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Global Mapping Congruence Influences Phonological Interference: ERP Evidence for Early and Persistent Ortho-Phonological Effects in Reading Chinese for Meaning

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Phonological interference during written-word meaning judgments occurs in both Chinese and English, suggesting that word-level phonological activation is universal rather than dependent on the sublexical structures that vary with writing systems. To accommodate this universality, we distinguish two sources of phonological congruence between a meaning-bearing orthographic unit (word or character) and other units in the orthographic lexicon: (a) Global congruence between a word (or character) and its orthographic neighbors having the same pronunciation and (b) Local congruence between a word (or character) and its graphic constituents (letters or radicals). Recent evidence by Zhou and Perfetti in 2021 shows a greater role for global than local congruence in covert naming of Chinese characters. We hypothesize this is true also for meaning processing and use behavioral and event-related potential (ERP) measures to test this hypothesis during character meaning judgments. As expected, we found word-level phonological interference in meaning decision times. Further, ERPs detected interference effects related to global congruence at early and mid-latency ERP components; local congruence effects emerged only in interaction with global congruence. A late ERP component (LPC) also showed phonological interference, but no effect on mapping congruence. These time-course results suggest two phases of phonological activation: (a) character identification, influenced mainly by global congruence, as indicated in early and mid-latency ERP components and (b) meaning comparison, influenced only by lexical phonology, as indicated by the LPC component. The early phase of lexical processing is much the same whether meaning or pronunciation is required because it engages ortho-phonological associations that are not easily suppressed.

Keywords: phonological interference, ERPs, mapping congruence, meaning judgment task

One of the main advances in word reading research is the conclusion that the phonological forms of words (word pronunciations) and their sub-word letter strings (phoneme strings) play an early and integral role in word reading (see Frost, 1998; Halderman et al., 2012; Leinenger, 2014, for a review), including word meaning access. This conclusion, based originally on alphabetic reading, includes a strong form in which the phonology is strongly obligatory (Frost, 1998) and was extended to non-alphabetic Chinese reading (Tan & Perfetti, 1998). What is less clear, and what we address here, is whether and how sublexical components play a role in the phonology that occurs during Chinese reading for meaning.

To address these questions, we rely on a framing of orthographic structures proposed by L. Zhou and Perfetti (2021) that accommodates the universal scope of orthography-to-phonology mappings. Rather than the standard concepts of consistency and regularity (the latter being a less universal concept), the mapping congruence characterization of orthography-to-phonology mappings distinguishes global (consistency) from local (regularity) *mapping congruence*. Global mapping congruence captures the global level congruence among a large set of orthographic neighbors across the entire lexicon: In English, it describes the extent to which the pronunciation of rime unit (e.g., *-ave*) of a word (e.g., *have*) matches that of its orthographic neighbors (e.g., *wave*, *save*, *cave*, *gave*) that contain the same rime unit (Jared et al., 1990). In Chinese, it describes the extent to which the pronunciation of a complex character (e.g., 炬, /ju/) matches that of its orthographic neighbors (e.g., 距, /ju/, 拒, /ju/, 矩, /ju/, 钜, /ju/, 柜, /gui/) that contain the same phonetic radical (e.g., 巨, /ju/, Fang et al., 1986). Local mapping congruence reflects the local level congruence between a given lexical unit and a sublexical unit: In English, it describes whether applying the grapheme-phoneme-correpondence (GPC) rules that are encoded locally in the Dual-Route Cascaded model (Coltheart et al., 2001) to letter or letter strings of a word (e.g., *pint*) can yield correct word pronunciation. In Chinese, it describes whether the pronunciation of a complex character (e.g., 炬, /ju/) is congruent with that of its phonetic radical (e.g., 巨, /ju/, X. Zhou & Marslen-Wilson, 1999). Based on an event-related potential (ERP) study centered on global and local congruence, L. Zhou and Perfetti (2021) concluded that global congruence is more important than local congruence in explaining covert naming effects.

