times** san san san three three three ‘three-three-three’ **iii) five times** san san san san san three three three three three ‘three-three-three-three-three’
b. test item: a T3-digit “9”	
9	**i) two times** jiu jiu nine nine ‘nine-nine’ **ii) three times** jiu jiu jiu nine nine nine ‘nine-nine-nine’ **iii) five times** jiu jiu jiu jiu jiu nine nine nine nine nine ‘nine-nine-nine-nine-nine’

Appendix C

Study 3 List of test and control items

A. Three-syllable compounds

Table 6.14 Study 3: List of tests and controls in three-syllable compounds

	Test (T) or Control (C)	Materials	Underlying tones	Surface tones	Syntactic structure	Translation
1	C	公雞 筆 gongji bi cock pen	113	Same	[[σσ]σ]	Cock-pen
2	T	老鼠 筆 laoshu bi mouse pen	333	**22**3	[[σσ]σ]	Mouse-pen
3	C	餅乾 鳥 binggan niao cookie bird	313	Same	[[σσ]σ]	Cookie-bird
4	T	水果 鳥 shuiguo niao fruit bird	333	**22**3	[[σσ]σ]	Fruit-bird
5	C	水 大象 shui daxiang water elephant	344	Same	[σ[σσ]]	Water-elephant
6	T	水 老虎 shui laohu water tiger	333	3**2**3	[σ[σσ]]	Water-tiger
7	C	紙 犀牛 zhi xiniu paper rhino	312	Same	[σ[σσ]]	Paper-rhino
8	T	紙 海馬 zhi haima paper seahorse	333	3**2**3	[σ[σσ]]	Paper-seahorse

B. Four-syllable NPs

Table 6.15 Study 3: List of tests and controls in four-syllable NPs

	Test (T)/ Control (C)	Materials	Under-lying tones	Surface tones	Syntactic structure	Translation
1	C	小 红 绵羊 xiao hong mianyang small red sheep	3222	Same	[σ[σ[σσ]]]	Small red sheep
2	C	小 藍 綿羊 xiao lan mianyang small blue sheep	3222	Same	[σ[σ[σσ]]]	Small blue sheep
3	T	小 紫 海馬 xiao zi haima small purple seahorse	3333	**2**3**2**3	[σ[σ[σσ]]]	Small purple seahorse
4	T	小 紫 雨傘 xiao zi yusan small purple umbrella	3333	**2**3**2**3	[σ[σ[σσ]]]	Small purple umbrella
5	C	小 長鼻 象 xiao chang bi xiang small long-trunked elephant	3224	Same	[σ[[σσ]σ]]	Small long-trunked elephant
6	C	綠 大眼 蛙 lü da yan wa green big-eyed frog	4431	Same	[σ[[σσ]σ]]	Green big-eyed frog
7	T	小 短腿 馬 xiao duan tui ma small short-legged horse	3333	3**22**3	[σ[[σσ]σ]]	Small short-legged horse
8	T	矮 小眼 鳥 ai xiao yan niao short small-eyed bird	3333	3**22**3	[σ[[σσ]σ]]	Short small-eyed bird

Appendix D

Study 3 Experimental materials

A. Three-syllable Compounds:

In Figure 6.7, target answers for the test items are in **bold type**, and target answers for the control items are underlined.

Figure 6.7 Study 3: Experimental materials for three-syllable compounds

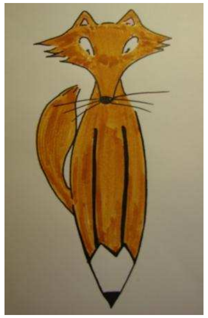
	Pictures (shown to subjects on a laptop computer)	Scripts (for the experimenter)	Target answers
1.		你看！這是狐狸（指著狐狸）。這支筆長得像狐狸 (*huli* T2T2 'fox')，我們叫它'狐狸筆'(*hulibi* T2T2T3 'fox-pen', UT=ST)。 Look at this pen. This is a fox (pointing to fox). The pen looks like a fox. We call it a 'fox-pen.'	(Modeling)
2.		這是什麼？(指著筆上方的動物) What is this? (pointing to the animal at the top of the pen) 這支筆長得像公雞，那我們叫它什麼？ This pen looks like a cock, so what do we call it?	gongji cock 'cock' 3 1 UT=ST gongji bi cock pen 'cock-pen' 3 1 3 UT=ST

Figure 6.7 (cont'd)

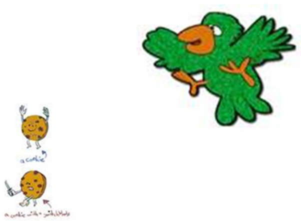
3.		這是什麼(指著筆上方的動物)? What is this (pointing to the animal at the top of the pen)? 對，這支筆長得像老鼠，那我們叫它…? The pen looks like a mouse, so we call it a…	laoshu mouse 'mouse' 3 3 UT **2** 3 ST **laoshu bi** mouse pen 'mouse-pen' 3 3 3 UT **2** **2** 3 ST
4.		你看這隻鳥 (*niao* T3 'bird')。他看到蛋糕好高興。我們叫他'蛋糕鳥' (*dangao niao* T4T1T3 'cake-bird', UT=ST)。 Look at this bird. He's so happy to see the cake. Let's call it a 'cake-bird.'	(Modeling)
5.		這是什麼？（指著餅乾） What are these? (pointing to the cookies) 他好喜歡餅乾，那我們叫他什麼? He loves cookies, so what do we call it?	binggan cookie 'cookies' 3 1 UT=ST <u>binggan niao</u> cookie bird 'cookie-bird' 3 1 3 UT=ST

Figure 6.7 (cont'd)

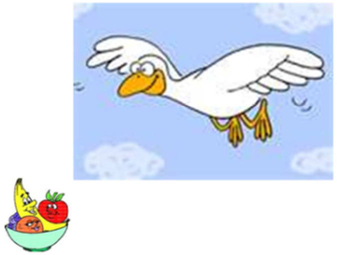
6.		這是什麼？（指著水果） What is this? (pointing to the fruit) 他好喜歡水果，那我們叫他什麼? He loves fruit, so we call it a…	shuiguo fruit 'fruit' 3 3 UT **2** 3 ST **shuiguo niao** fruit bird 'fruit-bird' 3 3 3 UT **2 2** 3 ST
7.		這是什麼？ What's this?	houzi monkey '(a) monkey' 2 0 UT=ST
8.		這是什麼？（小孩回答：猴子 *houzi* T2T0 'monkey') What's this? (Child answers: (A) monkey.) 對，這隻猴子很特別，他喜歡住在水裡。我們叫他'水猴子'(*shui houzi* T3T2T0 water-monkey, UT=ST)。 Yes. This monkey is very special. He loves to live in the water. Let's call it a 'water-monkey.'	(Modeling)

