

A Review of Research on The Neural Mechanisms of Lexical Tone Acquisition

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Abstract. The phenomenon of bilingualism is becoming more and more important as international communication becomes closer and closer. In the past, linguists' studies on second language acquisition by bilinguals seldom dealt with the language processing mechanism of the human brain itself, but the further development of science and technology has made it possible to quantify the laws of language learning at the neural level. In this paper, the author reviews the literature on the brain-neural mechanisms of tone perception in the primary stage of bilinguals from the perspectives of native language and bilingual tone perception in light of the previous research results. At present, the main research methods adopted in the study of tone acquisition are phonological experimental research and listening and dialectic research. However, the research on tone perception mostly focuses on differentiation and recognition experiments, the use of neuroscience technology is still insufficient, and the combination between disciplines is not close enough.

Keywords: Linguistics; Lexical Tone; Neural Mechanisms.

1. Introduction

Language, as a unique advanced function of the human brain, has always attracted many scholars to explore its acquisition and processing methods. In recent years, with the emergence of eye-tracking, positron tomography, functional magnetic resonance imaging and other means of brain function research, the limitations of neuropsychological and cognitive psychology on the study of the functional mechanism of the language brain have been greatly broken through, which enables the researcher to directly observe the activity of the brain of a normal subject when completing each speech task, which to a large extent enlarges the scope of the research object and improves the results of the study scientificity of the research results.

In this paper, the brain mechanisms for the perception and acquisition of tones are sorted out, and the influencing factors of native language acquisition and second language acquisition are explored separately. This literature review explores the patterns of tone acquisition and aims to help tone teaching to find better acquisition and teaching methods.

2. The Study of Chinese Tones

There is not as much research on the development and learning of Mandarin Chinese speech as there is on Indo-European languages. Modern Mandarin Chinese has a straightforward syllabic structure, and each syllable must be connected to one of the four tones (T1: high-level tone, T2: high-rising tone, T3: low-rising tone, and T4: high-falling tone) in order to transmit and identify various meanings. Beginning in the early 1920s, modern Chinese tones were studied. Zhao Yuanren once suggested using experimental techniques to investigate Chinese tones. He also made a comparison between Chinese tones and musical scales [1]. A turning point in the history of Chinese phonology came in 1924 when Liu Fu undertook empirical studies on Chinese tones and employed tools to examine the tones of 12 regional dialects of the language [2]. The development of Chinese tones has been greatly aided by the entrance of foreign acoustic and experimental equipment as well as by the growth of technology. Later, in the 1960s, Liang Zhian added psych-phonology to the study of Chinese tones, and he also started exploring Chinese tone perception [3]. Numerous linguists have

conducted additional research on Chinese tones since the 1980s and 1990s, including studies of tone characteristics, tone patterns, the Chinese tone height system, and continuous tone sandhi. With the ongoing updating and development of speech technology, the growth of speech acquisition theory has been encouraged in recent decades. A growing number of empirical research on the acquisition of second languages has been published, and linguists as well as educators from the United States and Taiwan have been doing long-term studies on the general speech and language development of children who speak Mandarin. Later, certain cross-sectional studies, primarily in Chinese, started to emerge, and other research on kids, like on speech sound disorders (SSDs) and the rehabilitation of people with disabilities, has been getting more and more attention. The acquisition of the Mandarin tone has been one of the subjects with the most investigation for more than 40 years. Babies are adept at recognizing phonetic differences in language. According to past research on children's tone production, children can produce the majority of Mandarin tones by the time they are 3 years old, and T1 and T4 are mostly learned before T2 and T3 [3-5]. The youngsters began to establish their lexical tone acquisition during their tenth month, according to Tse's longitudinal research on tone learning in Cantonese done in 1978 [4]. Based on previous literature, it can be assumed that many young people who speak Mandarin can learn four tones by the age of 4. However, little study has been done so far on the tone learning process in early toddlers whose first language is tone language.

