

The effect of phonotactic constraints on tone sandhi application: A cross-sectional study of Xiamen Min

Chunyu Ge¹, Peggy Mok¹

¹The Chinese University of Hong Kong

chunyu@ge@cuhk.edu.hk, peggymok@cuhk.edu.hk

Abstract

Nonce-probe test has been extensively used to investigate the productivity of tone sandhi. The nonce words used in previous studies on Xiamen tone sandhi were usually disyllabic wug words with accidental gap syllables. This study aims at isolating the effect of phonotactic constraints by investigating the application of Xiamen tone sandhi to both (1) disyllabic semi-wug words made up of real syllables and (2) disyllabic wug words consisting of one accidental-gap syllable and one real syllable. Picture-naming tasks were used to elicit the production of these conditions from children, teenagers, middle-aged adults and older speakers. The results showed that Xiamen tone sandhi was highly productive for semi-wug words but far less productive for wug words. Children and teenagers made some errors in applying the correct tone sandhi rules to real and semi-wug words, while their accuracy of applying tone sandhi to wug words was very similar to those of the middle-aged and older speakers. It is concluded that Xiamen tone sandhi is highly productive in phonotactically well-formed real syllables but less productive in phonotactically ill-formed syllables.

Index Terms: tone sandhi, phonotactic constraints, Xiamen Southern Min

1. Introduction

Languages consist of many linguistic processes/rules, some of which are productive in that they can apply to new forms [1]. Successful language acquisition implies the learning of these linguistic processes and children are expected to show productive knowledge of these processes [2].

In Chinese, a special and widely found phonological process, tone sandhi, has attracted much research attention and previous studies have investigated whether tone sandhi is productive or not in various Chinese dialects. Tone sandhi is the categorical change of citation tones into sandhi tones due to position, nearby tone environment or prosodic condition [3]. This study investigates a famous example in Xiamen Southern Min, the Xiamen tone sandhi circle (It is also referred to as Taiwanese tone sandhi circle in some other studies. The tone sandhi systems are largely consistent and the two varieties are basically the same.) There are seven lexical tones in Xiamen Min, five of which appear in unchecked syllables (with nasal coda or no consonantal coda) and two appear in checked syllables (with obstruent or glottal stop coda) [4]. All tones undergo tone sandhi in non-final positions in a tone group [5]. Xiamen tone sandhi is a tone substitution process [6] in that the citation tone is substituted with another sandhi tone and the entire tone sandhi processes of all citation tones in unchecked syllables form a circle (The tone sandhi of checked tones is not included here.), as shown in Figure 1. An example with tone 44 is shown in (1), in which a syllable with citation tone 44 surfaces as the sandhi tone 22 when it appears in non-final positions.

(1) hui⁴⁴ ki⁴⁴ → hui²² ki⁴⁴ “plane”

Another characteristic of Xiamen tone sandhi is that it is phonologically opaque [7]. Xiamen tone sandhi is not driven by surface-true generalizations such that the tone sandhi is not driven by surface phonotactic constraints or obligatory contour principles. Moreover, the output of one tone sandhi rule has the same form as the input of another tone sandhi rule [8].

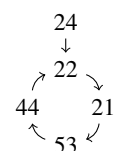


Figure 1: *The Xiamen tone sandhi circle*

Given the complexity and opacity of Xiamen tone sandhi, its productivity has been investigated by previous studies, and the most commonly used approach is nonce-probe tests. In nonce-probe tests, syllables with base tone are presented to speakers, and they are asked to combine the syllables as a real disyllabic word to see whether they can apply the correct tone sandhi rules [8]. [9] explored this question with nonce words combined by actually-occurring (AO) syllables and three children and five adults participated in the experiment. The results showed that the accuracy of correct tone sandhi application is lower for children than for adults. He suggested that Taiwanese speakers need to remember the surface forms and the tone sandhi rules are not productive. The finding that children were less accurate than adults in applying the tone sandhi rules was also replicated by [10] using picture-naming tasks. The productivity of separate Taiwanese tone sandhi rules was investigated by [11] and they found that the phonological opacity impairs the productivity of tone sandhi. However, some other studies proposed that lexical representation has a role to play in linguistic computation and it can influence the application of tone sandhi rules. For example, [12] asked Taiwanese speakers to recover the citation tone of the first syllable in a disyllabic word, and they found that the speakers were highly accurate for native Min words, and less accurate yet above chance level for Japanese loanwords. This study highlights the effects of the foreignness of materials and lexical status in correct tone sandhi application.

