The categorical perception of Mandarin tones in normal aging seniors and seniors with Mild Cognitive Impairment

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ABSTRACT

Aging plays an important role in cognitive degradation. This study examined the behavioural performance of the categorical perception (CP) of Mandarin tones in young adults, normal aging older people, and those with Mild Cognitive Impairment (MCI). The results revealed that in the identification function, boundary width of tone perception in MCI seniors was wider than that in young adults. In the discrimination function, the between-category accuracy in the MCI group was also significantly lower than that in young adults. No significant decline in tone perception was found in normal aging seniors, although they showed worse hearing sensitivity and cognitive ability compared with young adults. Our behavioural findings supported that the compensation mechanism might be observed in older people with normal performance, rather than those with degraded performance.

Keywords: Categorical perception, Mandarin tone, aging effect, cognitive degradation, compensation.

1. INTRODUCTION

Categorical perception (CP) of speech requires listeners to discretely perceive continuous acoustic cues [10]. Classic CP paradigm consists of identification and discrimination tasks, where the identification task depends on listeners' internalized categorical awareness, and discrimination task requires to simultaneously process conflicting sensory and categorical information. Thus, CP is a potential way to test the auditory-cognitive system in the brain. Aging is associated with hearing loss and degradation in cognitive processing. Normal aging people have been proven to suffer from decline both in the spectral and temporal processing of CP. Bidelman, Villafuerte, Moreno, & Alain [2] indicated that normal aging listeners presented slower performance than younger listeners in the identification experiment of English vowels /u/ and /a/, although the identification responses were similar in both groups. Only identification task was conducted in their study, and discrimination task was not included. Gordon-Salant, Yeni-Komshian, Fitzgibbons, & Barrett [6] found no significant difference in boundary position, slope and discrimination accuracy of voice onset time (BUY/PIE), while there was an aging-related difference in the perception of transition duration (BEAT/WHEAT). Harkrider, Plyler, & Hedrick [7] also showed that seniors had larger /d/ categories, greater N1 amplitudes and longer P2 latencies when perceiving the /ba/-/da/-/ga/ transition continuum, compared with young adults, while such differences decreased when the audibility of the transition information in stimuli was enhanced by adjusting the gain. In a recent study comparing the Mandarin tone perception in normal aging people and young adults [16], significantly shallower slopes in the identification function of tone 2-3 and smaller peakedness in the discrimination accuracy were found in the elderly group. Furthermore, this research team also investigated the influence of stimulus duration on the perception of Mandarin tone 1-2 and tone 1-4 in normal older people [15]. Results indicated that longer duration improved the behavioural performance of the categorical perception of Mandarin tones in the elderly.

Mild Cognitive Impairment (MCI) is a transitional stage from normal aging towards severe dementia and Alzheimer's disease. Bidelman, Lowther, Tak, & Alain [1] recently studied the perceptual processing of English vowels (/u/-/a/) of the elderly with MCI and normal elderly as a control group. No significant difference was observed in the behavioural identification of vowels between the normal elderly and those with MCI. However, for MCI participants, increased amplitudes were found in cortical evoked responses, and MCI was also associated with hypersensitivity of subcortical response, supporting the decline compensation mechanism. With the development of brain-imaging technology, several cognitive compensation models have been proposed. Some studies [11, 13] found that the compensation mechanism was only observed in older people with better performance in tasks, rather than those with worse performance.

The languages of the world exhibit a natural diversity which was not reflected in the mainstream of empirical speech perception studies. Previous research about categorical perception mainly focused on cohort in Western, educated, industrialized, rich, and democratic (WEIRD) countries [8], and most investigations mentioned above about aging effect and decline compensation mechanism were primarily based on English-speaking people, while the perceptual degradation of Chinese phonological contrasts remains unclear. Chinese is a tonal language where tones can distinguish different meanings of words [14, 20, 21]. In China, there were more than 240 million senior citizens above 60 years old, accounting for 17.3% of the total population [12]. It was reported that around 14.71% older people suffered from MCI, and a higher prevalence of MCI was related to people living in rural area, or with older age [18]. Different population/stimuli prevent a direct comparison of perceptual degradation of Mandarin tones. Thus, in this paper, we tested the behavioural identification and discrimination performance of Mandarin tones in Mandarin-speaking young adults, normal aging older people, and older people with MCI, in order to explore the CP of Mandarin tones under the influence of aging effect, and whether the normal aging elderly and those with MCI showed different compensation patterns of degradation.