Figure 6.7 (cont'd)

9.		這是什麼？ What's this?	daxiang elephant 'elephant' 4 4 UT=ST
10.		這是什麼？ What's this? 這隻大象也很喜歡住在水裡。我們叫他什麼？ This elephant also loves to live in the water. What do we call it?	daxiang elephant 'elephant' 4 4 UT=ST shui daxiang water elephant 'water-elephant' 3 4 4 UT=ST
11.		這是什麼？ What's this?	laohu tiger '(a) tiger' 3 3 UT **2** 3 ST

Figure 6.7 (cont'd)

12.		這是什麼？ What this? 這隻老虎也很喜歡住在水裡。所以我們叫他…？ This tiger loves to live in the water, too, so we call it…	laohu tiger ‘(a) tiger’ 3 3 UT **2** 3 ST **shui laohu** water tiger ‘water-tiger’ 3 3 3 UT 3 **2** 3 ST
13.		你看這隻大象(*daxiang* T4T4 ‘elephant’)，他是紙做的。我們叫他‘紙大象’(*zhi daxiang* T3T4T4 paper-elephant, UT=ST)。 Look at this elephant. It's made of paper. Let's call it a ‘paper-elephant.’	(Modeling)
14.		這是什麼？ What's this? 他也是紙做的。我們叫他什麼？ It's also made of paper. What do we call it?	xiniu rhino ‘rhino’ 1 2 UT=ST zhi xiniu paper rhino ‘paper-rhino’ 3 1 2 UT=ST

Figure 6.7 (cont'd)

15.		這是什麼? What's this? 他也是紙做的。我們叫他…? It's also made of paper, too, so it's a …	haima seahorse '(a) seahorse' 3 3 UT **2** 3 ST **zhi haima** paper seahorse 'paper-seahorse' 3 3 3 UT 3 **2** 3 ST

B. Four-syllable NPs

In this experiment, as there are layers in the syntactic structure, one layer is elicited at a time. The final target answer is elicited through multiple pictures.

In Figure 6.8, target answers for the test items are in **bold type**, and target answers for the control items are underlined.

Figure 6.8 Study 3: Experimental materials for four-syllable NPs

	Pictures (shown to subjects on a laptop computer)	Scripts (for the experimenter)	Target answers
1.		這是什麼? What's this?	haima seahorse '(a) seahorse' 3 3 UT **2** 3 ST

Figure 6.8 (cont’d)

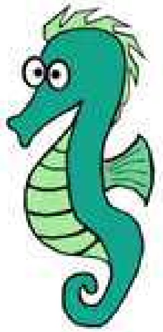
2.		這是什麼？ What’s this? （海馬 *haima* ‘(a) seahorse’ T3T3→**T2**T3) 他是綠色的。 The color is green. 我們叫他 ‘綠海馬’ (*lühaima*T4T3T3→T4**T2**T3 ‘green seahorse’)。 Let’s call it a green seahorse.	(Modeling)
3.		這是什麼？ What’s this? 是什麼顏色？ What color is it? 我們叫他什麼？ What do we call it?	haima seahorse ‘(a) seahorse’ 3 3 UT **2** 3 ST zise purple ‘purple’ 3 4 UT=ST zi haima purple seahorse ‘(a) purple seahorse’ 3 3 3 UT 3 **2** 3 ST

Figure 6.8 (cont’d)

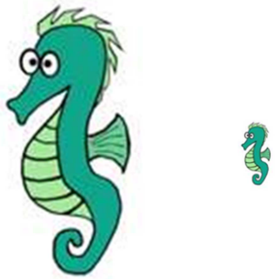
4.		你看這兩隻海馬，一隻大的，一隻小的。 Look at these two seahorses. One is big, the other is small. 我們叫這隻大隻的（指著大隻的）‘大綠海馬’ (*da lü haima* T4 T4 T3T3 →T4 T4 **T2**T3 ‘(a) big green seahorse’)；這隻小隻的‘小綠海馬’ (*xiao lü haima* T3 T4 T3T3 →T3 T4 **T2**T3 ‘(a) small green seahorse’)。 We call this one (pointing to the big one) a ‘big green seahorse, and this one (pointing to the small one) a ‘small green seahorse.’	(Modeling)
5.		現在你看這兩隻。大隻的是大紫海馬（*da zi haima* T4 T3 T3T3 →T4 T3 **T2**T3。小的呢（指著小隻的）？ Now look at these two. The big one is a “big purple seahorse.” What about this one (pointing to the small one)?	**xiao zi haima** small purple seahorse ‘(a) purple seahorse’ small purple seahorse 3 3 33 UT **2** 3 **2**3 ST
6.		這是什麼？ What are these? 他們的顏色好奇怪，對不對？ They have strange colors, don’t they?	mianyang sheep ‘sheep’ 2 2 UT=ST

Figure 6.8 (cont'd)

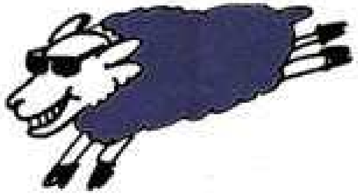
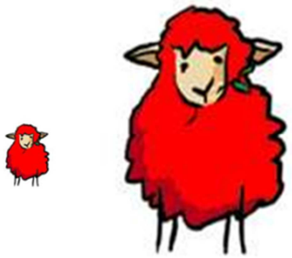
7.		這隻綿羊是紅的，我們叫她… The sheep is red, we call it a …	hong mianyang red sheep '(a) red sheep' 2 22 UT=ST
8.		這隻是藍的，我們叫他… This one is blue, so we call it a …	lan mianyang blue sheep '(a) blue sheep' 2 22 UT=ST
9.		你看這兩隻綿羊，一隻大的，一隻小的。 Look at these two sheep. One is big, the other is small. 我們叫這隻大隻的（指著大隻的）'大紅綿羊' (*da hong mianyang* T4 T2 T2T2 '(a) big red sheep')；這隻小隻的呢（指著小隻的）？ We call this one (pointing to the big one) a "big red sheep." What about this one? (pointing to the small one)	(Modeling) xiao hong mianyang small red sheep '(a) small red sheep' 3 2 22 UT=ST

