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Diadochokinetic rate in Thai adults using between auditory-perceptual and instrumental methods

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ABSTRACT

Background: Diadochokinetic (DDK) rate refers to the time taken to execute rapid repetitive movements of articulators during speech. DDK rate assessment has been used to screen or as part of an assessment to diagnose and plan treatment for motor speech disorders. It contained alternating motion rate (AMR) and sequential motion rate (SMR) assessments. There were two main methods for DDK assessment: perceptual speech assessment and instrumental speech assessment.

Objective: This study aimed to compare the DDK rate measured by auditory-perceptual and instrumental methods and investigate the effects of age and gender on the DDK rate in normal Thai adults.

Materials and methods: In this cross-sectional study, the participants were Thai adults aged 21-78. Sixty participants were divided equally into three age groups: young adult, middle-aged adult, and older adult group. All participants were asked to repeat four speech tasks as rapidly as possible, namely, AMR as [p^{h}a:], [t^{h}a:], [k^{h}a:], and SMR as [p^{h}a:-t^{h}a:-k^{h}a:]. DDK rates were measured using two methods, namely, the auditory-perceptual method and the instrumental method, which used the Praat program. The paired sample t-test examined the difference in average DDK rates between the two methods. The one-way ANOVA was utilized to analyze the average rate differences among three age groups, while gender differences were analyzed through an independent sample t-test.

Results: The averages of SMR between the auditory-perceptual method and the Praat program were significantly different (p<0.05), whereas the averages of AMR were not significantly different. The findings also found that averages of SMR had significant differences (p<0.05) between three age groups and two genders. The young adult group had a higher average of SMR than middle-aged adult and older adult groups. Males had a higher average of SMR than females.

Conclusion: This result indicates that different assessment methods result in different DDK rates, especially SMR. Therefore, choosing the DDK rate assessment method should be careful and consider its accuracy. Moreover, the SMR task may be more sensitive than the AMR task to age-related change and gender factors.

Introduction

Diadochokinetic (DDK) rate refers to the time taken for rapidly repetitive movements of the articulators during speech. It has been used to screen speech problems or evaluate speech motor control or speech motor coordination skills for use as part of the diagnosis and treatment planning of motor speech disorders.[1-4] The DDK rate contained two typical assessments: alternating motion rate (AMR) and sequential motion rate (SMR). AMR was obtained by repetitions of single syllable speech rapidly, such as /pə/, /tə/, /kə/ or /pʌ/, /tʌ/, /kʌ/, etc.

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AMR considers the rapidity of syllable repetition and consistency of articulatory movement. SMR was derived from repetitions of trisyllable sounds that sequence movements of the lips, the tip of the tongue, and the base of the tongue as speedily, such as /pə-tə-kə/ or /pʌ-tʌ-kʌ/ etc. SMR is used to consider the ability to quickly and accurately switch articulators.[1, 5-8]

Two standard DDK rate assessment methods were the auditory-perceptual and instrumental methods.[2,4,9] The auditory-perceptual method focuses on the perception of the characteristics of speech by primarily using the assessor's ears and eyes without any equipment or special tools except voice recorders and a stopwatch with miscellaneous items such as pen and paper.[1,2,10] The instrumental method used acoustic analysis programs[11] such as the Praat program,[12] the Motor Speech Profile program in the Computerized Speech Lab,[13] or the Visi-Pitch.[7]

Concepts for evaluating speech disorders were reported that the assessor's ears and eyes are the most essential tool and the gold standard method.[1] In clinical practice, the auditory-perceptual assessment method was more popular because it cost less and was more convenient to evaluate.[4,14] However, according to the opinions of many experienced speech-language pathologists, it is not easy to measure the DDK rate accurately and precisely, especially in patients who repeat the syllable tasks too speedily or intermittently, with low voice volume or unclear speech. As a result, it is difficult for the assessor to listen and perceive clearly during the DDK assessment.[2,5] On the other hand, the instrumental assessment method provides a visible quantitative result.[1,2]

