Effect of Perceptual Training with Noise on Chinese Learners' English Consonant Reception Thresholds

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***Abstract*—A group of native Chinese speakers underwent intensive perceptual training to identify English intervocalic consonants, with noise presented during the training procedure. Learners' Consonant Reception Thresholds (CRT) were measured before and after training, and their consonant identifications in quiet were also measured. The results showed that, after training, learners' overall CRT decreased significantly, and their consonant identification accuracy increased significantly. A significant negative correlation between individual consonant's CRT decrease and identification improvement was also found. These results indicated the general effectiveness of the training, and that CRT can be a useful metric in quantifying the abilities of non-native sound perception in noise.**

I. Introduction

Listeners' speech perception abilities deteriorate significantly in noisy environments. Previous studies have demonstrated that, compared to native speakers, non-native listeners' speech perception ability is more adversely affected by noise [1], [2], [3]. Although for some high-level L2 learners or bilinguals, native-like performance can be achieved in quiet conditions, their performance drops significantly in noise conditions [4], [5]. This native advantage may be due to the fact that native speakers can better use context and other perceptual cues in noise, because they have a larger vocabulary, a higher grammar and syntax level, and more experience with speech perception in adverse environments than L2 learners [6].

Although common sense tells us that earlier is better when learning an L2, theoretical frameworks such as Speech Learning Model (SLM) claim that learners' L2 sound learning ability remains intact over their entire life span [7]. Over the past few decades, a large body of studies have confirmed that high-variability perceptual training (i.e., using multi-talkers, multi-phonetic environments, natural speech, etc.) is an effective method to improve learners' L2 perception of consonants [8], [9], [10], vowels [11], [12], [13], tones [14] and for production as well [15], [16].

More recently, researchers have investigated the effectiveness of perceptual training on learners' L2 perception in adverse conditions. In a vowel training study, native Greek speakers underwent an intense high-variability perceptual training on English vowels, and their perception performance improved significantly in both quiet and noise conditions [17]. In a consonant study, native Spanish speakers were trained to identify English consonants, and noise was either presented or removed during training. The results showed that training in quiet can improve learners' perception in quiet better while training with noise leads to better performance in noise [18]. Another vowel study demonstrated that training with noise can better improve Chinese learners' English vowel perception in both quiet and noise conditions [19]. Existing studies suggest that training with noise is an effective method to improve learners' non-native perception ability in adverse conditions. However, more studies are still needed due to the differences between consonants and vowels, and the effects from different native and target language pairs. Therefore, one purpose of the current study is to investigate the effectiveness of perceptual training with noise on Chinese learners' English consonant perception.

Normally for speech perception in noise experiments, noise is set at fixed levels with different signal-to-noise ratios (SNR). However, this may raise problems when the purpose of the experiment is to quantify listeners' ability to perceive individual phonemes. Previous studies have demonstrated that a large range of SNRs is required for different consonants to reach equal intelligibility [20]. Therefore using several fixed SNRs for all consonants may not truthfully reflect the intelligibility for some consonants. Speech Reception Threshold (SRT) is commonly used to measure speech intelligibility in noise. However, most studies employing the SRT procedure are about native speech perception, with few trying to use it for non-native speech perception [21], [13]. More recently, researchers employed SRT procedures to investigate non-native Consonant Reception Thresholds (CRT) in noise [22]. However, to the authors' knowledge, no study has ever employed the CRT procedure to measure the non-native speech perception ability in a training study. Therefore another purpose of the current study is to examine whether CRT can be a useful metric to quantify the perception ability changes in noise.

II. Methods

A. Subjects

A cohort of 36 native Chinese subjects, including 17 males and 19 females, participated in the current study. These subjects were students from Jiangsu University of Science and Technology, with ages ranging from 19 to 30 years ($M = 23$ years). No subject had reported hearing or language problems, and all the subjects had passed a hearing test with pure-tone thresholds $\leq$ 15dB HL at octave intervals between 250 and 8000Hz [23]. Subjects were all from the Jianghuai Mandarin dialect spoken region (central-east China) and had certification in level II grade B or above in the National Proficiency Test of Putonghua (Mandarin). They were all EFL learners but majoring in various courses, and most of them had passed the College English Test Band 6 (CET-6). These subjects were further randomly assigned to a control group and a training group, each containing 18 people. The control group only participated in the pre- and post-tests, while the training group received extra intense perceptual training with noise in-between pre- and post-tests. Subjects were paid for their participation.

