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Phonetically balanced and psychometrically equivalent monosyllabic word lists for word recognition testing in Thai

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Word recognition testing may be defined as a procedure to assess a listener's ability to identify one-syllable words (such as phonetically-balanced/PB words) that are presented at a given suprathreshold level to arrive at a word recognition score. For Thai, Thammasat University and Ramathibodi Hospital Phonetically Balanced Word Lists 2015 (TU-RAMA PB'15) were created with five lists, each with 25 monosyllabic words. Besides its phoneme distributions being based on large-scale Thai spoken corpora, TU-RAMA PB'15 is in line with TU PB'14 with emphasis on phonetic balance, symmetrical phoneme occurrence, and word familiarity. To evaluate its homogeneity in terms of decibel intelligibility, the lists were recorded and presented to 10 normal hearing participants, ranging from 0 to 50 dB HL in 2 dB increments (ascending order) until they repeated correct verbal responses. Using logistic regression, regression slopes and intercepts were calculated to estimate percentage of correct performance at any given intensity and to construct psychometric functions for every list. Derived psychometric function slopes ranged from 0.2015 to 0.2262 while intensities required for 50% intelligibility ranged from 17.0876 to 20.8856. Two-way Chi-Square analysis performed on both parameters indicated that there was no significant difference among the five lists.

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I. INTRODUCTION

Speech audiometry includes series of tests, but the most common ones are patient's Speech Reception Threshold (SRT) through spondees and Word Recognition Score (WRS) through phonetically balanced word lists (PB lists). PB lists have been created for many languages and in addition to phonetic balance, various criteria have been taken into account, i.e., word frequency, word familiarity, syllable structure, lexical neighbors, and equal range of difficulty [1][2]. To prevent learning effect and memorization, several test lists, which are interchangeable should be available [1][2]. Brief descriptions of existing Thai monosyllabic word lists are described as follows:

A. Original Thai monosyllabic word lists (RAMA.SD-1 and RAMA.SD-2)

Original Thai monosyllabic word lists are a combination of two monosyllabic sets. First, Ramathibodi-Speech Discrimination Test No.1 (RAMA.SD-1) contains five lists of 25 monosyllabic words [3]. Ramathibodi-Speech Discrimination Test No.2 (RAMA.SD-2) was later developed to address an issue of word difficulty equivalency in terms of decibel intelligibility among words [4]. Construction of RAMA.SD-2 was based on words selected from samples of recorded conversations from 60 Thai children and adults. The lists started out with two lists of relatively equivalent 50 monosyllabic words, which then divided into four lists of 25 words to save testing time. Even though RAMA.SD-1 and RAMA.SD-2 are commonly used in hearing clinics across Thailand, many limitations of the lists have been observed [4][5][6]. There is a large degree of asymmetrical phoneme occurrences among the word lists (see Tables 2–5) and cases of duplicate words across different lists can be found [5][6].

B. Thammasat University Phonetically Balanced Word Lists 2014 (TU PB'14)

Focusing on major criteria, phonetic balance, test-retest reliability, and list equivalency, Thammasat University Phonetically Balanced Word Lists 2014 (TU PB'14) were created [5][6]. TU PB'14 reflects Thai phoneme distribution [7] based on large-scale written Thai corpora, InterBEST [8]. The lists were given in test and retest sessions to 30 normal-hearing subjects to evaluate in terms of relative inter-list equivalency and test-retest reliability [5][6]. Detailed analysis of listeners' misperceptions and confusion matrices were also analyzed revealing errors occurred predominantly in the case of initial only, final only, and initial along with final consonants [6].

II. TU-RAMA PB'15

Thammasat University – Ramathibodi Hospital Phonetically Balanced Word Lists 2015 (TU-RAMA PB'15) were recently developed to further meet clinical requirements at Ramathibodi hospital (Thailand's leading Audiology department in Thailand). Adjustments

were made to the TU PB'14 to address issues of word familiarity and difficulty equivalency in terms of decibel intelligibility. TU-RAMA PB'15 was developed based on Thai phoneme distribution from (casual-style) spoken corpora (rather than written corpora) [9]. Complete five lists of TU-RAMA PB'15 are given in Table 1; each with 25 monosyllabic words. Words were carefully selected to represent real use in everyday life.

