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The Control of Fundamental Frequency in Chinese Aphasics: Impaired or Intact Prosody*

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This study explores in what way the sentence-final peak-to-valley F_0 fall and the P1 effect manifest themselves in Chinese aphasic speech and detects the extent to which aphasics exert control over fundamental frequency concerning different sentence lengths and tones. Four Broca's aphasics, four Wernicke's aphasics and four age-matched normal controls are tested. The results indicate that the terminal peak-to-valley F_0 fall is a significant feature of intonation contour in both Chinese normal and aphasic speech. Regarding the P1 effect, Broca's aphasics are impaired in programming this prosodic feature, whereas Wernicke's patients remain intact in this ability. The information obtained here suggests that the impairments in different prosodic features are dissociable. Therefore, we need to reconsider the validity of the clinical view that differentiates Broca's from Wernicke's aphasics in terms of "dysprosody" or "normal prosody."

Key words**:** fundamental frequency, sentence-final peak-to-valley F_0 fall, the P1 effect, aphasia, prosody, dissociable impairment

1. Introduction

Through the observation of F_0 behavior of a female Norwegian left-brain-damaged patient, Monrad-Krohn (1947) initiates the investigation of prosody in aphasia. He separates prosodic faculty from musical faculty and introduces the term "dysprosody" into neurological terminology to refer to the disturbance in prosodic faculty.[1] By using a sentence repetition task, Goodglass, Fodor and Schulhoff (1967) indicate that the preservation or omission of grammatical function words in agrammatic speech is determined by the prosodic characteristics related, e.g., the initial unstressed function words are often omitted by Broca's aphasics. The well-established Boston Diagnostic Aphasia Examination (BDAE) by Goodglass and Kaplan (1983) uses prosodic performance as one of the rules to assign profile ratings which help to differentiate aphasic patients. Regarding therapeutic application such as speech pathology, certain speech programs for hearing-impaired children emphasize training on prosodic attributes to improve patients' speech production (Cooper and Paccia-Cooper, 1980, Carter et al., 2002). Within the last few decades, the intact and disordered elements of prosody have become increasingly useful media for making inferences about language representation and speech

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[1] In a later work, Monrad-Krohn (1963) relates prosodic quality to intelligence and proposes four kinds of prosodic disturbances, i.e., hyperprosody, hypoprosody, aprosody and dysprosody.

planning (Danly and Shapiro, 1982, Shapiro and Nagel, 1995, Blonder et al., 1995, Baum et al., 1997, Gandour and Dardarananda, 1984, Gandour and Petty, 1989, Gandour et al., 1994, Schirmer et al., 2001, Kimelman, 1999, Vijayan, 1998).

Speech prosody refers to suprasegmental features such as fundamental frequency (F_0), duration, and intensity. The present study is principally concerned with the control of fundamental frequency in Chinese Broca's and Wernicke's aphasics. We use the sentence-terminal F_0 contour, and the P1 effect[2] as the criteria to examine aphasic patients' speech production. From cross-linguistic viewpoint, we make acoustic analyses of F_0 in the utterances of Chinese aphasics (1) to explore in what way the sentence-terminal F_0 contour and the P1 effect manifest themselves in Chinese aphasic speech, (2) to detect the extent to which aphasics exert control over fundamental frequency concerning different sentence lengths and tones, and (3) to examine if the findings of aphasic studies on intonation languages (e.g., English) are replicated in studies on tone languages such as Mandarin Chinese.

2. Previous studies on sentence-terminal F_0 contour and the P1 effect in aphasics

2.1 Sentence-terminal F_0 contour

The peak-to-valley F_0 fall (hereafter as P-V F_0 fall) at the sentence-final position is one uniform feature of normal intonation (Maeda, 1976, Danly and Shapiro, 1982). Lieberman and Blumstein (1988) account for this phenomenon in terms of physiological mechanism. They notice that the pulmonary air pressure goes from a positive to a negative value at the end of the breath-group to prepare the lung for next inspiration. If the speaker leaves the laryngeal muscles in a neutral position without using compensating maneuvers, F_0 will drop along with the falling of the transglottal air pressure. Thus, the utterance-final F_0 fall is closely related to the act of breathing.

