SEVEN-YEAR-OLDS REACH AN ADULT-LIKE PRODUCTIVITY IN THE APPLICATION OF MANDARIN TONE SANDHI

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ABSTRACT

The application of Mandarin Tone 3 (T3) sandhi is highly productive in pseudo-words in Mandarin adult speakers. However, it remains unknown when the pattern becomes productive in Mandarin-speaking children. Children's acquisition of T3 sandhi has been found to undergo a gradual transformation from a rote-memory lexical mechanism to a computation-based productive mechanism, and their productivity hasn't reached the adult-like level at age 6. To find out when the children would enter the adult-like level, this study examined the speech productions of 7- and 8-year-old Mandarin-speaking children and adults in real words and two types of pseudo-words. The results showed that 7- and 8-year-old children applied the tone sandhi pattern similarly to adults in both real and pseudo-words. This may indicate the full utilization of a computation-based productive mechanism in the production of Mandarin T3 sandhi in 7-year-olds.

Keywords: Mandarin Tone 3 Sandhi; Productivity; speech production; Mandarin-speaking children

1. INTRODUCTION

Productivity is an elementary human cognitive ability in language learning. However, not all the linguistic patterns are equally productive to pseudowords. For example, the tone sandhi patterns in Chinese dialects have been found to have different productivity [1][2]. It is suggested that they are supported by two putative mechanisms, i.e., a rote-memory lexical mechanism and a computation-based productive mechanism. The lexical mechanism suggests that the linguistic item is processed via memorizing its surface-form representations. While the computation-based productive mechanism indicates that the sandhi forms of a tone are manipulated via applying the phonological pattern productively, regardless whether it is a real word or not [3] [4]. If the items are acquired by lexical mechanism, the pattern may only apply to real words (e.g.,[5][6]). In contrast, if operated via a computation mechanism, the pattern can be applied productively to both real and pseudowords (e.g.,[4][7]).

Tone 3 (T3) sandhi is a phonological pattern in Mandarin Chinese in which a canonical-form T3 syllable becomes Tone 2 (T2) or a T2-like syllable (213+213→35+213) when it is followed by another T3 syllable in connected speech [8][2][9]. Previous studies consistently showed that the application of the T3 sandhi pattern is highly productive in pseudowords in adult Mandarin speakers [1][4][5][10]. However, it is still unknown when this phonological pattern becomes productive in children learning Mandarin as their mother tongue.

Children's first language acquisition usually starts from memorizing lexical items (implying a lexical mechanism) [11], and they often try to regularize the linguistic patterns and apply them productively to new items during the learning process (implying a computation mechanism) [12]. For example during the learning process of the English past-tense inflections, English-speaking children were reported to overgeneralize '-ed' to irregular verbs at around three years old [12]. Besides, when they were asked to produce pseudo-verbs where past-tense inflections are required, a study found that children above five years old could spontaneously apply the pattern to pseudowords with more than 50% accuracy [13].

Cumulative empirical studies found that children's acquisition of Mandarin T3 sandhi also undergoes a similar developmental trajectory. They started from the actual occurring sandhi words at or before 3 years old [14][15], although their productions were not yet acoustically accurate enough [16][17][18][19]. While in the semi-pseudowords, the output of which can lean upon either the previously heard sandhi allomorphs or a computation mechanism, children reached an adult level of productivity at age five [19]. In the pseudowords, however, even the 6-year-old children have not achieved an adult-like application rate [19]. The results imply that the lexical mechanism becomes functional at around three years old, whereas the computation mechanism is not yet fully developed by

the age of six. To find out when Mandarin children would reach the adult-like application rate in the production of T3 sandhi in pseudowords, thereby demonstrating a developed computation mechanism, this study further examined the speech productions of 7- and 8-year-old Mandarin-speaking children and adults in real words and two types of pseudo-words.

Understanding how the tone sandhi pattern is acquired is crucial for accounting the language acquisition beyond the level of the segment. It also sheds light on the development of phonological acquisition among Chinese children.