B. *Speech materials*

The speech materials used in the current study were derived from a British English consonant corpus - the Interspeech 2008 Consonant Challenge corpus [24] - consisting of nonsense vowel-consonant-vowel (VCV) tokens. The vowel contexts for each VCV token in this corpus were the 9 combinations of the 3 vowels /æ, i, u/ in initial and final positions. A subset of the corpus produced by 12 male and 12 female speakers, containing 23 consonants (/p, b, t, d, k, g, tʃ, ʤ, f, v, θ, ð, s, z, ʃ, ʒ, h, m, n, l, r, j, w/, [25]) were used in the current study, with 4 male and 4 female speakers in the pre- and post-tests, and 8 male and 8 female speakers in the training.

There were two tasks in both pre- and post-tests, namely, an English CRT test and an English consonant identification in quiet test. Exactly the same speech materials were used in the pre- and post-tests. In the English CRT test, only the VCV tokens in /æCæ/ context were used in order to reduce the variability of phonetic context, which would make the CRTs more stable between listeners and more comparable across corpora [20]. Four VCV tokens for each consonant were selected, and were repeated 5 times during the test, which makes it 20 tokens for each consonant, and 460 tokens in total. In the English consonant identification in quiet test, 16 VCV tokens were used for each of the 23 consonants, making 368 VCV tokens altogether. The vowel contexts were balanced for each consonant. There were 4 training sessions in the current study, each containing 3 blocks and each block containing 230 VCV stimuli, 10 for each of the 23 consonants. Therefore, there were 2760 VCV stimuli altogether in the training, 120 for each consonant. As in the English consonant identification in quiet test, all 9 possible vowel contexts were used in training, and were balanced for each consonant.

Speech Shaped Noise (SSN) was used as the noise masker in the CRT test and training. All stimuli were normalized to have equal root-mean-square (RMS) energy and the noise was added immediately prior to presentation. The signal-to-noise ratio (SNR) for each stimulus was adjusted dynamically according to the same SRT measure procedure in [22] and [26] for CRT test, while three levels of fixed SNRs were used in training.

C. *Procedure*

1) Overall structure of the experiment: The whole experiment was carried out at a sound-treated audiology test lab at Jiangsu University of Science and Technology. Subjects were asked to finish all the tasks individually over 6 consecutive days. Pre- and post-tests were carried out in the first and last day, and 4 sessions of training were given in-between, one per day. Stimuli were delivered via a AKG K271 MkII headphone and a RME Fireface 800 sound card in all tasks, and the presentation of stimuli and collection of responses were controlled by a customized MATLAB [27] program.

2) Forced choice identification paradigm: In the pre- and post-tests, subjects finished the English CRT test first, followed by the English consonant identification in quiet test. The 23 alternative forced choice identification paradigm was used in both tasks, in which the subjects were asked to assign the consonant they heard in each VCV stimuli to one of the 23 English consonant categories by clicking the corresponding button on a 4×6 on-screen button grid. Real English words with capital letters to indicate the corresponding consonant were shown on the buttons.

3) CRT test procedure: Different from the identification in quiet test, the VCV tokens were delivered together with noise in the English CRT test. The SNR for each VCV token was modified dynamically according to the history of subjects' perception responses, following a 2-down 1-up adaptive procedure [28], and the step size was fixed at 2dB. For example, if the current SNR for an "aba" token was -4dB, and the listener gave an incorrect answer, then the SNR for the next "aba" token would be increased to -2dB. If the listener gave a correct answer, then the SNR for the next "aba" token would be kept at -4dB. If the listener could correctly identify the "aba" token at -4dB again, then the SNR for the third "aba" token would again be decreased to -6dB. The SRT for each consonant was calculated by averaging the SNR values for the last 5 tokens for that consonant.