With this backdrop, it is necessary to separate two effects in Xiamen tone sandhi application, i.e., the effect of lexical status/representation and the effect of phonotactic constraints. In previous studies, tone sandhi application in words with accidental gap (AG) syllables was used as an important evidence to answer the productivity question, such as in [11] and [13]. The speakers exhibited remarkably lower accuracy in these syllables than in real words. However, using AG syllables alone cannot tease apart the effect of phonotactics itself from the effect of

lexical status. This study aims to supplement this gap by using two types of nonce words. The first is semi-wug words consisting of two real syllables while the resulting disyllabic word is non-existent, and the second is wug words with the first syllable as an accidental-gap syllable and the second syllable as a real syllable. Moreover, to complement previous studies mainly focusing on adults, children and teenagers were also recruited to depict a fuller picture with regard to the acquisition of Xiamen tone sandhi.

2. Method

Speakers of different age groups were recruited, and the number of each age group and gender can be seen in Table 1. Since the tasks in this study are difficult for younger children and our pilot data showed that children aged five or below could hardly complete the task, only children aged six or older were included in this study. Previous study also showed that the acquisition of tone and tone sandhi is a protracted process and even older children still do not have adult-like performance [14]. Therefore, a larger age span was included in this study and teenagers were also recruited. Middle-aged and older adults were included to provide a baseline for children and teenagers, but could also reveal whether there is any difference in tone sandhi application depending on age. Older adults were included because the dominance of Standard Chinese in Xiamen has profound influence on Xiamen Min and older listeners are expected to be less influenced by Standard Chinese.

Table 1: Number of speakers in four age groups and their age range.

Age group (age range)	Female	Male
older (61-73)	3	2
middle-aged (36-55)	8	4
teenager (14-19)	4	1
children (6-11)	4	7

Previous studies usually used auditory stimuli to elicit the production of target words [9, 11]. This approach can lead to mere imitation of the auditory stimuli by the participants. Therefore, in this study, picture-naming tasks were used to elicit the production of disyllabic words. Two pictures appeared on the screen and the participants were asked to combine the two actually-occurring (AO) monosyllabic words corresponding to each picture into a disyllabic word. To investigate the effect of lexical status, the resultant disyllabic word can be real or nonce with both syllables as AO syllables in Xiamen Min. The first type is real words and the second type is referred to as semi-wug words in this study. For AG syllables, since they are non-existent, an auditory stimulus of the syllable was presented to the participants to familiarize them with the syllable. The AG syllables were read by a trained phonetician who is a female Xiamen native speaker. Each AG syllable was played three times. When the participants were listening to AG syllables, a cartoon figure also appeared on the screen so that the AG syllable would be associated with the cartoon figure, thus being treated as a new morpheme with a referential meaning, i.e., on a par with the real syllables. After the participants had heard the AG syllables, the novel cartoon figure would appear on the screen together with another picture, which represents a real syllable, and they were asked to combine the two syllables into a disyllabic word. This type of nonce word is referred to as wug

words in this study. Therefore, real disyllabic words capture the participants' knowledge of Xiamen tone sandhi, and semi-wug words can be used to capture the effect of lexical status without the interference of phonotactic constraints, while the effect of lexical status and phonotactic constraints were both manipulated in wug words. Examples of pictures and syllables used in the experiment are shown in Figure 2.

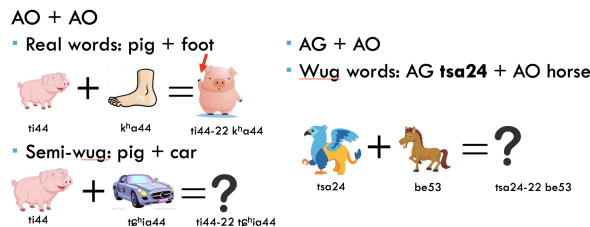


Figure 2: Example of pictures used in real, semi-wug and wug words

Five words for each tone sandhi rule were selected for real words and semi-wug words, amounting to 5 words \times 5 tones = 25 test words for real and semi-wug words. For wug words, three AG syllables were selected for each tone sandhi rule, resulting in 3 words \times 5 tones = 15 words in total. The production of the participants was recorded in the local community in Xiamen using a solid-state recorder ZOOM H2N. The recordings were manually checked and the accuracy of tone sandhi application was judged by one female Xiamen native speaker (21 years old) who has received phonetic training.