2. METHODS

Following the previous study [19], the current study used an elicited picture naming task to elicit children's spontaneous productions to examine children's application of T3 sandhi in three lexicality conditions: real words, semi-pseudowords, and pseudowords.

2.1. Participants

Eighteen children (nine 7-year-old children, nine 8-year-old children) and nine adults were recruited for the experiment. All the children were monolingual Mandarin speakers who had limited exposure to other languages. All the children accomplished the Intelligence test (WISC-R; [20]).

2.2. Stimuli

For the real word condition, to make sure that most children can recognize the picture, all the items were concrete and high-frequency disyllabic words, such as /ɕiɑu213 tsʻau213/ 'grass.' Considering the semi-pseudowords, they were all non-occurring combinations of real monosyllables. e.g., /pi213 kou213/ 'pen' 'dog'. While for the pseudowords, we used accidental gaps (AG) in Mandarin syllabary as the initial syllables and real monosyllables as the final syllables. The AG syllables were occurring syllables in Mandarin but yielded no real word when they were combined with either T2 or T3 (e.g., /miɛ213/; /miɛ51/ is an actual occurring word in Mandarin 'to destruct'). To elicit the productions of the pseudowords, each AG syllable was assigned a lexical meaning. For example, /miɛ213/ meant 'to carry something by two men.' The AG syllable was introduced in the underlying tone (i.e., unchanged base tone) by an experimenter to the children, and the children were asked to combine the AG item and the occurring word into a new word. Each type of conditions included 20 test items (T3 + T3 words) and 20 control items (T3 + Non-T3 words). Therefore, there were 120 items for each participant. In the test and control items, the initial syllables were comparable (e.g., /ma213 tsʻau213/ 'horse grass' vs. /ma213 ʂʻu51/ 'horse tree').

2.3. Procedure

Children were presented with slides of pictures on a computer and were instructed to play word-guessing games. In the real word condition, each item was presented with one picture. Children were instructed to name the picture as a disyllabic word. For the two types of pseudowords, two pictures were shown on one slide to indicate the two syllables respectively, and the children were asked to combine the two syllables into a new word. Before the experiment, children were given enough practice trials to make sure that they clearly understood the tasks. See the previous study [19] for more details. In the experiment, semi-pseudowords were presented first, while the real words were the last to be presented. The children were informed to produce the target form twice. The first production would be used unless it was not ideal due to the noisy background, overlapping of voices, etc.

The task lasted 30-60 minutes for a child. To avoid fatigue, we divided the whole test into at least six parts with a rest between two parts. Besides, a child would be awarded some gifts every time he/she remained actively engaged in the experiment for more than 6 minutes. All the participants' responses were recorded by digital recorders (Sony, ICD-PX470) at 16 bits and a 44.1 kHz sampling rate. They were manually examined and segmented by the first author in Praat [21] for further analysis.

2.4. Data analysis

Productions of each disyllabic sequence (e.g., /miɛ213 tsʻau213/), as well as the initial T3 syllable of that sequence (e.g., /miɛ213/), were segmented for ratings. Three Mandarin-speaking phoneticians who were from Northern dialect speaking areas participated in the rating task.

The rating task was presented with E-Prime 2.0. In each trial, a disyllabic sequence was presented first, and then the initial syllable of that disyllabic sequence. The raters were instructed to identify whether the initial T3 syllable underwent tone sandhi or not. If applied, they were asked to press 2, and if it was produced in the underlying form of T3, they should press 3; if the production was neither the underlying nor the surface form (mispronunciation), they were instructed to press 0. There should be 540 test items (20 items/lexicality condition *9 participants/age group *3 raters) to be rated for each condition. However, some items were removed from analysis because of the sound quality and so on (see Table 1).

We divided the whole task into ten blocks in which the three types of stimuli were randomly mixed. And the raters could take breaks at any time they desired.