Previous studies have demonstrated that different consonants have various reception thresholds [20], [29], and if the initial SNR is set too high, the SRT might not be reliable due to the lack of convergence in the last 5 SNR values (i.e., where SNR values have been still continuously going down for the last few tokens) [22]. In the current study, the initial SNRs were set based on individual consonants rather than a fixed value for all sounds (see TABLE I), according to a pilot study [26].

4) Training: The 4 training sessions were conducted over 4 consecutive days, each containing 3 blocks. The VCVs were mixed with SSN at 3 different fixed token-based SNRs of 4, 0 and -4dB, one for each block. Using different SNR values aimed to promote variability in the availability of speech cues in different noise level, and to simulate everyday noisy environments [18]. Similar to the English CRT test, the 23 alternative forced choice identification paradigm was followed in the training. Subjects had to classify the consonant they heard in each VCV into one of the 23 categories. However, feedback was given if the subject gave an incorrect response, that is, the correct answer would be highlighted and the subject had to click the right answer and listen again to proceed.

TABLE I
INITIAL SNRS FOR ENGLISH CONSONANTS

Consonant	p	b	t	d	k	g	tʃ	ʤ	f	v	θ	ð
Initial SNR(dB)	-6	0	-6	0	0	-6	-6	-4	-2	4	4	4
Consonant	s	z	ʃ	ʒ	h	m	n	l	r	j	w	
Initial SNR(dB)	-4	0	-6	0	-6	-2	-4	0	-4	-2	-6	

III. RESULTS

A. Consonant Reception Threshold

Fig. 1 shows the mean Consonant Reception Thresholds over all consonants for control and training group in pre- and post-tests. Repeated-measures ANOVA confirmed that there was a significant main effect of test (pre-post) $[F(1,34) = 102.8, p < 0.001, \eta_p^2 = 0.752]$. However, there was no significant main effect of group (control-train) $[F(1,34) = 0.802, p = 0.377, \eta_p^2 = 0.023]$, but the interaction between test and group was significant $[F(1,34) = 21.9, p < 0.001, \eta_p^2 = 0.393]$. Further simple effect analysis with Bonferroni adjustment revealed that there was no significant difference of CRT between the two groups before training ($p > .05$), but a significant difference after training ($p < .05$). There was a small but significant 1.30dB CRT change for the control group after training (-3.25dB for pre-test and -4.55dB for post-test, $p < .05$), while the training group's CRT had a significant 3.55dB decrease ($p < .05$) from pre-test (-2.86dB) to post-tests (-6.41dB).

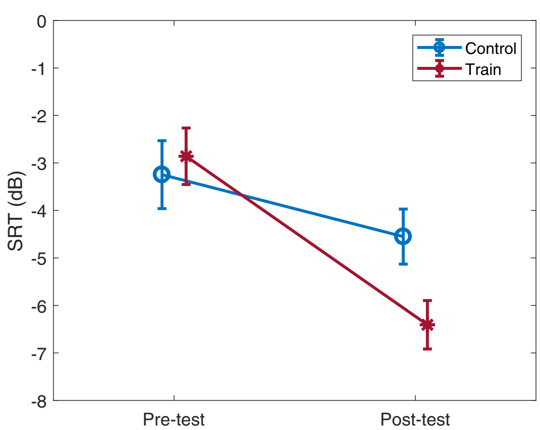

Fig. 1. Consonant Reception Threshold before and after training.

B. Identification accuracy in quiet

The mean identification accuracy across all 23 consonants for both control and training groups in pre- and post-test are shown in Fig. 2. Repeated-measures ANOVA indicated that there was a significant test effect $[F(1,34) = 45.1, p < 0.001, \eta_p^2 = 0.570]$. Similar to the CRT results, there was no significant group effect $[F(1,34) = 2.121, p > 0.05, \eta_p^2 = 0.059]$ but with a significant test×group interaction $[F(1,34) = 19.534, p < 0.001, \eta_p^2 = 0.365]$. Further simple effect analysis with Bonferroni adjustment revealed that there was no significant difference between the control group (81.1%) and the training group (82.3%) before training ($p > .05$). After training, the training group's performance significantly improved (89.5%, $p < .001$) while no significant change was found for the control group (82.6%, $p > .05$). The training group's overall identification accuracy was significantly better than the control group's after training ($p < .05$).