Phonological processing is an important element in language processing, and tones are the most important external rhythmic features of Chinese phonology and one of the important difficulties in Chinese acquisition. In order to express and discriminate between various meanings in modern Chinese, syllables must have one of the four tones attached to them. In the past many years, the acquisition of Mandarin tones has always been the most extensive research topic for researchers. Acquisition of Mandarin tones has been one of the most widely researched topics for more than 40 years. As acquisition can be divided into native language acquisition and second language acquisition, this paper reviews the existing studies on the brain-neural mechanisms of tone acquisition from the perspective of tone acquisition in tone native speakers and tone acquisition in non-native speakers and explores the direction of future development in the related fields.

3. Children's Lexical Tone Acquisition

Children's phonological acquisition from birth to 1 year of age is actually phonological perception, and phonological perception is one of the most widely studied language skills for both infants and adults. The study of pitch perception is generally a category perception study. Wang Shiyuan first proposed that pitch perception is a category-based perception by studying the performance of T1 and T2 in Beijing dialect [6]. However, the 1979 study of Thai tones from Abramson showed that although the recognition of the three flat tones in Thai was category-type, none of the distinction curves showed a peak of distinction at the category boundary [7]. From this, it can be speculated that perhaps the perception of curvilinear tones shows a categorical feature, whereas the perception of flat tones is characterised by continuity. Francis et al.'s results on the three flat tones as well as the two rising tones in Cantonese are similar to those of Thai flat tones [8]. Wang and Tan's study on the perception of rising and low rising in Mandarin also yielded inconsistent recognition and differentiation rates results [9]. Therefore, it can be concluded that there is no clear boundary of differentiation between tonally similar (acoustically similar) tones.

3.1. Children's Perception of Tones

The category perception of tones belongs to behavioural experimental research, and with the development of brain neuroscience, electrophysiological research methods have made it possible to explore the neural mechanisms behind the behaviour of tone perception. Event-related potential (ERP) technology has a more precise temporal resolution, which can be used to explore the processing of tone perception. Some ERP studies have shown that native speakers of tones do exhibit category-based features in the perception of tones in their native language [10]. Specifically, inter-category

deviant stimuli can induce greater electrophysiological responses than intra-category deviant stimuli. For example, Xi et al. examined the category perception of the Mandarin yangping-desheng continuum and showed that both intra- and inter-category components of MMN (Mismatch Negativity, MMN) could be induced in bilateral brain regions from the pre-cerebral to the mid-cerebral regions compared to the standard stimuli, and that the inter-category stimuli were able to induce a larger component of MMN in the left side of the brain region [10]. However, some other studies have obtained different results, and Chandrasekaran et al.'s T1-T2 perceptual acting results for Mandarin Chinese showed that the MMN evoked in the intra-category condition was larger than that in the inter-category condition [11]. The academic community has not yet reached a unified view on the reasons for such results. However, there are many potential reasons, such as the effect of stages in acoustic processing on perceptual outcomes. In the attentional processing stage, both acoustic and phonological information are relied upon for the perception of tones. However, in the pre-attentive processing stage, the presence or absence of phonological information for processing is at issue. If information at the phonological level can be processed at that stage, the electrophysiological response evoked by the inter-category stimulus will be greater; if only information at the acoustic level is processed at that stage, the category effect will be smaller or even absent.

3.2. Influencing Factors

There are many factors that influence the perception of tones, the most important factor for native speakers of tones is age. According to research on children's phonological development, infants undergo perceptual reorganization before their first year of life. This means that while infants can initially distinguish between native and non-native speech sounds, as their exposure to their native language increases, they gradually lose the ability to do so [12]. In other words, newborn infants can perceive tones regardless of whether their native language is a tonal language or not. Mattock and Burnham examined the ability of 6- and 9-month-old native English-speaking infants and native Chinese-speaking infants to discriminate between ascending-descending and ascending-flat tones in Thai [13]. The results showed that Chinese infants' tone perception was increasing, while English infants' tone perception was gradually decreasing, and the two already showed significant differences in tone perception between 6 months of age and 9 months of age. Liu and Kager's findings were different, as they found that infants of a non-tone language (Dutch) showed a U-shaped developmental pattern of tone perception, i.e., infants could make a 5-6-month-old differentiate tones, their sensitivity to perceive tones deteriorates by around 9 months, but then shows an upward trend in tone perception by 17-18 months [14]. This may be related to the ability to perceive acoustic information as mentioned above, and this "recovery" does not mean that non-native speakers have redeveloped their tone perception.

