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<td><strong>Author(s)</strong></td>
<td>Yu, Ka-man, Karen; 余嘉雯</td>
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Voice Onset Time Production of Affricates in Cerebral Palsied Children

Yu Ka Man, Karen

A Dissertation submitted in partial fulfilment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, April 29, 1996.
Abstract

This study investigated whether voice onset time (VOT) differences of affricates in Cantonese occurred among two types of cerebral palsy dysarthric children and normal children. The VOT productions of aspirated and unaspirated affricates ([ts] and [tsʰ]) at word initial position of 27 subjects from three groups (normal, athetoids and spastic) of children aged from 6;05 to 15;10 were measured. Both spastic and athetoid groups produced VOTs similar to those of their normal counterparts for unaspirated affricates. However, spastics and athetoids produced aspirated affricates with significantly larger VOTs than those of normal subject. No significance differences were found between the spastic and athetoid groups in both VOT productions of aspirated and unaspirated affricates.
Cerebral Palsy is defined as a non-progressive motor disorder of motion and posture that stems from brain insult or injury occurring in the period of early brain growth (Lord, 1984, cited in Love, 1992). As its nature suggests, cerebral palsy can result in a wide spectrum of neurological dysfunction. Depending on various sites of lesion in the central nervous system, cerebral palsy can be classified into different subtypes. In general, three types, namely spasticity, athetosis and ataxia, are identified. Spasticity is found to be resulting from damage to pyramidal system; athetosis, with damage to extrapyramidal system; whereas ataxia, with damage to cerebellum (Ingram and Barn, 1961, Hardy, 1983, Sommers, 1983, cited in Milloy and Morgan-Barry, 1990). Dysarthria is the speech disorder that is most commonly seen in the cerebral palsied population (Workinger, 1986). A review of a number of studies done by Yorkston, Benkelman and Bell (1987), reveals a close association between cerebral palsy and dysarthria. They find that speech disorders are a common sequela of cerebral palsy and it has been reported an incidence of occurrence of dysarthria in cerebral palsied speakers as high as 88% in one of the studies.

The speech characteristics of this population have been receiving much attention and researchers attempt to find patterns of speech to distinguish between the subtypes. Platt, Andrews, Young and Quinn (1980) investigated the speech
impairment of spastic and athetotic cerebral palsied adults and observe that spastic and athetotic speech differ only in terms of amount of accuracy, rather than in terms of distinctive phonetic differences. Ansel (1985) and Ansel and Kent (1992) found evidence of homogeneity in the phonetic characteristics of mixed, athetoid and spastic cerebral palsied adults. Their findings are in line with those found by Byrne (1959), Irwin (1955) and Workinger (1985), cited in Ansel and Kent (1992), all of them report no significant differences in consonant or vowel articulation error in spastic and athetoid cerebral palsied children. They take this overall similarity of the speech abnormalities of speakers as an indication of a uniformity in the effects of the neurologic disorders on speech production. In sum, these authors suggest that it is the manners fricative and affricate that pose much difficulties in the speech disordered production.

Despite the homogeneity in error patterns observed by the above authors, Workinger (1986) reported significant differences in voice onset time (VOT) for syllable initial voiced and voiceless consonants and in phrase duration between spastics and athetoids. Such findings further support the results obtained by Farmer (1980) who reported a significantly longer and more variable VOT duration in the production of six English stops by athetoid than that by spastic subjects.
Ladefoged (1982) defines voice onset time as the moment at which the voicing starts relative to the release of a closure. Therefore, VOT addresses the temporal coordination of voicing and oral articulation (Ansel, 1985). In other word, it can be treated as an index of the control of timing between laryngeal and upper airway articulation (Hoit, Soloman and Hixon, 1993). Lisker and Abramson (1964), describe three categories of VOT used by languages of the world including long lead, short lag and long lag. Each of them denotes different voicing time in relation to the release of closure. VOT has been an important acoustic feature distinguishing voiceless from voiced stop consonants in English (Lisker and Abramson, 1964; Zlatin, 1974, cited in Hoit et al, 1993). In Cantonese, it is described by Lisker and Abramson (1964) as having a contrast between short lag stops and long lag stops, which are corresponding to unaspirated and aspirated stops. In describing the Cantonese sound system, Matthews and Yip (1994) compare the distinctive features employed in English and Cantonese to distinguish stops and affricates. They define aspiration as a brust of air emitted immediately after oral release in the process of articulation. For both of the above manners of sound, it is the contrast of aspiration that differentiates different phonemes. For example, the following two monosyllabic words "

\[ \text{"遮" [ts] ss (umbrella) and "車" [tsʰ] ss (car) in Cantonese are minimal pairs contrasting by aspiration.} \]