3. Results

The production of the participants was judged based on the first syllable of the disyllabic words, and the first syllable can be pronounced as the citation tone, the sandhi tone, or another wrong tone. First of all, the accuracy of the correct tone sandhi application in real words is shown in Figure 3. Both older and middle-aged adults always apply correct tone sandhi rules when they combine the two syllables. Even for teenagers and children, their overall accuracies were also above 80%. Figure 6 displays the accuracy of tone sandhi application by age group as well as by tone sandhi rule. Teenagers were almost perfect at Tone 44 and Tone 24, but less so for other tones, while children were in general less accurate in all tones, but with almost perfect accuracy for Tone 21. Nevertheless, the high accuracy of children in real words may only indicate that they have learned the words, instead of the tone sandhi rules. Also, it indicates that the participants can understand the task well to combine the two syllables into a disyllabic word.

But have the children really learned the tone sandhi rules? The accuracy for semi-wug words among age groups is shown in Figure 4. In semi-wug words with AO syllables, there is one thing to note that one of the older speakers never applied tone sandhi rules to the disyllabic words, while all the other older speakers always applied tone sandhi rules correctly. To simplify the pattern, the data of that speaker who never applied tone sandhi rule was not included. The implication of this finding will be discussed further in the Discussion section.

For the remaining older speakers, it is obvious that the tone sandhi rules are productive such that they can always apply these rules correctly to semi-wug words, which they have never encountered before. It is also true for the middle-aged speakers, but with slightly lower accuracy than the older speakers. Teenagers

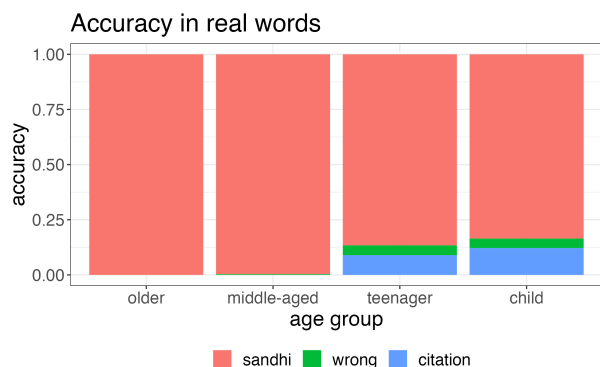


Figure 3: Accuracy of tone sandhi application for real words by age groups

have lower accuracy than the middle-aged speakers, but the accuracy is well beyond 75% for most tone sandhi rules, as shown in Figure 6. Children can also sometimes apply tone sandhi rules correctly, with an overall accuracy higher than 50%. Among the tone sandhi rules, the children have learned Tone 44 and Tone 24 better than other tones.

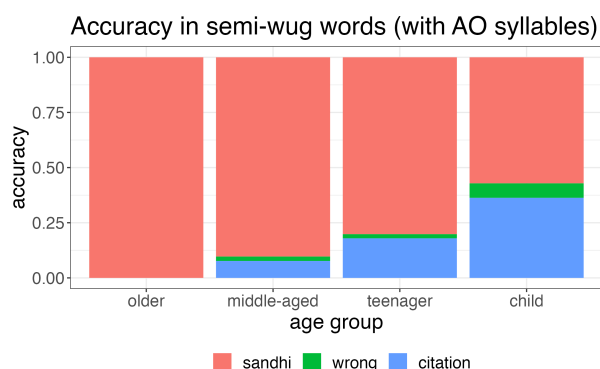


Figure 4: Accuracy of tone sandhi application for semi-wug words (with AO syllables) by age groups

The results of semi-wug words suggest that children and teenagers have learned the tone sandhi rules, but can they apply the correct rules to AG syllables, with the interference of phonotactic constraints? The accuracy of wug words with the first syllable as AG syllables is shown in Figure 5 and the results differ dramatically from those of real and semi-wug words. For all age groups, the accuracy is only around 25% consistently, in contrast to the almost perfect accuracy in real and semi-wug words for adults and even teenagers. When the older speakers did not apply tone sandhi rules, they used citation tones instead, as they heard in the auditory stimuli. The middle-aged speakers also used citation tones most of the time, but they also made several mistakes, using another irrelevant tone. Teenagers and children made even more errors.