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As we describe in more detail later, the greater role of global than local congruence was in evidence early and throughout the first 500 ms of ERP recording.

Based on the mapping congruence effects in naming, we address the classic question of whether and how phonology is engaged during reading for meaning—specifically whether phonological interference effects are mediated by the sublexical processes captured by global and local mapping congruence. The general question of whether phonology is activated during silent word reading for meaning received an affirmative answer from previous research on alphabetic reading: Phonological forms of words (word pronunciations) and their sub-word letter strings (phoneme strings) play an early and integral role in alphabetic word identification as evidenced in older research across multiple experimental paradigms (see Halderman et al., 2012; Leinenger, 2014, for a review): accuracy at threshold durations with backward masking (Perfetti et al., 1988), priming paradigms both with masking (e.g., Ashby et al., 2009) and without masking (see Rastle & Brysbaert, 2006, for a review), eye-tracking with parafoveal preview paradigm (e.g., Pollatsek et al., 1992), and word meaning judgment paradigms (e.g., Lesch & Pollatsek, 1993; van Orden, 1987). In alphabetic reading, although there are questions about the extent phonology "mediates" meaning access (e.g., Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994; Van Orden et al., 1988) or merely co-occurs with the encoding of orthography (e.g., Fleming, 1993; Jared & Seidenberg, 1991; Taft & van Graan, 1998), the activation of a word's phonology occurs routinely and early in the identification process. We turn now to the state of affairs in Chinese reading.

Phonology in Reading Chinese for Meaning

Written Chinese is a morphosyllabic writing system that does not encode phonemes and thus has no phoneme assembly from its sublexical units. However, the writing system does encode phonology at the syllable level, with a character typically mapping onto a spoken syllable. Furthermore, most characters have an internal orthographic structure of more than one component including components that convey syllable-level pronunciations. As many as 80% of characters are phonograms (Y.-G. Zhou, 1978), in which one component (the semantic radical) can convey meaning information and another component (the phonetic radical) can provide a whole-to-whole (i.e., syllable-to-syllable) mapping to the host character's pronunciation. However, these whole-to-whole mappings are often (56%[1]) invalid as cues to pronunciation of the character, while 44%, have valid cues to the syllable pronunciation (ignoring tonal differences). Thus, it can appear that the writing system does not encourage phonological processes even at the syllable level and certainly not at the individual phoneme level.

Despite writing-system differences, however, research on reading Chinese over 20 years ago reported consistent phonological effects (Tan & Perfetti, 1998). These effects are similar to those in alphabetic reading in meaning judgments on single-character presentations (e.g., Leck et al., 1995) and two-character presentations (e.g., Perfetti & Zhang, 1995; Xu et al., 1999). For example, Perfetti and Zhang (1995) asked participants to judge whether the critical character (e.g., 疲, /pi/, "*exhausted*") was semantically related to a preceding character, which was either a synonym (e.g., 累, /lei/, "***tired,***" requiring a "*yes*" response), a homophone (e.g., 批, ***/pi/***, "*batch*," requiring a "*no*" response), or a control (e.g., 麦, */mai/*, "*wheat*," unrelated in both meaning and pronunciation and requiring a "*no*" response). The critical results were that readers made slower "*no*" responses and more errors in the homophone than the control condition. These phonological interference effects were robust across a range of Stimulus-Onset Asynchronies (SOAs, e.g., 90, 140, 260, 310 ms in Perfetti & Zhang, 1995 and 190 ms in S. Zhang et al., 1999) between two homophone characters presented for meaning judgments. In addition, this phonological interference effect was found to be stronger in low-frequency than high-frequency characters (S. Zhang et al., 1999). However, this effect was not influenced by local congruence (regularity) in S. Zhang et al. (1999), where only local congruence (the radical's validity as a cue to character pronunciation) was manipulated. They concluded that phonological interference arose from phonological processing at the character level, regardless of whether sub-character structures (radicals) are involved.