There are not many studies investigating Cantonese phonology and the production of aspiration (Clumeck, Barton, Macken and Hungington, 1981; Kim, 1970). In these studies, the characteristics of affricates were not studied. Therefore, there is a lack of normative data about the production of affricates in Cantonese. In this study, the VOT of affricates produced by both cerebral palsied dysarthric and
normal children was investigated to look into the temporal timing of voicing in unaspirated and aspirated affricates. The main aim was to find out whether there were any differences in VOT between the cerebral palsied dysarthric speakers and normal speakers and whether subjects of the two subtypes of cerebral palsy chosen in this study, spastics and athetoids, differed in the production of unaspirated and aspirated affricates at word level.

An acoustic measurement was chosen in order to obtain an objective measurement of the speech characteristics of the cerebral palsied dysarthric and normal subjects. Spectrogram has the ability of displaying the rapidly changing spectral properties of speech. It has been widely suggested by different authors (e.g. Kent and Read, 1992; Banken and Daniloff, 1991) the direction of research and application of the study of speech acoustics for evaluating and therapeutic purposes in clinical practice. From my own clinical experiences working with dysarthric children, some deviations in their perceptually correct productions were occasionally noticed; however, it was difficult to tell exactly what such differences were when comparing their productions to the normal productions. Gerrat, Till, Rosenbek, Wertz and Boysen (1991) suggested that instrumental measures could complement the clinician's ear and provide information about speech physiology for both goals of evaluation and management. Such observation and suggestion made and the
difficulties I experienced motivated me to carry out this study.

Speech production is a complex process and it entails rapid-changing activities. Therefore, it might be beyond our capability to keep track with these transient activities simply by our hearing (Gerratt et al, 1991), since some of the information might be missing by then. Hence, there is a need to construct an objective, reliable and efficient means to analyze speech activities, especially in disordered speech. In this way, we can accurately measure any deviation in a particular subject's speech and try to understand the underlying production deficits. It is only after the cause of a problem is identified before such problem can be tackled with. The same logic should be applied clinically when treating with pathological speech. The perceptual disordered features in speech should be viewed as a secondary phenomenon resulting from a covert dysfunction in the system of speech production. Identification of the presence of specific neuromuscular abnormality is usually one of the clinical steps suggested for treatment. Unfortunately, the method to qualitatively and quantitatively describe a problem is rarely suggested. Therefore, I would study a parameter in acoustic measurement, the VOT in the production of affricates by cerebral palsied dysarthric children and attempted to explore the application of acoustic technology in the evaluation of pathological speech. VOT was measured in affricate productions of all groups of subject. The aim was to find
out whether the perceptually correct productions of cerebral palsied groups differed from those productions of normal speakers with reference to VOT measurement. As mentioned earlier, Cantonese affricates are classified by the presence or absence of aspiration. Such distinction in production involves precise temporal coordination of voicing during production. Therefore, the second objective in this study was to examine the ability of subjects to signal the contrast between aspirated \([ts^h]\) and unspirated affricates \([ts]\).

Cerebral palsied dysarthric children exhibit a possible range of dysfunctions in terms of respiratory, laryngeal, velopharyngeal and articulatory functions. It was hypothesized that they would demonstrate VOT different from that of normal subjects and their disordered production would give rise to a clearer picture of the underlying reasons for the difficulties observed.

**Method**

*Subjects*

Eighteen cerebral palsied school children comprising the Spastic (S) and Athetoid (A) groups from six physically handicapped schools in Hong Kong. Nine of them were medically diagnosed as principally spastic, and the other nine as principally athetoid. They were within the age range of 6-14 years old and diagnosed by speech
therapists as having dysarthric speech. They all had hearing within normal limits and IQ more than 70. They were native Cantonese speakers and were diagnosed by speech therapists as being capable of producing unaspirated and aspirated affricates. They had adequate vision for identifying an object or an action inside a 3.5" x 5" photograph. Nine normal subjects comprising the Normal group (N) were chosen randomly from normal primary and secondary schools. They were within the age range of 6 - 14 years old. They had no speech problem, normal IQ, hearing, vision and they were native Cantonese speakers with the mastery of the production of affricates. Summary of subjects in this study in all three groups was presented in Table 1.