2. METHODS

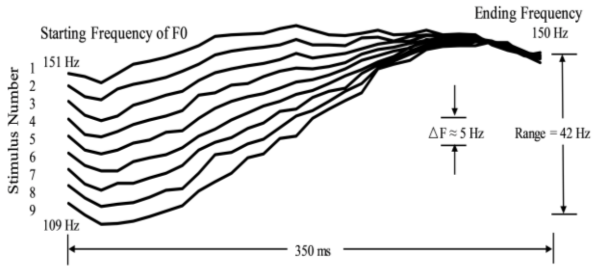
2.1. Participants

Twenty-four young adults aged 20-30 years (15 male, mean±SD: 24.58±2.75 yr), 25 older adults aged 60-81 years with normal cognitive ability (14 male, mean±SD: 73.79±5.82 yr), and 17 older adults aged 63-81 years with MCI (10 male, mean±SD: 72.93±6.23 yr) were recruited in this experiment. One normal older participant and two MCI participants were excluded from analysis because of severe hearing loss and illiteracy respectively. All participants were from northern China and spoke Mandarin fluently. Also, they were strongly right-handed, reporting no history of psychiatric illness and surgery in ear and head, and no experience of formal musical training. Two elderly groups matched in the age (t = 0.424, p = 0.674), hearing level (t = 1.649, p = 0.108), and total years of formal education (t = 1.904, p = 0.065). Also, older participants in this experiment were professors, teachers, doctors, or engineers before retirement, so their social economic statuses were similar as well. Consent forms were obtained from all participants with a protocol approved by the Human Subjects Ethics Sub-committee of The Hong Kong Polytechnic University, and they were compensated for participating in the experiment.

2.2. Material

All speech samples, including syllables /i/ with high-level tone (‘衣’, clothes) and rising tone (‘姨’, aunt), were produced by a male native Mandarin speaker from northern China and recorded at a 44.1 kHz sampling rate and 16-bit resolution using Praat [3]. The tone continuum with 9 stimuli was constructed by TANDEM-STRAIGHT software [9]. To make the loudness and duration of all stimuli comparable, the speech stimuli were delivered at 70 dB and adjusted to 350 ms. The F_0 of stimulus 1 (high-level tone) was around 151 Hz, and the starting and ending F_0 of stimulus 9 (rising tone) were 109 Hz and 150 Hz respectively. The step size between two adjacent stimuli was around 5 Hz (see Figure 1).

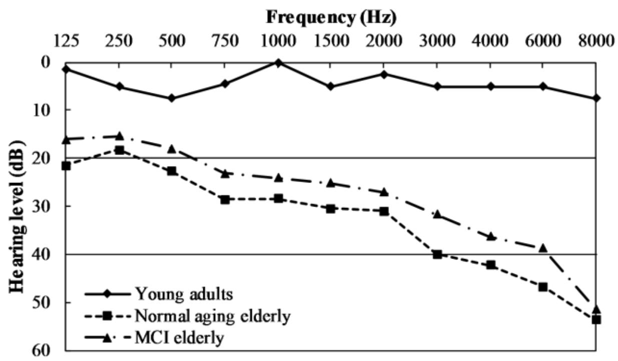
Figure 1: The schematic diagram of the pitch contours of tone continuum.



2.3. Procedure

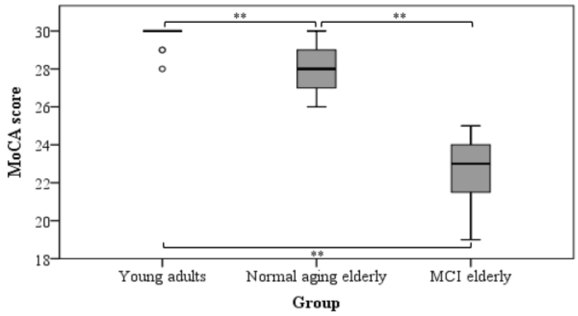
All participants were required to complete the hearing sensitivity test using an audiometer (GSI 18). Hearing thresholds were normal (≤ 20 dB HL) at frequencies between 125 and 8000 Hz in young adults group. The hearing thresholds in two elderly groups were near normal at low frequencies (125 – 500 Hz) and showed mild-to-moderate hearing losses (20 - 60 dB HL) in mid-to-high frequencies (750 – 8000 Hz) (see Figure 2). Ear difference was not found in three groups (all p_s > 0.05), suggesting that all participants had symmetrical hearing sensitivity.

