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Development of Mandarin Fricative-Affricate Nonsense Word Test: Part I. Selection of Best Exemplars

(Pembinaan Ujian Perkataan Tidak Bermakna Mandarin Frikatif-Afrikat: Bahagian 1. Pemilihan Contoh Terbaik)

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ABSTRACT

A speech test that emphasizes on fricatives and affricates with high-frequency components is recommended for testing individuals with high-frequency hearing loss. Validation of the frequency-lowering feature in modern hearing aids are also important. There has been no recorded speech material in Malaysia that focuses on Mandarin fricatives and affricates. Therefore, the objective of this study was to develop a nonsense word test that contains Mandarin sibilant fricatives and affricates. A total of 180 vowel-consonant-vowel (VCV) nonsense syllables were recorded from a female and a male talker. These VCV syllables included six targeted Mandarin fricatives and affricates in three vowel contexts. Perceptual and acoustic analysis were conducted and selected VCV syllables were validated by 24 native Mandarin talkers with normal hearing through identification testing. Hundred and three syllables were rated as having a good or excellent sound quality and free from at least one of the idiosyncrasy elements. The average percentage of correct identification of VCV tokens for the female and male talkers were 85.38% and 82.73%, respectively. Syllables that received the highest correct identification scores above the group mean were taken as the best exemplars. In total, 29 best exemplars were selected from 180 VCV syllables for the development of the Mandarin fricative-affricate nonsense word test. Future studies should include the development of performance-intensity function for individuals with normal hearing and a test manual so that the test can be used by non-native Mandarin clinicians.

Keywords: Mandarin; fricatives; affricates; identification testing; nonsense word

ABSTRAK

Ujian pertuturan yang menekankan komponen berfrekuensi tinggi frikatif dan afrikat adalah disyorkan untuk menguji individu yang bermasalah pendengaran frekuensi tinggi dan untuk mengesahkan ciri penurunan-frekuensi dalam alat bantu dengar moden. Tiada bahan pertuturan yang direkodkan di Malaysia yang memfokus kepada frikatif dan akfrikat Mandarin. Oleh itu, objektif kajian ini adalah untuk membina ujian perkataan tidak bermakna yang mengandungi bunyi frikatif dan afrikat Mandarin. Sejumlah 180 suku kata tidak bermakna vokal-konsonan-vokal (VCV) telah direkodkan daripada seorang penutur wanita dan lelaki, Suku kata ini mengandungi enam sasaran frikatif dan afrikat Mandarin dalam tiga konteks vokal. Analisis akustik dan persepsi telah dilakukan dan suku kata VCV yang terpilih telah disahkan oleh 24 penutur natif Mandarin berpendengaran normal melalui ujian identifikasi. Seratus tiga suku kata telah dikenalpasti mempunyai kualiti bunyi yang baik atau sangat baik dan bebas daripada salah satu elemen idiosinkrasi. Purata peratusan identifikasi token VCV yang betul untuk penutur perempuan dan lelaki adalah masing masing 85.38% dan 82.73%. Suku kata dengan skor identifikasi tertinggi yang melebihi skor purata kumpulan telah diambil sebagai contoh terbaik. Secara keseluruhannya, 29 contoh terbaik telah dipilih daripada 180 suku kata VCV untuk pembinaan ujian perkataan tidak bermakna frikatif dan afrikat Mandarin. Kajian masa depan perlu merangkumi pembinaan fungsi prestasi-intensiti untuk individual berpendengaran normal dan juga penghasilan manual supaya ujian ini boleh diguna pakai oleh klinisyen yang bukan penutur natif Mandarin.