Over the past two decades, many studies have been conducted to analyze the DDK rate using the Praat program because it is free, easy to access, and simple to use.[2, 8, 15-17] Praat is a software program developed by Paul Boersma and David Weenink. It was used to analyze and reconstruct acoustic sounds. The Praat program could display the waveform or spectrogram, including pitch, intensity, formant frequency, and duration of acoustic voice and speech samples.[12]

Studies of DDK rate measurement methods have been diverse and different from the past to the present. However, the primary purpose of the studies was to obtain an accurate and optimal measurement method for measuring DDK rates.[2,4,13,14,18] Many studies recommended instrumental measurement methods because they demonstrated clear graphs or spectrograms.[2, 4, 13, 18] On the other hand, a survey by Fletcher found that instrumental and auditory-perceptual measurements had similar results, which was acceptable.[14] Therefore, the present research compared the DDK rate between the method of measurement using the Praat program and the auditory-perceptual measurement. Moreover, gender and age factors were compared to consider the factors affecting DDK rate differences.

Methods

Study design and participants

Data was collected at the Speech Clinic in Ramathibodi Hospital between October 2021 and April 2022. The participants in this study were recruited using convenience sampling, and sixty normal Thai adults were selected from volunteers who were normal adults or relatives of patients receiving therapeutic services at Ramathibodi Hospital. The sample sizes were calculated using the GPower 3.1 program by computing the sample size of the One-Way ANOVA. Average DDK rates for each age group of the study by Chu *et al*.[19] was obtained to calculate sample sizes. The sample size of each group was calculated as fifteen. Thus, the total sample size was calculated as forty-five. However, the prevention of errors in data collection was reserved. An additional 5 participants per group increased the sample size of each group. Therefore, there were sixty participants. The age range of participants was 21-78 years. They were divided into three age groups: the young adult (21-39 years old), the middle-aged adult (40-59 years old), and the older adult (60-78 years old). The three age groups had 20 participants, equal for each group. Each group had an equal number of males and females. The demographic data are shown in Appendix 1.

The inclusion criteria were Thai native speakers. They did not have any previous instances of communication disorders, neurological disorders, trauma, or surgery involving the head, neck, or chest. Additionally, there were no records of lung or respiratory diseases such as tuberculosis, pleural fibrosis, flu, or asthma that might impact speech during the data collection. Furthermore, they were non-smokers who hadn't smoked in the past five years.

The exclusion criteria were participants with issues with controlling oral movement or hearing problems that affected daily communication. They were tested for oral movement control by the voluntary movement subtest in the Apraxia Test for Thai Adults[19] (Appendix 2). The hearing problems of participants were screened by the Speech Discrimination Screening Task in the Thai Adaptation of Arizona Battery for Communication Disorders of Dementia[20] (Appendix 3) by the researcher, a speech-language pathologist. If there were some problems, those participants were excluded. Five participants who did not meet the criteria during the data collection were excluded. However, the researcher selected additional participants who met the requirements until the total number reached sixty.

Instruments

The instruments used in this study consist of a laptop with the Audacity program, a broad program for recording speech samples,[21] and the Praat program.[12] Moreover, a condenser microphone was plugged into the computer to record audio using the Audacity program, and a stopwatch was employed to time the speech repetitions.

Procedure

The data collection procedure was divided into two parts. The first part was collecting speech samples of DDK tasks. The second part measured the DDK rate, which involved using an auditory perceptual method and analyzing it with the Praat program.

For the first part, the researcher collected speech samples from participants individually in a quiet room. The participants were given instructions and a demonstration of the DDK test by repeating a syllable as fast as possible. The tasks consisted of repeating each of [p^ha:], [t^ha:], and [k^ha:] twenty times and then repeating a group of syllables [p^ha:-t^ha:-k^ha:] ten times.[14] Each speech sample was digitally saved as a .wav file for later analysis.

