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Respiratory Changes during Reading in Mandarin-Speaking Adolescents with Prelingual Hearing Impairment

Wei-Chun Che[a] Yu-Tsai Wang[a] Hsiu-Jung Lu[a] Jordan R. Green[b]

[a]School of Dentistry, National Yang-Ming University, Taipei, Taiwan, ROC; [b]Department of Special Education and Communication Disorders, University of Nebraska-Lincoln, Lincoln, Nebr., USA

Key Words
Acoustics · Mandarin · Breath group · Reading · Hearing impairment

Abstract
Objective: Most people with severe to profound hearing impairment (SHI) exhibit speech breathing changes, but little is known about the breath group (BG) structure for this population. The purposes of this study were to investigate, compared to speakers with normal hearing, if Mandarin-speaking adolescents with prelingual SHI take inspirations more often at syntactically inappropriate positions and exhibit a difference in the temporal BG characteristics. ***Patients and Methods:*** Forty participants, 20 speakers with prelingual SHI and 20 normal-hearing controls matched for age, sex and education level were recruited. While wearing a circumferentially vented mask connected to a pneumotachograph, the subjects read three passages. The airflow signal was used to locate inspiratory loci in the speech samples. Temporal parameters of BG structure were derived from the acoustic signal. ***Results:*** The SHI group, compared to the control group, had significantly (1) more inspiratory loci at inappropriate and minor syntactic boundaries; (2) fewer syllables per BG, slower speaking rate, longer inter-BG pauses, and longer noninspiratory pauses, but comparable inspiratory duration, expiration duration, and BG duration. ***Conclusion:*** The slower speaking rate within BGs and longer inter-BG pauses mainly account for the respiratory changes in Mandarin-speaking adolescents with prelingual SHI.

Introduction

Severe hearing impairments (SHI) result in numerous speech difficulties due to long-term inadequate auditory feedback. One long-term consequence of inadequate auditory feedback is the abnormal patterns of inspiratory pauses during speech. Because pauses provide information used to decode speech, these abnormal pausing patterns may significantly contribute to speech intelligibility problems in SHI. The pausing patterns in SHI have been reported [1, 2], but the components of abnormal pausing patterns have not been studied.

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KARGER
Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

Accessible online at:
www.karger.com/fpl

Yu-Tsai Wang
School of Dentistry, Room 411, National Yang-Ming University
No. 155, Sec. 2, Li-Nong St. Beitou District
Taipei 11221, Taiwan (ROC)
Tel. +886 2 2826 7237, E-Mail yutsaiwang@ym.edu.tw

Although the basis of breathing anomalies and abnormal pausing is not understood, it could be related to aberrant functioning at all levels of the speech mechanism including the respiratory, phonatory, articulatory, and resonatory speech subsystems [1]. Compared to speakers with normal hearing, speakers with bilateral congenital profound hearing impairment tend to initiate speech at a level of lung volume that is either too high or too low, and to speak into functional reserve capacity [2]; moreover, the mean airflow per syllable is twice that of speakers with normal hearing [3]. Profoundly hearing-impaired speakers also demonstrated more aberrant rates of oral airflow than did normal-hearing (NH) and SHI speakers [3]. Consequently, these speakers produced fewer syllables per breath group and often paused for inspiration at grammatically inappropriate locations. The authors concluded that the disorders in the speech respiratory behaviors resulted from the combined influences of poor respiratory control, incoordination between larynx and upper airway, and/or failure to follow grammatical phrasing [2].

Laryngeal dysfunction has been documented in speakers with hearing impairments. Using transillumination to monitor glottal activity and an electrical transconductance technique to record temporal patterns of oral articulation, McGarr and Lofqvist [4] studied 3 adults with SHI and observed inappropriate abduction gestures between words for all their talkers. Metz et al. [5] also observed abnormal abductory behaviors in 4 adults with profound hearing impairment, which appeared to result in air wastage during speech production. Based on a comprehensive speech/voice physiological assessment of 14 adults with hearing impairment, Higgins et al. [6] observed both hypo- and hyperadduction of the vocal folds, although hyperadduction was more common. Both patterns have the potential to significantly affect speech breathing behavior.