Due to experimental constraints, there are still relatively few ERP studies of infant vocal pitch perception, and research on the neural mechanisms involved in perceiving vocal pitches in infants with and without tonal language needs to be further developed.

4. Second Language Lexical Tone Acquisition

In addition to their mother tongue, people often learn and use another language - a second language. With the rapid development of the economy and globalisation, more and more people need to learn and master one or more second languages. The acquisition of tones is undoubtedly one of the difficulties in language learning for learners whose mother tongue is a non-tone language.

4.1. The Interaction between L1 and L2

Best proposed the Perceptual Assimilation Model (PAM) theory in 1988 to explain the process of second language learners' non-native speech perception, and the core idea is that the influence of the first language phonological system on the acquisition of second language speech segments is not confined to the presence or absence of certain elements in either the first or the second language, but

rather to how learners perceive the differences [15]. Some non-native speakers of tones are susceptible to the influence of their mother tongue in perceiving tones. For example, White experimentally found that English stress has a greater effect on native English speakers' perception of Chinese tones, who hear a high-level tone (T1) in Mandarin as stress and a low-rising tone as non-stress [16]. Not only non-tone native speakers, but also tone native learners are affected by the tone of their native language when they learn another tone language. Yeung et al. compared the responses of Cantonese infants and Mandarin infants when they heard Cantonese tones T33 and T25 [17]. It was found that Mandarin-learning infants were more familiar with T25. The reason is that the Cantonese tone T25 can be assimilated into a "local" tone. For Mandarin learners, T25 is very similar to the native rising tone. Thus, Mandarin-learning infants may have preferred T25 to T33 because of the relative familiarity of the former, and the relative familiarity of the latter. Due to the relative familiarity of T25, Mandarin-learning infants might have preferred it to T33, whereas Cantonese infants might not have shown any clear preferences since both were native.

4.2. The Effect of Native Language Background

The effect of native language background on pitch perception is also reflected in brain neural mechanisms, and Gandour et al. were the first to demonstrate the differences caused by native language background on pitch perception in brain mechanisms [18]. While Thai native speakers activate the left-brain area related to language when performing Chinese tone perception and do not activate this area when performing non-verbal pitch perception, English native speakers do not activate the left-brain area when performing either verbal or non-verbal tone perception. This is not a permanent situation; Wang's experiments using functional magnetic resonance imaging revealed that tone-trained subjects showed increased activation in Brodmann area 42 of the left brain, and neighbouring areas became activated as well, revealing the plasticity of the adult brain during the acquisition of tones [19,20].

5. Conclusion

At present, the research on Chinese tone acquisition has not formed a certain theoretical framework. Most of the studies on lexical tone acquisition are based on the theories of phonological perception and output and the theory of linguistic variation, which, although they can provide detailed descriptions of the pronunciation and perception phenomena of non-native speakers, cannot effectively explain the mechanism of tone acquisition in non-native learners. Besides, the main research methods adopted in the study of tones acquisition are phonological experimental research and listening and dialectic research. Although such research methods can better describe learners' pronunciation characteristics, they cannot explain how learners acquire tones. In addition, research on the acquisition of tones in Chinese as a second language is mainly cross-sectional, and there is a lack of observation on the acquisition of tones at different levels of time, so the developmental process of tones has not been studied enough.

The review of the above studies reveals that the theoretical system of the brain neural mechanism of phonological acquisition has become more mature, and the diversity of research approaches has added to the theory building in this field. However, among the studies on speech acquisition, only the studies on tone acquisition account for only a small part, so the number of studies on the brain-neural mechanism of tone acquisition is relatively small. And due to the limitation of conditions, the research on tone perception mostly focuses on differentiation and recognition experiments, the use of neuroscience technology is still insufficient, and the combination between disciplines is not close enough. Therefore, by reviewing and critiquing the relevant studies, this paper hopes to promote the development of relevant research and apply the research results to the practice of teaching international second language tones.

