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An ERP study of Chinese speakers' rhyme judgments to Chinese and English words

Yuchun Chen^{a,c}, Jun Ren Lee^{b,c}, Wen-Jui Kuo^{c,d}, Daisy L. Hung^{c,e}, and Shih-kuen Cheng^{c,e}

^aDepartment of Special Education, National Taiwan Normal University, Taiwan

^bDepartment of Educational Psychology and Counseling, National Taiwan Normal University, Taiwan

^cLaboratories for Cognitive Neuroscience, National Yang-Ming University, Taiwan

^dInstitute of Neuroscience, National Yang-Ming University, Taiwan

^eInstitute of Cognitive Neuroscience, National Central University, Taiwan

Abstract

ERP studies of rhyme judgments in alphabetic languages show that non-rhyming word pairs elicit a larger negative-going wave peaking 450 ms post stimulus onset than rhyming word pairs. We use Chinese characters to explore the extent to which this N450 rhyming effect reflects phonological processing. Using Chinese provides an advantage over alphabetic scripts because rhyming characters can have non-overlapping orthographic forms, something not possible in alphabetic scripts. We recorded ERPs while Chinese speakers made rhyme judgments to Chinese and English words. An N450 effect was observed in both languages. Moreover, the N450 effects exhibited in the two languages were correlated. The results support the phonological account of the N450 effect and indicate that similar phonological operations are involved in different languages.

Keywords

ERPs; N450; Chinese; phonological processing; rhyme judgment

Introduction

Phonological processing is crucial for both speech and reading. The understanding of its mechanism in different languages helps to reveal both linguistic universality and specificity. In this study we used Chinese characters, a logographic writing system, to verify the functional significance of an event-related potential (ERP) effect that has been linked to phonological processing in English and other alphabetic languages. We also investigated whether this putative ERP correlate of phonological processing is exhibited when Chinese speakers, who learn English as a foreign language (EFL learners), process English words. To address these issues, we examined the ERP rhyming effects exhibited by Chinese native

Correspondence to: Shih-kuen **Cheng**, Address: Institute of Cognitive Neuroscience, National Central University, No.300, Zhongda Rd., Zhongli City, Taoyuan County 32001, Taiwan. Tel: +886 3 4227151 ext. 65208, Fax: +886 3 4263502, skcheng@cc.ncu.edu.tw.

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speakers while they made rhyme judgments to visually presented Chinese word pairs and English word pairs.

The ERP rhyming effect was initially demonstrated by Rugg [1], who had participants make rhyme judgments to pairs of English words that were visually and sequentially presented. Rugg reported that the ERPs elicited by the second words in non-rhyming pairs were more negative-going than those in rhyming pairs. This ERP difference, starting at and peaking around 300 and 450 ms post stimulus onset, with a maximum over the right hemisphere, was labeled as the N450 effect. Although the N450 effect was observed in the task of rhyme judgment, which presumably involves extensive phonological processing, a number of factors have cast doubt on whether the N450 wholly reflects phonological processing. First, the temporal and spatial overlaps between N450 and the N400 effect that is commonly associated with semantic processing [2] led to the suspicion that semantic processing is involved in rhyme judgments, hence the N450 effect. Second, the correspondence between spelling and pronunciation patterns in English, together with the finding that orthographically dissimilar pairs elicited a greater N450 effect than orthographically similar pairs [3], suggested that the N450 effect might reflect orthographic but not phonological processing.

The semantic processing account for the N450 effect was soon ruled out given that pseudowords, which contain little semantic information, also yielded the N450 effect [4]. Nevertheless, it was difficult to rule out that orthography is essential for eliciting the N450 effect. The difficulty comes from the fact that rhyming words in alphabetic languages tend to be orthographically similar (e.g., “sand” and “hand”) or composed of certain letter combinations (e.g., “ee” and “ea” for /i/). Some studies that observed the N450 effect have used pictures [5] or auditory words [6,7] as stimuli to reduce the involvement of orthographic processing in rhyme judgments. However, the modulation of orthography on phonology has been observed in auditory tasks [8]. It therefore remains unclear whether phonological processing alone might induce the N450 effect.