For the second part, all speech sample data were measured using the auditory perceptual method. Then, they were calculated by using the Praat program. The Praat measurement method was started one month after the auditory perceptual method to reduce bias in data analysis. The researcher played back the speech samples during the evaluation using both methods. So, the researcher conducted the assessment by Praat program one month apart to avoid being able to recognize the speech sample. For the auditory perceptual method, all speech samples were heard through a loudspeaker in a quiet room and timed with a stopwatch. The speech samples were assessed using the Praat program for the instrumental method. DDK rate measurement was performed by analyzing the waveforms and spectrograms displayed in the Praat program window. The time of the DDK rate was calculated using syllables per second.

Ethical consideration

This study was approved by the Human Research Ethics Committee, Faculty of Medicine Ramathibodi Hospital, Mahidol University, COA. MURA2021/635 on 04 August 2021. All participants signed informed written consent forms before starting data collection.

Statistical analysis

The STATA SE-64 version 17 program categorized and analyzed the data.[22] Descriptive statistics, including means and standard deviations, were calculated to describe the demographic information and DDK rate. The mean differences in DDK rate between the two methods, age groups, and gender were analyzed based on the normal distribution of sample data. A paired sample t-test was employed to compare the DDK rate differences between the two measurement methods. An independent sample t-test was used to compare the differences in DDK rate between genders. A one-way ANOVA was performed to compare the differences in DDK rate between the three age groups. The level of significance was set at 0.05.

Results

The statistical comparison results of DDK rates using two different measurement methods are presented in Table 1.

Table 1. Mean differences in DDK rates between the instrumental and perceptual methods.

Task	Method	Mean (syl./sec.)	SD	95%CI	*t*	*p*
[p^ha:]	Instrumental	4.63	0.79	4.43-4.84	0.36	0.721
	Perceptual	4.61	0.79	4.41-4.82		
[t^ha:]	Instrumental	4.56	0.85	4.34-4.78	- 1.06	0.296
	Perceptual	4.62	0.87	4.39-4.84		
[k^ha:]	Instrumental	4.39	0.87	4.17-4.62	- 1.59	0.118
	Perceptual	4.47	0.90	4.23-4.70		
[p^ha:-t^ha:-k^ha:]	Instrumental	5.32	1.15	5.02-5.62	- 17.07*	<0.001
	Perceptual	5.88	1.37	5.52-6.23		

**p<0.05*

The analysis demonstrates that the differences between the DDK rates measured with the two methods were not statistically significant for AMR values. On the other hand, they were statistically significant for SMR at $p<0.001$.

In addition, the Bland-Altman method was used to determine agreement between the two quantitative measurements and to consider the difference between the two measurement methods. The results of the Bland-Altman plot are shown in Figure 1.

