Tonal Perception of Thai: How Does Perceptual Accuracy Differ between Tonal and Non-Tonal Speakers?

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Abstract

The perceptual accuracy of tonal and non-tonal native speakers in discriminating high, low, and falling tones in Thai CVC syllable structures was investigated in this study. Participants included native English speakers and native Mandarin Chinese speakers, all of whom self-reported that they have never studied Thai before. Participants performed an AX discrimination task, and their correctness rates were calculated. According to statistical data generated through logistic regression in R, both English native speakers and Mandarin native speakers achieved comparable results, and the effect of L1 tonality was not significant. Mandarin listeners were predicted to perform between 0.6 times worse and 7 times better than their English counterparts in terms of odds ratios, which is a wide range. As the language effect was not evident in participants perceiving Thai CVC syllables, it is possible that the presence of codas in the current study might have affected the perceptual accuracy of the listeners. However, further studies are needed to confirm this by having participants perform the task on different types of syllable structures. The insignificance might also be due to not considering the participants' music background or a lack of normalisation of the audio stimuli, such as adjusting vowel duration or volume.

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1. Introduction

Imagine encountering a sound in a language completely foreign to you. Would you perceive this sound in the same way as native speakers of that language? Previous research has tackled this question with strong evidence. For instance, Cheng & Zhang (2015) found that Mandarin native speakers tend to perceive English syllable-initial consonants more accurately than syllable-final consonants, implying that some types of sounds are more easily perceived than others by a certain population of listeners. However, does this phenomenon hold true when listeners encounter tonal contrasts in an unfamiliar language? Does the tonal structure of their native language influence perception? The present study aims to delve deeper into this theme, as elaborated in the following sections.

1.1. Effects of interstimulus interval and tonality of native language on tonal perception

It has been widely shown that the tonal perception process differs in native speakers of tonal and non-tonal languages (eg. Gandour, 1983; Gandour & Harshman, 1978; Lee & Nusbaum, 1993). For instance, Wang, Jongman and Sereno (2001) investigated hemispheric lateralisation related to ear preference in American and Mandarin listeners through a dichotic perception experiment. They found that Mandarin speakers predominantly process Mandarin tones in the left hemisphere, whereas American English speakers process them bilaterally. The interaction effect of ear preference and different kinds of tones was significant, which means that the hemispheric lateralisation is greater in the former group than in the latter group.

Furthermore, some researchers have explored the effect of interstimulus interval (ISI) on tone perception (eg. Burnham and Francis, 1997; Werker and Tees, 1984). ISI refers to the interval between two consecutive stimuli (Werker and Tees, 1984). They claimed that since auditory memory is time-dependent, taking ISI into consideration is necessary. After the experiment, they proposed that a "phonological mode" of processing was activated in speakers who are experienced with tones, since tones exist in their phonological inventory. Therefore, this population can discriminate differences in several languages (e.g., English, Thompson language) better at 1500-ms ISI than at 500-ms ISI. Conversely, inexperienced speakers can perceive the differences at a 500-ms ISI more accurately than at a 1500-ms ISI, because they were not able to use their native sound categories stored in long-term memory (i.e., related to the longer 1500-ms ISI condition) during the experiment. In this case, they relied on a "phonetic mode" of processing as their performance was better in the shorter 500-ms ISI condition than the longer 1500-ms ISI

condition. Burnham and Francis (1997) examined this finding when they tested the performance of Australian English speakers and Thai native speakers perceiving Thai tonal contrasts. However, the effect of ISI is observed more acoustically salient at 500-ms intervals with contour-contour tone contrasts (eg., rising-falling) than other types of contrasts (i.e., contour-level and level-level contrasts) for both groups of speakers.

Some studies have focused on perceptual differences in mid tone versus low tone contrasts in Thai among English, Thai, and Chinese speakers, as these tones are the most difficult to distinguish (Burnham et al., 1992; Wayland & Guion, 2004). Wayland & Guion (2004) investigated discrimination and identification abilities across various ISIs (i.e., 500-ms ISI and 1500-ms ISI) before and after training. Results indicated that Thai native speakers have the highest perceptual accuracy, followed by Chinese speakers and lastly English speakers. Researchers found that there was a significant difference across the three groups of participants, but neither the ISI effect nor the interaction between language group and ISI was significant before the training. Furthermore, they compared the language effect in Chinese and English groups in all four conditions respectively (Pre500, Post500, Pre1500, Post1500). Results indicated that Chinese speakers obtained significantly higher scores than English speakers in Pre500, Post500 and Post1500. In conclusion, researchers suggested that prior experience with the tone system in one tonal language may be transferable to the perception of tones in an unfamiliar language.

Another study explored distinct mechanisms of linguistic versus non-linguistic tonal perception across various language backgrounds (Burnham et al., 2014). They recruited native speakers of tonal languages (Cantonese, Mandarin and Thai) and non-tonal languages (English) to perform three distinct discrimination tasks: one focusing on Thai tones in a noisy environment, another in a clear context, and a third involving violin sounds. The fundamental frequency of the tones remained consistent across these contexts. Tone language users showed comparable discrimination abilities across contexts, whereas English speakers performed better in identifying violin sounds than in the two other contexts. It is also worth noting that researchers introduced the effect of ISI (500-ms ISI condition and 1500-ms ISI condition) in the experiment as well, which did not show a significant interaction with language background.

1.2. Effect of syllable structure on phonological perception

Aside from tonal languages and the effect of ISI, syllable structure may also play a role in tonal perception, as proposed by House (2002). He introduced an adapted version of the model called

Optimum Tonal Movement Perception, which suggests that new spectral information integrates the amount of spectral change and relative intensity within a CVC syllable. As this complexity increases, listeners' pitch sensitivity decreases. For instance, the intensity of new spectral information peaks at the vowel onset and rapidly changes during the vowel, reducing listeners' capacity to resolve fundamental frequency movement (i.e., tones). Consequently, the optimal timing for perceiving a contour tone lies during the stable portion of the vowel. House tested this model with production and perception of Thai CVC syllables (ending with nasals) in contour tones (falling) and level tones (low and high). In production, the F0 movement placement of low tones occurs through the initial consonant, that of falling tones is within the vowel, and the high tones start to change at the coda's beginning. Regarding the perception of low and falling tones tested by the researchers, listeners predominantly utilise consonant information when the consonant is syllable-final (CVC structure) rather than followed by a vowel (CVCVC structure), since they found that their perception of both low and falling tones extends to the syllable coda. Although this model is unusual, it shows a possibility that different syllable structures might influence listeners' perception.