Table 1: Items numbers rated for each condition

group	real	semi-pseudo	pseudo
7y	430	428	400
8y	457	456	447
adult	496	498	497

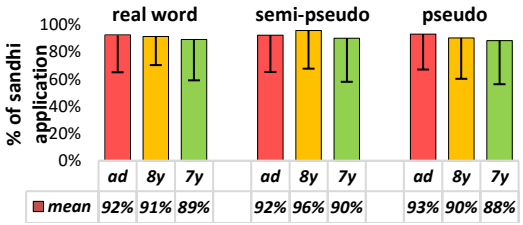
Furthermore, F0 values of the initial syllables were extracted for acoustic analysis by isometrically taking 20 points (in Hertz) over the time course of the rhyme. To minimize the pitch range difference due to gender and age, the F0 data were log-transformed first and then further normalized with z-scores [22].

3. RESULTS

3.1. Sandhi application result from the rating score

We measured the accuracy of sandhi application in T3 sandhi words according to the three raters' judgments. A trial would be judged as correct if an initial T3 sandhi syllable was judged to undergo tone sandhi, and as incorrect if the item fails to exhibit a tone sandhi pattern. There were only six mispronunciations in the three age groups, and they were removed from the analysis. Figure 1 summarizes the sandhi application rate of T3 productions in the three types of tone sequences in each age group. As is shown in the Figure, the application rate was above 88% in all conditions.

Figure 1: the sandhi application rate of the T3 sandhi items



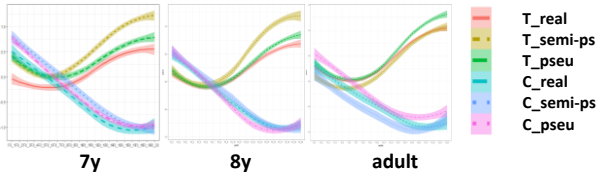
The accuracy scores were statistically analyzed by the binomial logic regression [23] with the package lme4 [24] in R [25]. The R package lmerTest was used to provide *p*-values for models [26]. The model included accuracy (1 or 0) as the dependent variable and the lexicality condition (real word, semi-pseudo word, pseudo-word), age groups (ad, 7y, 8y) as independent variables, and subject as a random factor. We began the analysis with a base model. Terms were added one at a time and models were compared using log-likelihood ratio tests to determine if a given term significantly contributed to the fit of the model.

Results showed that interactions between age and lexicality significantly improve the model. To compare whether children performed differently with adults in each condition, data were analyzed separately in the three conditions. Results found that the variable age did not contribute to the model considerably in real- and pseudo-word conditions. This suggests that the application rates of 7 and 8-year-old children were not significantly different than adults. However, in the semi-pseudowords, the best model included age groups. The results of the model revealed a significant difference between 8-year-old children and adults (z (0.6141) = 2.170, p < .05), where the accuracy in 8-year-old children was significantly higher than the adult group.

3.2. F0 measurements from the acoustic analysis

Further acoustic analysis was conducted to confirm the results from the rating task. The plotted tonal contours (Figure 2) were based on the mean, and the stand errors of the z-scores averaged across speakers. The six mispronunciations found in the rating task were removed from the analysis. To illustrate the contrast in the F0 realization of the initial syllables between tone sandhi items and T3+Non-T3 items, the control items were also included in the Figure.

Figure 2: Normalized F0 contours of the initial syllable for test items (T) and controls (C). Dotted lines stand for the mean. Dash areas hold for the ± standard error of the mean.



In the Figure, there is a clear divergence between the test items and the controls in all conditions, indicating the application of T3 sandhi in the test items. Three-way repeated measures ANOVA were conducted on the normalized F0 curves of the test items, with age (ad, 7y, 8y) as the between-subjects factor, and lexicality condition (real, semi-pseudo and pseudo) and time point as within-subject factors. Huynh-Feldt method was used to correct the violation of sphericity where appropriate. Results found no significant three-way interaction effect in the analysis. However, they confirmed a significant interaction effect between group and lexicality condition (F (4, 807.971) =5.545, p<0.001). To compare whether participants performed similarly in the three lexicality conditions, data were analyzed separately in each age group. Results showed no significant effect of lexicality in the adult and the 7-year-old children.