Previous findings show that the P-V F_0 fall at the sentence-final position is the largest fall in magnitude (Danly and Shapiro, 1982, Maeda, 1976). It is claimed that the largest P-V F_0 fall at the terminal position signals the end of a sentence, while the

[2] As Cooper and Sorensen (1979) mention, the P1 effect manifests itself in the first peak (P1) value in F_0 accompanying the first stressed syllable of a single-clause declarative sentence. In normal speech, P1 F_0 value is closely related to sentence length, with higher P1 values accompanying longer sentences.

non-terminal minor fall reveals a speaker's intention to continue the utterance.[3] Based on the larger P-V F_0 fall at the second key word than that at the first key word of the two-key-word sentence, researchers claim that both Broca's and Wernicke's patients can cluster separated words in speech production and that their F_0 planning-unit is larger than a single word (Danly et al., 1979, Cooper et al., 1979, Danly and Shapiro, 1982, Danly et al., 1983, Shapiro and Nagel, 1995). Thus, the presence or absence of the terminal P-V F_0 fall can serve as an indicator which allows us to make inferences about speech planning.

2.2 The P1 effect

The P1 effect refers to the higher F_0 value of the first peak in the longer sentence compared with that in the shorter sentence. The differences in P1 F_0 values in the long versus short utterances demonstrate normal speakers' look-ahead mechanism which programs the P1 F_0 value by taking into consideration the overall length of the upcoming utterance (Cooper and Paccia-Cooper, 1980, Cooper and Sorensen, 1981). As Lieberman and Blumstein (1988) point out, the amount of air that a speaker takes into his lung is proportional to the entire length of the upcoming sentence. Because, for the single-clause sentence, the F_0 declination slope remains fairly constant and the final peak of sentences occurs at approximately the same value; normal speakers set up a higher P1 value in longer sentences to ensure adequate F_0 range for declination (Danly et al., 1983).

In the experiment conducted by Danly and Shapiro (1982), Broca's aphasics fail to set up the appropriate P1 F_0 value, for they do not encode longer sentences by producing an initially higher F_0. To account for the deficit, the researchers suggest that the patients' speech planning units are smaller-than-normal. Likewise, Cooper and his colleagues (1979) find that their Wernicke's patients plan similar P1 F_0 values for sentences of various lengths, and thus demonstrate abnormal declination. However, in a later study, Danly, Cooper, and Shapiro (1983) claim that their Wernicke's aphasics demonstrate the P1 effect and indicate that the entire sentence length and F_0 declination properly coordinate in aphasics' speech programming. In the present study, the P1 effect is examined to explore whether sentence length and F_0 programming are properly coordinated in Chinese aphasic speech.

[3] Moreover, Danly and Shapiro (1982) suggest that Broca's aphasics and young children use F_0 fall as an alternative way in segmenting utterances, since their speech production is full of pauses which signal segmentation in normal speakers' speech.

3. Method

The acoustic methodology reveals things about aphasics' internal code more directly than perceptual judgements (Cooper and Paccia-Cooper, 1980, Ryalls, 1982, 1984, Cruttenden, 1986, Baum and Boyczuk, 1999); therefore, the present study adopts the acoustic method to obtain a more objective assessment of F_0 control in Chinese aphasic speech.

3.1 Subject

Eight aphasics and four age-matched normal controls serve as subjects in the experiment. All subjects are male and predominantly right-handed. The patient group comprises four Broca's and four Wernicke's aphasics; all of them suffer unilateral left-hemisphere damage subsequent to cerebral vascular disease or brain trauma, and have neither auditory nor visual disturbance. The diagnosis of aphasia is based upon a Chinese adaptation of the BDAE; the sites of lesions are determined by neurologists and corroborated by Computerized Tomography (CT) scan. The aphasic subjects are tested at least three months post onset. The normal controls roughly match in age and educational level to the aphasic subjects. All subjects are native speakers of Mandarin Chinese. Their personal background and medical data are illustrated in Table 1 (for Tables, see Appendix A).