Kata kunci: Mandarin; frikatif; afrikat; ujian identifikasi; perkataan tidak bermakna

INTRODUCTION

Consonant speech sounds with high-frequency components such as fricatives and affricates (Heinz & Stevens 1961; Jassem 1965; Behrens & Blumstein 1988; Jongman et al. 2000) are important in English and Mandarin languages. For example, fricatives /s, z/ serve as important grammatical markers in English (Rudmin 1983) whereas about half of the Mandarin consonants are fricatives and affricates (Zhao & Li 2009). High frequency information also gives the cue of place of production of the consonants such as the constriction sounds of fricatives while the intensity provides cue value to distinguish the class of consonants (Liberman 1957). The class of /s, ʃ/ is different from /f,θ/ with the detection of those information on word level. If the friction noise of /s/ in the word 'savvy' is not heard, it could be interpreted as 'heavy' or some offensive modern slang. Although recent speech perception theory suggests the envelope modulation cues have higher effects on sentence intelligibility than spectral or frequency-specific information (Humes 2013), but an assessment using magnetocephalography showed that the cortical entrainment to speech relies on spectro-temporal fine structure cues especially in degraded acoustic environment (Ding et al. 2014). The spectral information is needed to listen to speech in noise.

Hearing loss in the high-frequency region affects audibility of these speech sounds, even with the aid of a hearing aid (Boothroyd & Medwetsky 1992). Studies have shown that early-identified infants with hearing loss have delayed development in consonants; particularly fricatives, affricates and vocabulary production despite having access to current hearing aid technologies, when compared to their peers with normal hearing (Stelmachowicz et al. 2002; Moeller et al. 2007; Moeller et al. 2007; Stelmachowicz et al. 2008). Moreover, perception of fricatives by listeners with hearing loss is closely related to the audibility of high frequency frication noise (Zeng & Turner 1990; Hedrick 1997; Pittman & Stelmachowicz 2000). Bandwidth of fricative noise is also important for children to perceive the fricatives /s, z/ produced by female talkers (Kortekaas & Stelmachowicz 2000; Stelmachowicz et al. 2001; Stelmachowicz et al. 2002). Not having consistent exposure to these speech sounds will affect the speech and language development, as well as the learning process, among infants with hearing loss (Davis et al. 1986; Norbury et al. 2001; McGuckian & Henry 2007).

Hearing aid is one of the devices commonly used to assist individuals with hearing loss to hear better. It has moved on from analog to digital about 20 years ago (Dillon 2012). However, there is limited high frequencies amplification that is known for those in the field. The hearing aid frequency responses tend to roll off after 4000-6000Hz due to mechanical limitation. Besides that, the hearing aid tends to produce feedback when the gain of high frequencies sounds increases more than a certain limit.

Recently, an advanced digital processing feature in hearing aids, known as the frequency lowering technology, has been in the market to overcome the bandwidth limitation in hearing aids (Wolfe et al. 2010; Wolfe et al. 2015). This frequency lowering has different marketing names across different manufacturers but it serves the same purpose, to make the inaudible high frequency sounds audible. The general mechanism of this feature is to move, compress or shift the high frequency component of a sound to a lower frequency region where the hearing threshold levels are better so that a person can still hear. This enables a person with hearing loss to be able to detect or recognize high frequency sounds. In order to examine the effects of this feature on speech perception, a speech test containing high-frequency speech sounds (such as fricatives and affricates in Mandarin), is needed.

Both English and Mandarin languages are rich in sibilant fricatives and affricates. However, there are some differences between the fricatives and affricates in these languages. Firstly, all sibilant fricatives and affricates in Mandarin are voiceless, while English has voiced and voiceless fricatives or affricates. Secondly, there are six affricates in Mandarin, namely the alveolar /ts, tsʰ/, alveolo-palatal /tɕ, tɕʰ/, and retroflex /tʂ, tʂʰ/ affricates but there are only two palato-alveolar /tʃ, dʒ/ affricates in English. Thirdly, Mandarin has retroflex fricative /ʂ/ and retroflex affricate /tʂ, tʂʰ/ which are unavailable in English. Fourthly, the English affricates have no aspiration contrast but the Mandarin affricates have aspiration contrast. Lastly, Mandarin fricatives and affricates articulated at the same place of articulation exhibit a three-way contrast (e.g., /s/-/ʦ/-/ʦʰ/). Due to these differences, a Mandarin speech test that focuses on sibilant fricatives and affricates is highly needed for testing Mandarin-speaking individuals with hearing loss and validating the effectiveness of the frequency lowering technology in hearing aids.