Table 1. TU-RAMA PB'15 word lists.

List 1	List 2	List 3	List 4	List 5
กัด (bite) [kàt]	กาว (glue) [kāːw]	กุ้ง (prawn) [kûŋ]	กอ (clump) [kɔ̄ː]	กัน (protect) [kān]
กา (crow) [kāː]	แก (you) [kɛ̄ː]	เกณฑ์ (criteria) [kēːn]	แกะ (remove) [kɛ̀ʔ]	กำ (grasp) [kām]
ข้า (me) [kʰâː]	ขับ (drive) [kʰàp]	ไข่ (egg) [kʰàj]	ไข้ (fever) [kʰâj]	ข้อ (list) [kʰɔ̂ː]
ค้าง (remain) [kʰáːŋ]	คอ (neck) [kʰɔ̄ː]	ค้า (trade) [kʰáː]	คัน (itch) [kʰān]	ค้น (seek) [kʰón]
จำ (remember) [tɕām]	งอ (bend) [ŋɔ̄ː]	จิ้ม (stab) [tɕîm]	คิ้ว (eyebrow) [kʰíw]	เงาะ (rambutan) [ŋɔ́ʔ]
ชี้ (point) [tɕʰíː]	จี้ (rob) [tɕîː]	เชื้อ (germ) [tɕʰɯ̂a]	เจอ (meet) [tɕɤ̄ː]	จิ๋ว (tiny) [tɕɨ̌w]
ดอย (hill) [dɔ̄ːj]	ดื่ม (drunk) [dɯ̀ːm]	แดน (land) [dɛ̄ːn]	ช่อ (bouquet) [tɕʰɔ̂ː]	แช่ (soak) [tɕʰɛ̂ː]
ทัน (in time) [tʰān]	โต๊ะ (table) [tóʔ]	เตะ (kick) [tèʔ]	ดีด (flick) [dìːt]	ดึก (late) [dɯ̀k]
เทียม (artificial) [tʰīaːm]	ไทย (Thai) [tʰāj]	ถ้ำ (cave) [tʰâm]	ตา (eye) [tāː]	ตี่ (narrow eyes) [tìː]
ใน (in) [nāj]	นั่ง (sit) [nâŋ]	นับ (count) [náp]	เท่ (smart) [tʰêː]	ธูป (joss stick) [tʰûːp]
ปก (cover) [pòk]	ป่วย (sick) [pùaːj]	ใบ (leaf) [bāj]	นาง (madame) [nāːŋ]	เธอ (you) [tʰɤ̄ː]
ผ่า (chop) [pʰàː]	ปิ่น (hairpin) [pìn]	ปู (crab) [pūː]	เน่า (rot) [nâw]	นา (field) [nāː]
เฝ้า (watch out) [fâw]	ผี (ghost) [pʰǐː]	แพ (raft) [pʰɛ̄ː]	แบบ (model) [bɛ̀ːp]	บ่อ (pond) [bɔ̀ː]
มือ (hand) [mɯ̄ː]	มัน (it) [mān]	มอด (weevil) [mɔ̂ːt]	ป่า (forest) [pàː]	ไป (go) [pāj]