Aberrant pausing in SHI may also be due to aberrant articulatory and velopharyngeal behavior. Specifically, SHI speakers tend to speak slower [7, 8] and exhibit more nasality [9] than NH speakers. Slowed speech is probably associated with increased pauses as speakers need to replenish their air supply more frequently. Similarly, air escapage from the velopharyngeal port during speech could diminish the air supply for speech, resulting in more frequent inspirations. The purpose of this investigation is to identify the potential components of the abnormal pausing patterns. This information will serve as a basis for more in-depth investigations into speech subsystem changes that might account for the observed behavior.

Speech breathing anomalies in speakers with SHI have commonly been characterized using kinematic or aerodynamic technology [2, 3, 10]. It has been shown that speakers with SHI exhibit more inappropriate inspiratory loci; in addition, they tend to inspire at nongrammatical locations when reading passages, apparently because of improper respiratory control [2]. Aberrant pausing patterns could affect its temporal breath group structure, speaking rate within breath groups, and speech intelligibility. The current study examines the temporal breath group structure and linguistically inappropriate pauses for normal speech and the speech of hearing-impaired subjects, which has implications for speech intelligibility and is important to speech synthesis [11], dysarthria [12], and voice disorders [13].

Although, to our knowledge, there are no published articles focusing specifically on the temporal breath group structure of SHI, prior research findings suggest that speakers with SHI might have abnormal temporal breath group structure. The major temporal breath group parameters reported in the literature on populations other than SHI include breath group duration (BGD), inter-breath-group pause (IBP), inspiratory duration (ID), expiratory duration (ED), and proportion of speech per breath group [14–20]. These parameters could provide a deeper understanding of the (ID) abnormal speech breathing patterns in speakers with SHI.

This study aims to address the following questions: (1) do Mandarin speakers with prelingual SHI take inspirations more often at syntactically inappropriate positions than speakers with normal hearing? (2) Is there a difference in the temporal breath group characteristics between Mandarin speakers with normal hearing and with prelingual SHI?

Subjects and Methods

Subjects

Twenty Taiwanese adolescents aged between 16 and 25 years (mean = 18:7 years; SD = 2:4 years) with SHI were recruited. All subjects in the SHI group had prelingual or congenital sensorineural hearing loss with pure-tone average (500, 1,000, 2,000, and 4,000 Hz) greater than 70 dB in their better ear (mean = 87; SD = 10; minimum = 70; maximum = 103). According to the questionnaire filled out by the SHI group subjects, all of them used oral communication primarily and wore hearing aids daily except 1 subject who has not worn hearing aids for more than 10 years. Controls were 20 Taiwanese adolescents with normal hearing and matched for age, sex and education level. All subjects were native Mandarin speakers and had a negative history of respiratory systemic diseases, neurological disease, cognitive impairment, or craniofacial anomalies.