Although there are various Mandarin speech tests built in China (Ma et al. 2013), most of these speech tests do not focus on affricate and fricative consonants. In addition, recorded Mandarin speech test is insufficient in Malaysia. Therefore, the main aim of this study is to develop a recorded nonsense word test that contains Mandarin fricatives and affricates. The Mandarin speech sounds of interest are the alveolar and retroflex fricatives /s, ʂ/ and affricates / ts, tsʰ, tʂ, tʂʰ/. The Mandarin alveolo-palatal fricative /ɕ/ and affricates /tɕ, tɕʰ/ are excluded because they are considered to be allophonic with the alveolar and retroflex fricatives and affricates (Munro 2008). This study focuses on selecting the best exemplars as material to develop the Mandarin fricative-affricate nonsense words test.

MATERIALS AND METHODS

This study was approved by The National University of Malaysia's Research Ethics Committee (UKM PPI/111/1/JEP-2016-659). It involves two main parts: (i) stimulus development and (ii) acoustical and perceptual testing for best exemplar selection.

STIMULUS DEVELOPMENT

Six fricative and affricate consonants in Mandarin (/s, ʂ, ts, tsʰ, tʂ, tʂʰ/) were pronounced in three different vowel contexts (/a/,/i/, and /u/), in the form of vowel-consonant-vowel (VCV) syllables (e.g., /asa/, /isi/, and /usu/). These syllables were recorded using two native Mandarin talkers, a male and a female. The VCV syllables were pronounced using the first tone with a carrier in Mandarin (e.g., "I will say……"). Each VCV syllable was repeated for five times yielding a total of 180 samples. The recording was conducted in a sound-treated room. The samples were kept as WAV files for offline analysis with 44100 Hz sampling rate and 32-bit resolution.

The acoustical waveform and spectrogram of each sample were visually inspected to determine the boundary of each VCV syllable prior to extraction. A second tester repeated this process on 72 samples (20%). The duration difference between the samples extracted by first and second tester was examined to identify the inter-rater reliability. Next, the extracted VCV syllables tokens were evaluated by two native Mandarin-speaking listeners (one had undergone phonetic training) in terms of recording sound quality. It was rated using Likert scale with a score of 1 indicates poor sound quality; whereas a score of 5 indicates excellent quality.

Tokens that received a good (scale 4) or very good (scale of 5) score by both examiners were selected for further idiosyncrasy element screening. The acoustical waveform and spectrogram of the filtered tokens was inspected to ensure they were free from idiosyncrasy elements. Idiosyncrasy is defined as uneven tone contour, long pauses between the initial vowel and consonant, and unclear burst waveforms (for affricate consonants only).

IDENTIFICATION TESTING

Twenty-four native Mandarin speaking adults, aged between 20 to 40 years old participated in the identification testing. The calculated sample size for this pilot study was 21 based on the formula by Cochran (1963) and Cocks and Torgerson (2013). The inclusion criteria were (i) normal hearing thresholds (≤ 20 dB HL) from 250 to 8000 Hz, (ii) no apparent middle ear problems, and (iii) native Mandarin speakers of Malaysian descent. The exclusion criteria were (i) individual with speech and language problems and (ii) non-Malaysian Mandarin talkers (e.g., citizens from China, Taiwan, and Hong Kong). The identification testing was conducted at the sound proof room of Audiology and Speech Sciences Clinic, Universiti Kebangsaan Malaysia.

The test stimuli were tokens that were equalized to have the same root-mean-square electrical output. The tokens were then concatenated into word strings with a 3-second silence in between each syllable. A 1000 Hz calibration tone was inserted at the beginning of each word string. The word strings were divided into two blocks according to talker gender (one block for female talker and another for male talker). The stimuli were presented at a comfortable listening level (60 dB HL) via headphones through an audiometer (AC40 Interacoustic) connected with a CD player (TASCAM CD-200 SB).