Finally, the effects of native language background, age, context, and stimulus properties on the tones category perception are interactive, for example, the effect of stimulus. For example, the effect

of stimulus type on category perception differs between native and non-native speakers of tones, and how do they work together? Further research is needed.

References

- [1] Zhao Yuanren. The Experimental Research Method of the Tones of Chinese Speech. Science, 1922(9),871—882.
- [2] Liu fu & Liu Bannong. Four Tone Experiment Record. Shanghai: Qun Yi Bookstore Press. 1924.
- [3] H. Clumeck, “The acquisition of tone,” In G. H. Yeni-Komshian, J. F. Kavanagh, and C. A. Ferguson (Eds.), *Child phonology*. New York, NY: Academic Press, 1980(1), 257-275.
- [4] Zhu, H., & Dodd, B. The phonological acquisition of Putonghua (Modern Standard Chinese). *Journal of Child Language*, 2000, 27(1), 3–42.
- [5] P. S. Wong, R. G. Schwartz, J. J. Jenkins, “Perception and production of lexical tones by 3-year-old, Mandarin-speaking children,” *Journal of Speech, Language, and Hearing Research*, 2006, 48, 1065-1097.
- [6] Wang, W. S. Y. Language change. *Annals of the New York Academy of Sciences*, 1976,280, 61–72.
- [7] Abramson, A. S. Noncategorical perception of tone categories in thai. *The Journal of the Acoustical Society of America*,1977, 61(S1), S66-S66.
- [8] Francis, A. L. , & Ciocca, V. Stimulus presentation order and the perception of lexical tones in cantonese. *Journal of the Acoustical Society of America*, 2003,114(3), 1611-21.
- [9] Wang, & Tan. Recognition and Differentiation of Yangping and Shangsheng in Mandarin Single Character Tones--Annotation of the Effect of Experimental Design on the Outcome of Tone Category Perception. *Language Science*,2015,(4).
- [10] J. Xi, L. Zhang, H. Shu, Y. Zhang, P. Li, Categorical perception of lexical tones in Chinese revealed by mismatch negativity, *Neuroscience*,2010, 170(1), 223-231.
- [11] Chandrasekaran, B, Krishnan, A, & Gandour, J. T. Relative influence of musical and linguistic experience on early cortical processing of pitch contours. *Brain & Language*,2009, 108(1), 1-9.
- [12] Stager. CL, Werker. JF, Infants listen for more phonetic detail in speech perception than in word-learning tasks. *Nature*, 1997,388(6640),381-382.
- [13] Mattock, K, & Burnham, D. Chinese and english infants' tone perception: evidence for perceptual reorganization. *Infancy*, 2006, 10(3), 241-265.
- [14] Liu, L. , & Kager, René. Perception of tones by infants learning a non-tone language. *Cognition*, 2014, 133(2), 385-394.
- [15] Best, C.T. A direct realist view of cross-language speech perception. In W.Strange (Ed.), *Speech perception and linguistic experience*,1995,171-204. Baltimore:York Press.
- [16] White, C. M. Tonal perception errors and interference from English intonation. *Journal of Chinese Language Teachers Association*,1981, 16,27-56.
- [17] Yeung, H. H., Chen, K. H., and Werker, J. F. When does native language input reorganize phonetic perception? The precocious case of lexical tone. *J. Mem. Lang.* 2013, 68, 123–139.
- [18] Gandour, J.T.Tone perception in Far Eastern language. *Journal of Phonetics*, 1983, 11,149-175.
- [19] Wang,Y., Sereno, J.A., Jongman,A., and Hirsch, J.Cortical reorganization associated with the acquisition of Mandarin tones by American learners: An fMRI study. *Proceedings of the 6th International conference on Spoken Language*,2000.
- [20] Wang, Y, Sereno, J. A, Jongman, A, & Hirsch, J. Fmri evidence for cortical modification during learning of mandarin lexical tone. *Journal of Cognitive Neuroscience*,2003, 15(7), 1019-1027.