A similar study related to syllable structure involved Mandarin speakers, in which researchers analysed various syllable productions in Mandarin (Howie, 1974). They observed that basic contours of Mandarin tones are coextensive only with syllabic vowels and final voiced segments, not with non-syllabic vowels (or glides) or initial consonants. For instance, in /ɕjanˇ/ "fresh", the production of the first tone will focus on the syllabic vowel /a/ and the following nasal /n/, while the glide /j/ or the initial consonant /ɕ/ do not bear the tone. Although Howie's study focused solely on production, subsequent research sought to uncover the relationship between perceptual difference and syllable structure. Cheng & Zhang (2015) conducted research on how Mandarin-speaking individuals perceive consonants in syllable-initial and syllable-final position in English. Given that Mandarin has more consonants at onset than in coda position, participants exhibited positional asymmetry, performing better in perceiving syllable onsets than in syllable codas. Therefore, the researchers concluded that syllable structure has a significant impact on phonological perception.

1.3. Phonology of Thai, Mandarin and English

As the literature shown above, many researchers investigated perceptual accuracy by recruiting English and Mandarin native speakers to perceive Thai tones, but they have never taken different

syllable structures into account. The current study aims to fill this gap by using the same three languages. Relevant phonology is illustrated in this section.

1.3.1. Tones

Thai and Mandarin are tonal languages, where phonemic tones convey varied lexical meanings. However, languages can function without lexical tones, such as English. Pitch and contour are used paralinguistically in all languages to convey information about the emotion and demographics of the talker, or linguistically to mark intonation distinctions at supra-syllabic levels such as prosodic word and intonational phrase (Best, 2019). In contrast, tonemes, the contrastive sub-syllabic pitch variations, only exist in tonal languages (e.g., Jones, 1944). Therefore, this sub-section briefly introduces tones in two tonal languages, which are Thai and Mandarin Chinese.

Thai. Most studies of Thai phonemically distinguish five contrastive tones, which are low, mid, high, rising and falling (Slayden, 2009). These tones vary in pitch height, voice quality and pitch contour. Specifically, based on their pitch contours, level tones such as low, mid and high are referred to as static tones, while contour tones (falling and rising) are considered as dynamic tones (Abramson, 1978). An illustration of the five Thai tones is shown in Figure 1:

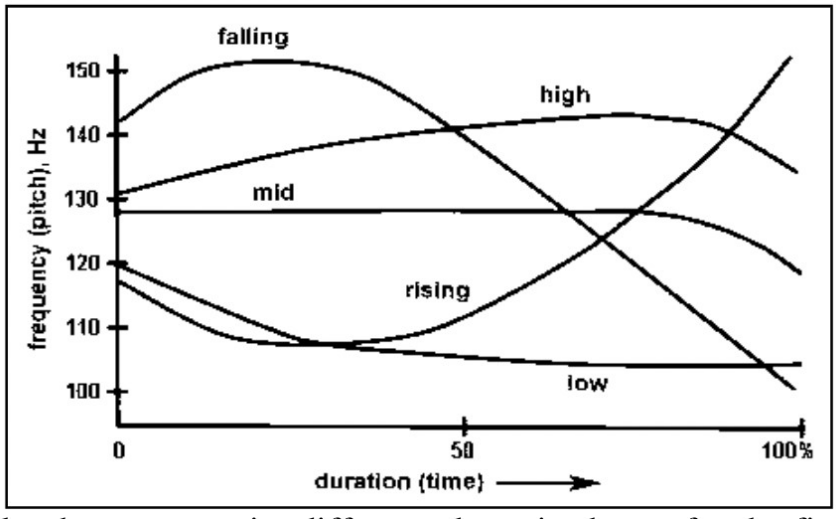

Figure 1. Fundamental frequency (F0) of the five Thai tones (Abramson, 1961)

Mandarin. Mandarin features four phonemic tones: high-level pitch (Tone 1), high-rising pitch (Tone 2), low-dipping pitch (Tone 3) and high-falling pitch (Tone 4), where only Tone 1 is static, and the rest are dynamic (Chao, 1948). An illustration of the four Mandarin tones is shown in Figure 2:

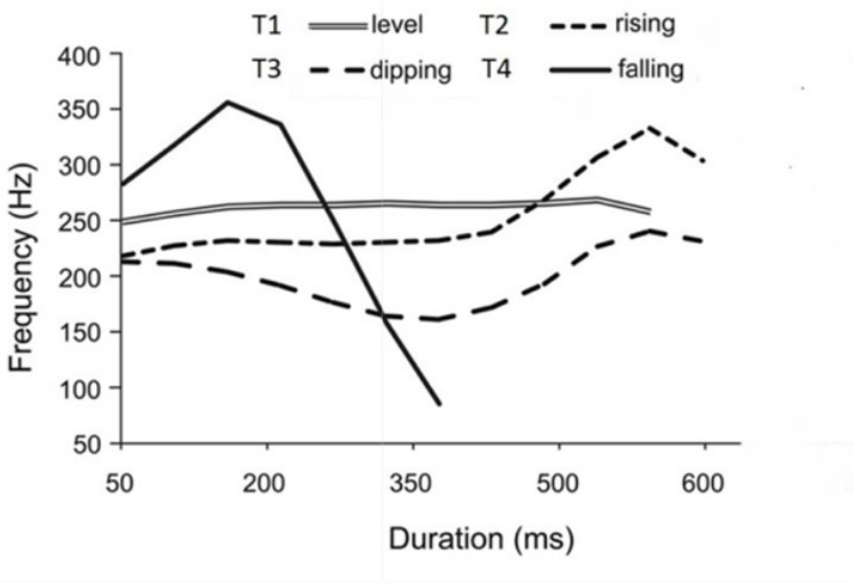

Figure 2. Fundamental frequency (F0) of the four Mandarin tones (Tillmann et al., 2011)

Comparison between Mandarin and Thai tones. Apart from high tone in Thai that does not exist in Mandarin, the rest of the Thai tones can find approximate correspondents to Mandarin tones. Specifically, mid tone ≈ Tone 1; rising tone ≈ Tone 2; low tone ≈ Tone 3; falling tone ≈ Tone 4. Additionally, Tone 2 and Tone 3 in Mandarin are shorter than rising tone and low tone in Thai in vowel duration (Kwanrean, 2001).

1.3.2. Syllable structure

Based on the previous sections, syllable structure potentially influences phonological perception. This sub-section illustrates the syllable structures of Thai, Mandarin and English and their relevant phonotactics (i.e., tones).

Thai. The structure of a maximal syllable in Thai is shown as follows (Iwasaki & Horie, 2005): $(C_1)(C_2)V^T(/a/)(C_3)$

C_1 = any consonant

C_2 = /w/, /l/, /r/

V = any monophthong

T = tone

/a/ = if a diphthong is activated

C_3 = /p/, /t/, /k/, /m/, /n/, /ŋ/, /j/, /w/

N.B. Every element in parentheses is optional

Thai phonology characterises syllables into live and dead syllables. The former ends with an open long vowel, nasal stop, or glide, while the latter ends in an open short vowel or a stop. Rising tones and mid tones are only attested in live syllables. In comparison, for dead syllables, only low, high, and falling tones are allowed (Slayden, 2009). Former studies mentioned in the previous sections have mostly focused on Thai live syllables. In comparison, the current study concentrates on the perception of the dead counterparts, with only high, low, and falling tones.