The spelling-sound correspondence in alphabetic languages leads to the confounding between orthography and phonology when accounting for the N450 effect. In contrast to alphabetic languages, Chinese characters are suitable for the dissociation between orthography and phonology. Two Chinese characters can rhyme with each other but have different orthographic structures (e.g., “梯” /ti/ and “低” /di/). The current study therefore investigated the phonological account for the N450 rhyming effect by recruiting Chinese native speakers to make rhyme judgments to Chinese words. Additionally, if the phonological processing is indeed reflected by the N450 effect, the effect induced in Chinese rhyme judgments should be similar to that induced in phonological processing of other languages at the same grain-size. We therefore also had our participants make rhyme judgments to English words, aiming to test whether the phonological sensitivities to native and foreign languages are correlated.

Materials and methods

Participants

Twenty-three Chinese native speakers in Taiwan participated in the study. All were college student who had started learning English as a foreign language at the age of 13. Written consent was obtained from all participants and they were each paid 500 New Taiwan Dollars for participation. Data from 5 participants were excluded from analysis due to low accuracy rates (<.80, 2 participants), system errors (2 participants), and insufficient valid ERP trials (<16) in critical conditions (1 participant).

Stimuli and design

A total of 192 Chinese and 192 English semantically unrelated prime-target pairs were used. For both languages, half of the prime-target pairs were rhymed. The prime and target items in the Chinese pairs were characters selected from a database of Ministry of Education, Taiwan [9]. The frequency and stroke number of these characters were matched for the rhyming and non-rhyming pairs (All p s > .05). In addition, the two characters in each of the Chinese pairs were of the same lexical tone and were orthographically dissimilar. For the English pairs, both the prime and target items were monosyllabic words. The familiarity, letter length, and phoneme number of these words were matched for the rhyming and non-rhyming pairs (All p s > .05). The familiarity ratings to the English words were rated by 92 students who did not participate in this experiment.

Procedure

Each trial started with a fixation cross shown at the center of the screen for 1000 ms. After the fixation, the prime was presented for 300 ms followed by a blank of 200 ms. The target then appeared and remained on the screen for 800 ms. The inter-trial interval was 2.4 s, and participants were instructed to blink if necessary during this interval. Participants were told to judge whether the target word was rhymed with the prime accurately and rapidly. Response hand was counterbalanced across participants. Reaction times were measured from the onset of target stimulus presentation. The whole experiment was divided into a Chinese block and an English block. The order of the two blocks was counterbalanced across participants. Within each block, the presentation of the rhyming and non-rhyming pairs was randomized for each participant. Prior to the testing session, there was in a practice session of 24 word pairs. There were short breaks after every 64 trials and a longer break between the two blocks.

ERP recording and analysis

EEG was recorded from 64 Ag/AgCl electrodes, 62 of which embedded in an elastic cap, and the other two electrodes were placed on the mastoids. All channels were referenced to an electrode located between Fz and FCz, and were re-referenced off-line to the represent recordings of the linked mastoids. Vertical and horizontal EOG were recorded bipolarly from electrodes placed above and below the left eye, and on the outer canthi of each eye respectively. Data were continuously recorded and sampled at 250 Hz. All channels were amplified with a bandpass filter of 0.05–70 Hz (3dB points). Linear regression was used to correct the contribution of blink artifact to the EEG [10]. ERPs were computed for epochs of 800 ms relative to the onset of the target stimuli, with a 100 ms pre-stimulus interval as baseline. Data were low-pass filtered by 30Hz (12dB/octave). Trials containing non-blink eye movements or with a baseline drift exceeding 70 μ V in any channel were rejected. Average ERPs from each channel were computed for each participant for rhyming and non-rhyming conditions. The mean trial numbers for Chinese rhyming and non-rhyming pairs were 82 and 85, respectively. For English pairs, the mean trial numbers were 82 and 84.

Results

Behavioral data

Mean RTs and accuracy rates of the Chinese and English rhyme judgments are shown in Table 1. The accuracy rates, which were greater than 89% across all conditions, indicated that participants were proficient at the task. Reaction times were calculated for correct responses only. Latencies exceeding more than 2 standard deviations from the mean for each subject were adjusted into the value from further analysis (4.5% in Chinese and 4.4% in English conditions). Participants responded faster to rhyming pairs than to non-rhyming

pairs, whether the pairs were in Chinese [$t(17)=2.44$, $p=.03$] or English [$t(17)=2.34$, $p=.03$]. Further analysis of the behavioral data is not considered due to the fact that comparisons of rhyming and non-rhyming pairs confounds yes/no judgments in this task.