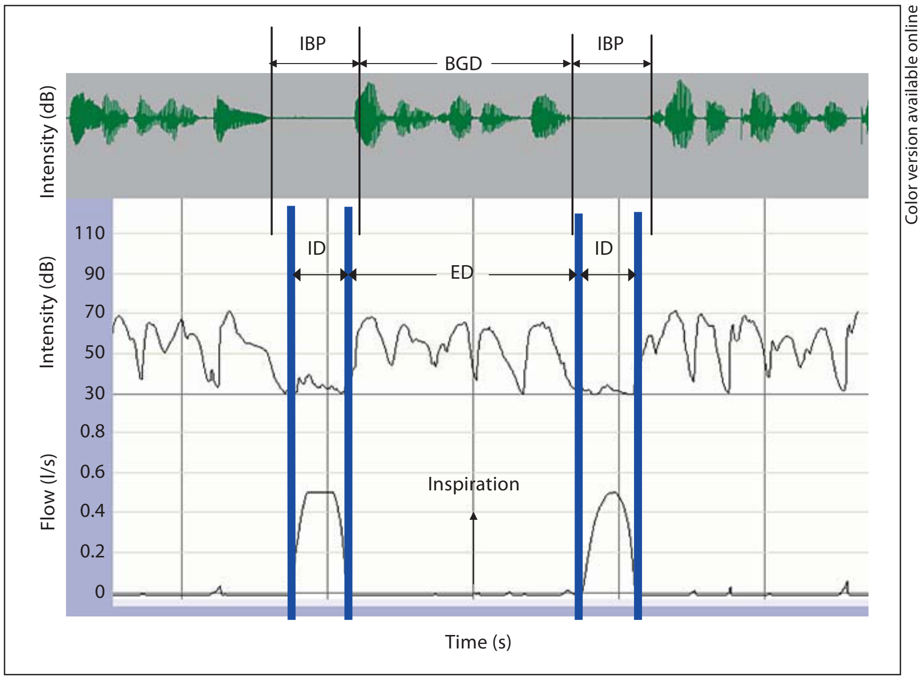

Fig. 1. The lower panel is the aerodynamic signal generated by AP-2 for part of a passage read by a subject with profound hearing impairment. The peaks indicate actual inspiratory loci. The upper panel is the corresponding acoustic signal generated by TF32.

Experimental Protocol

Speech samples included three selected short Mandarin passages with punctuation marks. The subjects were asked to read the three selected passages, and they were given time to familiarize themselves with the passages before the recording was initiated. During the passage reading task, the subjects held to their face a circumferentially vented mask (Glottal Enterprises MA-1L), which was connected to Aerophone II (KayPENTAX, Model 6800, AP-2) via an air-pressure transducer. A head-mounted microphone (Crown CM311A) was placed approximately 1–2 cm from the vented mask. While reading the three passages, subjects were recorded with a digital audio recorder (Marantz PMD 660) set at 44.1 kHz sampling rate and 16-bit quantization level. The three passages were recorded in separate files. When a recording started, the start buttons on the Aerophone II and recording machine were pressed almost simultaneously, so that the timelines in both files were about the same. Because the default direction of inspiratory airflow in AP-2 was downward, the direction of airflow was inversed to display inspiratory airflow upward to mark the actual inspiratory loci. The actual inspiratory loci were easily and reliably located in the aerodynamic and acoustic signals. The first author then marked all the onsets of inspiration. These speech samples were later used to determine the appropriateness of inspiratory loci and further analyze the temporal breath group structure.

Appropriateness of Inspiratory Loci

The appropriateness of inspiratory loci for the speech samples was determined on the basis of rules given by Henderson et al. [21] and Li and Thompson [22]. Appropriate syntactic boundaries for inspiration included major and minor syntactic boundaries. Major syntactic boundaries were defined as the sentence boundaries or locations where punctuation marks like commas and colons occurred. Minor syntactic boundaries were locations before noun, verb, adverbial phrases or other phrases. Inspiratory pauses within the phrases were considered syntactically inappropriate locations.

Temporal Breath Group Structure

The breath group structure analysis was based on the actual inspiratory loci, which were fairly reliable and easily identified manually using prominent landmarks in the oral flow signal. As displayed in figure 1, the beginning and ending of each inspiration were marked. The beginning and ending points of an inspiration were defined as the values that are nearest to zero, left and right to the peak, respectively. Then the ID and ED were calculated. Acoustic measures were performed by using a computer program, TF32 [23]. The inspiratory loci in the acoustic signal were identified by reference to the time points of the inspiratory loci in the aerodynamic signal. As shown in figure 1, inspiratory loci in the aerodynamic signal were used to segment the acoustic signal into BGD and IBP. BGD in this study was defined as the duration of groups of speech events produced on a single breath [24], and was measured from the start to the end of the speech signals produced on a breath group based on the acoustic waveform. The first BGD of every passage was excluded to avoid the influence of speech initiation [18], and the last BGD was also excluded because the last BGD was dependent on the words remaining to the end of the passage. IBP was measured as the interval between two BGDs. The number of syllables per breath group (BGS) was counted for each subject. Finally, the speaking rate within a breath group (SR) was defined as the ratio of BGS/BGD. A noninspiratory pause (NIP) during IBP was defined as the IBP subtracted by the ID.