Mandarin. A maximal Mandarin syllable structure is given as follows (Třísková, 2011):

$$(C)(G)V^{T}(X)$$

C = consonant

G = glide

V = main vowel

X = ending (a vowel or a nasal consonant)

N.B. Every element in parentheses is optional

In Mandarin phonology, there are several constraints on syllables and tones (Dong, 2024). Firstly, syllables that have unaspirated voiceless plosives and affricates as initials do not take Tone 2 with nasal codas. Secondly, syllables containing voiced initials usually cannot take Tone 1 except for some onomatopoetic characters such as [mi˥] and some colloquial terms [ma˥]. Thirdly, syllables that start with [s] can only take Tone 2 when the finals are "closemouth" vowels such as [u] rather than "open mouth". For instance, [suu] and [suiu] are acceptable, but [sau] and [saiu] are not. Finally, since coda consonants do not allow plosives such as [t], [p] or [t^{h}], dead syllables ending with a stop in Thai are unfamiliar structures to Mandarin speakers.

English. English, as a non-tonal language, has more complex syllable structures than Thai and Mandarin. The main element in English is a vowel, which may be preceded and/or followed by a consonant or a cluster of consonants. A brief illustration is shown below (Aslam & Kak, 2007, pp. 60–68):

(C)(C)(C)V(V)(C)(C)(C)(C)

C = consonant

V = vowel

N.B. Every element in parentheses is optional

In English, if a consonant or a consonant cluster is in the coda position, the syllable is called a closed/dead syllable; if no consonants are in the coda position, the syllable is then called an open/live syllable. Since dead syllables in both Thai and English can take plosives such as /p/, /t/, /k/ at coda position, this kind of structure may be beneficial for English native speakers to perceive Thai tones.

1.4. Research question and predictions

Previous studies on tone perception have primarily focused on Thai live syllables such as ending with approximants or long vowels (i.e., Burnham et al., 1992; Burnham et al., 2014; Wayland & Guion, 2004). Given the potential impact of syllable structure on tonal perception (House, 2002), the current study aims to fill in the gap by investigating whether differences in syllable structures affect the perceptual accuracy of speakers of tonal and non-tonal languages who have never been exposed to Thai. This will be done by answering the general research question: *How does perceptual accuracy differ between native speakers of tonal languages and non-tonal languages?* Specifically, the stimuli in Thai will comprise CVC dead syllables with voiceless plosives in the coda position (/p/, /t/, /k/) and a vowel bearing low, high, and falling tones as these tones are the only ones allowed in dead syllables. As one of the first studies examining this linguistic phenomenon, the hypothesis for the main question is that speakers of tonal languages will exhibit higher accuracy than non-tonal speakers, consistent with previous findings.

2. Methodology

2.1. Participants

Thirty-one listeners participated in the experiment, and all of them provided informed consent. However, six of them were deemed invalid due to reasons such as incomplete surveys or inappropriate language backgrounds. Thus, their responses were eliminated from Qualtrics before exporting the data, resulting in twenty-five valid responses for further analysis.

Mandarin. Thirteen native Mandarin speakers (one male, twelve females) were recruited via snowball sampling. Their average age was 21 years (range: 20 - 22), and all came from the People's Republic of China. None of them has reported any prior experience with the Thai language.

English. Twelve native English speakers (two males, ten females) were also recruited through snowball sampling. Their average age was 21 years (range: 20 - 22). Except from one participant who did not specify their English variant, five were British English monolinguals,

two were American English monolinguals. One participant reported that they spoke both British and Australian English. Three participants were American English bilinguals, but none of them have tonal language background (French, Slovene, Hindi). Similar to the Mandarin group, none of them has reported any prior exposure to the Thai language or other tonal languages, ensuring that participants had never been exposed to tonal contrast in a linguistic context.

2.2. Design

The experimental design for each language group encompassed a combination of factors: 1 ISI condition (1500-ms ISI) * 1 vowel (/a/) * 1 onset consonant (/k/) * 3 coda consonants (k, t, p) * 3 tones * 3 tonal combinations. This design was applied in an AX (same-different) task. The 1500ms condition was used since no significant ISI effect was found in the discrimination and identification tasks performed by English and Mandarin speakers based on findings from Wayland & Guion's study (2004). Furthermore, this ISI condition was also chosen to avoid the potential ISI effect in 500-ms condition and ceiling effect due to the "phonetic mode" of processing mentioned in the previous section. The two factors with varying levels were coda consonants and the type of tonal combinations. In the stimulus language, Thai, three tones are allowed in CVC dead syllables. The possible tonal combinations were High-Low (HL), LowLow (LL), High-High (HH), Low-Falling (LF), Falling-Falling (FF), Falling-Low (FL), LowHigh (LH), Falling-High (FH), High-Falling (HF). The second factor is the coda consonant. Each coda consonant was only paired with the same consonant but different tones in each tonal combination.

2.3. Stimuli materials

The stimuli consisted of three Thai syllables (/kat/, /kak/, /kap/), each carrying one of the three tones. Plosive codas in Thai syllables are unreleased. The resultant syllables were presented either as words (n = 3) or nonwords (n = 6). In Burnham et al.'s (2014) study, the researchers used both real words and nonwords in a similar perception experiment as they wanted to include a variety of syllable combinations. They indicated that although words and nonwords might play a role in speech processing, a mix of words and nonwords would not affect the overall crosslanguage differences compared to using solely real words. Given that the primary focus of the current study is on the perceptual variance among participants with no prior experience with the Thai language, the inclusion of both words and nonwords is unlikely to affect the test results.

The 27 syllables were recorded by an accomplice, a 22-year-old Thai native female speaker from Bangkok, Thailand. The speaker was required to read aloud the form syllables

displayed on a screen. Following recording, the exemplars were combined in minimal pairs with a 1500-ms ISI using a Praat script (Boersma & Weenink, 2024). The original Praat script and the explanation are shown in Appendix A. Subsequently, all trials were inserted into a Qualtrics questionnaire in a randomised order for further data collection (Qualtrics, 2023). A short layout of the questionnaire is demonstrated in Appendix B. All audio stimuli were saved on the website of Archive of the Institute of Phonetics Sciences (IFA), Amsterdam for potential future use by other further researchers.

2.4. Procedure

Participants were asked to complete the test individually in a sound-attenuated room or a room with minimal noise interference on their individual devices (preferably laptops). They were also instructed to perform the task with their headphones or earphones on. All of them were accompanied by the author either physically or remotely in a Zoom meeting. Before the experiment, participants who are unfamiliar with tonal languages watched a tutorial video from YouTube created by Vulgar Lang (2021). They were told to expect two sounds within an audio during the task. Each participant received a total of 27 test trials in a randomised order distributed into three blocks (9 trials within one block). During the discrimination task, subjects were instructed to listen to the speaker pronounce syllables and to determine whether the two tones were the same or different by pressing the appropriate key as quickly and accurately as possible. Two types of trials were presented: change-trials and no-change trials. In change trials, two consecutive stimuli with the same coda consonant had different tones (e.g., /kâk/ - /kàk/). In no-change trials, two stimuli had the same final consonant and the same tones (e.g., /kâk - /kâk/). The question shown with each trial was “Please indicate whether the tones of the two words are the same or different.” Participants needed to choose the left option if they perceived the two syllables within a trial to be the same, and the right option if different. After the task, participants did not receive any reimbursement, but they were informed of their right to receive test results.