ERP data

Figure 1 displays the grand average waveforms elicited by the target items of the Chinese and English pairs, overlaid by the prime-target rhyming relationship. The waveforms elicited by targets in the non-rhyming pairs were more negative-going than those elicited by targets in the rhyming pairs. This negativity, starting at around 300 ms post target onset and resembling the N450 effect reported in previous studies, was observed in both Chinese and English pairs. To analyze this N450 effect, ERPs elicited by the targets were quantified by measuring the mean amplitudes of the 320–500 ms time period after stimulus onset. This time window was selected based on visual inspection and corresponded to the time window for N450 analyses in previous studies [11]. Two repeated-measures ANOVAs, for Chinese and English pairs respectively, were conducted on the data from eight electrodes (F3/F4, C3/C4, P3/P4, T7/T8). Factors entered into these ANOVAs were prime-target rhyming relation (rhymed vs. non-rhymed), hemisphere (left vs. right), and caudality (frontal, central, parietal, temporal).

For the Chinese pairs, the main effect of prime-target rhyming relation was significant [$F(1,17) = 28.86$, $p < 0.01$], reflecting the N450 effect of more negative-going waveforms for targets in non-rhyming pairs than those in rhyming pairs. The N450 effect is more apparent in central and parietal sites, as reflected by a significant interaction between caudality and prime-target rhyming relation [$F(3,51) = 8.64$, $p < 0.01$]. Furthermore, the interaction between hemisphere and prime-target rhyming relation was significant [$F(1,17) = 7.30$, $p < 0.05$], suggesting that the N450 effect was greater over the right hemisphere sites in comparison to the left hemisphere sites.

For the English pairs, the main effect of prime-target rhyming relation was significant [$F(1,17) = 32.82$, $p < 0.01$], revealing the N450 rhyming effect. In addition, the interaction effect between caudality and prime-target rhyming was significant [$F(3,51) = 9.30$, $p < 0.01$], as well as the interaction between hemisphere and prime-target rhyming relation [$F(1,17) = 8.99$, $p < 0.01$]. These results, similar to those observed in the rhyme judgments to Chinese word pairs, suggested that Chinese native speakers exhibited the N450 rhyming effect when making rhyme judgments to English word pairs.

In addition to revealing the similar N450 rhyming effects induced in Chinese and English rhyme judgments, we further examined whether these two sets of N450 effects are correlated. To this end, difference waves were generated by subtracting the waveforms elicited by the rhyming targets from the non-rhyming targets within each language. The mean amplitudes of the 320–500 ms time region from these difference waves were calculated. Data from electrodes C4 and P4 were submitted to correlation analysis because the N450 effect was most pronounced in the right central/parietal recording sites. The result showed that the correlation between the two N450 effects approached significance (Electrode P4, $r = .42$, $p = .08$). Considering that the relatively wide time window selected might cause variations, we turned to measure the peak value within 320–500 ms individually and looked for the correlations between the peak values of the N450 effects from Chinese and English. The peak values of the N450 effects for the two languages were significantly correlated in the central (electrode C4, $r = .59$, $p = .01$) and parietal (electrode P4, $r = .61$, $p < .01$) sites.

Discussion

To recapitulate the ERP findings, a reliable N450 effect was revealed in the rhyme judgment task. Target words that were not rhymed with the preceding primes elicited a greater N450 wave than those that were rhymed with the preceding primes. Importantly, the N450 rhyming effect was observed whether the rhyme judgments were in the participant's native language (Chinese) or in a language that they learned as a foreign language (English). In addition, the N450 effects yielded in these two languages were correlated. As discussed below, these results clarified the functional significance of the N450 rhyming effect and revealed a similar phonological sensitivity to native and foreign languages.