Measurement Agreement

About 2 months after completion of the data analysis, 10% of the speech samples (2 subjects from the SHI group and 2 from the

Table 1. Pearson coefficients and the means of absolute difference (in parentheses) for intra- and interanalyst measurement agreement

Parameter	Intra-analyst	Interanalyst
Aerodynamic signal		
ID	0.99 (1.6 ms)	0.99 (2.9 ms)
ED	0.99 (1.7 ms)	0.99 (2.9 ms)
Acoustic signal		
BGD	0.99 (10.9 ms)	0.99 (12.7 ms)
IBP	0.99 (10.6 ms)	0.99 (12.3 ms)

Table 2. Group means ± SD for aerodynamic measures (ID and ED) and acoustic measures (BGD, BGS, SR, IBP, and NIP)

Parameter	NH group	SHI group	t(38)	p
ID, s	0.34 ± 0.08	0.39 ± 0.09	1.60	0.1190
ED, s	2.28 ± 0.59	2.29 ± 0.46	0.51	0.9600
BGD, s	2.16 ± 0.59	2.11 ± 0.44	–0.31	0.7590
BGS	10.0 ± 2.23	6.68 ± 1.56	–5.48	0.0001
SR, syl/s	4.73 ± 0.48	3.28 ± 0.63	–8.24	0.0010
IBP, s	0.46 ± 0.10	0.56 ± 0.13	2.85	0.0070
NIP, s	0.12 ± 0.02	0.17 ± 0.05	4.51	0.0001

NH group) were randomly selected to be remeasured by the first author and a second-year graduate student in communication disorders with experience in acoustic measurement to gauge intra- and interanalyst measurement agreement. Intra- and interanalyst agreement was determined for both aerodynamic signal and acoustic signal measures. The results are shown in table 1. Both Pearson coefficients and absolute intra- and interanalyst differences of measurement are reported. The intra- and interanalyst agreement of aerodynamic and acoustic measures was judged to be satisfactory.

Statistical Analysis

Descriptive and χ^2 analyses were used to describe group differences of the appropriateness of inspiratory locations. Multiple t tests were performed for group differences in the temporal parameters of the aerodynamic signal (including ID and ED) and the acoustic signal (including BGD, BGS, SR, IBP, and NIP) at $\alpha = 0.05$ level by using SPSS 11.0. Bonferroni correction was adapted (0.05/2 = 0.025 and 0.05/5 = 0.01 for aerodynamic and acoustic signals, respectively).

Results

Breath Group Temporal Structure

The total numbers of actual inspiratory locations determined by the aerodynamic signal for the SHI group and NH group were 1,162 and 709, respectively. The average numbers of breath groups used per subject to read the three short reading passages were 55.1 (SD = 17.8) and 32.5 (SD = 9.48) for the SHI and NH groups, respectively. The average breath group number used to complete the same tasks for the SHI group was significantly larger than that for the NH group [t(38) = 5.031, p = 0.0001].

Table 2 shows means and standard deviations of all the measures for the SHI and NH groups. Measures presented in the table include ID, ED, BGD, BGS, SR (BGS/BGD), IBP, and NIP during IBP.

Appropriateness of Inspiratory Loci

The NH group had nearly perfect scores on the percentage of appropriate inspiratory locations, whereas only half of the subjects in the SHI group had perfect appropriateness of inspiratory locations. The percentage of occurrence of inspiratory loci at major, minor and *inappropriate* syntactic boundaries was 84% (977/1,162), 7.8% (89/1,162), and 8.1% (96/1,162) for the SHI group. The percentage of occurrence of inspiratory loci at major, minor and *inappropriate* syntactic boundaries was 98.7% (700/709), 0.6% (4/709), and 0.7% (5/709) for the NH group. Compared with the NH group, the SHI group had significantly more inspirations at minor and inappropriate inspiratory loci ($\chi^2 = 45$, after continuity correction) and significantly less inspirations at major inspiratory loci ($\chi^2 = 100$, after continuity correction) during passage reading.

Aerodynamic Measurements

The mean ID and ED for the SHI group tended to be longer than those for the NH group. However, neither ID nor ED group comparisons reached statistical significance (table 2).

Acoustic Measurements

Although group differences in BGD were not significant, the SHI group produced significantly less BGS, significantly slower SR (BGS/BGD), significantly longer IBP and significantly longer NIP (table 2).

Discussion

The results of this study confirm and extend earlier reports on respiratory changes in reading for speakers with SHI. The primary finding is that the SHI group had significantly more inspiratory loci at inappropriate and minor syntactic boundaries. These speakers also exhibited a slower speaking rate that was marked by prolonged inspiratory and noninspiratory pauses. However, some temporal breath group features, such as ID, ED, and BGD, were spared in speakers with SHI.

