A Preliminary Study on the Productivity of Mandarin T3 Sandhi in Mandarin-speaking Children

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Abstract

Mandarin Tone 3 (T3) sandhi is highly productive in novel words produced by native adult speakers. However, it is unclear when the sandhi pattern becomes productive in young children learning Mandarin Chinese as their mother tongue. To address this issue, this preliminary study examined the productivity of T3 sandhi in different age groups (children aged 3 to 6 and adults) in real words and two types pseudowords, real words that were actual occurring words (AO), semi-pseudowords that were non-occurring combinations of two real monosyllables (*AO) and pseudowords where the first syllable was an accidental gap (AG). Preliminary results showed that children's application of T3 sandhi might reach an adult level in real words as early as three years old. However, in the *AO condition, children may reach an adult-like application at five years old. In the AG condition even the 6-year-old children may not reach an adult-like application rate; besides, among the children, the 3-year-old children performed worse than the older children although none of them were adult-like. These preliminary results imply that children's learning of the tone sandhi words undergoes a gradual transformation from a rote-memory based lexical mechanism to a computation-based productive mechanism. Until six years of age, Mandarin-speaking children may not have developed the adult-like competence of computation mechanism.

Index Terms: Mandarin T3 sandhi, productivity, Mandarin-speaking children

1. Introduction

Tone sandhi refers to tonal alternations in speech production that are conditioned by linguistic context [1]. Tone sandhis are manifested in different ways among Chinese dialects. For example, in Mandarin Chinese, when two Tone 3 (T3) syllables are juxtaposed in connected speech, the first T3 becomes tone 2 (T2) or a T2-like (213+213→35+213) [2]-[5]. For instance, the T3+T3 word /mei213nv213/ ('beauty') is ultimately pronounced as /mei35nv213/. On the other hand, in Southern Min, every tone undergoes sandhi, unless it occurs in a final word position [6]. For example, the word /pai24 kai51/ ('to eliminate') is pronounced as /pai33 kai51/. What we focus on in this study is the T3 sandhi in Mandarin Chinese.

Tone sandhis in different dialects are suggested to be manipulated via two mechanisms, i.e., the computation mechanism or the lexical mechanism [5],[6]-[11]. The computation mechanism suggests that the sandhi forms of a tone are computed by applying the phonological pattern, no matter whether it is a real word or a novel word (e.g.,[9] and [10]). In contrast, the lexical mechanism maintains that the encoding of tone sandhi is manipulated through memorizing the lexical forms and the surface phonological representations, and it therefore only applies to real words (e.g., [6] [11] and [12]).

A key factor to examine what mechanism is involved in the production of a phonological pattern is productivity. When listeners are asked to produce a new word, the tone sandhi is not always generalizable to new words to the same degree. Previous studies have consistently shown that the tone sandhi pattern in Mandarin Chinese is highly productive in new words and is encoded by the computation mechanism in adult speech [13] [5] [9] and [10]. However, it is still unclear when this phonological pattern becomes productive in children learning Mandarin as their mother tongue.

Children's acquisition of some linguistic patterns is assumed to undergo several developmental stages, progressing from a memory based lexical mechanism, to a computation mechanism, finally to a combination of both [14] [15]. For example, the acquisition of English plural inflection is reported to go through stages from occasional productions with plural inflections (implying a lexical mechanism) to the stage where children produce more plurals with frequent overgeneralizations (implying a computation mechanism). At the final stage, both computation and lexical mechanism are involved in the manipulation of the plural ending: for the regular nouns (e.g., shoe-shoes), the computation mechanism is adopted, whereas the irregular nouns (e.g., man-men) are possibly operated via the lexical mechanism. It is likely that the acquisition of Mandarin tone sandhi undergoes a similar developmental trajectories, i.e., from the lexical mechanism to the computation mechanism. For example, children may learn to speak the word /ɕiɑu213kou213/ ('puppy') by storing the surface-form-word /ɕiɑu 35kou213/ as a frozen chunk in mind. However, the acquisition of T3 sandhi goes beyond the storage of surface-form tone sandhi words at a certain age, such that the children may become capable of applying the pattern to new words they have not heard before. Besides, it is also possible that both mechanisms are available for them. For highly familiar real words, the sandhi form could be retrieved directly from memory, meaning that some real words could be encoded via the lexical mechanism. However, for the unfamiliar or pseudo-words, they tend to utilize the computation mechanism and apply the tone sandhi pattern productively to those words.