Additionally, it is worth noting that before actually performing the task in the Qualtrics survey, subjects were required to provide some personal information, including their native language(s), gender, age and whether they have studied Thai before. Those who selected “yes” on the question about prior exposure to Thai were automatically prevented from finishing the survey.

2.5. Analysis

To evaluate the participants' ability to discriminate the presented tone stimuli, each response for every token was scored either 1 or 0. For each question, a correct response was assigned a score of 1, while an incorrect response received a score of 0.

Given that the dependent variable, correctness, is binary, a logistic regression model was employed for further statistical analysis using lme4 package in R Studio (RStudio Team, 2023). This model was used to obtain key values such as confidence intervals, intercept, and p-value, etc. Furthermore, descriptive statistics, including standard deviation, median and mean values for each language group were calculated.

The anonymised data collected from the experiment were stored in a CSV file on the author's individual laptop and subsequently uploaded to UvA OneDrive for backup. All statistical analysis methods mentioned above were performed using R Studio (RStudio Team, 2023). Additionally, to ensure transparency and reproducibility, all data for statistical analysis were saved on the website of Archive of the Institute of Phonetics Sciences (IFA), Amsterdam.

3. Results

The raw data gathered from the Qualtrics questionnaire were initially converted into a CSV file for further analysis. A TSV version can be found on the Archive of the Institute of Phonetics Sciences website. Subsequently, the accuracy of responses to each question was manually recorded using Microsoft Excel, and the processed data is provided in Appendix C. The following subsections consist of both quantitative and qualitative analyses of this data.

3.1. Quantitative results

To examine group-level outcomes, a logistic regression model was applied to the individual tokens (each question per participant), and confidence intervals were computed. Two main effects are observed from the model's output.

3.1.1. Overall performance

Firstly, according to the estimated coefficient of the intercept, the average value for participants from both language groups was 3.2643. This log-odds value represents the baseline performance for participants across both language groups. After converting this log-odds into a probability, we found that participants have an approximate chance of 96.32% to answer all the questions correctly. Moreover, this high probability is statistically significant, with a p-value of <2e-16, which is extremely lower than the threshold of 0.05. This indicates that the probability is higher

than the chance level of 50% of accuracy. Statistical significance is furthered supported by the confidence interval for the intercept as well. The coefficients for the 2.5% and 97.5% percentiles are approximately [2.682, 4.092]. The general effect that both language groups could perform the task at around 96.32% of percentage rate is significant since the upper and lower bounds do not cross zero. Moreover, by calculating the probabilities of the log-odds values of the confidence interval, the average score of both groups ranges from 93.64% to 98.37%. Therefore, it can be inferred that the average rate of the generalised population of the two language groups could demonstrate a high level of accuracy in their responses, as the minimum value, 93.64%, is larger than 50%.

3.1.2. Language effect

Secondly, the model examined the impact of language on perceptual accuracy. According to the estimated coefficient of the language effect, Mandarin native speakers achieved a log-odds value that was 0.6560 higher than their English-speaking counterparts. For English native speakers, the log-odds point estimate was 2.9363. After further computation, it is known that English-speaking participants would have a probability of 94.96% for correctly answering the questions. In comparison, according to the estimated coefficient of the language effect, Mandarin native speakers achieved a log-odds value around 3.5923, resulting in a percentage rate of approximately 97.32%. The comparison of the perceptual accuracy between the two groups is shown in Figure 3. Although Mandarin speakers exhibited a higher perceptual accuracy than English speakers, the effect is not significant. Regarding the confidence interval, the coefficients for the 2.5% and 97.5% percentiles are around [-0.522, 1.97]. Since the upper and lower bounds includes zero, this effect is statistically insignificant. Furthermore, the p-value for the language effect was 0.269, which exceeds the threshold of 0.05, supporting the conclusion that the effect of language on perceptual accuracy is insignificant. Therefore, while Mandarin speakers exhibited slightly higher perceptual accuracy than English speakers, this difference is not strong enough to be considered statistically significant, as shown in the p-value and confidence intervals.

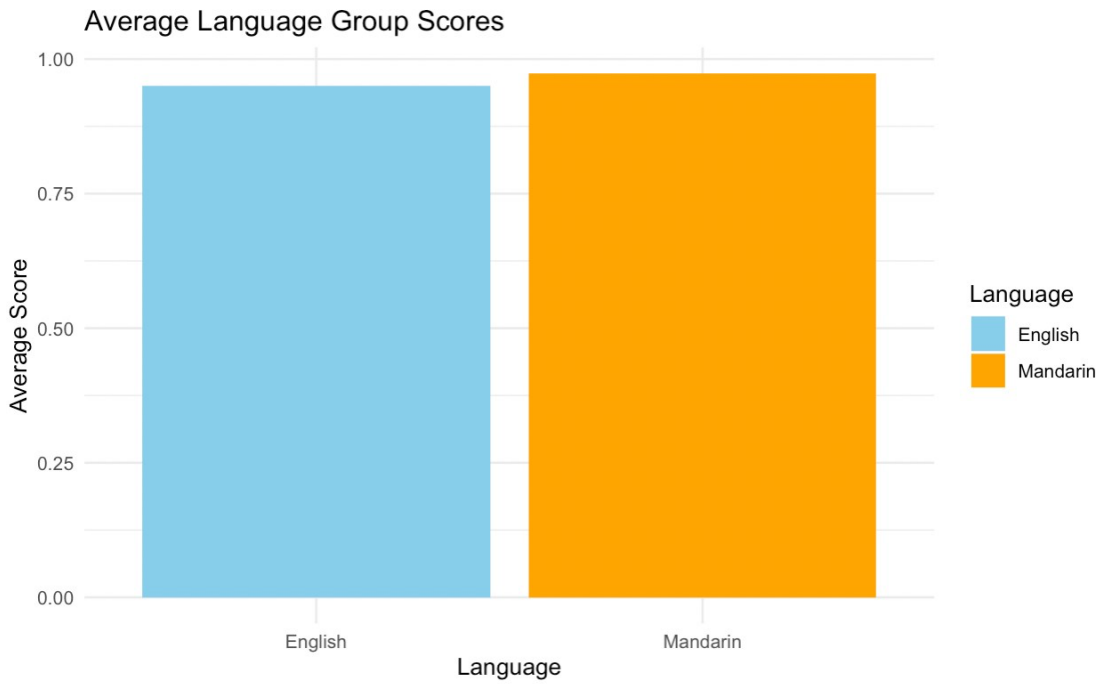

Figure 3. Average Successful Rate for Each Language Group (Native English Listeners vs Mandarin Listeners)

Additionally, the confidence interval for the language effect can be translated to a probability range. The lower bound of the interval, -0.522, corresponds to a probability of 0.593, while the upper bound, 1.97, can be converted to 7.172. This indicates that this group of Mandarin participants would perform between approximately 0.6 times worse and 7 times better than their English counterparts.