All subjects had undergone a speech screening test to ensure that they were all capable of producing affricates [ts] and [tsʰ] with photographs as elicitation stimuli.

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<tr>
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<td>Normal (N)</td>
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<td>Mean Age</td>
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Table 1 Summary of subjects in Normal, spastic and athetoid groups
Speech sample

Ten pairs of stimulus words used are listed in Appendix 1. They are minimal pairs of Cantonese words contrasting in aspiration. Words were chosen were among those which could be represented in photographs and the targets elicited would be either monosyllabic word with [ts] or [tsʰ] as the initial consonant or bisyllabic words with the target phonemes present at the syllabic initial word initial position.

Procedures

Spontaneous productions of the target words were obtained through a naming task. Photographs representing an object, an action or an attribute were used as the stimuli for eliciting such productions. When a subject failed to produce a target word, say, for example, he produced a synonym of the target word, a model of the target word was given by the experimenter and a delay response of the word from the child was obtained.

Each word was produced twice by each subject. Each photograph was presented to a subject for two times and a total of forty trials were obtained from each subject. The forty target stimuli were presented in random order to avoid learning effect and to minimize the variation in production of target words which were located at the bottom of the list due to the fatigue phenomenon of a subject. In addition, 'foil'
stimuli presenting non-target words were included in order as to increase stimulus diversity.

The speech data were recorded on Sony Type XI 90 audiotapes using Sony TC-D5M tape recorder and Sony ECM-909 electret condenser microphone in quiet clinic rooms or classrooms inside the schools. The stimuli were then low-pass filtered at 22kHz and sampled 44.1kHz using a DigiDesign Audiomedia II DSP card on a Macintosh computer.

VOT was measured by examining wide band spectrogram and waveform of each production. The VOT was measured from the beginning of the release closure to the onset of periodic vibrations in the first formant. The VOT measurements of the twenty productions for each phonemic contrast were averaged for each subject.

Results

Mean and Standard Deviation

Mean and standard deviation of the VOT for each subject was calculated. (see Figures 1 and 2)
Fig. 1
Mean, Standard error and Standard deviation of VOT of [ts] of Groups N, S & A.

Mean and Standard Deviation of [ts]

VOT (ms)

GROUP

N S A

Fig. 2
Mean, Standard error & Standard deviation of VOT of [tsh] in Groups N, S & A.

Mean and Standard Deviation of [tsh]

VOT (ms)

GROUP

N S A

12
Two one-way (between groups) analysis of variance (ANOVA) designs were applied to the dependent variables VOT for unaspirated and aspirated affricates respectively. Significant group effect was noticed for the VOT of aspirated affricate \( (F = 4.129, p < .05) \) and LSD post hoc test showed that there was significant difference between groups N and S \( (p < .05) \) and groups N and A \( (p < .05) \). No statistically significant group difference was found for the production of VOT of unaspirated affricate. A 3 (between groups) by 2 (repeated measures) analysis of variance (ANOVA) design was applied to the independent variables including three groups \( (N, S \text{ and } A) \); dependent variable at two levels including the VOT of unaspirated and aspirated affricates. Statistically significant interaction between the main effects, groups and VOTs for the two types of affricates, was noticed \( (F=6.32, p < .01) \). LSD post hoc test revealed significant difference between groups N and S \( (p < .001) \) and groups N and A \( (p < .001) \) for VOT of aspirated affricate and no significant difference was found between the two disordered groups, S and A. For unaspirated affricate, there was no significant difference in VOT in all groups. In addition, all groups had significant different VOTs for unaspirated and aspirated cognates of affricates which were statistically significant \( (F = 191.85, p < .0001) \).
Discussion

The results obtained answered adequately the questions posed in this study. It was shown that the cerebral palsied dysarthric children recruited here did perform differently from the normal speakers in terms of VOT in the production of aspirated affricates (Fig.2). Despite their production were considered by speech therapists and the experimenter as perceptually correct and acceptable, significant differences were found in acoustic analysis. However, no statistical significant difference was found between the subjects in the two subtypes of cerebral palsy.