3.2 Stimuli

Four groups, each with eight sentences, are constructed to test the subjects. Each group comprises four pairs; the target words in each pair represent one distinct Mandarin tone. Sentences range in length from six to fourteen syllables (Appendix B). The target words are the second syllable of disyllabic words which are all content words of high frequency.[4] One sample set appears below with the target words in parentheses. Filler sentences that match with the real target sentences in terms of length, phonetic environment and syntactic structure are used as the first and the last sentences of each recording session to minimize initiation and completion effects.

Ala 小(柯)想去逛(街)
Bla 小(柯)想跟小(湯)去逛(街)

[4] As previous studies demonstrate, there are more phonological errors on content words than on function words and the speech production of Broca's aphasics is predominantly full of content words and often omits function ones (Blumstein, 1973).

Cla 小(柯)想跟小(湯)去東(區)逛(街)

Dla 小(柯)想跟台(玻)的小(湯)去東(區)逛(街)

3.3 Procedure

The test sentences are randomized across the subjects. An interval of approximately three seconds exists between the presentation of each sentence. The subjects were asked to read the test materials as naturally as possible and not to place contrastive or emphatic stress on any word. Before recording, the sentence was presented to the subject who was asked to read it aloud to ensure that he recognized the words and to practice it several times until at least one clearly articulated version of the completed sentence was produced.[5] The whole process of performing the task was audio-taped.

3.4 Data measurement and analysis

For each target-word, we use Visi-Pitch to measure the F_0 values of the tone-bearing unit at the peak and the valley. Two features concerning the sentence-terminal F_0 contour are examined. First, the sentence-final P-V F_0 fall exhibits if the P-V F_0 contour of the sentence-final target-word is falling. The falling contour is not determined by eyeballing. Rather, the peak and the valley F_0 values of the last target word are the reference points used to judge whether the contour is falling. When the peak F_0 value is larger than the valley F_0 value, the contour is considered falling. Second, the largest sentence-final P-V F_0 fall displays if the magnitude of the P-V fall in F_0 of the terminal target word is larger than that of the non-terminal target word(s) in a given sentence.[6]

To test the P1 effect, we pair two-target-word sentences with four-target-word ones, and three-target-word sentences with five-target-word sentences (e.g., A1a with C1a, B1a with D1a). The P1 effect manifests itself in the higher peak F_0 value at the beginning of the longer sentence than that of the shorter sentence. For instance, comparing the P1 F_0 value of Sentence A1a with that of Sentence C1a, we find such effect for the normal speaker, TL, with P1 F_0 4 Hz greater in the longer sentence, i.e., Sentence C1a.

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[5] The Broca's aphasic HT could not read sentences D2b and D4b on his own, so he was asked to repeat after the experimenter. He did not present any difficulty in repeating. Among the data collected, only these two are the repeated sentences. Owing to the scarcity of the repeated sentences, the possible practice effects of the repeated sentences are not considered here.

[6] Since the target words within the same sentence are of the same tone, the comparison in F_0 values among words is based on the same tonal level. Thus, the possible tone effects on the largest sentence-final P-V F_0 fall are attenuated.

Because the effects investigated in this study are analyzed in terms of frequency of occurrence, viz., on an all-or-none, discrete scale, we use overall and individual log-linear tests and the supplementary proportional z-test to assess the data. For the log-linear test, the probability (p) value has to be smaller than 0.05 to reach the significant level, while the z-score has to be larger than 1.96 to reach significance.

4. Results and discussion

4.1 Sentence-terminal F_0 contour

We first examine the sentence-final P-V F_0 to determine whether the terminal falling F_0 contour is a significant feature in Chinese speech. There are 243 out of the 360 sentences (67.5%) exhibiting the terminal P-V F_0 fall, which indicates that this effect is the robust tendency in the utterances of Chinese speakers. Table 2 displays not much difference with regard to the occurrence rate of the F_0 fall among various subject categories, among different tonal categories or among sentences of various lengths. Tables 2, 3, 4 and 5 display the distribution of this feature for cross-sections of all three variables. A log-linear analysis is performed on all F_0 values, which reveals non-significant main effect for subject category (χ_2^2= .81, p= .669), for tonal category (χ_2^2 = 3.80, p = .149) or for sentence length (χ_3^2= .13, p= .989), and non-significant interactions among these variables. The presence of the terminal F_0 fall implies that our aphasic subjects remain intact in processing this feature.