3.1.3. Hypothesis Testing

The null hypothesis of average performance across two groups is that the average perceptual accuracy rate is 50%. Since the probability rate is 96.32%, and the confidence interval does not cross zero, along with a p-value smaller than 0.05, the null hypothesis can be rejected. In other words, both groups were able to perform the task very well.

The main null hypothesis of this study regarding the language effect is that there is no difference in perceptual accuracy/correctness rate between native speakers of Mandarin and English when they are first exposed to Thai tones. Given the p-value of 0.269 for the language effect, the null hypothesis cannot be rejected. This implies that the tonality of the native language may not necessarily play a role in the perceptual accuracy of Thai tones in this study.

3.2. Qualitative analysis

Although the language effect is statistically insignificant, some patterns can still be observed according to the correct/incorrect tokens of each participant. This section provides descriptive statistics and identifies estimated error types encountered by participants.

3.2.1. Exploratory observation

Figure 4 and Figure 5 illustrate the number of questions each participant answered correctly or incorrectly. According to the bar plots, 4 out of 12 (33.33%) English-speaking listeners and 6 out of 13 (46.15%) Mandarin-speaking listeners answered all the questions correctly. The range of incorrect answers for the English-speaking group spans from 1 to 5, while that for the Mandarinspeaking group extends from 1 to 9. In general, English-speaking participants (mean = 2.875, median = 2.5, sd ≈ 2.717) who made mistakes tended to commit more errors than their Mandarin-speaking counterparts (mean ≈ 2.714, median = 1, sd ≈ 1.327). Furthermore, standard deviations provide insights into the performance patterns of each language group. Those who had incorrect responses in the English group exhibited a wider range of incorrect answers than those in the Mandarin group, which indicates a less consistent performance within the group.

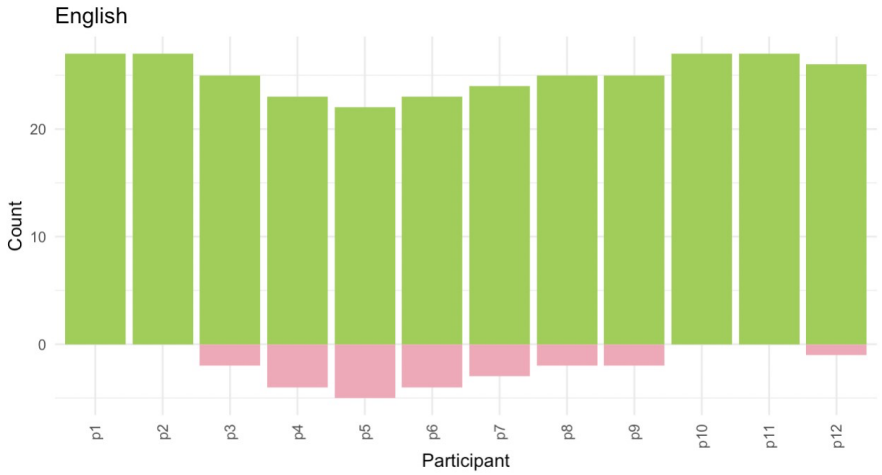

Figure 4. Correct and incorrect answers of each participant from English group

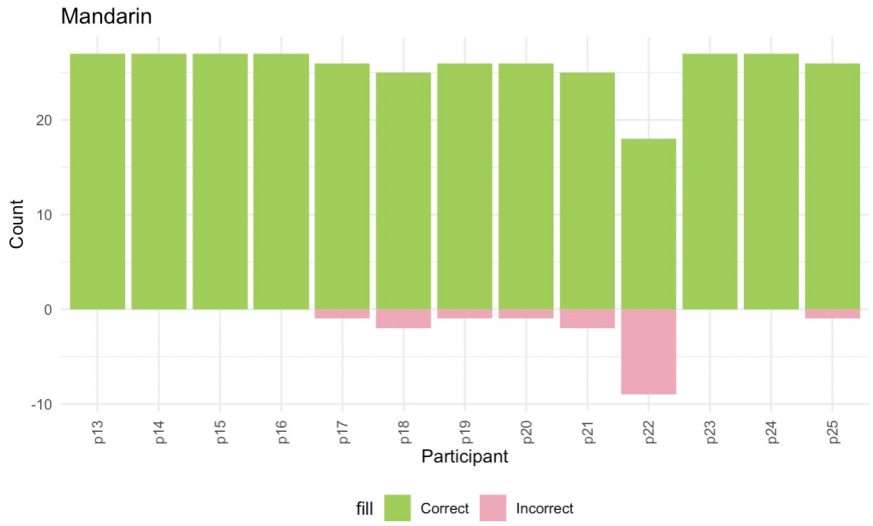

Figure 5. Correct and incorrect answers of each participant from Mandarin group

3.2.2. Individual error analysis

Among the eight English-speaking participants who answered some questions incorrectly, six of them erred in tonal pairs low-high and/or high-low. This contradicts Burnham et al.'s findings, where both Australian English and Thai native speakers exhibited higher perceptual accuracy for static contrasts (i.e., low-high, high-low) than static vs. dynamic contrasts (e.g., high-falling, low-falling) (1992). This should be further investigated in future studies. Additionally, the frequency effect might play a role in listeners' judgements, as shown in p6's responses. This participant had five incorrect responses, and she perceived four "same" tonal pairs (HH, LL, FF) as "different". She self-reported that after listening to many "different" pairs, she started to hesitate if a "same" one was "different". This might be due to the disproportionate exposure to "different" pairs in the experimental design, where the number of "different" responses (18 questions) is higher than that of "same" responses (9 questions).

Mandarin monolinguals exhibited similar error patterns to English participants, with four out of six participants incorrectly responding to some HL and/or LH tonal pairs. Notably, two other participants both perceived some FL or LF trials as "same". According to their report after the experiment, questions containing "low sounds" are more difficult to answer. This suggests that the potential transfer of the two individuals' Mandarin tonal system, as mentioned in previous studies (e.g., Wayland & Guion, 2004), was not necessarily shown when listening to these stimuli. The values of these two tones in Thai and Mandarin are comparable. The low (i.e., Tone 3) tone and the falling tone (i.e., Tone 4) in Mandarin have values of [214] and [51]

respectively, while those in Thai have values of [21] and [41] (Chao, 1948; Thepboriruk, 2009). Among all participants, one listener (p22) obtained the lowest score, who answered one-third of the questions incorrectly. After ensuring that they fully comprehended the task requirements and definitions of tones, it is hypothesised that her incorrect responses may be due to the frequency effect as p6, as she perceived six of nine "same" responses as "different". Additionally, this phenomenon might be attributed to her self-reported tone-deafness, which could potentially interfere with her ability to process tones to a certain extent (Tillmann et al., 2011).