A second noteworthy finding was that both disordered groups had VOT more variable than the normal group (Fig. 1 and 2) in both the production of unaspirated and aspirated affricates.

Thirdly, all subjects had the ability to produce the two cognates of affricate in Cantonese that differed in aspiration by the measurement of VOT.

The above findings would be addressed to with reference to the phases in the production of an aspirated affricate, the vocal folds mechanism during phonation and also the motor abnormalities in cerebral palsied individuals reported.
Production of an aspirated affricate

The nature of production of affricate is still a controversial issue, and the view of taking an affricate as a stop with a delayed release onto a fricative (Katamba, 1989; Schane, 1973; cited in Stokes, Whitehill, Yuen and Tsui, 1996) would be adopted here. In the phonetic descriptions of sound (e.g. Ladefoged, 1982; Mackay, 1987; Abercrombie, 1967), there was no full description of stages in the production of an aspirated affricate, but its nature could be better understood when referring to the different phases in producing a stop (Henton, Ladefoged and Maddieson, 1992).

Fig. 3 Phases in the production of an aspirated affricate
Figure 3 represents the various stages of mouth passage and vocal folds in the production of an aspirated affricate. One articulator approaches the other in phase i, and by the end of this phase, it is the onset of closure. During the closure (phase ii), articulators are held together and airflow is obstructed along the mouth passage. The release of closure marks the beginning of phase iii. It has been proposed by Abercrombie (1967) that phase iii can be modified in a way the separation of the articulators would be slowed down so that the escaping compressed air would pass through a stricture of close approximation and results in frication. This mechanism of production of a noisy turbulence is similar to that for creating fricative sounds (Mackay, 1987; Kent and Read, 1992; Ladefoged, 1982). Phase iv would be attributed as aspiration phase. It was regarded by Lisker and Abramson (1964) as a large delay in voice onset. Lastly, voicing occurs at phase v.

The status of vocal folds and the degree of opening of glottis change in various phases described above. There is no vibration in the vocal folds till phase v (dotted line stands for vibration in the vocal folds in Fig. 3); whereas the glottis would stay open from phase i to phase iv and it would be closed at the beginning of vibration.
Mechanism of vocal folds for phonation

During phonation, there are quasi-periodic open and close in the vocal folds (Lieberman and Blumstein, 1988). Van den Berge (1958), cited in Mackay (1987) explain the mechanism of vocal folds for voicing in accordance with the myoelastic-aerodynamic theory of voice production. The cycle of voicing commences with vocal folds being adducted by a speaker, subglottal pressure could be created below the glottis and exerts a static force against the adducted vocal folds. Whenever the subglottal pressure has been built up to such an extent which is greater than what the vocal folds can withstand, the folds would be pushed apart (abducted). The cycle of adduction and abduction repeats during phonation.

Motor abnormalities in cerebral palsy

Motor impairments in cerebral palsied individuals have been well-documented. Deficits in the subsystems subserving speech production including respiration, phonation, resonance and articulation have been reported (e.g. McDonald and Chance, 1964, Lencione, 1976, Hardy, 1983, cited in Milloy and Morgan-Barry, 1990, Love and Webb, 1992, Rosenbek and Lapointe 1985, Yorkston et al, 1987). Problems of any or all of the subsystems may give rise to various effects on speech production.
Why did the spastic and athetoid speakers had significantly longer VOT in the production of an aspirated affricate?