Figure 6.8 (cont'd)

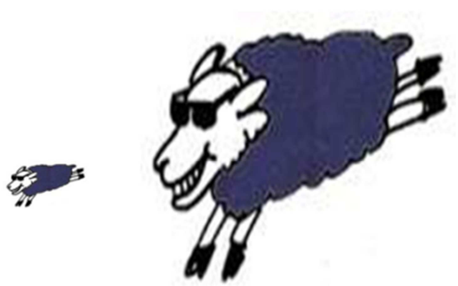
10.		你看這兩隻綿羊。我們叫這隻（指著大隻的）(*da lan mianyang* T4 T2 T2T2 '(a) big blue sheep'); 這隻呢（指著小隻的）？ Look at these two sheep. We call this one (pointing to the big one) a "big blue sheep." What about this one? (pointing to the small one)	<u>xiao lan mianyang</u> small blue sheep '(a) small blue sheep' 3 2 22 UT=ST
11.		這是什麼？ What's this?	yusan umbrella 'umbrella' 3 3 UT **2** 3 ST
12.		這是什麼？ What's this? 這是藍色的，我們叫它'藍雨傘'。 The color is blue. Let's call it a blue umbrella	(Modeling)

Figure 6.8 (cont'd)

<table>
<tr><td>13.</td><td></td><td>這是什麼？
What's this?

是什麼顏色？
What color is it?

我們叫他什麼？
What do we call it?</td><td>yusan
umbrella ‘(an) umbrella’
3 3 UT
2 3 ST

zise
purple ‘purple’
3 4 UT=ST

zi yusan
purple umbrella ‘(a) purple umbrella’
3 3 3 UT
3 2 3 ST</td></tr>
<tr><td>14.</td><td></td><td>你看這兩支雨傘，一支大的，一支小的。我們叫這支大的（指著大的）‘大藍雨傘’ (da lan yusan T4 T2 T3T3 →T4 T2 T2T3 ‘(a) big blue umbrella’)；這支小的‘小藍雨傘’ (xiao lan yusan T3 T2 T3T3 →T3 T2 T2T3 ‘(a) small blue umbrella’)。

Look at these two umbrellas. One is big, the other is small. We call this one (pointing to the big one) a ‘big blue umbrella, and this one (pointing to the small one) a ‘small blue umbrella.’</td><td>(Modeling)</td></tr>
</table>

Figure 6.8 (cont’d)

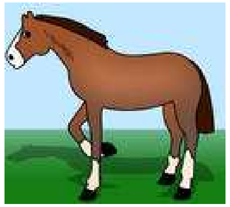
15.		現在你看這兩支。大的是大紫雨傘(*da zi yusan* T4 T3 T3T3 →T4 T3 **T2**T3。小的呢(指著小支的)? Now look at these two. The big one is a “big purple umbrella.” What about this one (pointing to the small one)?	**xiao zi yusan** small purple seahorse ‘(a) purple seahorse’ small purple seahorse 3 3 33 UT **2** 3 **2**3 ST
16.		這是什麼? What’s this?	ma horse ‘horse’ 3 UT 3 ST
17.		這是什麼? What’s this?	qingwa frog ‘frog’ 11 UT 11 ST
18.		你看這隻青蛙。他的腿好長哦（指著青蛙長長的後腿）。我們叫他‘長腿蛙’ (*chang tui wa* T2 T3 T1 UT=ST ‘(a) long-legged frog’)。 Look at this frog. His legs (pointing to the long hind leg) are so long. Let’s call it a “long-legged frog.”	(Modeling)

Figure 6.8 (cont'd)

19.		這是什麼？ What's this? 他的腿也這麼長（指著馬的長腿），我們要叫他什麼？ His legs are very long (pointing to the horse's long legs), too. What do we call it?	ma horse 'horse' 3 UT 3 ST chang tui ma long leg horse '(a) long-legged horse' long leg horse 2 3 3 UT 2 **2** 3 ST
20.		這是什麼？ What's this? 他的腿這麼短（指著馬的長腿），我們要叫他什麼？ His legs are so short (pointing to the horse's short legs), too. What do we call it?	ma horse 'horse' 3 UT 3 ST duan tui ma short leg horse '(a) long-legged horse' short leg horse 3 3 3 UT **2** **2** 3 ST

Figure 6.8 (cont'd)

21.	 	你看這兩隻青蛙，一隻大的，一隻小的。我們叫這隻大的（指著大的）'大長腿蛙'（*da chang tui wa* T4 T2 T3 T1 UT=ST '(a) big long-legged frog'）；這隻小的'小長腿蛙'（*xiao chang tui wa* T3 T2 T3 T1 UT=ST, '(a) small long-legged frog'）。 Look at these two frogs. One is big and the other is small. We call this one (pointing to the big one) a "big long-legged frog" and this one (pointing to the small one) a "small long-legged frog."	(Modeling)
22.	 	現在你看這兩隻。大的是大長腿馬（*da chang tui ma* T4 T2 T3T3 →T4 T2 **T2** T3 '(a) big long-legged horse'）。小的呢(指著小隻的)? Now look at these two. The big one is a "big long-legged horse." What about this one (pointing to the small one)?	xiao chang tui ma small long leg horse '(a) small long-legged horse' small long leg horse 3 2 3 3 UT 3 2 **2** 3 ST

Figure 6.8 (cont'd)