Stimulus was presented monaurally, a common practice in speech audiometry which allows testing each ear separately, and the test ear was counterbalanced across participants. The test ear and presentation of talker-gender block was counterbalanced across participants to control for order effect. Prior to the identification testing, familiarization was carried out using VCV syllables containing /p, b, t, d/ through live voice to ensure participants understand their tasks. During the identification testing, each subject was required to listen to the VCV syllables and indicate the consonants they heard in a close-set answered sheet. The close-set choices were written in *Pinyin* (C, CH, S, SH, Z, ZH) that represent the six targeted Mandarin fricatives and affricates /tsʰ/, /tʂʰ/, /s/ /ʂ/, /ts/, and /tʂ/, respectively.

RESULTS

A total of 180 VCV syllables (5 repetitions X 2 talkers X 6 consonants X 3 vowel contexts) were recorded. In order to determine the inter-rater reliability of the duration of the VCV syllables extracted from the samples, a Pearson Correlation test was conducted and the result showed high positive correlation between the duration of VCV syllables extracted by tester 1 and tester 2 where r = +.94, n = 36, p < 0.01, two tails. This suggested good inter-rater reliability of the duration of the VCV syllables extracted by different testers.

Sound quality ratings were conducted on all extracted VCV syllables by two native Mandarin speakers (Tester A and Tester B). Figure 1 shows the distribution of sound quality ratings of these syllables. A total of 114 VCV syllables (64 syllables by female talker and 50 syllables

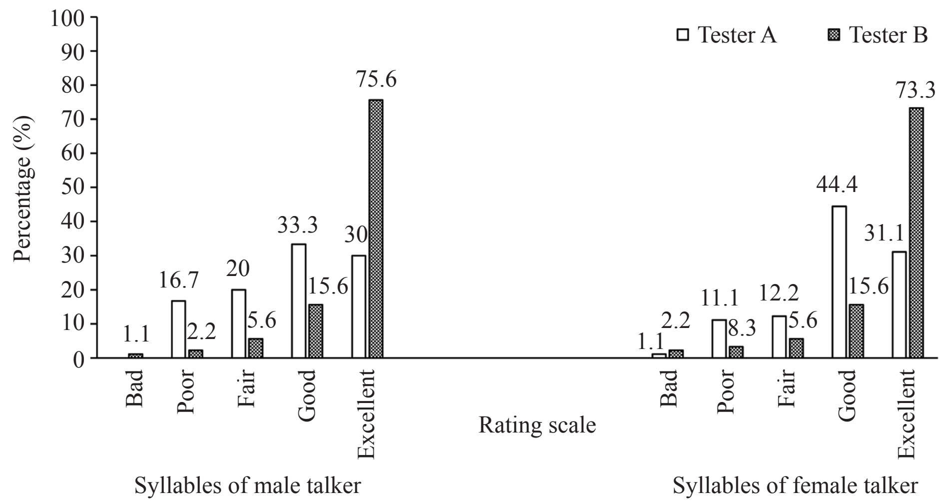

FIGURE 1. Sound quality ratings for nonsense syllables (n = 180) between Tester A and Tester B