The results obtained in this study reflect dysfunctions originating at laryngeal and respiratory level. Both the spastics and athetoids had VOTs resembled to that of the normals for the production of unaspirated affricate (Fig. 1). Hence, one can plausibly assume that subjects from these two groups were performing similarly to their normal counterparts from phase i to phase iii (Fig. 3). It was the addition of aspiration in phase iv that posed difficulties in their productions. In fact, unaspirated and aspirated sounds differ from each other with respect to the time at which vibration starts at the vocal folds. If voicing started later, the glottis would stay open for a longer period of time and more air would keep coming out. Consequently, aspiration would be resulted. The longer time measured between the release of closure and the onset of voicing should be arising from a dysfunction at the larynx. Referring back to the myoelastic-aerodynamic theory mentioned above, the vocal folds have to be adducted before voicing could take place. Laryngeal dysfunctions including spasticity, weakness, limitation of range and slowness of movement were noticed in spastic syndromes with UMN lesion (Darley, Aronson and Brown, 1975). Love (1992) also reported dysfunction of laryngeal muscles in children with cerebral palsy and adds his personal observation of increased VOT in spastic children. Moreover, McDonald and Chance (1964), cited in Yorkston et
al (1987) suggest that adductor spasm of laryngeal muscles in cerebral palsy may prevent the initiation of voicing. Whereas for the athetoids, laryngeal dysfunctions had also been reported and they are found to impair these speakers' voluntary movement due to extreme muscle tone or extreme flaccidity (Love, 1992). Therefore, both the spastic and athetoid dysarthric speakers need longer time to overcome the hypertonicity in the vocal folds and voluntarily adduct them in order for voicing to take place.

Apart from taking into account the motor impairment at the laryngeal level, respiratory dysfunction in cerebral palsied children is another feature observed in this population and this may also contribute to the longer VOT observed in this study. In spastic dysarthria, mild disturbances of general respiratory control were found. Hardy (1983) cited in Love (1992) reported reduced respiratory reserve and subsequent lowered vital capacities and he also observed the reverse breathing in athetoid subjects. This is a type of breathing that would result in reduction in the volume of inhalation, hence, it would indirectly affect exhalation and consequently speech production. As a result, dysarthric speakers may have difficulty in initiating vocalisation, and also their efficiency in breathing may be reduced in terms of volume of outflux of air and the coordination of breathing in and out, therefore, longer time would be required in order to build up sufficient subglottal pressure
after releasing the puff of air during aspiration, so as to push apart the adducted vocal folds and start the cycles of voicing.

Concluding from the performance of the spastic and athetoid subjects in this study, they had the ability to signal the phonemic contrast of aspiration in affricate, however, they did it in a way which was different from normal speakers in terms of the duration between the release of closure and the start of voicing. In sum, taken together the deficits reported in respiratory and laryngeal functions in cerebral palsied individuals, and relating such impairments to the stages of production of an aspirated affricate, the role and status of vocal folds in various phases in the production, possible explanation to account for the longer VOT observed in the spastic and athetoid subjects can be inferred.

Why did the spastic and athetoid subjects had VOTs which were more variable than the normal?

Another prominent phenomenon observed in this study (see Figures 1 and 2) was the greater variability of mean VOT in the two disordered groups when compared to the normal group. This reflected individual differences among dysarthric subjects in the present study. Besides, the fact that the severity of dysarthrias and muscle involvement in the cerebral palsied children was not controlled could also result in
more variable mean VOTs obtained in the spastic and athetoid groups.

Cross-linguistic comparison

According to the studies done by Farmer (1980) and Workinger (1986), longer and more variable VOTs were reported in the subjects in the production of English stops when compared to those produced by normal speakers. Similar trend was noticed here in this study, that both spastic and athetoid subjects had longer and more variable VOTs in aspirated affricate. This indicates poorer coordination in speech production in the cerebral palsied individuals in general.

Differences in VOTs had been found between spastic and athetoid speakers in the previous studies (Farmer, 1980; Workinger, 1986). However, such phenomenon was not observed here. This could be due to the different research designs in the previous studies and the current one. Firstly, English stops which are under investigation are distinguished by the feature of voicing; while the phonemic contrast being focused here was the contrast of aspiration in Cantonese affricates. They are two different types of phonetic contrasts in speech production. Voiced, voiceless unaspirated and voiceless aspirated sounds have been described as a continuum (Lisker and Abramson, 1964) differing in the time at which phonation
starts. In fact, apart from viewing the above three types of speech sounds as a
function of the time at which phonation occurs, respiratory function regulating
the amount and speed of exhaling air also plays an important role in distinguishing
the unaspirated and aspirated cognates. Aspiration contrast is being investigated
here in this study and the performance made by the subjects showed that both the
spastic and athetoid subjects were performing similarly to one another when
signalling the contrast of aspiration.