23.	 	現在你看這兩隻。大的是大短腿馬（*da duan tui ma* T4 T3 T3T3 →T4 **T2 T2** T3 '(a) small short-legged horse'）。小的呢（指著小隻的）？ Look at these two. This big one is called a "big short-legged horse." What about this one? (pointing to the small one)	**xiao** **duan** **tui** **ma** small short leg horse '(a) small short-legged horse' small short leg horse 3 3 3 3 UT 3 **2** **2** 3 ST
24.		這是什麼？ What's this? 你看這隻大象。他的鼻子好長哦（指著大象長長的鼻子）。我們叫他'長鼻象'。（*chang bi xiang* T2 T2 T4 UT=ST '(a) long-trunked elephant'）。 Look at this elephant. His trunk (pointing to the long trunk) is so long. Let's call it a "long-trunked elephant."	daxiang elephant 'elephant' 44 UT 44 ST (Modeling)

Figure 6.8 (cont'd)

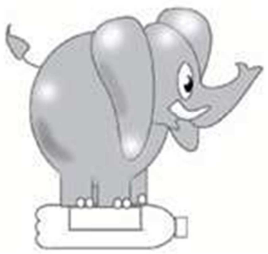
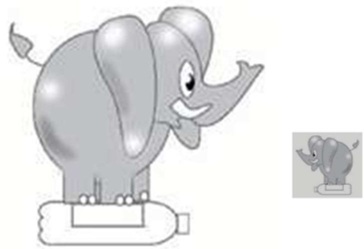
25.		這是什麼？ What's this? 他的鼻子這麼短（指著大象很短的鼻子）。我們要叫他什麼？ His trunk is so short (point at the elephant's short trunk). What do we call it?	daxiang elephant 'elephant' 44 UT 44 ST duan bi xiang short trunk elephant '(a) short-trunked elephant' short trunk elephant 3 2 4 UT=ST
26.		現在你看這兩隻。大的是大長鼻象(*da chang bi xiang* T4 T2 T2 T4 '(a) big long-trunked elephant')。小的呢(指著小隻的)？ Look at these two elephants. The big one is a "big long-trunked elephant." What about this one (pointing to the small one)?	xiao chang bi xiang small long trunk elephant '(a) small long-trunked elephant' small long trunk elephant 3 2 2 4 UT=ST
27.		現在你看這兩隻。大的是大短鼻象(*da duan bi xiang* T4 T3 T2 T4 '(a) big short-trunked elephant')。小的呢(指著小隻的)？ Look at these two elephants. The big one is "big short-trunked elephant." What about the small one?	xiao duan bi xiang small short trunk elephant '(a) small long-trunked elephant' small short trunk elephant 3 3 2 4 UT **2** 3 2 4 UT

Figure 6.8 (cont'd)

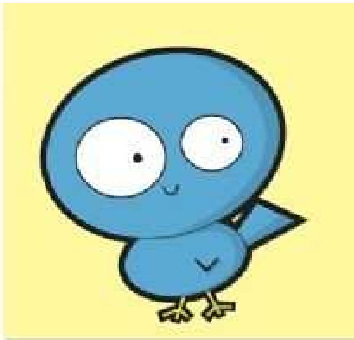
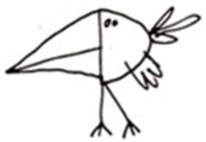
28.		這是什麼？（指著眼睛） What are these? (pointing at the eyes) 你看這隻青蛙。他的眼睛好大哦（指著青蛙大大的眼睛）。我們叫他‘大眼蛙’。 (*da yan wa* T4 T3 T1 UT=ST ‘(a) big-eyed frog’)。 Look at this frog. His eyes are so big. Let's call him a "big-eyed frog."	yanjing eyes ‘eyes’ 31 UT=ST (Modeling)
29.		這是什麼？ What's this? 他的眼睛好大哦（指著小鳥大大的眼睛）。我們叫他什麼？ His eyes are also very big (pointing at the bird's big eyes), so what do we call it?	(xiao)niao bird ‘(a) bird’ (3)3 UT (**2**)3 ST da yan niao big eye bird ‘(a) big-eyed bird’ 4 3 3 UT 4 **2** 3 ST
30.		你看這隻小鳥。他的眼睛麼小（指著鳥小小的眼睛），我們要叫他什麼？ Now look at this bird. His eyes are so small (pointing at the bird's small eyes). What do we call it?	xiao yan niao small eye bird ‘(a) small-eyed bird’ 3 3 3 UT **2** **2** 3 ST

Figure 6.8 (cont'd)

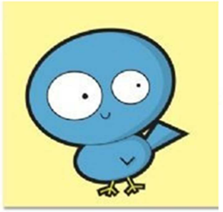
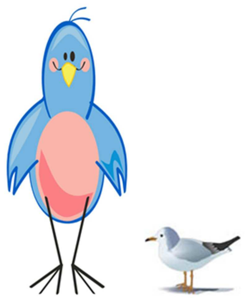
31.	 	這兩隻鳥你再看一次。這一隻(指著大眼睛的那隻) 是… Let's look the two birds one more time. This is (pointing to the big-eyed one)… 這一隻(指著小眼睛的那隻)是… And this is (pointing to the small-eyed one)…	da yan niao big eye bird '(a) big-eyed bird' 4 3 3 UT 4 **2** 3 ST xiao yan niao small eye bird '(a) small-eyed bird' 3 3 3 UT **2** **2** 3 ST
32.	 	你看這兩隻青蛙。一隻白的，一隻綠的。他們的眼睛好大（指著青蛙大大的眼睛），這隻白的，我們叫他'白大眼蛙' (*bai da yan wa* T2 T4 T3 T1 UT=ST '(a) white big-eyed frog') Look at these two frogs. A white one and a green one. Their eyes are very big. This one is white (pointing at the white one). We call it a "white big-eyed frog." 這隻綠的我們要叫他什麼（指著綠的那隻）？ What about this green one (point at the green one)?	(Modeling) lü da yan wa green big eye frog '(a) green big-eyed frog' green big eye frog 4 4 3 1 UT=ST

Figure 6.8 (cont'd)