This indicates that the 7-year-old children and adults perform similarly in the three lexicality conditions. However, there was a significant main effect of lexicality in 8-year-old children, with the sandhi application in semi-pseudowords being significantly higher than in real words and pseudowords ($ps<0.05$).

5. DISCUSSION

This study examined at what age Mandarin children would reach adult-like productivity in the application of tone sandhi, especially in pseudowords that are entirely operated via a computation mechanism. In the previous study [19], it has been found that 6-year-old children still have not reached adult-like performance in the production of pseudowords. To find out the developmental course, we recruited children from 7 to 8 years old. The results showed that both 7 and 8-year-old children reached the adult-level application in the three types of words.

Prior to the discussion of the development of productivity of T3 sandhi in Mandarin-speaking children, it is worth mentioning the differences between the three types of words. The three types of words were different in lexical entries, and they required different operational ability and mechanisms. The real words were expected to be listed in the children's mental lexicon and can be retrieved directly from memory. For the semi-pseudowords, two possible operational mechanisms may underlie correct applications of T3 sandhi. First, the sandhi allomorph of the initial syllables may still be listed in the mental lexicon. However, to employ the sandhi allomorph, children should be able to extract those syllables from the previously heard disyllabic words that undergo tone sandhi. Secondly, children may solely rely on the phonological pattern and apply the pattern computationally. As for the pseudowords, since no possible lexical entry can be retrieved from memory, children can only lean on the phonological pattern to compute it productively.

Integrating the results of 7-8-year-olds in the current study with those of the 3-6-year-old children [19], a developmental trajectory emerged. To be specific, the children can produce T3 sandhi in real words as accurately as adults at three years old. This implies that children aged three are already capable of taking advantage of the mental lexicon and relying on the lexical mechanism to produce T3 sandhi words. This result mirrors the timing of acquisition of real T3 sandhi words in previous findings [14][15] that children have acquired tone sandhi words at or before three years old, even though not being acoustically accurate enough [16][17][18]. As for semi-pseudowords, previous studies found that children aged five reached an adult-like sandhi application in this condition [19]. As mentioned above, T3 sandhi application in semi-pseudowords could be supported by two strategies. A possible way to segregate these two explanations is to check the frequency of the sandhi allophones that a child may encounter in the input speech, and examine whether the children's sandhi application rate follows the frequency. If the frequency is high, then children are more likely to take advantage of the previously heard sandhi allophones. If not, children may tend to use the computation mechanism when applying the sandhi pattern in this condition. To this end, we made use of existing Mandarin corpora, and both the adult corpus [28] and the toddler's checklist [29] verified children's limited exposure to those sandhi allophones. Finally, in the pseudoword condition, the 7-year-old children reached ceiling productivity like an adult, indicating the full acquisition of computation mechanism at the age of seven. This result also provides extra support for the explanation above that 7- to 8-year old children may engage the computation mechanism in the sandhi application in some semi-pseudowords.

Then what is driving force of the transformation from the memory-based lexical mechanism to the computation-based productive mechanism at the age of seven? The development of the computation mechanism presumably depends on the collaborative effort of a syllable, tone, and morphological awareness. To begin with, children are expected to have syllable awareness, that is to analyze a disyllabic word into syllables [30]. On top of syllable awareness, tone awareness could also be essential, that is the ability to identify the tones carried by the syllables[30]. Lastly, it also requires some morphological awareness [31], that relates to the ability to link the surface allophones of an initial syllable (e.g., /ɕiɑu35/) appearing in different tonal contexts (e.g., /ɕiɑu35 kou213/ and /ɕiɑu213 xua55/) to the same morpheme. These will be further discussed in future studies.

6. CONCLUSION

This experiment scrutinized the development of T3 sandhi in Mandarin-speaking children. By adding the 7 and 8-year-old children to the productions of three types of disyllabic sequences with tone sandhi, the results showed that children's learning of the T3 sandhi words underwent gradual progress 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 onwards, and they reached adult-like performance with regard to the computational process at 7 years old.

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