4. Discussion

4.1. Interpretation of results

In general, the overall performance of both language groups has shown statistical significance, which indicates that both English and Mandarin native speakers achieved high score of perceptual accuracy in this task. However, the statistical insignificance of the language effect suggests that the tonality of native language(s) does not significantly influence the perceptual accuracy of tones. Although the effect is statistically insignificant, the range of probabilities indicates that the potential language effect might be by chance, as Mandarin-speaking participants would perform between 0.6 times worse and 7 times better than their English counterparts. Overall, the failure to reject the main null hypothesis can be interpreted in the following ways.

On the one hand, since perceptual accuracy does not show a significant difference in the two language groups in this study, it can be inferred that when there is an unfamiliar syllable structure in phonological perception, the advantage that native tonal speakers typically hold in perceiving unfamiliar tones within familiar syllable structures, as mentioned in former studies in the previous sections, is no longer observed. Although Mandarin speakers did not show a large decrease in perceptual accuracy, English speakers exhibited a notable increase compared to previous research findings (e.g., Burnham et al., 2014; Wayland & Guion, 2004), which results in comparable accuracy scores between the two groups. Given that the CVC syllable structure is more familiar to English speakers than CV structures, it is possible that their increase in perceptual accuracy in this task is due to the change in syllable structure. However, future studies should test various syllable structures within a single experiment. This approach would allow researchers to compare participants' performance across different conditions to determine if

language tonality actually affected perceptual accuracy across various types of syllable structures, which would enhance the robustness of the current prediction.

On the other hand, the statistical insignificance of the language effect might be due to the experimental design. Firstly, when recruiting the participants, the researcher did not account for extralinguistic factors, such as music training background. Tone is a property shared by both language and music, and experience in either domain is known to produce similar effects on perceiving melody or lexical tone (Bradley, 2013). In this case, controlling for the music background of participants might be necessary, especially since one outlier in the current Mandarin group reported herself as "tone deaf", which might also play a role in perceptual accuracy (Tillmann et al., 2011). Additionally, normalising the audio stimuli is crucial even if only one speaker recorded them. This normalisation controls for external factors that might influence the experiment results, such as volume inconsistency or background noise (Strand & Johnson, 1996).

4.2. Potential considerations for future research

As a pilot study that investigates the role of syllable structures in determining tonal perceptual accuracy among native speakers of tonal and non-tonal languages, the current finding provides an insight into how people from diverse language background may utilise syllable structures in their native language(s) to aid in the perception of tones in other languages. However, several considerations need to be addressed when considering the findings to previous studies in the relevant field.

Firstly, since Thai is a monosyllabic tonal language (Iwasaki & Horie, 2005), future studies could explore polysyllabic tonal languages in order to examine how syllable structures work in tonal perception. For example, Yoruba, a Niger-Congo language consisting of multiple syllables and three level tones could be used as the target language (Bamgbose, 2000). As Yoruba allows more than one tone in syllable structures, future studies might investigate the perceptual accuracy of specific tones across varying numbers of syllables within a single entity. For instance, participants could be asked to determine the first tone in a minimal pair, such as /òkúrùn/ ("hunchback") and /ókúrún/ ("difficulties").

Instead of using audio stimuli, future research could incorporate audiovisual and visual stimuli. A study that tested all the three conditions revealed that visual information could be beneficial for perceiving tones by listeners across language groups, especially when the stimuli contain noise (Burnham et al., 2014). Furthermore, they found that non-tonal language speakers

(e.g., English speakers) demonstrated an advantage in perceiving mid tones in Thai, which led them to predict that these speakers may rely on visual information more often than other groups of speakers. Conversely, they also discovered that tonal language speakers (in this study, Mandarin and Cantonese speakers) performed achieved higher accuracy rate in audio-only condition and audiovisual condition than visual-only condition. In this case, including other types of conditions may help determine if using audio-only stimuli in the current study influenced the results for different types of listeners.

Apart from stimulus design, other discrimination tasks can be employed to assess listeners' discrimination and identification abilities. For example, a categorical oddity discrimination task (ABX discrimination task) has been implemented in similar studies involving auditory training (Wayland & Guion, 2004). Researchers asked speakers of English or Chinese not only to judge the Thai mid and low tones, but also to choose the odd one (the token different from the others in a three-token trial) after training. English native speakers showed a larger increase in discrimination and identification scores than Chinese speakers after training. This type of task was not used in the current study since auditory training was not introduced, which means participants were only tested with their discrimination ability, but not the identification one. Investigating whether different syllable structures impact tonal perception with auditory training could be valuable for future research.

It may also be beneficial for future studies to include speakers of pitch-accent languages. Burnham et al. (2014) recruited Swedish native speakers to examine if their performance differed from other groups of speakers. Although their perceptual accuracy was comparable to that of tonal native speakers, the effect of syllable structures other than CV syllables remains unclear. Pitch-accent languages often have more varied syllable structures than the tonal languages previous researchers have considered in their studies, particularly as tones are related to syllables in such languages. For instance, according to Swedish phonotactics, the syllable structure of Swedish is (C)(C)(C)V(C)(C)(C) (Sigurd, 1965). Furthermore, more than one syllable is allowed in a word, resulting in complex combinations such as /vê stˌkəstskt/ ('west coast'). Therefore, taking pitch-accent language speakers into account when studying the relationship between perceptual accuracy and syllable structures is recommended.

Last but not least, further studies could consider the duration of the vowels. Previous research has shown a cross-linguistic fact that dynamic tones typically have longer syllable durations than static tones, which plays a role in tonal perception (Yu, 2010). The researcher

claimed that they achieved perceived duration equality by adjusting acoustic duration of the syllables. While the current study has used both dynamic (falling tone) and static tones (low and high tones) as the testing stimuli, the effect of tones on vowel durations was not considered. Since this could possibly affect the results, addressing this phenomenon in future studies is essential for ensuring the equality of perceived durations when designing stimuli. Additionally, exploring various syllable structures related to vowel duration, such as diphthongs, could provide further insights.

5. Conclusion

The aim of this research was to determine the difference in perceptual accuracy between native speakers of tonal and non-tonal languages, especially by using a different set of syllables (CVC syllables in Thai) from those used in previous studies (e.g., Burnham et al., 1992; Burnham et al., 2014; Wayland & Guion, 2004). It was first hypothesised that tonal language speakers (in this case, Mandarin speakers) would outperform non-tonal language speakers (i.e., English speakers), as previous researchers concluded. In other words, the former group would have higher perceptual accuracy in tones than the latter, regardless of the syllable structures they encounter. However, in the current study, although Mandarin native speakers had slightly higher accuracy than English speakers, the language effect was not statistically significant. Since the null hypothesis cannot be rejected, whether there is an effect of L1 tonality on determining the perceptual accuracy of Thai tones in CVC syllables is inconclusive. One interpretation of this different pattern could be that listening to familiar syllable structures is predicted to enhance the perception of tones in a tonal language that listeners have never encountered before. However, introducing various syllable structures in further research, rather than solely CV syllables, is recommended to determine if this different pattern from previous studies is due to using other syllable structures or by chance (e.g., Burnham et al., 1992; Burnham et al., 2014; Wayland & Guion, 2004).