แม้ว (tribe in Thailand) [mɛ́:w]	ม่าน (curtain) [mâ:n]	โยน (throw) [jō:n]	ผา (cliff) [pʰă:]	พัง (collapse) [pʰāŋ]
รอด (survive) [rô:t]	ยาก (difficult) [jâ:k]	ลอก (copy) [lô:k]	มั่น (confident) [mân]	ม้า (horse) [má:]
ล้วน (all) [lúa:n]	ลับ (secretive) [láp]	ล้า (tired) [lá:]	ยื้อ (pull) [jɯ́:]	รั้ง (hold back) [ráŋ]
ล่อ (attract) [lô:]	ลุง (uncle) [lūŋ]	เลีย (lick) [līa:]	ลอย (float) [lō:j]	เลข (number) [lê:k]
สระ (pool) [sàʔ]	เลย (pass) [lɤ̄:j]	วัง (palace) [wāŋ]	ลึก (deep) [lɯ́k]	ไว (quick) [wāj]
สี่ (four) [sì:]	วัด (temple) [wát]	สั่ง (command) [sàŋ]	เว้น (skip) [wén]	สัตว์ (animal) [sàt]
หญิง (woman) [jǐŋ]	เสีย (broken) [sǐa:]	ส่าย (swing) [sà:j]	สั้น (short) [sân]	ไส้ (filling) [sâj]
หุ้น (share) [hûn]	เสื้อ (shirt) [sɯ̂a:]	หนี้ (debt) [nî:]	หลัง (back) [lăŋ]	หนา (thick) [nă:]
ไหว (be able) [wăj]	หาร (divide) [hă:n]	หมี (bear) [mǐ:]	ใหม่ (new) [màj]	ไหล่ (shoulder) [làj]
เอน (lean) [ʔē:n]	อัน (piece) [ʔān]	หาว (yawn) [hă:w]	อม (keep in mouth) [ʔōm]	อ่าน (read) [ʔà:n]
โอบ (embrace) [ʔò:p]	อูฐ (camel) [ʔù:t]	อับ (stuffy) [ʔàp]	ไอ (cough) [ʔāj]	เอ็น (tendon) [ʔēn]

Tables 2–5 give the number of occurrences of initial consonants, vowels, tones, and final consonants across RAMA.SD-1, RAMA.SD-2 and TU-RAMA PB'15 lists. Shaded areas highlight degrees of phonemic asymmetry of the word lists in each set.

Tables 2–5. Number of occurrences of initial, vowel, tone and final phonemes across RAMA.SD-1, RAMA.SD-2 and TU-RAMA PB'15 lists (In isolation, short-vowel syllables with no final consonant are phonetically ended with [ʔ]; ø denotes the lack of final consonant.).

RAMA.SD-1																													
List	pʰr	pr	kʰw	kʰr	kl	kr	tr	p	pʰ	b	t	tʰ	d	tɕ	tɕʰ	k	kʰ	ʔ	f	s	h	m	n	ŋ	l	r	w	j	pl	kw
1			1		1			1	2	1	1	2	1	1	2			1	2	1	1	1	1	1	1	1	1	1		
2								1	2	1	1	2	1	1	2	1	2	1	1	2	1	1	1	1	1	1	1	1		
3		1							1	1	1	1	1	1	2	1	3	1	2	2	1		1	1	1	1	1	1		
4								1	2	1	1	2	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1		
5			1		1			1	2	1	1	2	1	1	2			1	2	1	1	1	1	1	1	1	1	1		
RAMA.SD-2																													
List	pʰr	pr	kʰw	kʰr	kl	kr	tr	p	pʰ	b	t	tʰ	d	tɕ	tɕʰ	k	kʰ	ʔ	f	s	h	m	n	ŋ	l	r	w	j	pl	kw
1.1			1					1	1		2		2	1		2	2	2	1	1	1	2	1	1	2		1		1	
1.2					1			2		1		2		1	1	2	3			2	1	3	1		2	1	1			1
2.1											1	1	1	2		4	2		1	2	1	3	2	1	3				1	
2.2			1					1		1	2	1	1	1	1	2	2	1		2		1	3		2		2	1		
TU-RAMA PB' 15																													
List	pʰr	pr	kʰw	kʰr	kl	kr	tr	p	pʰ	b	t	tʰ	d	tɕ	tɕʰ	k	kʰ	ʔ	f	s	h	m	n	ŋ	l	r	w	j	pl	kw
1								1	1			2	1	1	1	2	2	2	1	2	1	2	1		2	1	1	1		
2								2	1		1	1	1	1		2	2	2		2	1	2	1	1	3		1	1		
3								1	1	1	1	1	1	1	1	2	2	1		2	1	2	2		3		1	1		
4								1	1	1	1	1	1	1	1	2	3	2		1		2	2		3		1	1		
5								1	1	1	1	2	1	1	1	2	2	2		2		1	2	1	2	1		1		