33.		你看這兩隻小鳥。他們的眼睛都好大（指著小鳥大大的眼睛），一隻高的，一隻矮的。這隻高的，我們叫他‘高大眼鳥’ (*gao da yan niao* T1 T4 T3 T3 UT→ T1 T4 **T2** T3 ST '(a) tall big-eyed bird')。矮的呢（指著矮的那隻）？ Look at these two birds. Their eyes are also very big eyes (pointing at the birds' big eyes). One is tall, and the other is short. Let's call the tall one a "tall big-eyed bird." What about this short one?	(Modeling) ai da yan niao short big eye bird '(a) short big-eyed bird' green big eye frog 3 3 3 3 UT 3 4 **2** 3 ST
34.		你看這兩隻小鳥。他們的眼睛都好小（指著小鳥大大的眼睛），一隻高的，一隻矮的。這隻高的，我們叫他‘高小眼鳥’ (*gao xiao yan niao* T1 T3 T3 T3 UT→ T1 **T2** **T2** T3 ST '(a) tall small-eyed bird')。矮的呢（指著矮的那隻）？ Look at these two birds. They both have very small eyes (pointing at the birds' small eyes). One is tall, and the other is short. Let's call the tall one a "tall small-eyed bird." What about this short one?	(Modeling) **ai xiao yan niao** short small eye bird '(a) short small-eyed bird' short small eye bird 3 3 3 3 UT 3 **2** **2** 3 ST

Appendix E

Study 4 (NSR) Experimental Materials

Narration: 我們要玩一個遊戲。你看, 這是機器人, 這隻熊熊叫做小莉。機器人跟熊熊小莉說話, 熊熊小莉聽不到。你可以幫她聽機器人說什麼嗎？聽到以後告訴小莉, 好不好？你想玩這個遊戲嗎？

We are going to play a game. Look, this is a Robot, and this is Bear *Xiaoli*. Robot says something to Bear *Xiaoli*, but Bear *Xiaoli* cannot hear her. Could you help her by listening to what the Robot is saying? After you hear it, you tell *Xiaoli*, okay?

Figure 7.12 Study 4: List of materials

A1		Ni you 3 **2**	xiang want 3 **2**	mai buy 3 3	hua flower 1 1	 'You want to buy flowers.' UT ST used
A2		Wo I 3 **2**	xiang want 3 **2**	mai buy 3 **2**	bi pens 3 3	 'I want to buy pens.' UT ST used
A3		Ta he 1 1	xiang want 3 3	kan read 4 4	shu book 1 1	 'He wants to read books.' UT ST used

Figure 7.12 (cont'd)

A4		Ni xiang xi che you want wash car 'You want to wash (the) car.' 3 3 3 1 UT **2** **2** 3 1 ST used
A5		Wo xiang xi ma I want wash horse 'I want to wash (the) horse.' 3 3 3 3 UT **2** **2** **2** 3 ST
A6		Ta xiang chang ge he want sing song 'He wants to sing.' 1 3 4 1 UT 1 3 4 1 ST used
B1		Banma xiang zhao xiongmao Zebra want look for panda bear 'Zebra wants to look for Panda Bear.' Zebra want look for panda bear 13 3 3 21 UT **12** **2** 3 21 ST used
B2		Haima xiang zhao shuimu seahorse want look for jelly fish 'Seahorse wants to look for Jelly Fish.' seahorse want look for jelly fish 33 3 3 33 UT **22** **2** 3 **2**3 ST used

Figure 7.12 (cont’d)

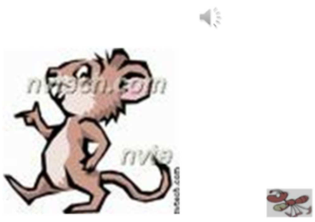
B3		Guoniu xiang bian qingwa snail want become frog ‘Snail wants to become Frog.’ snail want become frog 12 3 4 11 UT 12 3 4 11 ST used
B4		Hema xiang deng wugui hippo want wait for turtle ‘Hippo wants to wait for the turtle.’ snail want become frog 23 3 3 11 UT 2**2** **2** 3 11 ST used
B5		Laoshu xiang deng mayi mouse want wait for ant ‘Mouse wants to wait for Ant.’ mouse want wait for ant 33 3 3 33 UT **22** **2** 3 2**3** ST used
B6		Haibao xiang bian jingyu seal want become whale ‘Seal wants to become Whale.’ seal want become whale 34 3 4 12 UT 34 3 4 12 ST used
C1		Wo xiang zhao da hema I want look for big hippo ‘I want to look for Big Hippo.’ I want look for big hippo 3 3 3 4 23 UT **2** **2** 3 4 23 ST used

Figure 7.12 (cont’d)

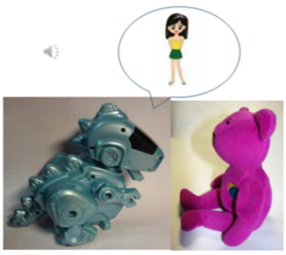
C2		Ni xiang yang xiao laohu you want raise small tiger ‘You want to have (raise) a small Tiger.’ you want raise small tiger 3 3 3 3 33 UT **2** **2** 2 3 **2**3 ST used
C3		Ta xiang chuan duan qunzi she want wear short skirt ‘She wants to wear a short skirt.’ she want wear short skirt 1 3 1 3 25 UT 1 3 1 3 25 ST used
C4		Wo xiang zhao pang xiongmao I want look for fat panda bear ‘I want to look for Fat Panda Bear.’ I want look for fat panda bear 3 3 3 4 21 UT **2** **2** 3 4 21 ST used
C5		Ni xiang yang xiao laoshu you want raise small mouse ‘You want to have (raise) a small mouse.’ you want raise small mouse 3 3 3 3 33 UT **2** **2** 2 3 **2**3 ST used
C6		Ta xiang ting hao yinyue she want listen to good music ‘She wants to listen to good music.’ she want listen to good music 1 3 1 3 14 UT 1 3 1 3 14 ST used

Figure 7.12 (cont'd)