This prediction may aid second language acquisition. For instance, if non-tonal language speakers would learn a tonal language, using syllables structures that are familiar to them might help them identify the tones when they learn to distinguish the tones for the first time. In a previous study, tonal and syllabic information was proven to be interfered with each other for English monolinguals when they learned a new tonal language (Wang & Saffran, 2014).

Therefore, familiar syllable structures can help to reduce the cognitive load, making it easier to focus on tonal information.

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7. Appendix A

```
Create Strings as file list: "fileList", "./*wav"
procedure CreateSilence
   silence = Create Sound from formula: "Silence", 1, 0, 1.5, 48000, "0"
endproc
for i from 1 to 3
   for j from i*3-2 to i*3
      for k from i*3-2 to i*3
         selectObject: "Strings fileList"
         front$ = Get string: j
         rear$ = Get string: k
         front = Read from file: front$
         @CreateSilence
         rear = Read from file: rear$
         selectObject: front
         plusObject: silence
         plusObject: rear
         Concatenate
         Save as WAV file: "./stimuli"+"/"+front$ - ".wav" + " " + rear$
      endfor
   endfor
endfor
```

Explanation of the code: it is necessary to order the audio files in a fixed sequence. The three files with the same coda should be grouped together. For instance, if the first file is p-H, the second and third files should be p-L, p-F. It is also recommended to sort the files alphabetically, which will automatically result in grouping the files with the same coda. The sorting can be done in Praat by using the “Sort” command after creating a file list.

8. Appendix B

Information brochure for Non-Native Speakers Perceiving Thai Words

Dear participant,

You will be taking part in the Non-Native Speakers Perceiving Thai Words research project conducted by Yimeng Zhang under supervision of Paul Boersma at the University of Amsterdam of the Faculty of Humanities. Before the research project can begin, it is important that you read about the procedure. Make sure to read this brochure carefully.

Purpose of the research project

There is lots of research on how people listen to a language that they are not familiar with. In this experiment, we will try to figure out how you listen to sounds of the Thai language. This research is important because it offers insight into understanding how people learn a new language. This is helpful for making appropriate teaching materials for language learners with different language backgrounds.

Who can take part in this research?

For this research, we are inviting people who don't know Thai. In view of the nature of the research, it is important that you have good hearing and eyesight (wearing glasses or contact lenses is fine). We will ask you a number of questions about your language background. You can take part in this research project if English or Mandarin is your mother tongue.

Instructions and procedure

During the experiment, you will be performing a task online. You will be accompanied by the researcher either physically or remotely. You will then hear a number of sounds over your headphones, at a volume of approximately 70 dB. You will then be requested to choose which sound you think you hear. You will hear 27 sounds in total. This entire testing procedure will take approximately 15-20 minutes.

Voluntary participation
You will be participating in this research project on a voluntary basis. This means you are free to stop taking part at any stage. This will not have any consequences, and you will not be obliged to finish the procedures described above. You can always decide to withdraw your consent, until your data has been anonymised. If you decide to stop or withdraw your consent, all the information gathered up until then will be permanently deleted. However, once information has been anonymised, it can no longer be deleted because it is no longer possible to trace back the information to individual participants.

Discomfort, Risks & Insurance
The risks of participating in this research are no greater than in everyday situations at home. Previous experience in similar research has shown that no or hardly any discomfort is to be expected for participants. For all research at the University of Amsterdam, a standard liability insurance applies.

Confidential treatment of your personal details
The information gathered over the course of this research will be used for the purpose of this research project. Your personal identifying details (name, contact details, IP address) will be erased immediately after you finish your experiment. The anonymous data gathered during the research (age, gender, language background, and your clicks on the buttons "same" and "different") will be stored for at least 10 years, and probably be made public. We guarantee that you will remain unidentifiable in all publications.

Data subject rights according to the GDPR
Participants can request more information from the researcher at any time about their rights as data subjects under the EU privacy law, the GDPR.

Reimbursement
You will not receive any reimbursement for taking part in the research project. However, if you wish, we can send you a summary of the general research results at a later stage.

Further information
For further information on the research project, please contact Yimeng Zhang or Paul Boersma (phone number: +31 68 – 4322415; email: yimeng.zhang@uva.nl, p.p.g.boersma@uva.nl; Spuistraat 134, 1012VB Amsterdam, The Netherlands).
If you have any complaints regarding this research project, you can contact the secretary of the Ethics Committee of the Faculty of Humanities of the University of Amsterdam, commissie-ethiek-fgw@uva.nl; Binnengasthuisstraat 9, 1012 ZA Amsterdam, The Netherlands.

◯ I have read the information provided to me

UNIVERSITEIT VAN AMSTERDAM

Informed consent form

'I hereby declare that I have been clearly informed about the research project Non-Native Speakers Perceiving Thai Words at the University of Amsterdam, Faculty of Humanities, conducted by Yimeng Zhang under supervision of Paul Boersma as described in the information brochure. My questions have been answered to my satisfaction.

I realise that participation in this research is on an entirely voluntary basis. I retain the right to revoke this consent without having to provide any reasons for my decision. I am aware that I am entitled to discontinue the research at any time, and that I can always withdraw my consent after the research has ended, until my data has been anonymised. If I decide to stop or withdraw my consent, all the information gathered up until then will be permanently deleted.

If my research results are used in scientific publications or made public in any other way, they will be fully anonymised. My personal information may not be viewed by third parties.

If I need any further information on the research, now or in the future, I can contact Yimeng Zhang or Paul Boersma (phone number: +31 68 – 4322415; e-mail: yimeng.zhang@uva.nl, p.p.g.boersma@uva.nl; Spuistraat 134, 1012 VB Amsterdam, The Netherlands.

If I have any complaints regarding this research, I can contact the secretary of the Ethics Committee of the Faculty of Humanities of the University of Amsterdam; email: commissieethiek-fgw@uva.nl; Binnengasthuisstraat 9, 1012 ZA Amsterdam, The Netherlands.

◯ Yes, I consent to participate in this research, and my anonymous data (language background, age and gender) to be stored for a period of at least 10 years and to be made public.

◯ No, I withhold my consent

How old are you?

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Non-binary / third gender
- ◯ Prefer not to say

What is your native language(s)?

- ☐ Mandarin
- ☐ English (Please specify which English variant you speak below, e.g., British English, American English, etc.)
- ☐ Other

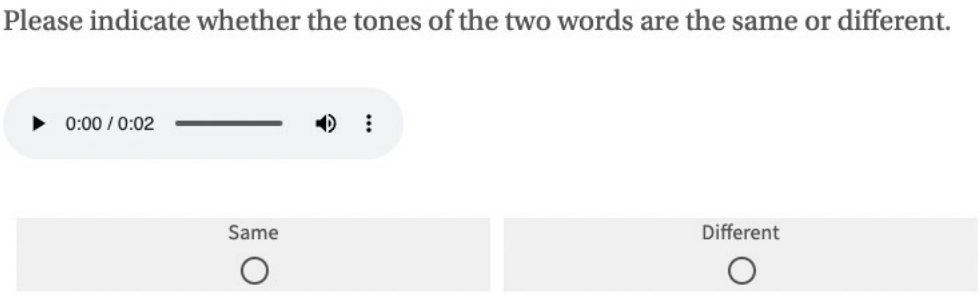
Have you ever studied Thai before?