In addition, there is another point worth noting. The accuracy of tone sandhi application for wug words is almost the same across different age groups. In other words, the accuracy does not develop as the proficiency of Xiamen Min develops. To validate this finding, a generalized mixed-effects model was fitted to the data with the judgment (sandhi vs. non-sandhi, i.e., citation or wrong) as the dependent variable, age group as in-

dependent variable, and the speaker as random intercept. The coefficients of the model show that there is no significant difference between the older speakers and the middle-aged speakers ($\beta = 0.03, SE = 0.44, z = 0.08, p = 0.94$), neither do teenagers ($\beta = 0.20, SE = 0.56, z = 0.35, p = 0.72$) and children ($\beta = 0.25, SE = 0.45, z = 0.55, p = 0.58$).

Consistent with this observation, the accuracy by tone sandhi rule also shows some similarities among age groups. Tone 44 and Tone 24 have considerably higher accuracy than other tones for all age groups. Tone 44 and Tone 24 have accuracy over 50%, but the tone sandhi rules barely apply for other tones, which holds among all age groups. This agrees well with previous studies that Tone 44 and Tone 24 are more productive than other tones [11].

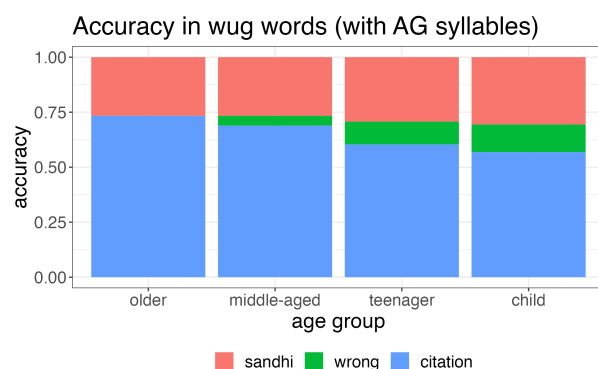


Figure 5: Accuracy of tone sandhi application for wug words (with AG syllables) by age groups

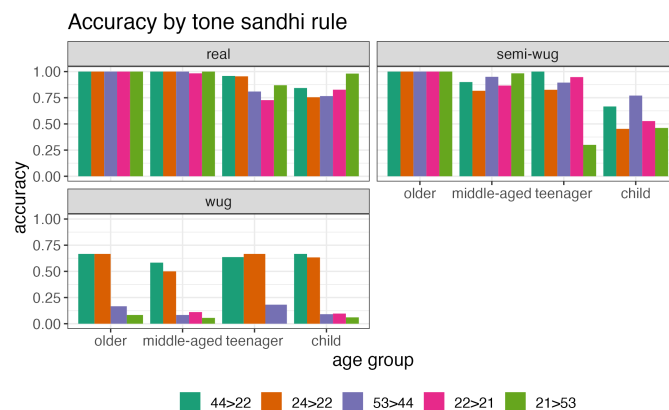


Figure 6: Accuracy of tone sandhi application for real, semi-wug, wug words (with AG syllables) by age groups and tone sandhi rules

Taken together, Xiamen speakers can apply tone sandhi rules to new forms with almost perfect accuracy, even if the forms do not have a lexical representation (semi-wug words). But for disyllabic word combinations consisting of AG syllables (wug words), the accuracy is considerably lower.

4. Discussion

The productivity of Xiamen tone sandhi circle is a contentious issue and this study aims to answer this question by teasing apart

the effect of phonotactic constraints from lexical representation and also by investigating the patterns of children and teenagers as compared to middle-aged and older speakers. In semi-wug words with AO syllables, adults can apply the correct tone sandhi rules with almost perfect accuracy, suggesting high productivity. As expected, children were less accurate in applying tone sandhi rules in semi-wug words, but the accuracy of teenagers was also very high, indicating that speakers can learn the tone sandhi rules and that productivity increases as language proficiency develops. This finding replicates the results of a previous study [10]. However, in wug words with AG syllables, although the tone sandhi rules can sometimes apply, there was no significant difference among adults, teenagers and children in tone sandhi application accuracy. In other words, although Xiamen tone sandhi was not completely unproductive in wug words, its application did not develop as language proficiency develops, i.e., fossilized.