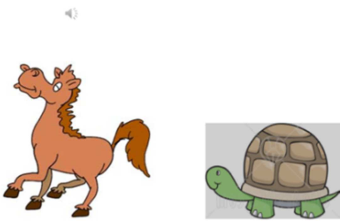
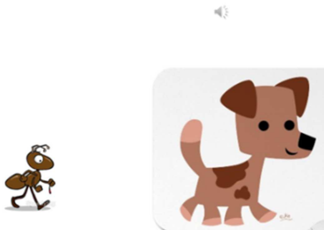
D1		Gou xiang zhao da xingxing dog want look for big gorilla 'Dog wants to look for (the) big gorilla.' dog want look for big gorilla 3 3 3 4 11 UT **2** **2** 3 4 11 ST used
D2		Ma xiang zhao xiao haigou horse want look for small fur-seal 'Horse wants to look for (the) small fur-seal.' horse want look for small fur-seal 3 3 3 3 33 UT **2** **2** **2** 3 **2**3 ST used
D3		Niu xiang bian lü qingwa bull want become green frog 'Bull wants to become (a) green frog.' bull want become green frog 2 3 4 4 11 UT 2 3 4 4 11 ST used
D4		Ma xiang deng da wugui horse want wait for big turtle 'Horse wants to wait for Big Turtle.' horse want wait for big turtle 3 3 3 4 11 UT **2** **2** 3 4 11 ST used
D5		Gou xiang deng xiao mayi dog want wait for small ant 'Dog wants to wait for (the) small ant.' dog want wait for small ant 3 3 3 3 33 UT **2** **2** **2** 3 **2**3 ST used

Figure 7.12 (cont'd)

D6		Zhu xiang bian lan jingyu pig want become blue whale 'Pig wants to become (a) small fur-seal.' pig want become blue whale 1 3 4 2 12 UT 1 3 4 2 12 ST used

Appendix F

Study 5 (RTR) Experimental materials

Narration: 我們要玩一個遊戲，這個遊戲叫“機器人說話”。你看這個機器人。她說話怪怪的，這隻熊熊都聽不懂。熊熊小莉只聽得懂小朋友說的話, 她不懂恐龍說的話。你可以幫她聽機器人說什麼嗎？聽到以後告訴小莉，好不好？你想玩這個遊戲嗎？
We are going to play a game called “Robot Talk (RT).” “Look at this Robot. She talks funny, and the bear doesn’t understand a word she says. The bear *Xiaoli* understands Child Talk only, not the Robot Talk. Can you help her? Listen to the Robot Talk, and then tell *Xiaoli* what she says, okay? Do you want to play the game?”

Figure 7.13 Study 5: List of materials

A1		Ni xiang mai hua you want buy flower ‘You want to buy flowers.’ 3 3 3 1 UT=RT[42]
A2		Wo xiang mai bi I want buy pens ‘I want to buy pens.’ 3 3 3 3 UT=RT
A3		Ta xiang kan shu he want read book ‘He wants to read books.’ 1 3 4 1 UT=RT

42 RT= Robot Talk (the manipulated speech)

Figure 7.13 (cont'd)

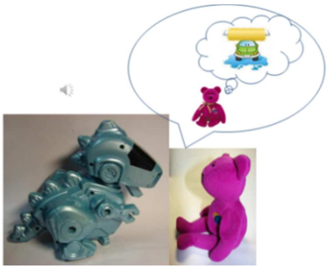
A4		Ni xiang xi che you want wash car 'You want to wash (the) car.' 3 3 3 1 UT=RT
A5		Wo xiang xi ma I want wash horse 'I want to wash (the) horse.' 3 3 3 3 UT=RT
A6		Ta xiang chang ge he want sing song 'He wants to sing.' 1 3 4 1 UT=RT
B1		Banma xiang zhao xiongmao Zebra want look for panda bear 'Zebra wants to look for Panda Bear.' Zebra want look for panda bear 13 3 3 21 UT=RT
B2		Haima xiang zhao shuimu seahorse want look for jelly fish 'Seahorse wants to look for Jelly Fish.' seahorse want look for jelly fish 33 3 3 33 UT=RT

Figure 7.13 (cont'd)

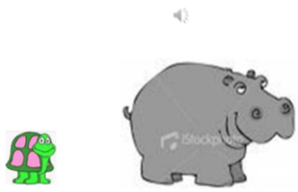
B3		Guoniu xiang bian qingwa snail want become frog 'Snail wants to become Frog.' snail want become frog 12 3 4 11 UT=RT
B4		Hema xiang deng wugui hippo want wait for turtle 'Hippo wants to wait for the turtle.' snail want become frog 23 3 3 11 UT=RT
B5		Laoshu xiang deng mayi mouse want wait for ant 'Mouse wants to wait for Ant.' mouse want wait for ant 33 3 3 33 UT=RT
B6		Haibao xiang bian jingyu seal want become whale 'Seal wants to become Whale.' seal want become whale 34 3 4 12 UT=RT
C1		Wo xiang zhao da hema I want look for big hippo 'I want to look for Big Hippo.' I want look for big hippo 3 3 3 4 23 UT=RT

Figure 7.13 (cont'd)

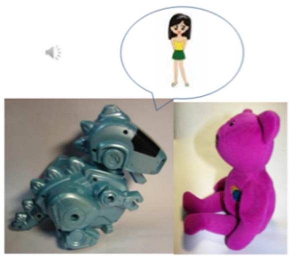
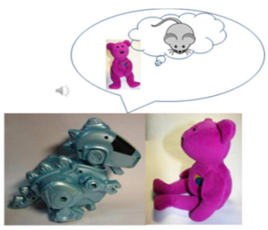
C2		Ni xiang yang xiao laohu you want raise small tiger 'You want to have (raise) a small Tiger.' you want raise small tiger 3 3 3 3 33 UT=RT
C3		Ta xiang chuan duan qunzi she want wear short skirt 'She wants to wear a short skirt.' she want wear short skirt 1 3 1 3 25 UT=RT
C4		Wo xiang zhao pang xiongmao I want look for fat panda bear 'I want to look for Fat Panda Bear.' I want look for fat panda bear 3 3 3 4 21 UT=RT
C5		Ni xiang yang xiao laoshu you want raise small mouse 'You want to have (raise) a small mouse.' you want raise small mouse 3 3 3 3 33 UT=RT
C6		Ta xiang ting hao yinyue she want listen to good music 'She wants to listen to good music.' she want listen to good music 1 3 1 3 14 UT=RT

Figure 7.13 (cont'd)