The second feature examined here concerns about the largest terminal F_0 fall. According to Lea (1973) and Maeda (1976), in normal speech, the largest P-V F_0 fall occurs on the last word of a sentence or clause. By comparing the magnitude of the P-V F_0 fall of final and non-final target words, we assess whether the sentence-final P-V F_0 fall is the largest F_0 fall of a sentence in Chinese speech. Our data from Chinese speakers, normal or aphasic, contradict earlier findings. There are only 75 out of the 360 sentences (20.83 %) that display the largest terminal F_0 fall, which means that the largest terminal F_0 fall is not a significant feature in Chinese speech. Thus, the universality of the largest terminal F_0 fall proposed by Maeda (1976) needs to be reconsidered.

Tables 6, 7, 8 and 9 display the distribution of the largest terminal P-V F_0 fall for individual major categories and for cross-sections of all three variables. The result from a log-linear analysis reveals a significant sentence length main effect (χ_2^2= 10.96, p = .012). On the other hand, no significant tone (χ_2^2 = 1.06, p = .588) or subject (χ_3^2= .06, p= .968) main effect, and no significant interactions are obtained between variables. Table 7 reveals that nearly two-thirds (72%) of the largest terminal F_0 fall effect comes from the shorter sentences, i.e., two-target-word and three-target-word sentences. Moreover, the percentage of such effect for the two-target-word sentences (45.33%) is exceedingly higher than that for the longer sentences (26.67%, 14.67% and 13.33%, respectively). The obtained data suggests that the sentence length main effect comes from the differences between shorter sentences and the longer ones, because it is more difficult for the longer sentences than for the shorter ones to trigger the largest terminal F_0 fall effect. From the non-significant subject main effect we infer that Chinese normal and aphasic speakers show similar tendency in producing the largest terminal P-V F_0 fall, despite so slight the frequency for this feature to appear in Chinese speech.

4.2 The P1 effect

We detect the presence of the P1 effect in Chinese speakers using matched long vs. short sentences. There are 90 out of total 176 pairs of sentences that exhibit the P1 effect (51.14 %). The results of the z-test reveal that the frequency difference of the P1 effect between normal and Broca's subjects is significant (z = 2.07), whereas these between normals and Wernicke's aphasics (z = .78) or these between Broca's and Wernicke's aphasics (z= 1.31) do not reach significant levels. No significant influence from the four Mandarin tones is demonstrated with regard to this prosodic feature (Table 10). Consistent with previous findings (Danly and Shapiro, 1982, Danly et al., 1983), the above-mentioned statistics reveal that Wernicke's aphasics exhibit the P1 effect as often as normals, whereas Broca's aphasics fail to demonstrate normal tendency in this respect. The information obtained here suggests that only Broca’s subjects are impaired in coordinating the information of sentence length with the programming of the initial F_0 value.

5. General discussion and conclusion

Consonant with earlier findings, the sentence-final P-V F_0 fall is a significant feature of intonation contour in Chinese normal and aphasic speech, which is explicable in terms of the least effort strategy in dealing with the falling air pressure at expiration-terminal position (Lieberman and Blumstein, 1988). Both aphasic groups remain intact in processing the terminal P-V F_0 fall, for this feature is closely related to the breathing mechanism. As long as the patients have no problem with the act of breathing, they can process this prosodic feature well.

Previous studies on English aphasics claim that the sentence-final P-V F_0 fall is the largest fall in magnitude. Surprisingly, the present work shows that the terminal F_0 fall is not the largest F_0 fall for Mandarin Chinese speakers, normal or aphasic.

The discrepancy between Chinese and English speakers concerning the largest terminal F_0 fall can be attributed to the difference in sentence lengths used in different studies. The test sentences in studies on English speakers are restricted to five-syllable sentences containing two target words. In contrast, the test sentences used in the present work are comparatively longer, ranging from six to fourteen syllables and containing more target words. As stated in Section 4.1, the shorter the sentences are, the more easily they can trigger the largest terminal F_0 fall effect. Accordingly, this effect is not so robust in our study as in previous studies. To versify the universality of the largest terminal P-V F_0 fall, claimed by Maeda (1976) and Danly and Shapiro (1982), future research needs to employ longer test sentences for English speakers and to collect more data from Chinese speakers.