One primary question this study explored was whether phonological processing alone would elicit the N450 effect. By employing pairs of rhyming Chinese characters that have distinct orthographic forms, the potential influence of orthographic processing on rhyme judgments was removed in the current study. The N450 effect observed in Chinese rhyme judgments therefore provided strong evidence that the N450 effect is induced by phonological processing, irrespective of orthographic overlap. The present study surely is not the first one to examine the N450 rhyming effect with Chinese characters. Valdes-Sosa et al. [12], for instance, observed an N450-like effect when participants from Mainland China made homophone judgments to Chinese characters. The findings reported here further our understanding of the functional significance of the N450 effect in two aspects. First, the task employed in the present study was rhyme judgment but not homophone judgment. The results could therefore be directly compared with those of previous rhyme judgment studies in English and other alphabetic languages. Second, participants in the current study were less likely to adopt an alphabetic spelling mapping strategies, such as using the *Pinyin* system, to complete the task. Valdes-Sosa et al [12] recruited participant from Mainland China. The phonetic symbols used in Mainland China, the *Pinyin* system, is based on Roman letters, hence an alphabetic system. When engaging in a phonologically related task, participants might have retrieved and compared the *Pinyin* symbols (i.e., Roman letters) of the presented characters. The possible confounding between orthography and phonology in alphabetic languages therefore might still remain in their study. On the other hand, the *ZhuyinFuhao* system used in Taiwan (where participants of the current study are from) employed simplified characters as phonetic symbols. The possible confounding between orthography and phonology should therefore be avoided even if our participants indeed had to retrieve *ZhuyinFuhao* to complete the rhyme judgment task.

In regard to the rhyme judgments to English words, our participants exhibited an N450 effect as they did in the rhyme judgments to Chinese characters. The spatial and temporal properties of the N450 effects exhibited by our participants, whether to Chinese characters or to English words, were similar to those of the N450 effects observed in previous studies of English rhyme judgments [1,11]. Our results therefore indicate that there is a common neural network of phonological processing for native and foreign languages. The results also suggested that the phonological operations, when the phonological processing was under similar grain size and compatible tasks, are the same for speakers of alphabetic languages and those of non-alphabetic languages.

The correlation between the N450 effects to Chinese characters and English words further supports the argument for a common phonological processing neural network for native and foreign languages. It also shed lights on how Chinese EFL learners process the phonology of an alphabetic language. Our design did not allow us to directly address the issue of whether the phonological information of native language and that of foreign languages are represented in a unitary system or in separate ones; nevertheless, the correlation between the N450 effects elicited by the two languages indicates that the phonological representations of

native and foreign languages might employ the same system or engage the same mechanisms. Further investigation is needed to examine these possibilities. On a practical side, we suggest that the measure of the N450 effect may provide a useful index of phonological sensitivity in investigations of foreign language learning. For instance, the N450 effect exhibited by native English speakers in a letter rhyming judgment was found to be correlated with standardized behavioral measures of English vocabulary and non-word reading [11]. It would be of theoretical and practical interests to test whether the N450 effect induced in foreign languages, such as the English rhyme judgment of the present study, also correlates with reading abilities in foreign languages.

In conclusion, this study clarifies the functional significance of the N450 rhyming effect and provides converging evidence for linking the N450 effect to phonological processing. The current study also highlights a role of linguistic universality by showing that the electrophysiological correlates of phonological processing observed in alphabetic languages are also observed in non-alphabetic orthographies. Further studies are needed to examine how the phonological representations of native languages are utilized for learning foreign languages.

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Figure 1.
Grand average ERP waveforms showing the N450 effect in Chinese and English conditions
(selected time Window: 320~500 ms, marked in grey).

Table 1

Example characteristics and subject responses (Mean RT and accuracy rate) to the Chinese and English prime-target word pairs in the rhyme judgment tasks (SD in parentheses).

	Rhyming pairs		Non-rhyming pairs	
	prime	target	prime	target
Chinese stimulus example	梯	低	妹	訴
pronunciation	/ti1/	/di1/	/mei4/	/su4/
mean frequency (per million)	47.2	35.4	47.2	36.6
mean number of strokes	11.6	11.4	11.4	11.7
mean RT (msc) to prime-target pairs	681(150)		729 (186)	
mean accuracy rate (%) to prime-target pairs	91.1 (4.0)		93.5 (3.8)	
English stimulus example	power	sour	gain	wall
mean familiarity(1–6) *	5.6	5.5	5.6	5.5
mean letter length	4.2	4.3	4.3	4.3
mean number of phonemes	3.3	3.3	3.4	3.4
mean RT (msc) to prime-target pairs	629 (124)		654 (123)	
mean accuracy rate (%) to prime-target pairs	89.3 (4.9)		91.4 (4.7)	

*
1 not familiar at all; 6: very familiar