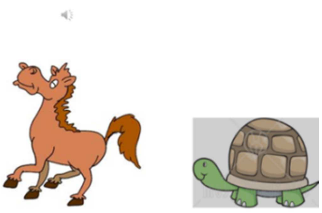
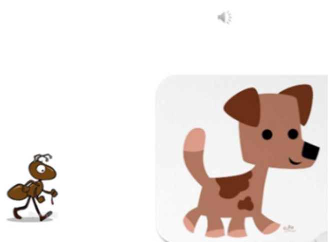
D1		Gou xiang zhao da xingxing dog want look for big gorilla 'Dog wants to look for (the) big gorilla.' dog want look for big gorilla 3 3 3 4 11 UT=RT
D2		Ma xiang zhao xiao haigou horse want look for small fur-seal 'Horse wants to look for (the) small fur-seal.' horse want look for small fur-seal 3 3 3 3 33 UT=RT
D3		Niu xiang bian lü qingwa bull want become green frog 'Bull wants to become (a) green frog.' bull want become green frog 2 3 4 4 11 UT=RT
D4		Ma xiang deng da wugui horse want wait for big turtle 'Horse wants to wait for Big Turtle.' horse want wait for big turtle 3 3 3 4 11 UT=RT
D5		Gou xiang deng xiao mayi dog want wait for small ant 'Dog wants to wait for (the) small ant.' dog want wait for small ant 3 3 3 3 33 UT=RT

Figure 7.13 (cont'd)

D6		Zhu xiang bian lan jingyu pig want become blue whale 'Pig wants to become (a) small fur-seal.' pig want become blue whale 1 3 4 2 12 UT=RT

Appendix G

Predicted surface patterns for test items in Study 4 NSR and Study 5 RTR

1. Four syllables, four words

a. Three T3*

[Ni	[xiang	[mai	[hua]]]]	
you	want	buy	flower	'You want to buy flowers.'
3	3	3	1	UT
3	3	3	1	Word: no T3S
3	3	(3	1)	Phrase: disyllabic foot for the smallest domain, no T3S
(**2**	3)	(3	1)	Phrase: Disyllabic foot for the remaining syllables, T3S; ST1
(**2**	**2**	3	1)	Larger domain in fast speech; ST2

b. All T3*

[Wo	[xiang	[mai	[bi]]]]	
I	want	buy	pen	'I want to buy pens.'
3	3	3	3	UT
3	3	3	3	Word: no T3S
3	(**2**	3)	Phrase: disyllabic foot for the smallest domain, T3S	
(**2**	3)	(2	3)	Phrase: Disyllabic foot for the remaining syllables, T3S; ST1
(**2**	**2**	**2**	3)	Larger domain in fast speech; ST2

2. Six syllables, four words

a. Three T3*

[[banma]	[xiang	[zhao	[xiongmao]]]]	
zebra	want	look for	panda bear	'Zebra wants to look for Panda bear.'
13	3	3	21	UT
(13)	3	3	(21)	Word: two disyllabic feet, T3S
(13)	(**2**	3)	(21)	Phrase: disyllabic foot, T3S; ST1
(1**2**	2	3)	(21)	Larger domain in fast speech, T3S; ST2

b. All T3*

[[haima]	[xiang	[zhao	[shuimu]]]]	
seahorse	want	look for	jellyfish	'Seahorse wants to look for Jellyfish.'
33	3	3	33	UT
(**2**3)	3	3	(**2**3)	Word: two disyllabic feet, T3S
(23)	(**2**	3)	(23)	Phrase: disyllabic foot, T3S; ST1
(2**2**	2	3)	(23)	Larger domain in fast speech, T3S; ST2

3. Six syllables, subject pronoun

a. Three T3*

[Wo	[xiang	[zhao	[da	[hema]]]]]	
I	want	look for	big	hippo	‘I want to look for (a) big hippo.’
3	3	3	4	23	UT
3	3	3	4	(23)	Word: T3S
3	3	3	(4	23)	Word: Incorporation, no T3S
(**2**	3)	3	(4	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(4	23)	Phrase: Incorporation, T3S; ST1

ii. Rightward incorporation:

(2	3**)**	(3	4	23)	Phrase: Incorporation, T3S; ST2
(2	**2**)	(3	4	23)	Optional: T3S across domains; ST3

b. All T3*

[Ni	[xiang	[yang	[xiao	[laohu]]]]]	
you	want	raise	small	tiger	‘You want to have/raise (a) small tiger.’
3	3	3	3	33	UT
3	3	3	3	(**2**3)	Word: T3S
3	3	3	(3	23)	Word: Incorporation, no T3S
(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2

ii. Rightward incorporation:

(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3

4. Six syllables, subject noun

a. Three T3*

[Gou	[xiang	[zhao	[da	[xingxing]]]]]	
Dog	want	look for	big	gorilla	‘Dog wants to look for Gorilla.’
3	3	3	4	11	UT
3	3	3	4	(11)	Word: T3S
3	3	3	(4	11)	Word: Incorporation, no T3S
(**2**	3)	3	(4	11)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(4	11)	Phrase: Incorporation, T3S; ST1

ii. Rightward incorporation:

(2	3**)**	(3	4	11)	Phrase: Incorporation, T3S; ST2
(2	**2**)	(3	4	11)	Optional: T3S across domains; ST3

b. All T3*

[Ma	[xiang	[zhao	[xiao	[haigou]]]]]	
horse	want	look for	small	fur-seal	‘Horse want to look for the small fur-seal.’
3	3	3	3	33	UT
3	3	3	3	(**2**3)	Word: T3S
3	3	3	(3	23)	Word: Incorporation, no T3S
(**2**	3)	3	(3	23)	Phrase: Disyllabic foot from left to right, T3S

Directionality for the Incorporation in the next step:

i. Leftward incorporation:

(2	**2**	3)	(3	23)	Phrase: Incorporation, T3S; ST1
(2	2	**2**)	(3	23)	Optional: T3S across domains; ST2

ii. Rightward incorporation:

(2	3**)**	(**2**	3	23)	Phrase: Incorporation, T3S; ST3

Appendix H

Statistics notes
Multinomial logistic regression and Odds Ratio (OR)

Multinomial logistic regression is a powerful model that can handle outcomes that are ordinal (ordered categories) or nominal (unordered categories). In this model, given a set of independent variables, we can generate the predictions of the probabilities of different outcomes.

The odds is a ratio of the probability that an event will occur versus the probability that the event will not occur. Odds ratio is the ratio of probability of choosing one outcome category over the probability of choosing the reference category (UCLA: Academic Technology Services, Statistical Consulting Group). Field (2005/2009:739) illustrates Odds Ratio (OR) with an example as follows.