Previous research reported that Mandarin-speaking children acquired lexical tones and T3 sandhi words in real words relatively early in life (at or before age 3) [16]-[19], even though their productions may not be phonetically accurate enough [20]-[22]. However, correct production of tone sandhi in real words does not imply its productivity in novel words. It is likely that children just memorize the tone sandhi words as frozen chunks from the adult input at this stage. A previous experiment [23] found that child participant only recognized the

surface-form T3 sandhi words (e.g., /iy35 san213/), but failed to map the underlying-form sandhi words (e.g., /iy213 san213/) in identifying the same signal (e.g., 'umbrella') at age 3-5. This result suggests that children may maintain tacit knowledge that underlying-form sandhi words (e.g., /iy213 san213/) are not lexically equivalent to the surface-form sandhi words (/iy35 san213/). According to the study, children at age 5 have not yet listed two forms (underlying T3 form and surface sandhi form) as allomorphs of the same morpheme/word. This is possibly a hint that they only process the tone sandhi words at the level of unanalyzed examplars (subserved by the lexical mechanism) up to age 5.

Then, when would the children gain a productivity in the application of Mandarin T3 sandhi pattern? It is likely that children's productivity in pseudowords may undergo several stages that involve the acquisition of phonological awareness and computation mechanism. Before acquiring the computation mechanism, they are expected to acquire the awareness of the smaller units of the T3 sandhi words. Phonological awareness refers to the ability to perceive that spoken words consisted of smaller units of sound, as well as the ability to manipulate the spoken words in a language [24] - [26]. In this study, it refers to the ability to analyze a tone sandhi word into syllables, namely, the initial and final syllable and the tones carried by them, and to link the surface form of the initial syllable (e.g., /ɕiɑu35/) to the same word in a different tonal context (e.g., /ɕiɑu35 kou213/ and /ɕiɑu213 xua55/). This may be important for the productivity of tone sandhi.

While considering the adult production of Mandarin T3 sandhi, the sandhi form is suggested to be computed productively from the underlying form [27]. Combined with the aforementioned results reported on children, it is possible that children undergo the transformation from the lexical mechanism to the adult-like computation mechanism after 5 years old. This study examines when the Mandarin-speaking children acquire T3 sandhi and when the sandhi pattern becomes productive in novel words in four age groups (3-6 years old) and a group of adults as a control group.

2. Methods

2.1. Participants

19 children (age range: 3;1–6;7) and 4 adults were recruited for the preliminary study. Among the children, five were aged 3 (mean: 3;5), five were aged 4 (mean: 4;9), five were 5-year-old (mean: 5;8), and four were 6-year-old (mean: 6;4). All children were monolingual Mandarin speakers who had limited exposure to other languages, like English or other dialects. All children passed the hearing screening at 1 KHz, 2 KHz, and 4 KHz at 30 dB under headphones using Interacoustic AS608 Screening Audiometer. All children were instructed to do the Intelligence test (WPPSI-R; [28]). The children above four years old passed the test. Those who did not fulfill the test would be retested this year.

2.2. Stimuli

To examine the productivity of T3 sandhi, three types of disyllabic sequences were designed: real words, semi-pseudowords, and pseudo-words. Each type of the sequences included 20 test items (T3 + T3 words) and 20 control items (T3 + Non-T3 words). For items in the test and control group, the initial syllables within each pair were always the same. Among the sequences, the real words are actual occurring words in the daily life (AO). They are mostly high-frequency disyllabic words with concrete meaning, e.g., /ɕiɑu213 ts'au213/ 'grass' vs. /ɕiɑu213 xua55/ 'flower.' The semi-pseudowords are the non-occurring combinations of real monosyllables (*AO), that is, both initial and final syllables are occurring morphemes, but their combination is seldom found in everyday communication. In *AO condition, the two syllables are animals or other objects which are familiar to children. For example, /ma213 ts'au213/ 'horse grass' vs. /ma213 ʂ'u51/ 'horse tree'. In the pseudoword condition, we used accidental gaps (AG) in Mandarin syllabary as the initial syllable and a real monosyllable as the final syllable. The AG syllables were occurring syllables in Mandarin but yielded no real word when combined with either T2 or T3 (e.g., /miɛ213/; /miɛ51/ is a real word 'to destruct'). The AG syllables were introduced in the underlying form. To elicit the productions of the AG items, the experimenter gave each AG syllable a lexical meaning (e.g., /miɛ213/ 'to carry something by two men') and asked the children to combine the AG word and the occurring word into a new word. For example, /miɛ213 ts'au213/ 'to carry grass by two people.'