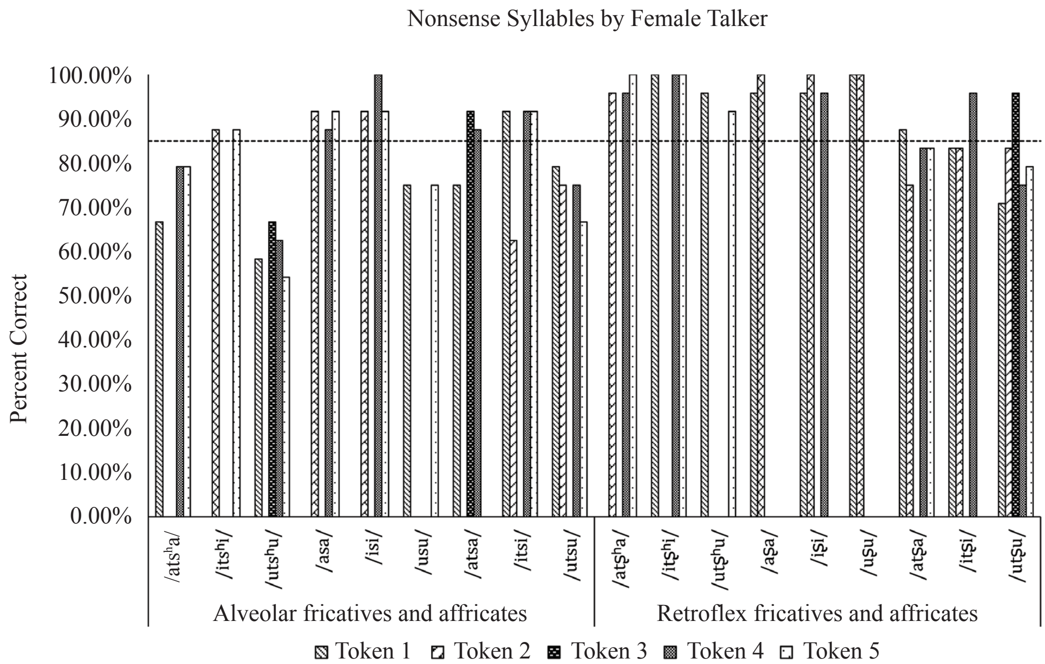

FIGURE 2. Identification scores (%) for nonsense syllables (in vowel-consonant-vowel format) spoken by a female talker

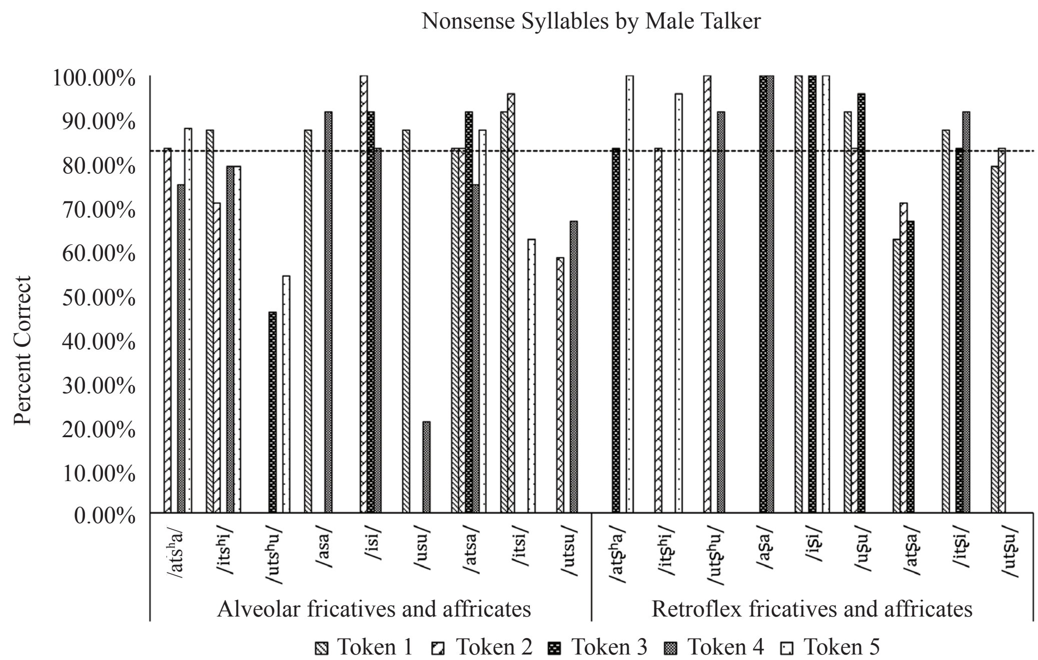

FIGURE 3. Identification scores (%) for nonsense syllables (in vowel-consonant-vowel format) spoken by a male talker

by male talker) were rated as having a good or excellent sound quality.