RAMA.SD-1																							
List	a	aː	i	iː	u	uː	e	eː	ɛ	ɛː	ɤ	ɤː	o	oː	ɔ	ɔː	ɯ	ɯː	ia	iaː	ua	uaː	ɯa	ɯaː
1	3	7	2		2	2	2			1			2		1	1								2
2	5	7	1		1		1			1			1		2		1	1				3		1
3	3	8	4	1					1				2		2	2		2						
4	6	6			2	2			1	1			2			4						1		
5	3	7			2	2	2			1			2		1	1								2
RAMA.SD-2																								
List	a	aː	i	iː	u	uː	e	eː	ɛ	ɛː	ɤ	ɤː	o	oː	ɔ	ɔː	ɯ	ɯː	ia	iaː	ua	uaː	ɯa	ɯaː
1.1	8	7	1	1		1	1			1				3					1		1			
1.2	6	7		1	2	1				1		1		1		3						1		1
2.1	9	5			1	2	1			1			2			2				1				1
2.2	10	4	1	1			1			2			1			3		1		1				
TU-RAMA PB' 15																								
List	a	aː	i	iː	u	uː	e	eː	ɛ	ɛː	ɤ	ɤː	o	oː	ɔ	ɔː	ɯ	ɯː	ia	iaː	ua	uaː	ɯa	ɯaː
1	7	4	1	2	1			1		1			1	1		3		1		1		1		
2	7	4	1	2	1	1				1		1	1			2		1		1		1		1
3	7	4	1	2	1	1	1	1		2				1		2				1				1
4	8	4	1	1			1	1	1	1		1	1			3	1	1						
5	9	4	1	1		1	1	1		1		1	1		1	2	1							

RAMA.SD-1						
List	ˉ	ˋ	ˆ	ˊ	ˇ	
1	1	5	3	2	5	
2	7	4	9	4	1	
3	6	6	7	4	2	
4	8	2	7	4	4	
5	1	5	3	2	5	
RAMA.SD-2						
List	ˉ	ˋ	ˆ	ˊ	ˇ	
1.1	7	5	6	3	4	
1.2	9	2	8	4	2	
2.1	8	5	6	3	3	
2.2	12	5	3	5		
TU-RAMA PB' 15						
List	ˉ	ˋ	ˆ	ˊ	ˇ	
1	8	6	5	4	2	
2	9	5	5	3	3	
3	8	5	6	4	2	
4	8	5	6	4	2	
5	8	6	5	4	2	

RAMA.SD-1											
List	ø	ʔ	p	t	k	m	n	ŋ	w	j	
1	6			1	1		8	5	1	3	
2	4		1	4		4	4	2	3	3	
3	4	2	2	2	1	4	5	1		3	
4	1		1	2	1	4	7	4	2	3	
5	6			1	1		8	5	1	3	
RAMA.SD-2											
List	ø	ʔ	p	t	k	m	n	ŋ	w	j	
1.1	7	1	1				6	2	2	6	
1.2	7			1	1	1	5	4	2	4	
2.1	5		2	1	2	3	3	3	2	4	
2.2	6		1	2	1	2	3	3	1	4	
TU-RAMA PB' 15											
List	ø	ʔ	p	t	k	m	n	ŋ	w	j	
1	7	1	1	2	1	2	4	2	2	3	
2	7	1	2	2	1	1	5	2	1	3	
3	8	1	2	1	1	2	3	3	1	3	
4	8	1	1	1	1	1	4	2	2	4	
5	8	1	1	1	2	1	4	2	1	4	

The following steps were carefully followed for the construction of TU-RAMA PB'15:

1. Evaluation and elimination of words (from TU PB'14 [5][6]) deemed low familiarity by a team of 24 audiologists at Ramathibodi Hospital. Together, 59 words were eliminated from 125 words (7 words removed from List 1 of TU PB'14, 10 from List 2, 15 from List 3, 13 from List 4, and 14 from List 5).

2. Use phoneme distribution from casual-style spoken corpora, LOTUS-Cell 2.0 [9][10] to calculate relative frequencies (%) of 81 Thai phonemes (initial and final consonants, vowels, and tones) which are multiplied by 125.

3. Based on the relative frequencies, generate word lists (using a developed software) by selecting words from 3 Thai elementary children's textbooks [5][6], LEXiTRON Thai-English Online Dictionary [11] and by combining the remaining words from TU PB'14. Each phoneme was equally distributed into each list as much as possible.