2.3. Procedure

This study adopted an elicited picture-naming task. An experimenter presented slides of pictures on a computer to the subjects and instructed them that they were going to play a word-guessing game. For the AO items, one picture was presented in each trial (see Figure 1a). The children were asked to produce the word. In the *AO condition, two pictures were shown on one slide to indicate the two syllables (see Figure 1b), and the children were required to combine the two words into a new word. In the AG condition, the experimenter gave each AG syllable a lexical meaning and asked the children to combine the AG word and a real monosyllabic word into a new word. Before the experiment, children were provided with practice trials to make sure that they understood the tasks. Use the novel word /miɛ213 ts'au213/ as an example: First, the experimenter showed a picture to indicate that 'miɛ213' means 'to carry something by two men' (see Figure 1c). Second, the experimenter familiarizes the children with the word with examples, such as "If two men carry a book, we would say /miɛ213 ʂ'u55/. Then if two men carry the grass (ts'au213), what we should say?" The children were instructed to produce the target form twice.

Lexicality	Test item	Control item
1a. AO 手表-手机		
1b. *AO 笔狗-笔猪		
1c. AG mie3 草- mie3 树		

Figure 1: *Sample materials in the three types of disyllabic sequences.*

The subjects' responses were recorded by digital recorders (Sony, ICD-PX470) at 16 bits and a 44.1 kHz sampling rate. The elicited production task lasted 30-60 minutes for a child and approximately 10 minutes for an adult. To avoid fatigue and keep the children engaged, the whole experiment was divided into at least six parts with rest between two parts. Moreover, a child would be awarded some gifts every time he/she actively engaged himself/herself in the experiment for more than 5 minutes.

3. Data analysis

The tone production judgment of the first T3 syllable of the disyllabic productions was analyzed. Before the analysis, the trials were scrutinized, and some trials were discarded if meeting the following criteria: (i) the initial syllable was mispronounced (e.g., tʂei213-tʂən213); (ii) there was a larger gap between the two syllables compared with the other productions of the speaker, indicating that they apparently did not form a disyllabic word; (iii) for the items that were produced twice, the first production was preferentially used, and the second production would be used only when the first production was unsuitable due to noise or other factors. A total of 2148 stimuli out of 2760 were preserved for analysis.

For the tones production judgments, eight Mandarin-speaking phoneticians who at least being postgraduate students in experimental phonetics were recruited as raters. They were all from Northern dialect speaking areas. The results of the three phoneticians were disregarded for analysis due to the following reasons: (i) the rating accuracy of the adult T3+Non-T3 trials was lower than 90% (it is consistent that the first syllable is T3 in T3+Non-T3 trials); (ii) they failed to reach a significant inter-judge agreement with others on tone sandhi application/non-application in the trials of the adult participants.

The judgment task was presented with E-Prime 2.0. In each trial, production of the disyllabic sequence (e.g., /miɛ213 tsʻau213/) was presented to the phoneticians first, and then the initial T3 syllable of that disyllabic sequence (e.g., /miɛ213/). The raters were instructed to identify whether the T3 syllable underwent the tone sandhi pattern or not. If applied, they should press 2, and if it was the underlying form of T3, they should press 3; if the production was neither the underlying form nor the surface form (mispronunciation), they were instructed to press 0. The stimuli were divided into eight blocks in which the three types of the stimuli were randomly mixed. Each block took the raters about 30 minutes. The raters were allowed to take breaks at any time they desired.