Researchers of earlier studies provide the largest terminal P-V F_0 fall as the evidence for speech planning. According to these researchers, the largest F_0 fall signals that the speaker can cluster separated words and process more than one word at a time (Danly, et al., 1979, Cooper et al., 1979, Danly and Shapiro, 1982, Danly et al., 1983). However, our data show that the largest terminal F_0 fall is not a common feature for Chinese speakers. Thus, based on the findings about this prosodic feature, we can not make any concluding remark about the scope of speech planning for Chinese aphasics.[7]

Regarding the P1 effect, we hypothesize that if aphasics have a limited capacity to plan linguistic material, they may not encode sentence length by appropriately planning the initial F_0 value. Our result for Broca's subjects suggests that they do not process entire sentences and set the starting F_0 values in the same manner as normal speakers. On the other hand, our Wernicke’s speakers remain intact in this ability, which means that they are able to combine the factors of sentence length and F_0 contour in order to produce higher values of P1 for longer sentences.

In the assessment of aphasia, the intonational contour or melodic line of speech is used as a factor (Goodglass and Kaplan, 1983). Clinically, Broca’s and Wernicke’s speakers are contrasted in terms of verbal fluency and the control of melodic line of an entire sentence. According to this view, speech prosody in

[7] One possible inference is that the upper limit for aphasics’ speech planning unit may be five syllables. This inference is less surprising in the light of the contradictory findings in studies employing sentences of different lengths. As stated earlier, English aphasic speakers display the largest terminal F_0 fall for sentences of five syllables, while Chinese aphasics fail to exhibit such feature for sentences of more syllables. Yet, the issues whether the five-syllable unit is the cutting point and exactly how the speech planning units of Chinese aphasics are like are beyond the scope of the present work. More empirical data is needed to provide a clearer picture about these issues.

Another inference can also be drawn from the discrepancy between Chinese and English speakers concerning the largest F_0 fall. That is, English speakers rely on the largest terminal F_0 fall to signal utterance ending, while Chinese speakers may primarily use other strategies, such as longer pauses, to indicate utterance ending, though more empirical data is needed to further verify this hypothesis.

Wernicke's aphsics is considered to remain intact, whereas Broca's aphasics are characterized by dysprosody (Hecaen and Albert, 1978). However, our results from acoustic analysis show that Broca's aphasics still possess the ability in programming certain prosodic feature, i.e., the sentence-final P-V F_0 fall. As Danly and Shapiro (1982) state, under limited syntactic domains, some of Broca's aphasics' F_0 attributes remain intact despite the clinical impression of dysprosody.

In a series of studies, we examined Chinese Broca's and Wernicke's aphasic' control of F_0 declination and sentence-final lengthening (Sah 2001, 2004),[8] and found that both groups of aphasics have disturbances in programming these prosodic features. In the present work, we note that both Broca's and Wernicke's aphasics exhibit the normal tendency of the sentence-final P-V F_0 fall, whereas only Broca's subjects fail to demonstrate the P1 effect. Taken together, the findings show that our aphasic subjects demonstrate different behavior with respect to the P1 effect rather than other features (Table 11). The information listed in Table 11 reminds us that the speech prosody of Wernicke's aphasics is not strictly normal. Although the intonational contour of Wernicke's aphasics sounds quite normal to the clinician, it may contain certain deficits, such as the abnormalities in final lengthening and F_0 declination, which may be imperceptible. The results also challenge the common view that dysprosody is a major deficiency in Broca's population, since our patients are intact in programming the sentence-final P-V F_0 fall.

Previous studies point out that there are separate disruptions of prosodic features in aphasic speech (Gandour and Dardarananda, 1984, Baum and Boyczuk, 1999). In the present work, we document an apparent dissociation of impairments between the sentence-final P-V F_0 fall and the P1 effect.[9] The dissociable prosodic impairments suggest that "prosody" should be regarded as a heterogeneous collection. The problem with the clinical impression of dysprosody or normal prosody may be that the concept about prosody is used in a too general way. When we use prosody as the

[8] The present study employs the same subjects and test material as those used in these experiments.