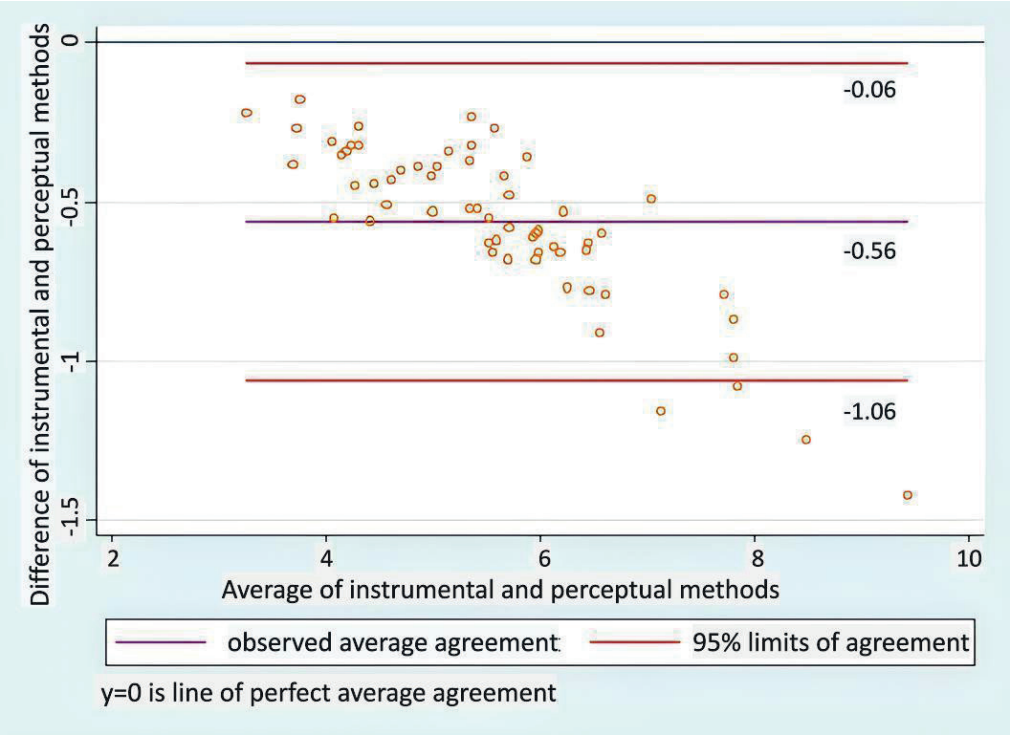


Figure 1. *Bland-Altman plot analysis for [pʰa:-tʰa:-kʰa:].*

According to Figure 1, there was a systematic difference in SMR between the two different measurement methods. As the SMR was produced faster, the difference between the rates measured by the two methods became greater.

The results of the statistical comparison of mean DDK rates between the three age groups are presented in Table 2.

There were no statistically significant between the three age groups for AMR values. On the other hand, there was a statistically significant difference between the three age groups for only SMR at $p<0.001$.

Then, a post-hoc Bonferroni test was used to determine the difference between SMR for three age groups by group-wise comparison in Table 3.

Table 2. Mean differences in DDK rates between age groups.

Task	Group	Mean (syl/sec)	SD	F	*p*
[pʰa:]	Young	4.73	0.91		
	Middle-aged	4.55	0.69	0.25	0.779
	Older	4.62	0.79		
[tʰa:]	Young	4.69	0.98		
	Middle-aged	4.60	0.72	0.61	0.546
	Older	4.39	0.86		
[kʰa:]	Young	4.67	0.98		
	Middle-aged	4.45	0.70	2.57	0.086
	Older	4.07	0.84		
[pʰa:-tʰa:-kʰa:]	Young	6.13	1.14		
	Middle-aged	5.27	0.81	13.18*	<0.001
	Older	4.56	0.93		

**p<0.05*

Table 3. A post-hoc Bonferroni test result for SMR between three age groups.

Group-wise comparison		Mean difference	*p*
Young	Middle-aged	0.86*	0.020
Young	Older	1.57*	<0.001
Middle-aged	Older	0.71	0.074

**p<0.05*

The mean SMR between the young and middle-aged adults was statistically significant at p=0.020. Moreover, the mean SMR rate in young adults differed significantly from that in older adults, with a p<0.001. The mean of SMR indicated that the young adult group had a considerably faster rate than other groups. The differences in the DDK rates between females and males are shown in Table 4.

Table 4. Mean differences in DDK rate by gender.

Task	Gender	Mean (syl/sec)	SD	*t*	*p*
[p^{h}a:]	Female	4.50	0.70	-1.27	0.209
	Male	4.76	0.86		
[t^{h}a:]	Female	4.42	0.78	-1.26	0.212
	Male	4.70	0.92		
[k^{h}a:]	Female	4.25	0.76	-1.32	0.193
	Male	4.54	0.96		
[p^{h}a:-t^{h}a:-k^{h}a:]	Female	4.97	1.07	-2.43*	0.018
	Male	5.67	1.14		

**p<0.05*

From Table 4, the DDK rate of males tends to be faster than females. However, there were no statistically significant differences in DDK rate between females and males for AMR values. On the other hand, there was a statistically significant difference in DDK rate between the two genders for SMR at p=0.018. The mean of SMR indicated that males had a significantly faster rate than females.