4. Results

We calculated the total number of test T3 items according to the result of the tone production judgment. Then we counted the percentage of items that were judged to undergo the tone sandhi pattern, and that failed to undergo the tone sandhi pattern, as well as that were judged to be mispronunciations (neither as the sandhi form nor the underlying form). Table 1 summarizes the sandhi application/non-application rate of T3 productions of the three types of the tone sequences in each age group. As is shown in the Table, the application rate in all conditions except that of the *AO and AG items in 3-year-old children were above 70%. And that of the 3-year-old children showed a tremendous difference between the AO word and the two types of pseudo-words. Among different age groups, the 3-year-old children also have more mispronunciations (others) compared with other

age groups. Statistic analysis with one-sample *t*-tests comparing the sandhi rate to the chance level showed that all the conditions except that of the AG items in 3-year-old children were above chance-level ($ps <.01$).

Table 1: *the sandhi application/non-application rate of the T3 word.*

	Lexicality	Sandhi	Underlying	Others
3y	AO	75.68%	19.46%	4.86%
	*AO	53.31%	30.58%	16.12%
	AG	54.92%	37.88%	7.20%
4y	AO	84.35%	15.65%	0.00%
	*AO	74.48%	25.52%	0.00%
	AG	74.70%	21.20%	4.10%
5y	AO	81.42%	18.58%	0.00%
	*AO	82.67%	16.73%	0.60%
	AG	77.82%	21.56%	0.62%
6y	AO	80.44%	19.56%	0.00%
	*AO	80.74%	19.26%	0.00%
	AG	77.69%	22.31%	0.00%
adult	AO	89.45%	10.55%	0.00%
	*AO	88.35%	11.65%	0.00%
	AG	88.72%	11.28%	0.00%

The sandhi application rates were analyzed using two-way repeated measures ANOVA with *age group* (3y, 4y, 5y, 6y, and adult) as the between-subjects factor, and *lexicality* (AO, *AO, and AG) as the within-subject factor. Results showed that there was a significant main effect of *age group* [F (4, 330) = 17.046, p = .000], and a significant main effect of *lexicality* [F (1, 660) = 5.461, p < .005], as well as a significant two-way interaction effect [F (7, 660) = 2.543, p < .05]. Post-hoc analysis found that there was no significant difference among different age groups in the AO condition. In the *AO condition, the rate of sandhi application in 3y and 4y children was significantly lower compared with the other three age groups (ps < .005). No significant difference was found among the other age groups. In the AG condition, the rate of sandhi application in children of all age groups was significantly lower compared with the adults (ps < .001). Among the children, the T3 sandhi rate of the 3-year-old children was significantly lower than the other children (ps < .001) even though that of children aged 4-6 years old was also significantly lower compared with adults. The results of sandhi application rates of T3 test items in each age group are shown in Figure 2.
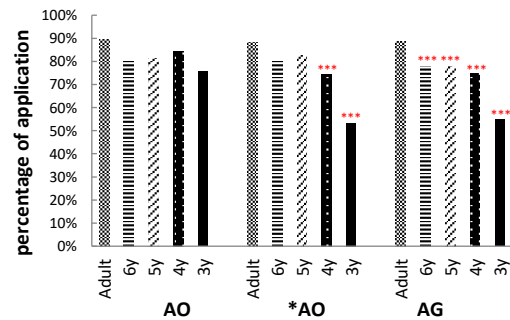

Figure 2: *the sandhi application rate of T3 test items in each age group*

The preliminary results indicated that children's application of tone sandhi might reach an adult level in the real word condition as early as three years old. However, in the *AO condition where both the initial and final syllable were real words, but the combination of the two syllables was non-occurring, children may reach an adult-like application rate at five years old. In the AG condition where the initial syllable was never seen in the daily life, even the 6-year-old children did not reach an adult-like level of performance. Among the children's performances in AG condition, the 3-year-old children performed even worse than the older children although none of them were yet adult-like. However, all the sandhi application rates but that of the AG items in 3-year-old children were above chance, although not all of them reached an adult-like level.

5. Discussion

This study examines the productivity of the Mandarin T3 sandhi in children learning Mandarin Chinese as their mother tongue with three lexicality conditions, i.e., real words (AO), semi-pseudowords (*AO), and pseudo-words (AG). The three types of words are different in lexical entries, and they require different operational ability and mechanisms. In this study, children showed a different degree of application in the three lexicality conditions at different age groups.