[9] As Baum and Boyczuk (1999) mention, the dissociation of impairments can be interpreted in the context of the autosegmental theory, proposed by Goldsmith (1976, 1990). Adopting the multi-tier approach, Levelt (1989) proposes a possible architecture of speech production. He hypothesize that there exist autonomous multi-tiers in charge of different prosodic features. Under this framework, the dissociation of prosodic deficits in aphasic speech is explicable, since various events can take place at the different tier (e.g., temporal control, the terminal P-V F_0 fall, or the P1 effect) without necessarily having any effect on what goes on at another tier. Thus, an aphasic speaker may remain intact in the tier which processes one prosodic feature (e.g., the sentence-final P-V F_0 fall), while he may have deficits in other tier which programs certain other features (e.g., the P1 effect).

Though such interpretation seems rather plausible, we need more experiments to show that there is really a hierarchical relationship between these F_0 attributes, to show the difference among these tiers, and to show how these prosodic parameters are conceived as structural constructs in the competence model such as the autosegmental theory. These research questions are beyond the scope of the present work. Before any valid interpretation can be made, we need more investigations to further explore these issues.

criterion for clinical assessment, we have to specify which prosodic feature is actually involved to make the classification or the comparison viable.

The present project demonstrates that the acoustic analysis may clarify the notion about prosody in clinical application and reminds us that we need more detailed and systematic investigations on different aspects of F_0 programming in aphasic speech to thoroughly understand aphasics' ability in F_0 control. The statistics obtained here should not be generalized to the whole Broca's or Wernicke's population. The scarcity of available patients limits our subjects to a very small population, so we yielded only limited amount of information regarding these prosodic attributes. These findings ought to be amended or augmented by studies using larger and better-defined subject population, from which more credence will be gained.

Appendix A

Table 1： Personal data of aphasic and normal subjects

Subject Category*	Name	Sex	Age yrs	Educ. yrs	Post Onset	Etiology	Lesion Site CT
B	TC	M	34	12	3;1	CVA	frontal
B	CC	M	38	16	3;8	trauma	frontal- temporal-parietal
B	HT	M	74	12	1;11	CVA	frontal
B	FL	M	75	19	0;4	CVA	frontal- temporal
W	SM	M	16	9	2;8	trauma	frontal- temporal
W	LM	M	51	12	2;7	trauma	temporal
W	MN	M	54	6	0;11	CVA	frontal
W	ML	M	58	16	1;10	CVA	frontal-parietal
Mean			50.00	12.75			
SD			18.83	3.90			
N	PC	M	75	9			
N	WM	M	56	12			
N	TL	M	38	12			
N	KP	M	24	17			
Mean			48.25	12.5			
SD			19.16	2.87			

* B=Broca's aphasics W=Wernicke's aphasics N=Normals

Table 2： Frequency distribution of the sentence-final P-V F_0 fall for individual major categories(N = 243)

		Raw Frequency	Percentage
Subject Category	Broca	74	30.45 %
	Wernicke	84	34.57 %
	Normal	85	34.98 %
Sentence Length	Two*	63	25.93 %
	Three	60	24.69 %
	Four	60	24.69 %
	Five	60	24.69 %
Tone[10]	Tone 1	66	27.16 %
	Tone 2	0	0 %
	Tone 3	88	36.21 %
	Tone 4	89	36.63 %

*"Two," "three," "four," or "five" stands for the number of target words contained in the test sentences.

Table 3：Frequency distribution of the sentence-final P-V F_0 fall for different subject categories and sentence lengths (N=243)

Sentence length / Subject Category	Two	Three	Four	Five	Total (raw frequency)	Percentage (%)
Broca	18	20	18	18	74	30.45
Wernicke	21	19	21	23	84	34.57
Normal	24	21	21	19	85	34.98
Total (raw frequency)	63	60	60	60	243	
Percentage (%)	25.93	24.69	24.69	24.69		

[10]The raw frequency for Tone 2 is 0 here, which indicates that there is no occurrence of the sentence-terminal P-V F_0 fall for Tone 2 target words. As mentioned in Section 3.4, the F_0 contour is considered falling, if the peak F_0 value is larger than the valley F_0 value. In the present work, Tone 2 sentences are omitted from analysis on falling contour, since Tone 2 target words demonstrate the rising contour which is irrelevant to the purpose of examining the terminal falling contour in F_0. Though we notice that the rising contour of Tone 2 words is less obvious at the sentence-final position, more systematic investigations are needed to explore the possible influence of the terminal falling F_0 contour on the rising contour of Tone 2 words.