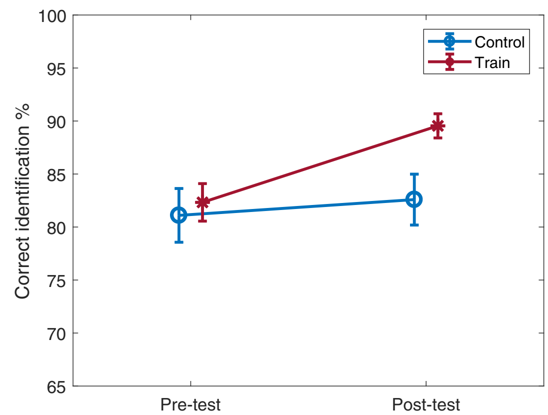

Fig. 2. Identification accuracy before and after training.

C. Individual consonants

Individual consonant's CRT changes from pre- to post-test for the training group are shown in Fig. 3. It can be seen that most of the consonants (19 of 23) demonstrated a CRT decrease after training. Paired-samples t-test indicated that 11 of them (/p, b, tʃ, θ, ð, ʃ, ʒ, m, n, j, w/) reached significance ($p < 0.05$), while the other 8 (/t, d, k, ʤ, s, z, l, r/) were not significant ($p > 0.05$). There were 6 consonants (/θ, ð, ʒ, m, n, w/) that demonstrated large CRT decrease (over 5dB) after training, and interestingly, 5 of them were voiced sounds. The largest CRT change came from the voiced fricative /ʒ/, with a huge 17dB decrease after training. Only 4 consonants (/g, f, v, h/) demonstrated CRT increase after training. However, the increase in CRT for these sounds were rather small (from 0.22dB to 2.98dB), and only /h/ reached significance ($p < 0.05$). In summary, these results indicated that training was generally effective in improving Chinese learners' individual English consonants' perception in noise.

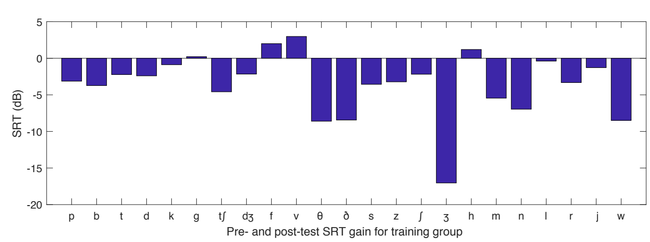

Fig. 3. Individual consonants' CRT changes from pre-test to post-test.

D. Relation between CRT and identification

To better demonstrate the training effect on consonant perception in quiet and in noise , Fig. 4 displays the CRT gains and identification gains for individual consonants after training. It can be seen that all the consonants are distributed roughly along the diagonal from top-left to bottom-right, and most of them are located near the bottom-right quadrant. This result indicates that Chinese learners' perception performances improved in both quiet and noise conditions after training, for most of the consonants. Statistical analysis revealed that there was a significant negative correlation between individual consonant's CRT decrease and identification improvement ($r = -0.7493, p < 0.001$), indicating a general tendency that, for Chinese learners, the more their performance improved in noise, the more their performance improved in quiet. It is quite noticeable from Fig. 4 that consonant /ʒ/ and /v/ are located at the two ends, with /ʒ/ improving greatly in both quiet and noise, while the performance for /v/ deteriorated in both conditions.

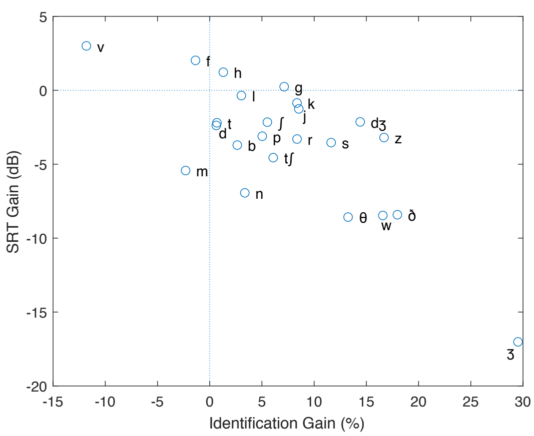

Fig. 4. Individual consonant's CRT and identification gains after training. Note that for CRT, a negative gain indicates better performance in noise.