In addition to the difference in the target of contrast being studied, ability in muscle
coordination in subjects may also differ between previous and the present study. As
listed above, one of the criteria in the screening procedure for subjects in this study
was the ability to produce both unaspirated and aspirated affricates in Cantonese.
Affricate has been considered a class of complex sound in terms of the load in
articulation and it is prone to error production in oral-motor disordered subjects
(Ansel and Kent, 1992). Therefore, subjects in this study who had mastered the
production of perceptually correct affricates could be regarded as having better
ability in speech production. They may have an overall better muscular control and
coordination during speech production in comparison to the subjects in the previous
studies targeting on English stops.
Clinical Implication

The data obtained in this study provide preliminary data on the performance of cerebral palsied children in the production of Cantonese affricates.

As a clinician, the above findings about the performance of cerebral palsied subjects in the production of affricates provide valuable measurement for both assessment and intervention purposes. It has been suggested by Strand (1995) and Love (1992) that the necessity of finding out the deficits in the components of speech processes including respiration, phonation, articulation, resonation and prosody; and functional structures including abdominal muscles, diaphragm, ribs cage, larynx, tongue, pharynx, velopharynx, jaw and lips that reduce a dysarthric speaker's intelligibility, and determine how such deficits influence each other. As seen in this study, despite of the different sites of lesion in the central nervous system in the spastic and athetoid subjects, they were found to have similar VOTs and this reflected similar deficits in the subsystems for speech production. This is suggestive for a method to search for underlying problems among the above described components by instrumental measurement.

In clinical practice, various authors (e.g. Strand (1995), Yockston et al (1987) and Dworkin (1991)) summarize the steps in assessing motor speech disorders. It has
been suggested that in the assessment phase, speech features that are disrupted should be identified perceptually in the initial stage. Hypotheses to explain the perceived disturbances should then be proposed and verified. Acoustic analysis would be an objective and reliable method in the verification of the hypotheses. Instrumental assessment is recommended here because speakers exhibiting similar perceptual features could have been caused by different underlying problems in each speakers. After the identification of an underlying problem(s) that is affecting speech production, approaches to intervention including reducing the impairment, behavioural compensation, prosthetic compensation or elimination of maladaptive behaviours (Yorkston et al, 1987) can be applied accordingly. Moreover, a hierarchy of sequential treatment of subsystems with deficits is outlined clearly with rationale and recommended by Dworkin (1991). The importance of finding out an underlying problem in the speech production system is obvious before an appropriate step and the direction of therapy can be designed.

Further Investigation

From this study, it was found that we could infer deficits in subsystems for speech production from parameters of acoustic measurement. Therefore, it would be suggested that for further studies, speech samples from different populations of
motor speech disorders could be investigated acoustically. This could give rise to a clearer picture about the deficits in the systems subserving speech and the correlated observation in acoustic analysis.

In addition, as mentioned earlier, that the nature of production of affricate still remains a controversial issue, acoustic measurements (e.g. rise time, noise duration) may help understanding more about its nature in production.

Acoustic measurement is a fascinating method to study activities during speech production. VOT is one of the measurement studying voiced/voiceless and aspiration contrast, and there are some other types of acoustic measures which are corresponding to different phonemic contrasts (e.g. rise time for the fricative-affricate contrast). There is a need for normative data for these measures before instrumental means can be applied in clinical practice in the evaluative and therapeutic processes.
Acknowledgment

The author would like to thank the following dissertation supervisors, Professor Paul Fletcher, Dr. Stephanie Stokes, Dr. Valter Ciocca & Dr. Samuel Leung, for their guidance and advice in accomplishing this dissertation. Lecturers and staff from this Department, especially Miss Tara Whitehill (your advice and encouragement have inspired me to carry out this study), Mr. M.T. Leung & Mrs. Lydia So. School Principles, Speech Therapists, TASTs and the subjects from: Kwai Shing School (Spatic Association of H.K.), Ko Fook Iu School (Spastic Association of H.K.), JFK Centre, Margret Trench Red Cross School, Princess Alexandra Red Cross Residential School, Hongkong Christian Service Pui Oi School. My dearest and lovely classmates, my family members. My very special friend! 

Thank You! 😊
References:


## Appendix 1  List of stimulus words

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<td>Words</td>
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<td>[tsɛ]₃</td>
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<td>2</td>
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