Table 4：Frequency distribution of the sentence-final P-V F_0 fall for different subject categories and tones (N=243)

Subject Category \ Tone	Tone 1	Tone 2	Tone 3	Tone 4	Total (raw frequency)	Percentage (%)
Broca	19	0	27	28	74	30.45
Wernicke	24	0	29	31	84	34.57
Normal	23	0	32	30	85	34.98
Total (raw frequency)	66	0	88	89	243	
Percentage (%)	27.16	0	36.21	36.63		

Table 5：Frequency distribution of the sentence-final P-V F_0 fall for different sentence lengths and tones (N=243)

Sentence Length \ Tone	Tone 1	Tone 2	Tone 3	Tone 4	Total (raw frequency)	Percentage (%)
Two	18	0	24	21	63	25.93
Three	15	0	22	23	60	24.69
Four	17	0	20	23	60	24.69
Five	16	0	22	22	60	24.69
Total (raw frequency)	66	0	88	89	243	
Percentage (%)	27.16	0	36.21	36.63		

Table 6： Frequency distribution of the largest terminal P-V F_0 fall for individual major categories (N = 75)

		Raw Frequency	Percentage
Subject Category	Broca	23	30.67 %
	Wernicke	26	34.67 %
	Normal	26	34.67 %
Sentence Length	Two	34	45.33 %
	Three	20	26.67 %
	Four	10	14.67 %
	Five	11	13.33 %
Tone	Tone 1	21	28.00 %
	Tone 2	0	0 %
	Tone 3	30	40.00 %
	Tone 4	24	32.00 %

Table 7：Frequency distribution of the largest terminal P-V F_0 fall for different subject categories and sentence lengths (N=75)

Sentence Length / Subject Category	Two	Three	Four	Five	Total (raw frequency)	Percentage (%)
Broca	10	6	4	3	23	30.67
Wernicke	12	7	3	4	26	34.67
Normal	12	7	3	4	26	34.67
Total (raw frequency)	34	20	10	11	75	
Percentage (%)	45.33	26.67	14.67	13.33		

Table 8：Frequency distribution of the largest terminal P-V F_0 fall for different subject categories and tones (N=75)

Tone / Subject Category	Tone 1	Tone 2	Tone 3	Tone 4	Total (raw frequency)	Percentage (%)
Broca	6	0	10	7	23	30.67
Wernicke	8	0	9	9	26	34.67
Normal	7	0	11	8	26	34.67
Total (raw frequency)	21	0	30	24	75	
Percentage (%)	28.00	0	40.00	32.00		

Table 9：Frequency distribution of the largest terminal P-V F_0 fall for different sentence lengths and tones (N=75)

Sentence Length \ Tone	Tone 1	Tone 2	Tone 3	Tone 4	Total (raw frequency)	Percentage (%)
Two	9	0	13	12	34	45.33
Three	4	0	10	6	20	26.67
Four	4	0	3	3	10	14.67
Five	4	0	4	3	11	13.33
Total (raw frequency)	21	0	30	24	75	
Percentage (%)	28.00	0	40.00	32.00		

Table 10：Frequency distribution of the P1 effect for matched sentence pairs (N =90)

Subject Category \ Tone	Tone 1	Tone 2	Tone 3	Tone 4	Total (raw frequency)	Percentage (%)
Broca	5	7	6	5	23	25.56
Wernicke	10	9	6	6	31	34.44
Normal	9	10	8	9	36	40.00
Total (raw frequency)	24	26	20	20	90	
Percentage (%)	26.67	28.89	22.22	22.22		

Table 11：Prosodic performance of aphasics*

Prosodic Features	Broca's	Wernicke's
Sentence-final Lengthening	impaired	impaired
F_0 Declination	impaired	impaired
Sentence-final P-V F_0 Fall	intact	intact
P1 Effect	impaired	intact

*The results are from two previous studies (Sah, 2001, 2004) and the present one.