4. Reevaluation of newly added words by audiologists at Ramathibodi Hospital.

III. EXPERIMENTAL SETUP

An experiment was carried out to investigate whether there were any significant differences in terms of level of word difficulty (decibel intelligibility) among the five word lists of TU-RAMA PB'15 as well as those of RAMA.SD-2. Words from TU-RAMA PB'15 and RAMA.SD-2 were recorded in a professional recording studio by a male speaker, who was born and grew up in Bangkok. Afterwards, the sound files were selected.

Test words (using MATLAB) were presented from 0 to 50 dB HL in 2 dB increments (ascending order) to 10-normal hearing, untrained subjects (male and female between 18 to 25 years, who had passed the pure tone screening test from 250 through 8,000 Hz), until they repeated correct verbal responses. The right ear was served as the test ear. Tests were conducted individually in a sound attenuated chamber at Ramathibodi Hospital. Each participant listened to a playback speech stimulus via a headphone. The maximum intensity level was set to 60 dB HL in case the subjects did not perceive the correct words. After that, the results were recorded and analyzed. For the scope of this paper, only results from TU-RAMA PB'15 are given.

IV. EXPERIMENTAL RESULTS

Decibel intelligibilities of each word were averaged and a whisker chart of each list was plotted as shown in Figure 1. There was no outlier in TU-RAMA PB'15 lists.

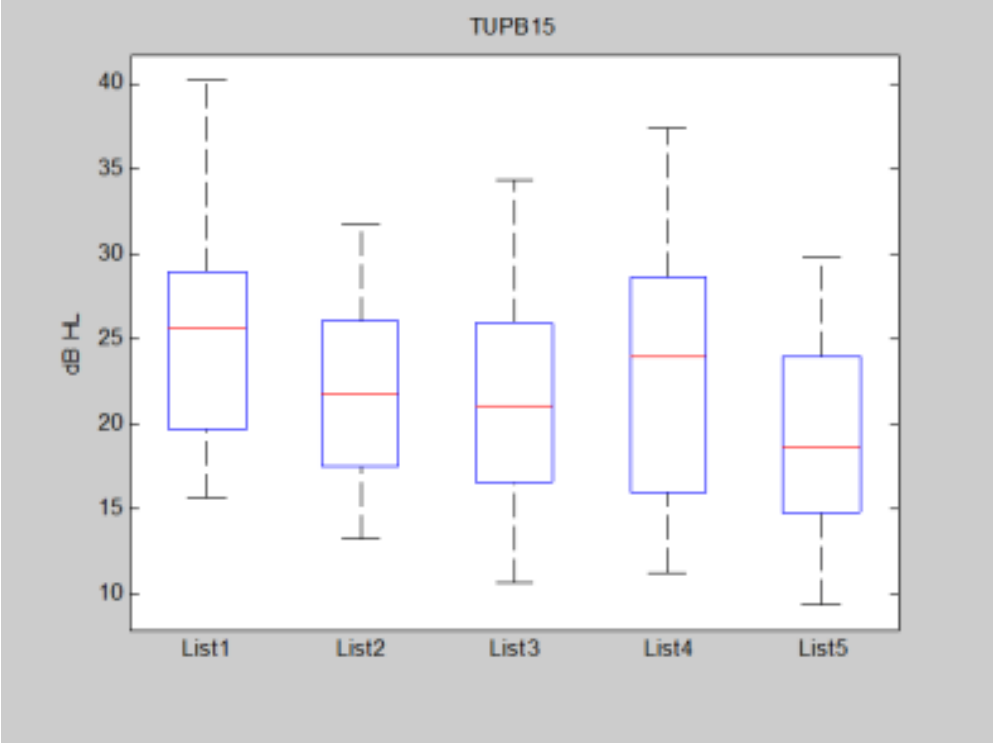

Figure 1. Whisker charts show no outlier of word intelligibility in TU-RAMA PB'15 lists.