Discussion

The current study's findings indicated that the DDK rate between the perceptual and instrumental methods was different, which there was only statistically significant for SMR as [p^{h}a:-t^{h}a:-k^{h}a:] ($p < .05$). From the literature review, no studies compared the difference between auditory-perceptual method and instrumental method by using Praat program. Nevertheless, a study by Fletcher compared the DDK rate between using auditory perception with a stopwatch and instrumental measurement by an oscilloscope, in which oscillography displayed the DDK rate in the waveform. His study found that the DDK rates were similar between a stopwatch and an oscilloscope. He concluded that using a stopwatch could be as accurate as using instrumental measurement.[14] However, this study's results were inconsistent with Fletcher's study.[14] This study and Flecther's study might be because it employed different research methodologies. Namely, the participants of this study were adults, whereas Fletcher's study was children. Moreover, both studies had different DDK tasks. This study consisted of [p^{h}a:], [t^{h}a:], [k^{h}a:], and [p^{h}a:-t^{h}a:-k^{h}a:] while the Fletcher's study comprised /pʌ/, /tʌ/, /kʌ/, /fʌ/, /lʌ/, /pʌtə/, /pʌkə/, /tʌkə/, and /pʌtəkə/. Furthermore, there was a contrast in the approach to compare the differences between DDK rate measurement methods. This study separately compared each task of DDK rate, while Fletcher's study used the total DDK rate.[14]

This study found a statistically significant difference between the two measurement methods for SMR. This may be because of the sound characteristics of the SMR task. It was the sequential trisyllable repetition of the bilabial-alveolar-velar sound,[4] which was more complex. Furthermore, the more incredible speed of the sequential trisyllable repetition might affect the more difficult auditory perception during evaluation.[23] From the result of the Bland-Altman plot in this study, the graph demonstrated a tendency for more significant differences between the Praat measurement method and the auditory-perceptual method when the SMR rate was faster. It is possible that the SMR with a more rapid rate can make it more challenging to recognize and count the repetitions of the DDK rate.[23] For the auditory-perceptual assessment method, factors affecting auditory perception, such as speed of speech and complexity, also play a role in the difficulty of listening and auditory error.[2,4,24]

For the DDK assessment using the auditory perceptual method with a stopwatch, the uncertainty of the timekeeper's response or human error may occur, such as the speed to press the start/stop button. The timekeeper's response to the start and stop was an essential issue in the human error of using the stopwatch.[25] Moreover, there was a report on Gadesmann and Miller's study about the reliability of DDK rate measurement. They found that the reliability among and within raters was below the acceptable level for clinical diagnosis and outcome evaluation.[2] Therefore, this issue should be considered with very caution. The DDK rate assessment using the acoustic analysis instrument could prevent and reduce the occurrence of evaluation errors. The accuracy and reliability are the issues of concern in the DDK evaluation,[4] possible problems for measuring the DDK rate should be avoided, such as human errors.[2] The assessment using instruments does not replace the necessity for expert clinical interpretation. However, it helps mitigate the quantification issues highlighted in this study and may enhance the effective integration of DDK tasks in evaluating motor speech disorders.[2] The researcher recommends that if an auditory perceptual assessment is necessary, it should be done in a quiet room, and the assessor must be prepared for the evaluation. Furthermore, there are currently a variety of acoustic analysis instruments available to evaluate DDK rates, and some of them are easy to access, have lower costs,[2] and

are widely used in research,[2,15-17,26] such as the Praat free program.[12] Therefore, the acoustic analysis instrument was suggested for accuracy in the DDK assessment.[2]

The difference in DDK rate among the three age groups, obtained by the Praat measurement method, showed that the young adult group had higher DDK rates than the middle-aged and older adult groups. The reasons might be the change in the anatomy and physiology of speech production with age-related changes. It was reported that the young adult had a better structure and function of speech mechanism than the older adult.[27] Moreover, the coordination of speech movement declined with age, primarily due to decreased muscle strength and alterations in the neuromotor function of the speech mechanism.[16,28,29]