Appendix B*

Filler Sentence:小曾想去買書

Group A: Two-Target-Word Sentences

Ala** 小(柯)想去逛(街)

A1b 小(高)想去野(餐)

A2a 小(彭)想去打(球)

A2b 小(田)想去旅(行)

A3a 小(管)想去游(泳)

A3b 小(許)想去慢(跑)

A4a 小(賴)想去吃(飯)

A4b 小(畢)想去散(步)

Group B: Three-Target-Word Sentence

Bla 小(柯)想跟小(湯)去逛(街)

B1b 小(高)想跟小(周)去野(餐)

B2a 小(彭)想跟小(程)去打(球)

B2b 小(田)想跟小(錢)去旅(行)

B3a 小(管)想跟小(郝)去游(泳)

B3b 小(許)想跟小(沈)去慢(跑)

B4a 小(賴)想跟小(戴)去吃(飯)

B4b 小(畢)想跟小(紀)去散(步)

Group C: Four-Target-Word Sentences

Cla 小(柯)想跟小(湯)去東(區)逛(街)

C1b 小(高)想跟小(周)去深(坑)野(餐)

C2a 小(彭)想跟小(程)去新(竹)打(球)

C2b 小(田)想跟小(錢)去溪(頭)旅(行)

C3a 小(管)想跟小(郝)去淡(水)游(泳)

C3b 小(許)想跟小(沈)去操(場)慢(跑)

C4a 小(賴)想跟小(戴)去木(柵)吃(飯)

C4b 小(畢)想跟小(紀)去學(校)散(步)

Group D: Five-Target-Word Sentences

Dla 小(柯)想跟台(玻)的小(湯)去東(區)逛(街)

D1b 小(高)想跟台(新)的小(周)去深(坑)野(餐)

D2a 小(彭)想跟台(航)的小(程)去新(竹)打(球)

D2b	小(田)想跟台(僑)的小(錢)去溪(頭)旅(行)
D3a	小(管)想跟台(北)的小(郝)去淡(水)游(泳)
D3b	小(許)想跟台(鐵)的小(沈)去操(場)慢(跑)
D4a	小(賴)想跟台(電)的小(戴)去木(柵)吃(飯)
D4b	小(畢)想跟台(汽)的小(紀)去學(校)散(步)

Filler Sentence:小葉想跟台亘的小蔡去新店上課

*For ease of reference, we put the target words in parentheses in this appendix.
** “1”, “2”, “3”, and “4” stand for Tone 1, Tone 2, Tone 3, and Tone 4, respectively.

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由漢語失語症病人的基頻表現看其音律掌控能力

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臨床上依聽覺判斷，一般將維氏 (Wernicke’s) 病人定位爲音律表現完好，而將布氏 (Broca’s) 病人歸爲音律異常 (dyprosody)。然音律(prosody)一辭包羅甚廣，舉凡基頻、字長、強度等聲學特性均在其範疇中。本研究以句首基頻效應 (P1 effect) 及句尾基頻下降現象(peak-to-valley F_0 fall) 爲指標，檢驗以音律表現完好與否來區分布氏及維氏兩種病人的有效性。本研究實驗組有八名失語症病人。根據波士頓失語診斷測驗，布氏病人共四位，維氏病人共四位。控制組爲四位健康的正常人。實驗者設計了四組長度不同的句子；每組八句，每句之關鍵字爲同一聲調，八句平均使用國語中四個聲調。受試者須將實驗者所呈現的句子唸出，所有語料均錄音並進行聲學分析。最後，將分析結果加以統計考驗。實驗結果顯示，布氏病人的基頻表現並非全面性損壞，他們仍能掌控某些特性；而維氏病人未如一般預期能完好地處理基頻。是以，不同基頻特性的損壞彼此間是可分離的 (dissociable)。此外，若僅以音律一詞來界定，而不釐清是以音律(甚至於基頻)的那些特性作區分，未免失之籠統，以致無法作出有效的失語症分類判斷。

關鍵詞：基頻、句首基頻效應、句尾基頻下降、失語症、音律、分離性的損壞