Idiosyncrasy element screening revealed that, 40 of the 50 VCV syllables (80%) by the male talker have flat pitch contour and did not have long pauses between the first vowel and the following consonant. Twenty-five of the 35 syllables that contained affricates have clear release-burst waveforms. For the female talker, 25 (39.2%) have flat pitch contour and 37 (57.8%) did not have long pauses between the first vowel and the following consonant; 31 of 43 syllables have clear release-burst waveforms. In total, only 103 syllables (55 by the female talker and 48 by the male talker) were selected to be examined in the identification testing. These syllables were rated as having a good or excellent sound quality and free from at least one of the idiosyncrasy element.

Recall that for each VCV syllable, there were five repetitions spoken by each talker. Each repetition is referred as a "Token #" where # indicates the number of repetition. Figure 2 and Figure 3 shows the percentage of correct identification of VCV tokens for the female and male talkers, respectively. The horizontal dotted lines in both figures show the group mean for the female (85.38%) and male (82.73%) talkers. Figure 2 shows that 43.63% of tokens spoken by the female talker had identification scores lower than the group mean whereas Figure 6 shows that 31.25% of tokens spoken by the male talker had identification scores lower than the group mean.

Since only one token is needed for nonsense syllables with the same consonant and vowels, the one that had the highest score above the mean were selected to develop the final test materials. If there were more than one tokens that had the same high scores, token will be selected based on how many idiosyncrasy elements it was free from. Table 1 summarizes the tokens that were selected to develop the Mandarin Fricative-Affricate nonsense word test. From Table 1, /utsʰu/ and /utsu/ were omitted in both female and male speaker list; whereas /atsʰa/ and /usu/ were absent from the female speaker list only, /atʂa/ was absent from the male speaker list only.

TABLE 1. Nonsense syllables selected to build the Mandarin Fricative-Affricate Nonsense Syllable Test

Number	Nonsense Syllables	Selected Tokens	
		Female Talker	Male Talker
1	/atsʰa/	-	Token 5
2	/itsʰi/	Token 5	Token 1
3	/utsʰu/	-	-
4	/asa/	Token 2	Token 4
5	/isi/	Token 4	Token 2
6	/usu/	-	Token 1
7	/atsa/	Token 3	Token 3
8	/itsi/	Token 1	Token 2
9	/utsu/	-	-
10	/atʂʰa/	Token 5	Token 5
11	/itʂʰi/	Token 5	Token 5
12	/utʂʰu/	Token 1	Token 2
13	/aʂa/	Token 2	Token 4
14	/iʂi/	Token 2	Token 3
15	/uʂu/	Token 1	Token 3
16	/atʂa/	Token 1	-
17	/itʂi/	Token 4	Token 4
18	/utʂu/	Token 3	Token 2

DISCUSSION

This main aim of the study was to select the best VCV tokens for developing a Mandarin Nonsense Syllable Test. In this study, we adopted the guideline as stated by (Cheesman & Jamieson 1996): tokens selected should be a good exemplar with minimal idiosyncrasy elements and identifiable as the target consonant by normal-hearing listeners.

A total of 180 VCV syllables (90 syllables from one female talker and another 90 from one male talker) were recorded and extracted from speech samples. The extracted VCV syllables had good inter-rater reliability in terms of the VCV duration. VCV syllables (n = 66) that did not receive good to excellent quality ratings were rejected. The syllables were rejected because they were contaminated by background noise such as paper flipping or typing sound during the speech recording, obvious treble felt in the voice, over nasalized, excessive long pause between C-V or V-C, and the presence of unintentional clicks either at the beginning or the end of each VCV syllables.