Age-related changes in speech rate are attributed to anatomical and physiological changes in oral structure and reduced lung capacity, which can be measured by oral DDK assessment.[28] Nevertheless, this study found significant age-related differences only in SMR values, especially among older adults. A Thai study reported that SMR significantly decreased with age.[10] For age-related changes, the SMR task may better reflect the decline in motor speech control than the AMR task. A study by Lancheros *et al*. reported that the SMR task may be more sensitive to age-related changes in oral motor abilities than the AMR task.[26]

The different DDK rates between genders, obtained by the Praat measurement method, demonstrated that the different AMR of males had slightly faster average rates than the females as 0.26, 0.28, and 0.29 syllables per second for [pʰa:], [tʰa:], and [kʰa:]. The different SMR of males had a faster average rate than the females at 0.7 syllables per second for [pʰa:-tʰa:-kʰa:].

The tendency of the current study showed that males had a faster average rate than females for SMR and AMR. This may be because men had larger muscle fibers, stronger muscles, and greater lung size than women.[30-32] Furthermore, Bennett et al. studied tongue control for speech, and the SMR task was one of the speech tasks used in their study. They found that males exhibited significantly greater movement ranges of tongue body than females.[33] In addition, men's lung capacity for respiration was greater than that of women in the same age group.[34,35] This result was consistent with the study of Pierce *et al*.,[8] Alshahwan *et al*.,[15] Topbaş *et al*.,[36] and John *et al*.[37] Those studies found that the male group's average rates of SMR and AMR tend to be faster than the female group.[8,15,36,37] For the statistical result of this study, it was observed that SMR had significant differences between genders, whereas AMR did not demonstrate significant differences. This result was inconsistent with the resulting research of Pierce et al.[8] They found that AMR was an essential difference between genders, and SMR was not significant. However, their participants were only older adults, who were 65 to 86 years old. Pierce et al. reported that it was unclear why the SMR was not affected by gender while the AMR was affected.[8] From the statistical results of the SMR in this study, it may be due to tongue movements during speech contributing to the observed gender differences. A study using electromagnetic articulography was conducted to compare SMR and AMR tasks. It found that the tongue demonstrates greater speed and range of motion during SMR than AMR.[38] Moreover, men showed significantly greater ranges of tongue body movement than women during the SMR task.[33]

Limitations of this study

A limitation of this study was the small sample size. The DDK rate obtained in this study cannot be a normative value. Thus, future studies should collect data from a large group of normal Thai adults to establish normative data. This study considered the factors of gender and age that affect DDK rates. However, some factors may affect the DDK rate, such as the use of dentures and chronic respiratory-related conditions.

Consequently, those factors should be considered in the future. This study used only one speech and language therapist to evaluate DDK rates. Therefore, future research might investigate the inter-rater and intra-rater reliability of auditory-perceptual measurement for DDK rate assessment. Finally, the Praat program was used to measure the DDK rate in this study. However, other instruments, such as the Dr. Speech program or the Computerized Speech Lab (CSL) program, could measure DDK rates. Therefore, future studies may use such tools to compare auditory-perceptual and instrumental measurements.

Conclusion

The current study aimed to measure DDK rates using instrumental and auditory-perceptual methods. The oral DDK rates consisted of the alternating motion rate (AMR) and the sequential motion rate (SMR). The study involved 60 adults with normal speakers, evenly separated by gender and age.

The average of AMR and SMR were compared between the instrumental and the perceptual measurement methods. The results demonstrated that the differences in the SMR between the two methods were statistically significant ($p<0.05$). Conversely, the differences in AMR were statistically non-significant. However, using instruments for DDK rate measurements, especially the SMR, should yield more accuracy and precision.

Regarding the age factor, the average DDK rate decreases from young to older adults. The comparison of the SMR of the three age groups showed significant differences ($p<0.05$). In contrast, the differences in AMR among the three age groups were not statistically significant ($p>0.05$).