> "Odds ratio is the ratio of the odds of an event occurring in one group compared to another. So for example, if the odds of dying after writing a glossary are 4, and the odds of dying after not writing a glossary are .25, then the odds ratio is 4/.25 = 16. This means that if you write a glossary you are 16 times more likely to die than if you don't. An odds ratio of 1 would indicate that the odds of a particular outcome are equal in both groups."

Assume that there are two correct T3S surface patterns, Pattern A and Pattern B. When speakers produce a T3S phrase/sentence, the response can be Pattern A, Pattern B, or incorrect. The outcome measure in this study is the speakers' responses – Pattern A, Pattern B, and incorrect answer. From the outcomes, we will see what relationships exist with other important independent variables. I will use this study as an example to illustrate the interpretation of the analysis. In Table 9.1, 'age' and 'structure' are two independent variables to the outcome. These two variables are both categorical, rather than gradient. For the variable 'age,' there are three age groups— 4-year-olds, 6-year-olds, and adults. For the variable 'structure,' there are two structures, Structure X and Structure Y.   I select incorrect answer as the reference category.

Table 9.1 An example of the statistics output and the interpretation of the results

Parameter Estimates									
T3S surface patterns[a]		B	Std. Error	Wald	df	**Sig.**	**Exp(B)**	95% Confidence Interval for Exp(B) Lower Bound	Upper Bound
Pattern A	Intercept	1.130	.480	5.534	1	.019			
	age_group=4	-1.504	.531	8.030	1	**.005**	**.222**	.079	.629
	age_group=6	.323	.600	.290	1	**.590**	**1.382**	.426	4.480
	age_group=adults	0[b]	.	.	0	**.**	**.**	.	.
	structure= X	.943	.381	6.113	1	**.013**	**2.567**	1.216	5.421
	structure= Y	0[b]	.	.	0	.	.	.	.
Pattern B	Intercept	2.319	.485	22.820	1	.000			
	age_group=4	-1.458	.639	5.205	1	**.023**	**.233**	.067	.814
	age_group=6	-.375	.669	.315	1	**.575**	**.687**	.185	2.550
	age_group= adults	0[b]	.	.	0	**.**	**.**	.	.
	structure= X	-2.841	.470	36.564	1	**.000**	**.058**	.023	.147
	structure= Y	0[b]	.	.	0	.	.	.	.

a. The reference category is: Incorrect answer.

b. This parameter is set to zero because it is redundant.

A quick general information in Table 9.1 shows that the difference between 4-year-olds and adults has been found to be statistically different for Pattern A (or Pattern B) to Incorrect answer given that **age** and **structure** are in the model (Pattern A: p = .005, Pattern B: p = .023), but there are no difference between 6-year-olds and adults (Pattern A: p = .590, Pattern B: p = .575). Variable "structure" is statistically significant in Pattern A (p = .013) and Pattern B (p < .001[43]), it means the difference between structure X and structure Y has been found to be statistically different for Pattern A (Pattern B) to incorrect answer. Next, I will show specifically what the values in Exp (B) tell us.

An important concept in this model is comparison, and in the comparison, there is always a reference category. For instance, Pattern A and Pattern B are both compared to the reference category "Incorrect answers." Both child groups are being compared to adults. Between the two structures, Structure Y is selected to be the reference category. Reference categories are not fixed, so if we want to use 4-year-olds as the reference group, it is fine, but it is more meaningful to

[43] Although in Table 9.1, we see .000, it is typically reported as < .001 because this is an extremely small number such as .00000000173 which the table does not show.

have the two child groups compared to the adults (reference group) for the purpose of the studies in this dissertation. Similarly, we can use Structure X as a reference category if we choose to.

Two columns (Table 9.1) we should read are in bold, “sig.” and “Exp (B).” “Sig” tells us whether or not it is statistically significant. Typically, a value less than .05 is considered statistically significant. Exp (B) in the table is the so-called Odds Ratio (OR) value. The Exp (B) column can tell us that a particular thing of interest is more likely or less likely to be in the referent group.

Pattern A:

The use of Pattern A relative to errors in Structure X and Structure Y is significantly different (*Odds Ratio* (*OR*) = 2.567, $p = .013$). The OR value indicates that Structure X is about 2.5 times (exact number is 2.567) more likely to have Pattern A than Structure Y.

For the surface Pattern A relative to incorrect answers, 4-year-olds (*OR* = .222, $p = .005$) are significantly different from adults, but 6-year-olds are not (*OR* = 1.382, $p = .590$).

Given that adults are the reference group, an OR value smaller than 1 in another age group indicates that Pattern A is less likely to happen in that age group, and an OR value greater than 1 indicates that Pattern A is more likely to happen in that age group. For instance, the OR value for 4-year-olds is .222, which means 4-year-olds are less likely than adults to prefer to use Pattern A over incorrect answers. Four-year-olds are “.222 times more likely” to use this pattern, which is not as easy to process. This actually means that adults are more likely to use the pattern by 4.5 times (1/.222= 4.50). For 6-year-olds, the OR value is greater than 1, so that means they are more likely (roughly 1.4 times, OR = 1.382) than adults to prefer to use this pattern over incorrect answers.

Pattern B:

The use of Pattern B relative to errors in Structure X and Structure Y is also significantly different (*OR* = .058, $p < .001$). Notice that the OR value is smaller than 1. This means that Pattern B is less likely to occur in Structure X than in Structure Y. If we take Structure Y (reference category) as “1,” Structure X is .058 (the OR value), and we can say Pattern B is more likely to be used by approximately 17 times (1/.058= 17.24) in Structure Y than in Structure X.

For the surface Pattern B relative to incorrect answers, 4-year-olds (*OR* = .233, $p = .023$) are significantly different from adults, but 6-year-olds are not (*OR* = .687, $p = .575$). By looking at the OR values of the two child groups, the OR values are smaller than 1, indicating that children are less likely than adults to prefer to use Pattern B over incorrect answers. Adults are about 4.3 times (1/.233= 4.29) more likely than 4-year-olds, and about 1.5 times (1/.687= 1.46) more likely than 6-year-olds to use this pattern.

Overall, in addition to the information on statistical significance, Multinomial logistic regression generates OR which allows us for additional interpretation. By how many times of that one event occurs more than the other is encoded in the OR value and can be calculated if we are interested in learning the information.

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