The key difference between semi-wug and wug words was that semi-wug words lack lexical representations, but wug words also violate phonotactic constraints, in addition to their lack of lexical representations. Based on the results, Xiamen tone sandhi is productive if the target syllable is an existing syllable, but it is less productive if the syllable is not a real syllable (but not totally unproductive). Therefore, the productivity of Xiamen tone sandhi is decreased by the manipulation of phonotactic constraints.

The effect of phonotactic constraints can help us answer a long-standing question in the study of Xiamen tone sandhi. It has been shown for a long time that the most critical factor in the productivity of Xiamen tone sandhi is the foreignness of materials, which [9] defined as how detached the material is from everyday language. It has also been proposed that the low productivity of Xiamen tone sandhi should be attributed to the foreignness of the materials [12], instead of the unproductivity of tone sandhi. But the question is which linguistic factors determine or contribute to foreignness. This study is a step toward understanding this question and reveals that phonotactic constraint is one important factor that contributes to foreignness. Nevertheless, the syllables used in this study were all accidental gaps in Xiamen Min, and one natural question is what the results would be like if syllables of systematic gaps were used. Further study is underway to explore the effect of systematic gaps on the productivity of Xiamen tone sandhi.

In terms of tone sandhi rules, even if there were some variations with regard to semi-wug words, Tone 44 > 22 and Tone 24 > 22 were the most accurate tone sandhi rules for all age groups in wug words. The high productivity of Tone 24 > 22 agrees well with previous findings of [13, 11]. They attributed its high productivity to the transparent characteristic that Tone 24 can never appear non-finally. However, this cannot account for the finding that Tone 44 > 22 is also highly productive, which is also the second most productive tone sandhi rule in [13]. Moreover, [12] reported that Tone 22 > 21 is the most productive rule. The reason for the discrepancy may be due to both the materials and the tasks, but a deeper understanding requires further study.

Cross-linguistically, in contrast with the weaker productivity of Xiamen tone sandhi in wug words, Mandarin Tone 3 sandhi is highly productive even in wug words [15, 16]. [8] proposed that the difference is due to the transparent nature of Mandarin Tone 3 sandhi. However, in Xiamen Min, for the transparent Tone 24 > 22 rule, it still fails to reach 100% accuracy in wug words in our data. The effect of phonotactics on tone sandhi application may be the key to understanding this puzzle and more study is needed.

Although there was no difference between the accuracy for

AG syllables across age groups in this study, it is still possible that the accuracy may be different if age is more finely delineated. For instance, children were treated as one group without sub-grouping due to the limited number of children in this study. However, it is possible that younger children may behave differently from older children in applying tone sandhi rules in wug words. More children data need to be collected to further investigate the developmental trajectory of Xiamen tone sandhi.

Individual difference was not investigated systematically in this study, although we did find evidence of individual difference, as mentioned above when presenting the results of semi-wug syllables. One older speaker never applied tone sandhi in semi-wug words, but he always applied tone sandhi rule in real words and could even sometimes apply in wug words. That is to say, his reluctance of applying tone sandhi to semi-wug words may not be due to the fact that he did not understand the task. The cause of this phenomenon needs to be investigated with data from more speakers. Last but not least, the results were based solely on perceptual judgement and acoustic analysis is under way to investigate the subtle patterns of tone sandhi realization.

5. Conclusions

This study investigated the productivity of Xiamen tone sandhi circle using a picture-naming task with materials varying in both lexical representation and phonotactic constraints. Data from adults, teenagers, and children were collected, and the results highlighted that phonotactic constraints can considerably decrease the productivity of Xiamen tone sandhi, which is not influenced by the lack of lexical representation alone. It is also found that the accuracy in wug words is stable across age groups, and Tone 44 > 22 and Tone 24 > 22 were the most productive rules.

Further study of the acquisition of Xiamen tone sandhi is underway, and many more participants, including both adults and children, have been recruited. It is expected to depict a more fine-grained picture of the development of Xiamen tone sandhi and also to contribute to the understanding of the productivity of tone sandhi and opaque phonological processes in general.