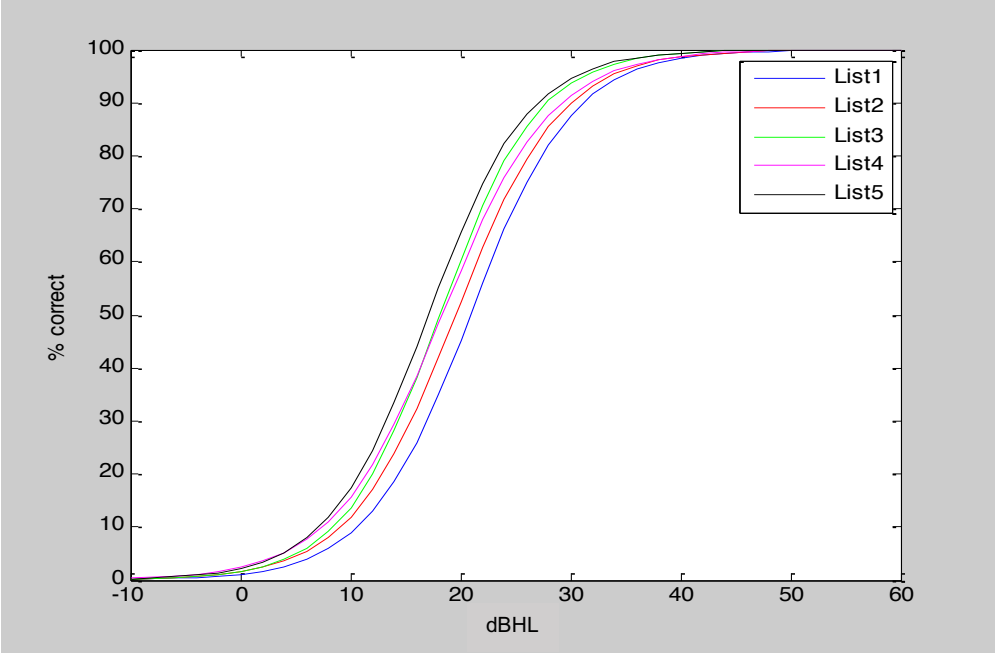

Figure 2. Psychometric functions of TU-RAMA PB'15 (lists 1-5).

Table 6. Threshold at 50% and slope of TU-RAMA PB'15 lists.

TU-RAMA PB'15		
List	50% correct	slope
1	20.8856	0.2143
2	19.5455	0.2095
3	18.1185	0.2262
4	18.3105	0.2015
5	17.0876	0.22

As shown in Figure 2 and Table 6, regression slopes and intercepts were calculated to estimate percentage of correct performance at any given intensity and to construct psychometric functions [12]. Derived psychometric function slopes ranged from 0.2015 to 0.2262 while intensities required for 50% intelligibility ranged from 17.0876 to 20.8856. Two-way Chi-Square analysis performed on both parameters indicated that there was no significant difference among the five lists.

Using a modified logistic function, i.e., regression slope and intercept value, the correct percentage for any intensity level can be calculated as follows:

$$P_i = \left(\frac{x_i}{250} \times 100\right) + P_{(i-1)},$$

where

P = correct percentage of word recognition

x = frequency of word recognition

i = integer from 1 to 31 at the intensity level from 0 to 60 dB increasing by 2.

The threshold at 50% was used to calculate the slope, which demonstrates the intensity level of the required 50% word recognition and the percentage correct was brought to the logistic test function in MATLAB.

$$\text{Plot} = \exp\frac{\frac{1}{4}(p-b)}{1+\exp\left(\frac{1}{4}(p-b)\right)} \times 100,$$

where

p = correct percentage of word recognition

b = the constant from the linear equation.

A two–way Chi-Square analysis was performed on both lists namely TU-RAMA PB'15 and RAMA.SD-2. The two-way Chi-Square results demonstrated that there were no significant differences among the lists. Chi-Square results were calculated as follows:

$$\chi^2 = \sum \frac{(observed-expected)^2}{expected}.$$

V. CONCLUSION AND FUTURE DIRECTIONS

Good phonetic balance, symmetrical phoneme occurrence, word familiarity, relative inter-list equivalency, and decibel homogeneity have been achieved in TU-RAMA PB'15,

importantly with the use of large-scale spoken corpora. More analyses: SINFA, lexical effect, neighborhood density, and bigram frequency should be carried out.

To further examine variability of discrimination scores, similar tests on sensorineural and conductive hearing impaired subjects, which are less homogeneous groups, will be carried out. Comparisons will be made across similar results obtained from RAMA.SD-1, RAMA.SD-2, and TU PB'14.

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