Figure 2: The audiograms for younger adults, normal aging seniors and those with MCI.



We also assessed cognitive function for each participant using the Beijing version of Montreal Cognitive Assessment (MoCA) [19] in a quiet room by a trained experimenter who was familiar with neuropsychological testing. All young adults and normal older adults gained normal MoCA scores (26 - 30 points), and the scores for MCI people were 19 - 25 points (see Figure 3).

Figure 3: The box plots of MoCA scores for younger adults, normal aging seniors and those with MCI.



Note: ** $p < 0.001$, two-tailed.

Identification task required participants to press key '1' when they judged a stimulus as sound 1 ('衣'), and press key '2' when they judged a stimulus as sound 2 ('姨'). A practice block with feedback was available for participants to familiarize with the procedure before the testing block. There were 5 repetitions of each stimulus in the testing block, and all stimuli were randomly presented.

In the AX discrimination task, listeners were asked to determine whether the two sounds they heard were the same (pressing key '1') or different (pressing key '2'). There were 14 pairs of different stimuli which were separated by two steps (1-3, 2-4, 3-5, 4-6, 5-7, 6-8, 7-9, 3-1, 4-2, 5-3, 6-4, 7-5, 8-6, 9-7) and 9 pairs of same stimuli (1-1, 2-2, 3-3, 4-4, 5-5, 6-6, 7-7, 8-8, 9-9). Each pair was repeated five times. There was also a practice block for participants before the testing block.

2.4. Data analysis

The identification score was defined as the percentage of responses, and boundary position and width of identification function were calculated by Probit analysis [4], defined respectively as the 50% crossover point and the linear distance between 25% and 75% percentiles. The discrimination score of each comparison unit which consisted of four types of pairs (AA, BB, AB and BA) was assessed using the formula proposed in [17]: $P = P(\text{'S'}|S) \times P(S) + P(\text{'D'}|D) \times P(D)$, where P (S) represented the percentage of the same pairs (e.g., 1-1, 3-3) and P (D) represented the percentage of different pairs (e.g., 1-3, 3-1). P ('S'|S) and P ('D'|D) respectively represented the percentage of 'the same' and 'different' responses to the same and different pairs. The between-category discrimination accuracy was defined as the mean of discrimination scores of two comparison units straddling the phonetic boundary, and the within-category accuracy was the mean of discrimination scores of the remaining comparison units.

3. RESULTS

Identification and discrimination curves of tones in three groups were shown in Figure 4 (a, b), and the within-category accuracy and between-category accuracy of tone discrimination in three groups were shown in Figure 4 (c). The boundary position and width of tone perception were presented in Table 1. Results of one-way ANOVA indicated no significant group difference in the boundary position ($F(2,62) = 0.053$, $p = 0.948$), but a marginal difference in the boundary width ($F(2,62) = 3.016$, $p = 0.057$). MCI seniors showed a wider boundary than young adults ($p = 0.051$).

Figure 4: (a) Identification curves of tones in three groups; (b) Discrimination curves of tones in three groups; (c) Within-category and between-category accuracy of tone discrimination in three groups.