Regarding gender factors, males tend to demonstrate faster average DDK rates than females. However, gender significantly influenced SMR.

Therefore, it is important to consider both gender and age ranges when determining or comparing normative values for DDK rates, especially SMR.

Conflict of interest

The authors declare no conflict of interest regarding the publication of this paper.

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Appendix 1. Demographic data

Group	Gender	N	Age (years)	
			Mean (SD)	Range
Young adult	Males	10	28.7 (6.88)	21-38
	Females	10	31.3 (3.74)	25-38
	Both	20	30 (5.55)	21-38
Middle-aged adult	Males	10	47.4 (5.78)	40-56
	Females	10	52.1 (5.86)	42-59
	Both	20	49.75 (6.15)	40-59
Older adult	Males	10	67 (5.12)	60-78
	Females	10	64.6 (5.27)	60-74
	Both	20	65.8 (5.21)	60-78
Overall	Males	30	47.7 (16.92)	21-78
	Females	30	49.3 (14.79)	25-74
	Both	60	48.5 (15.78)	21-78

Appendix 2. Oral movement control by the voluntary movement subtest in the apraxia test for Thai adults

แบบประเมินการเคลื่อนไหวอวัยวะที่เกี่ยวข้องกับการพูด

รหัส __ __ __ วันที่บันทึกข้อมูล วันที่ __ __ เดือน __ __ ปี พ.ศ. __ __ __ __

	ความถูกต้อง (precise)			**ความเร็ว** (speed)			**ความแข็งแรง** (strength)		
	ถูกต้อง	ถูกบางส่วน	ไม่ถูก	ได้ทันที	ทำได้ช้า	ทำไม่ได้	แข็งแรง	อ่อนแรงเล็กน้อย	ไม่แข็งแรง
แลบลิ้นยาว									
ห่อปากกลม									
เตาะลิ้น									
แลบลิ้น เข้า-ออก									
ยิงฟัน									
ยกลิ้น แตะจมูก									
ทำแก้มป่อง									
ส่ายลิ้น ซ้าย-ขวา									

☐ ผ่าน ☐ ไม่ผ่าน ผู้เก็บข้อมูล .....

Appendix 3. The speech discrimination screening task

แบบคัดกรองการประเมินการฟัง

รหัส __ __ __ วันที่บันทึกข้อมูล วันที่ __ __ เดือน __ __ ปี พ.ศ. __ __ __ __

การคัดกรองการฟังแยกเสียง คะแนน 1 หรือ 0 0.5 หรือ 1 0.5 หรือ 1				การแยกคู่คำ	การพูดตามคำ	
ตัวอย่าง	แนบ	แลบ	(แตกต่าง)			
1	แบ	เด	(แตกต่าง)			
2	พาด	ฟาด	(แตกต่าง)			
3	ห่ม	ห่ม	(เหมือน)			
4	ทิน	ชิน	(แตกต่าง)			
5	ฉาบ	ฉาบ	(เหมือน)			
6	ชิพ	จิ๊บ	(แตกต่าง)			
7	เก็บ	เก็บ	(เหมือน)			
8	เด	เท	(แตกต่าง)			
9	เทา	เทา	(เหมือน)			
10	ซิบ	ซิบ	(เหมือน)			
11	กำ	กำ	(เหมือน)			
12	เวทย์	เวทย์	(เหมือน)			
13	บัตร	ผัด	(แตกต่าง)			
14	หอบ	หอบ	(เหมือน)			
15	โหวต	โบสถ์	(แตกต่าง)			
16	ชิด	ชิด	(เหมือน)			
17	สอย	ฝอย	(แตกต่าง)			
18	วาย	วาย	(เหมือน)			
คะแนนรวม = 18						

☐ ผ่าน ☐ ไม่ผ่าน (ตอบผิด 5 ข้อขึ้นไป) ผู้เก็บข้อมูล .....