IV. Discussion

The current study investigated the effect of perceptual training with noise on native Chinese learners' identification of English intervocalic consonants. After just 4 sessions of intensive training, Chinese learners' overall English CRT was significantly decreased, suggesting a significant improvement of consonant perception ability in noisy environment. This result is in line with several previous studies' findings that indicate perceptual training with noise is generally an effective method to improve non-native perception in adverse conditions [18], [30], [31], [19]. Although the control group demonstrated a slight but significant CRT decrease after training, the much larger improvement for the training group was solid evidence that the training was effective. The CRT decrease for the control group might be due to task familiarity or adaptation to the noise masker, reflecting the procedural learning suggested in [29] and [22].

Previous studies demonstrated that training with noise can not only benefit non-native perception in adverse environments, but can also improve learners' perception performance in quiet condition [18], [30], [31], [19]. In the current study, Chinese learners' English consonant identification accuracy improved significantly after training, providing new evidence that perceptual training in noise is an effective protocol to improve non-native perception in all conditions. The results from the current study are particularly comparable to that of [18], where the same VCV corpus was used and the training program was quite similar. An improvement of around 10 percentage points was observed for native Spanish subjects after 10 sessions of training in [18], with about 200 VCV training tokens for each consonant in total. Interestingly, in the current study, a 7 percentage points improvement was achieved for Chinese subjects using 120 VCV tokens all together in 4 training sessions. Would the amount of training materials leading to this level of improvement remain constant across different L1s? This is worth further study in the future.

Most of the consonants demonstrated a CRT decrease in the post-test for the training group, indicating the general effectiveness of the training in noise protocol for individual consonants. Voiced fricative /ʒ/ was the consonant with the largest improvement in both noise and quiet conditions in the current study, which was consistent with the findings reported in [18]. In fact, English /ʒ/ was among the most difficult sounds for Chinese learners, and it was largely confused with the approximant sound /r/ in a similar VCV identification experiment reported in [32]. In the current study, the training in noise protocol might help the Chinese learners to focus more on the high frequency frication cue of /ʒ/, which survives better in SSN, and the Chinese learners learnt to apply this new knowledge not only in noise but also in quiet. In fact, 5 of the 6 consonants with the largest CRT decrease in the current study were voiced sounds. Training with SSN as the noise masker might improve learners' ability to use perceptual cues outside the low frequency region.

Previous studies derived different results on whether training in noise is more effective than training in quiet. Mi and colleagues found that training in noise was more effective than training in quiet for vowel perception in both quiet and noise conditions [19]. However, Cooke and Garcia Lecumberri demonstrate that training in quiet leads to better consonant identification performance in quiet while training in noise shows some advantages for noise conditions [18]. They argue that training in quiet can maintain all the spectral-temporal information, while training in noise might lose some of them. However, listeners undergoing noise-based training might compensate for this by learning the noise-robust cues, leading to better performance in noise conditions. The current study didn't directly tackle this issue, however, the fact that there was a significant high correlation between CRT decrease and identification improvement, especially for the /ʒ/ case, indicated that Chinese learners could possibly benefit from the noise-based training and apply the robust perceptual cues they learned to normal and adverse environments.

A dynamic CRT procedure was applied in the current study to investigate Chinese learners' consonant perception in noise. Most of the consonants showed a CRT decrease after training, and significant correlation was found between CRT decrease and identification improvement. These results suggest that CRT can be a useful metric in quantifying the ability of non-native sound perception in noise. The results also demonstrated that the CRT change can vary greatly among different consonants, suggesting that a fixed SNR might not be able to measure the real change of perceptual ability for individual sounds in noise environments, especially when there was a ceiling effect. Interestingly, previous studies demonstrate that applying dynamic adaptive noise adjustments similar to the CRT procedure in training can lead to better training effects than using fixed noise level [30]. Future studies could investigate the effect of using dynamic procedures in both training and test phrases.

Acknowledgment

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