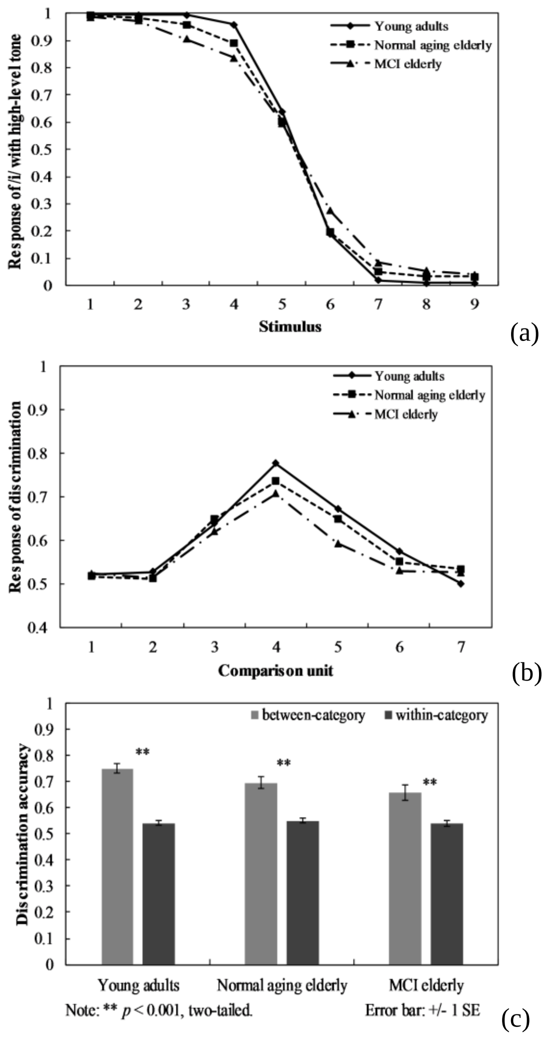


Table 1: Boundary position and width of tones in three groups.

Group	Position	Width
Young adults	5.314	1.020
Normal aging elderly	5.260	1.423
MCI elderly	5.275	1.957

Repeated measure analysis (*category* × *group*) revealed a significant main effect for *category* (within-subject factor) (F(1,60) = 161.450, p < 0.001) and a significant *category* × *group* interaction effect (F(2,60) = 4.709, p = 0.013), while no main effect for *group* (between-subject factor) (F(2,60) = 2.452, p = 0.095). Simple main effect analysis indicated a significant difference in between-category accuracy between the young adults and MCI elderly (p = 0.034). In each group, there was a significant difference between the within-category accuracy and between-category accuracy (all p_s < 0.001, see Figure 4 (c)).

4. DISCUSSION

There were significant differences in the identification and discrimination of tone perception between MCI elderly and young adults, indicating that MCI seniors presented the perceptual decline of Mandarin tones. However, no significant degradation was found in the behavioural performance of normal aging seniors, although they obtained lower MoCA score and showed worse hearing sensitivity than young adults. These findings might be explained by the decline compensation mechanism proposed in previous studies [11, 13], indicating that when conducting the same task, older people could show normal behavioural performance by utilizing more brain regions, while those presenting degraded performance had little compensation in the brain, which might also be correlated with cognitive impairment.

Although it was difficult to determine whether the hearing loss or cognitive decline fundamentally led to the perceptual degradation, several studies had tried to explore the roles of hearing loss and cognitive decline in categorical perception separately. Gordon-Salant et al. [6] compared the identification and discrimination of different English temporal cues in normal-hearing seniors and those with mild-to-moderately severe hearing loss, which distinguished the hearing impairment from other aging-related decline. They discovered a shallower slope and larger difference limens in hearing-impaired elderly only when perceiving DISH/DITCH which were different in the silence duration between the vowel and fricative, indicating that the perception of DISH/DITCH could be influenced by primary auditory capacity. However, the hearing loss played a limited role in the perception of other temporal cues, such as transition duration, VOT, and vowel duration [6]. In this study, we examined the role of cognitive degradation in the CP of spectral cues, and found that the cognitive impairment could affect the identification and between-category discrimination of Mandarin tones, while the within-category discrimination was not affected. Fujisaki & Kawashima [5] proposed a dual-process model, assuming that the identification and between-category discrimination relied on the long-term developed intrinsic categorical awareness, and the within-category discrimination was based on the short-term auditory memory code. Our results suggested that the cognitive impairment might be associated with the impaired internal categorical phonetic memory of tone which consequently impaired the perceptual ability of Mandarin tones.

There were some limitations in this pilot study that could not be ignored. First, only behavioral experiment was included, and electrophysiological recordings would be necessary in order to explore the cognitive compensation mechanism in the brain. Second, cognitive ability was only tested by MoCA. More detailed cognitive tests focusing on memory and language ability would be included in the further research to explore the influence of hearing loss and the decline in cognitive memory on the degradation of categorical perception.

5. CONCLUSION

In this study, we tested the behavioural CP performance of Mandarin tones in young adults, normal aging older people, and those with MCI. The results indicated a wider boundary of tone perception in MCI seniors than in young adults. Also, the between-category accuracy in the MCI group was significantly lower than that in young adults. No significant degradation in the behavioural performance of tone perception was found in normal aging seniors, although they showed worse hearing sensitivity and cognitive ability compared with young adults. Our findings supported that the compensation mechanism might be observed in older people with normal performance, rather than those with degraded performance. Besides, cognitive impairment might be related to the impairment of internalized categorical memory and led to the degradation of tone perception.

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