- ◯ No
- ◯ Yes

In the upcoming sections, you'll listen to a total of 27 audio clips. One clip consists of two sounds that only differ in tones, and there is a long silence between the two sounds. Your task is to determine whether the tones of the two sounds in each audio clip are the same or different.

Feel free to take a short break of 1-2 minutes after listening to 9 audio clips / finishing 1 page. Good luck!

→



We thank you for your time spent taking this survey.

Your response has been recorded.

N.B. There are twenty-seven stimuli in the experiment, but this screenshot is a demonstration of three of them. All the stimuli look the same.

9. Appendix C

participant	language group	tone contrast type	coda consonant	response	correct
p1	English	FF	k	Same	1
p1	English	FH	k	Different	1
p1	English	FL	k	Different	1
p1	English	HF	k	Different	1
p1	English	HH	k	Same	1
p1	English	HL	k	Different	1
p1	English	LF	k	Different	1
p1	English	LH	k	Different	1
p1	English	LL	k	Same	1
p1	English	FF	p	Same	1
p1	English	FH	p	Different	1
p1	English	FL	p	Different	1
p1	English	HF	p	Different	1
p1	English	HH	p	Same	1
p1	English	HL	p	Different	1
p1	English	LF	p	Different	1
p1	English	LH	p	Different	1
p1	English	LL	p	Same	1
p1	English	FF	t	Same	1
p1	English	FH	t	Different	1
p1	English	FL	t	Different	1
p1	English	HF	t	Different	1
p1	English	HH	t	Same	1
p1	English	HL	t	Different	1
p1	English	LF	t	Different	1
p1	English	LH	t	Different	1
p1	English	LL	t	Same	1
p2	English	FF	k	Same	1
p2	English	FH	k	Different	1
p2	English	FL	k	Different	1
p2	English	HF	k	Different	1
p2	English	HH	k	Same	1
p2	English	HL	k	Different	1
p2	English	LF	k	Different	1
p2	English	LH	k	Different	1
p2	English	LL	k	Same	1
p2	English	FF	p	Same	1

p2	English	FH	p	Different	1
p2	English	FL	p	Different	1
p2	English	HF	p	Different	1
p2	English	HH	p	Same	1
p2	English	HL	p	Different	1
p2	English	LF	p	Different	1
p2	English	LH	p	Different	1
p2	English	LL	p	Same	1
p2	English	FF	t	Same	1
p2	English	FH	t	Different	1
p2	English	FL	t	Different	1
p2	English	HF	t	Different	1
p2	English	HH	t	Same	1
p2	English	HL	t	Different	1
p2	English	LF	t	Different	1
p2	English	LH	t	Different	1
p2	English	LL	t	Same	1
p3	English	FF	k	Same	1
p3	English	FH	k	Different	1
p3	English	FL	k	Different	1
p3	English	HF	k	Different	1
p3	English	HH	k	Same	1
p3	English	HL	k	Same	0
p3	English	LF	k	Different	1
p3	English	LH	k	Different	1
p3	English	LL	k	Same	1
p3	English	FF	p	Same	1
p3	English	FH	p	Different	1
p3	English	FL	p	Different	1
p3	English	HF	p	Different	1
p3	English	HH	p	Same	1
p3	English	HL	p	Different	1
p3	English	LF	p	Different	1
p3	English	LH	p	Different	1
p3	English	LL	p	Same	1
p3	English	FF	t	Same	1
p3	English	FH	t	Different	1
p3	English	FL	t	Different	1
p3	English	HF	t	Different	1
p3	English	HH	t	Same	1
p3	English	HL	t	Different	1
p3	English	LF	t	Different	1

p3	English	LH	t	Same	0
p3	English	LL	t	Same	1
p4	English	FF	k	Same	1
p4	English	FH	k	Different	1
p4	English	FL	k	Different	1
p4	English	HF	k	Same	0
p4	English	HH	k	Same	1
p4	English	HL	k	Same	0
p4	English	LF	k	Different	1
p4	English	LH	k	Same	0
p4	English	LL	k	Same	1
p4	English	FF	p	Same	1
p4	English	FH	p	Different	1
p4	English	FL	p	Different	1
p4	English	HF	p	Different	1
p4	English	HH	p	Same	1
p4	English	HL	p	Different	1
p4	English	LF	p	Same	0
p4	English	LH	p	Different	1
p4	English	LL	p	Same	1
p4	English	FF	t	Same	1
p4	English	FH	t	Different	1
p4	English	FL	t	Different	1
p4	English	HF	t	Different	1
p4	English	HH	t	Same	1
p4	English	HL	t	Different	1
p4	English	LF	t	Different	1
p4	English	LH	t	Different	1
p4	English	LL	t	Same	1
p5	English	FF	k	Same	1
p5	English	FH	k	Different	1
p5	English	FL	k	Different	1
p5	English	HF	k	Different	1
p5	English	HH	k	Different	0
p5	English	HL	k	Different	1
p5	English	LF	k	Different	1
p5	English	LH	k	Different	1
p5	English	LL	k	Different	0
p5	English	FF	p	Different	0
p5	English	FH	p	Different	1
p5	English	FL	p	Different	1
p5	English	HF	p	Different	1

p5	English	HH	p	Same	1
p5	English	HL	p	Different	1
p5	English	LF	p	Different	1
p5	English	LH	p	Different	1
p5	English	LL	p	Same	1
p5	English	FF	t	Same	1
p5	English	FH	t	Same	0
p5	English	FL	t	Different	1
p5	English	HF	t	Different	1
p5	English	HH	t	Same	1
p5	English	HL	t	Different	1
p5	English	LF	t	Different	1
p5	English	LH	t	Different	1
p5	English	LL	t	Different	0
p6	English	FF	k	Different	0
p6	English	FH	k	Different	1
p6	English	FL	k	Different	1
p6	English	HF	k	Different	1
p6	English	HH	k	Same	1
p6	English	HL	k	Different	1
p6	English	LF	k	Different	1
p6	English	LH	k	Different	1
p6	English	LL	k	Same	1
p6	English	FF	p	Same	1
p6	English	FH	p	Different	1
p6	English	FL	p	Different	1
p6	English	HF	p	Different	1
p6	English	HH	p	Different	0
p6	English	HL	p	Different	1
p6	English	LF	p	Different	1
p6	English	LH	p	Different	1
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p7	English	FF	k	Same	1

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p7	English	HH	k	Same	1
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p20	Mandarin	LH	t	Different	1
p20	Mandarin	LL	t	Same	1
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p22	Mandarin	LF	k	Different	1
p22	Mandarin	LH	k	Different	1
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