6. Acknowledgements

This study is supported by the RGC General Research Fund Project Reference 14611322 The acquisition of complex tone sandhi. Thanks also go to Jingyi Wang for collecting data for us, and Zihao Wei and Yiyang Hu for processing the data. The authors would particularly like to thank Xiaolin Li for her important contribution in the early stages of the project.

7. References

- [1] J. Bybee, *Phonology and Language Use*, ser. Cambridge Studies in Linguistics. Cambridge: Cambridge University Press, 2001.
- [2] R. Shi and E. Emond, "The threshold of rule productivity in infants," *Frontiers in Psychology*, vol. 14, 2023.
- [3] M. Y. Chen, *Tone Sandhi: Patterns across Chinese Dialects*, ser. Cambridge Studies in Linguistics. Cambridge, UK ; New York: Cambridge University Press, 2000.
- [4] C. Luo, *The Phonology of Xiamen Min [in Chinese]*. Beijing: The Science Press, 1956.
- [5] M. Y. Chen, "The syntax of Xiamen tone sandhi," *Phonology*, vol. 4, no. 1, pp. 109–149, May 1987.
- [6] J. Zhang, "A directional asymmetry in Chinese tone sandhi systems," *Journal of East Asian Linguistics*, vol. 16, no. 4, pp. 259–302, Dec. 2007.

- [7] P. Kiparsky, "Abstractness, Opacity, and Global Rules," in *Three Dimensions of Linguistic Theory*, O. Fujimura and D. L. Smith, Eds. Tokyo, Japan: TEC Company, Ltd., 1973.
- [8] J. Zhang, "Using Nonce-probe Tests and Auditory Priming to Investigate Speakers' Phonological Knowledge of Tone Sandhi," in *5th International Symposium on Tonal Aspects of Languages (TAL 2016)*. ISCA, May 2016, pp. 12–18.
- [9] H.-I. Hsieh, "How generative is phonology?" in *The Transformational-Generative Paradigm and Modern Linguistic Theory*, E. F. K. Koerner, Ed. Amsterdam: John Benjamins Publishing, 1975, pp. 109–144.
- [10] X. Li and P. P. K. Mok, "The acquisition of tone sandhi of the Xiamen dialect," in *Speech Prosody 2020*. ISCA, May 2020, pp. 479–483.
- [11] J. Zhang, Y. Lai, and C. Sailor, "Opacity, phonetics, and frequency in Taiwanese tone sandhi," in *Current Issues in Unity and Diversity of Languages: Collection of Papers Selected from the 18th International Congress of Linguists*. Linguistic Society of Korea Seoul, 2009, pp. 3019–3038.
- [12] C.-t. Chuang, Y.-c. Chang, and F.-f. Hsieh, "Productivity in Taiwanese tone sandhi redux," in *Proceedings of ICPHS XVII*, Hong Kong, 2011, pp. 492–495.
- [13] J. Zhang and Y. Lai, "Phonological Knowledge beyond the Lexicon in Taiwanese Double Reduplication," in *Interfaces in Chinese Phonology: Festschrift in Honor of Matthew Y. Chen on His 70th Birthday (Language & Linguistics Monograph Series, Number W-8)*, Y. Hsiao, H.-C. Hsu, L.-H. Wee, and D. Ho, Eds. Academia Sinica, 2008, pp. 183–222.
- [14] P. P. K. Mok, V. G. Li, and H. S. H. Fung, "Development of Phonetic Contrasts in Cantonese Tone Acquisition," *Journal of speech, language, and hearing research: JSLHR*, vol. 63, no. 1, pp. 95–108, Jan. 2020.
- [15] J. Zhang and Y. Lai, "Testing the role of phonetic knowledge in Mandarin tone sandhi," *Phonology*, vol. 27, no. 1, pp. 153–201, May 2010.
- [16] C. Zhang and G. Peng, "Productivity of Mandarin Third Tone Sandhi: A Wug Test," in *Eastward Flows the Great River: Festschrift in Honor of Prof. William S-Y. Wang on His 80th Birthday*, G. Peng and F. Shi, Eds. Hong Kong: City University of Hong Kong Press, 2013, pp. 256–282.