More Frequent Pauses at Inappropriate and Minor Syntactic Locations

The SHI group paused more often at inappropriate and minor syntactic locations than the NH group. This result is comparable with research in English-speaking SHI speakers [2]. The poor respiratory airflow control and coordination between the speech subsystems in the SHI group, as Forner and Hixon [2] and Whitehead and Barefoot [3] suggested, may contribute to compulsory pauses for inspiration at minor syntactic locations and even at inappropriate locations.

Because the participants with SHI spoke slowly, they would be expected to inspire more frequently within a sentence to replenish their air supply for speech [2]. Slower speaking rate in SHI individuals may relate to the increase in the production and perception of nasality due to insufficient velopharygeal closure [9]. If our talkers also exhibited aberrant velopharyngeal function, the diminished speech air supply may also have been due to excessive nasal flow. This need for inspiratory refill may explain why the participants with SHI tended to pause at minor syntactic locations for inspiration. Previous studies indicated, however, that speakers with SHI tend to inspire at nongrammatical locations when reading passages due to improper respiratory control and insufficient linguistic knowledge [2, 10, 25]. Therefore, persons with SHI and poor language and reading comprehension might be expected to inspire more frequently not only at minor syntactic locations but also at inappropriate locations. The language skills of the participants with SHI in this study were not tested, but were more than sufficient to perform the reading tasks.

No Significant Group Differences in ID, ED, and BGD

Compared to the NH controls, speakers with SHI needed more respiratory cycles and longer total speaking time to complete the same reading tasks. It is important to note that certain aspects of temporal breath group structure were preserved in the SHI group, such as ID, ED, and BGD, while others, such as BGS, SR, IBP, and NIP, were not. These results have implications for speech assessment and for speech training.

The observation that ID and ED were similar between the SHI and control groups suggests that the basic speech breathing cycle is unaffected by long-term hearing loss. Moreover, the BGD in these subjects with SHI was comparable to that in NH control subjects. This finding was not unexpected because speakers with SHI are presumed to have intact respiratory function. Furthermore, almost all of the subjects in our study used oral communication as their primary mode of communication.

The average BGD in the current study was 2.16 s for NH control speakers, which was much shorter than the 3.58 s [26] and 3.36 s [18] for the English-language Rainbow Passage [27] reported in the literature. This difference might be because (1) Mandarin is a monosyllabic tonal language that is different from a stress-timed language, like English, and (2) the average sentence length of the selected reading passages differs across studies.

Slower Speech Rate Accounting for Abnormal Pausing Patterns in Deaf Speech

The key factor contributing to the significantly slower SR for the SHI speakers was significantly fewer BGS, since the group difference in BGD was not significant. Slow SR could be a possible causal factor for aberrant pausing patterns in hearing-impaired speech, which could be the byproduct of aberrant respiration due to abnormal phonatory, articulatory, and resonatory patterns. The slower rates in Mandarin speakers with SHI show that the slower rates in previous literature on English are probably not related to the stress-timed syllable pattern of that language, but rather may be an outcome of speech in hearing impairment regardless of the rhythmic structure of the language. The results of the current study suggest that speaking rate may be the primary driving force for multiple speech subsystem changes and that in Mandarin, aberrant pausing could have a similar deleterious effect on speech intelligibility as in English, regardless of the causes.

NIPs: Most Deviant Aspect of Speech Breathing in Speakers with SHI

On average, speakers with SHI paused more and longer between breath groups than speakers with normal hearing. Taking into account that speakers with SHI had comparable ID, ED and BGD as NH speakers, longer IBP in the SHI group were due to longer NIP. The significant difference in NIP between the two groups confirmed this hypothesis. Although the group differences in BGD and ED were not significant, the SHI group exhibited a relatively smaller BGD/ED ratio than the NH group (table 2), which is consistent with the observations of inefficient inhalation after the end of speech in Parkinson's disease subjects reported by Bunton [14]. Therefore, significantly longer NIP and relatively smaller BGD/ED for the SHI group possibly reflect the inefficiency of using the respiratory system to speak. Respiratory movement coordination between inspiration and expiration deserves further investigation.

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