Idiosyncrasy element were screened as tokens should be free of idiosyncrasy and anomaly in pronunciation or intonation (Cheesman & Jamieson 1996). Some of the token were rejected because the pitch contour was not flat for the initial and final vowel. The pronunciation done using the first tone in Mandarin should result in flat contour. Other syllables with long pauses between the initial vowel and following consonant were excluded because the consonant should be pronounced at the intervocalic position giving rise to the contextual cues in a running speech (Cheesman & Jamieson 1996). An affricate consonant is also a sequence of a plosive sound followed by a homorganic fricative sound (Ladefoged & Johnson, 2011). The syllables without the transient burst in the speech waveform could be confused with the fricatives.

Cheesman & Jamieson (1996) used a 95% correct identification criterion in their pilot testing. This criterion was not implemented in the current study for four reasons. Firstly, the 95% correct identification criterion is too stringent which may lead to unacceptably high number of exclusions of tokens if it is used. Furthermore, the use of different vowel contexts in the present study could be more challenging than the fixed vowel context used in Cheesman and Jamieson's study. This notion is supported by the fact that the average identification score for our participants were lower than 95%. Secondly, the target consonants in the current study are different from the target consonants tested by Cheeseman & Jamieson (1996) in terms of language and the format of the nonsense words. Thirdly, the stimuli were presented at 60 dB HL through a clinical audiometer in the current study instead of 70 dB SPL as in Cheesman & Jamieson (1996). Lastly, the population tested in the current study is different from the population tested in Cheeseman & Jamieson (1996). Hence, the average identification scores for each talker block were used as the criteria to define VCV syllables that were readily identifiable by the normal-hearing listeners in a quiet condition.

There are a few limitations in the current study. A few VCV syllables had to be excluded in the final selection list because of identification scores lower than the average scores, particularly those that contained the alveolar affricates /tsʰ, ts/. The alveolar affricates were confused with the retroflex affricates /tsʰ, ts/ in the vowel /u/ context for both talker genders. This confusion pattern occurred between 21.88% to 47.92% of the time depending on the talker gender. Confusion between manner of articulation (e.g., aspiration vs. no aspiration, fricative vs. affricates) was not apparent. The spectral properties of the frication noise of fricatives and affricates can distinguish the place of articulation of these consonants (Jongman et al. 2000; Lee et al. 2012). Generally, alveolar consonants have higher spectrum as compared to retroflex consonants but the spectra can be lowered when these consonants occurred in rounded vowel context such as /u/ (Jongman et al. 2000). Another limitation of this study was that each token was only presented once during the identification testing. The results may be affected by the participants' attention. Future study should consider increasing the number of presentation of each test tokens and test-retest reliability of the participants' responses should be examined.

The procedures implemented in this study for selecting the best exemplars of recorded speech materials in this study offers a guide for future research involving development of any recorded speech test materials. Although the speech samples were restricted to Mandarin fricatives and affricates, the basic steps of quality judgement, acoustic analysis, and identification testing can be applied in other studies; the type of acoustic analyses may be modified to suite the targeted speech materials. The development of the Mandarin fricative-affricate nonsense word test may benefit clinicians and clients, particularly in Malaysia. The recorded materials can be used by non-Mandarin speaking clinicians to test Mandarin-speaking clients. In addition, one of the advantages of the study was that the recorded speech materials included two talkers with different gender. This will increase generazability because it is well-known that frication noise of female and male talkers has different spectral properties. The next phase of study will involve the development of a performance-intensity (PI) function and a manual for the Mandarin fricative-affricate nonsense word test. A PI function documents the speech recognition performance of listeners at different intensities level, from a level of inaudibility to maximum audibility (Boothroyd 2008). Information from a PI function such as the level at which 50% performance is achieved can be used clinically to cross-check pure tone audiometry results. PI function is also commonly used in research to evaluate newly developed speech materials such as word lists (Ji et al. 2011; Nissen et al. 2007).

CONCLUSION

Twenty-nine out of the 180 VCV tokens were selected to be included as the test item in the Mandarin fricative-affricate nonsense word test. The selected tokens were considered as the best exemplars after a systematic acoustical and perceptual assessment. Future studies should include the development of performance-intensity function for normal-hearing adults and children and a test manual to be used by non-native Mandarin clinicians.

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