First, the AO words are expected to be listed in the children's lexicon so that they can be retrieved directly from memory. The children reached an adult level of application in real words where the lexical memory can be retrieved directly, at three years old. This implies that children aged 3 may have already started to rely on the lexical mechanism to produce real words with T3 sandhi. The period is consistent with the previous findings [18] [19].

Secondly, for the *AO words, although the combination is never seen, the sandhi allomorph of the initial syllables may still be listed in the lexicon because they are occurring in daily life. However, to take advantage of the sandhi allomorph, children could not merely rely on the analyzed memorized lexicons. Instead, they should be able to extract those syllables from the previously heard tone sandhi words. As is introduced in the introduction, this process may require the ability of syllable and tone awareness to some extent. The acquisition of syllable awareness in Mandarin-speaking children is relatively early. An experiment [26] found that the accuracy of syllable awareness reached 80% at 4 years old. But the tone awareness was acquired relatively later. Research [26] found that even though the accuracy was above chance in 4-year-old preschoolers, it was still 55% before 6 years old. Even in 6 to 7-year-old school children, the accuracy of tone awareness still had not reached 80%. In this study, children aged 5 reached an adult-like sandhi application in those semi-pseudowords. This might indicate that their ability to take advantage of the analyzed sandhi-form initial syllables is undergoing significant development.

For the AG sequences, since no lexical entry can be retrieved, children can only rely on the phonological pattern to produce the novel T3 sandhi words. It requires not only phonological awareness but also the ability to compute the pattern productively. In the AG condition where a computation-based productive mechanism is required, even the 6-year-old children did not reach an adult-like application rate. This may be firstly due to their underdeveloped tone awareness at this age [26]. Secondly, it also indicates that they have not yet acquired the adult-like computation mechanism at this age.

It is noteworthy that although the Mandarin-speaking children have not reached the adult-like level, their tone sandhi application rate in pseudowords is still higher than adults' application rate in pseudowords where the sandhi items are operated lexically. For example, the sandhi application rate of adults in AG items was below 30% for Southern Min and Wuxi Wu [6] [29], but it was above 70% for Mandarin children aged 4 to 6. This may suggest that even though children adopt lexical mechanism at the early ages, they did not entirely rely on the lexical mechanism, for the productivity is apparently higher than the items that were purely operated via lexical mechanisms. Computation mechanism is also involved and undergoing development to some extent.

The result is similar to our predictions that children's application of T3 sandhi undergoes a developmental process, progressing from a lexical-dominant to a computation-dominant process. Considering the critical period for the transformation, the current preliminary results indicate that children before age 5 may still primarily use the lexical mechanism in the application of tone sandhi words. However, it is unaccounted for when the children adopt the computation mechanism in the production of the T3 sandhi pattern. At least at 6 years old, the preliminary results have not found evidence for a fully functional computation mechanism in the production of Mandarin T3 sandhi.

Lastly, this is only a preliminary study with several drawbacks. Due to the limited number of samples analyzed, further data analysis and more studies are required to verify the results. First, only a portion of children's data was analyzed in the current study. Till now, 40 children aged three to six have been recruited for the study. With more data it will allow us to better assess the developmental features and productivity of T3 sandhi in Mandarin-speaking children in different age groups. Besides, based on the current preliminary results, more age groups that include children from 7-9 years old will also be recruited for the experiment. Finally, detailed acoustic analyses of production patterns will also be needed to verify the judgment result.

6. Conclusion

The study explored the productivity of T3 sandhi in Mandarin-speaking children. By comparing the productivity in three types of disyllabic sequences with tone sandhi in different ages groups, this experiment scrutinized the developmental features of Mandarin T3 sandhi. Results indicated that children's learning of the T3 sandhi words underwent a gradual transformation from a rote-memory based lexical mechanism to a computation-based productive mechanism. Children started to rely on the lexical mechanism to produce real words with T3 sandhi from 3-year-old. However, Mandarin-speaking children did not reach adult-like computational processing until 6 years old.

7. Ackowlegemnt

8. References

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