ERPs allow researchers to detect stages of linguistic information processing over the few hundred milliseconds. The N170 has been interpreted as an indicator of orthographic detection at the initial stage of perceptual categorization (e.g., Bentin et al., 1999; Lin et al., 2011), and as an indicator of the activation of connections between orthographic forms and phonological representations (e.g., Maurer & McCandliss, 2007). The P200 also has been associated with early orthographic (e.g., Kong, et al., 2012; H. Zhang et al., 2020; Zou et al., 2019) and phonological processing (e.g., Kong et al., 2010) in Chinese as well as alphabetic word reading (e.g., Barnea & Breznitz, 1998; Kramer & Donchin, 1987). Finally, the later N400 is well-known as an indicator of meaning processing, among other aspects of language processing (Kutas & Federmeier, 2011).

However, subsequent ERP studies of phonological interference in Chinese (e.g., Chen et al., 2007; Liu et al., 2003; Q. Zhang et al., 2009) show variable onsets of the phonological interference effect, perhaps affected by word frequency (e.g., Q. Zhang et al., 2009). Following Liu et al. (2003), these ERP studies adopted the SOA of 360 ms and set the ERP recordings time-locked to onset of the second character ("the critical character") of a two-character sequence. Phonological interference effects were measured during meaning judgments on the critical character (e.g., 疲, */pi/*) when it followed a preceding homophone (e.g., 批, */pi/*), compared to when it followed a preceding control (e.g., 麦, */mai/*). Liu et al. (2003) first reported that lexical-level, homophone pairs elicited a reduced N400, but no P200 effect. However, subsequent studies (e.g., Chen et al., 2007; Q. Zhang et al., 2009) found that when the characters were of low frequency, phonological interference effect was observed as an enhanced P200 and a reduced N400. These studies did not consider sublexical structures, either globally or locally. Thus, these results, by the design, cannot test the possibility that (sublexical) radical-related phonological processes may mediate this phonological interference, which can be captured by the mapping congruence as we described later.

Bringing Mapping Congruence into the Picture

Of particular important for phonology of Chinese are that complex characters contain a sub-character component (referred to as

[1] The number is an estimation from the database (containing 5,200 characters in total), developed by the authors. Out of the 5,200 characters, 3,987 characters (77%) are phonograms, of which 1,220 are regular (31%), 519 are semiregular (i.e., sharing the syllable but with different tones, 13%), and 2241 (56%) are irregular.

phonetic radicals) that vary in their mapping relations to the whole character. For example, the character 炬 (*/ju/*, "*torch*") contains a phonetic radical 巨 (*/ju/*, "*huge*"). This phonetic radical provides a valid whole-to-whole (syllable-to-syllable) mapping to its host character's pronunciation. Multiple characters share this phonetic radical (巨), thus creating an orthographic neighborhood of six characters (距, 拒, 柜, 矩, 炬, 钜) (Fang et al., 1986; Lee et al., 2005).

In the mapping congruence framing (L. Zhou & Perfetti, 2021), we distinguish global congruence—the extent to which the pronunciation of a phonogram (e.g., 炬, */ju/*) matches that of its orthographic neighbors (e.g., 距, */ju/*, 拒, */ju/*, 矩, */ju/*, 柜, */gui/*) defined by their shared phonetic radical (e.g., 巨, */ju/*). This factor, which was referred to as consistency in prior research (e.g., Hsu et al., 2009; Lee et al., 2005), can be quantified by either type or token counts. For example, the character 炬 (*/ju/*), with its character frequency of 12 per million, has a total of five orthographic neighbors (i.e., 距, 拒, 矩, 钜, 柜): four friends (i.e., four homophonic orthographic neighbors: 距, 拒, 矩, 钜, with their character frequencies of 98, 74, 16, and 1 per million, respectively) and 1 enemy (i.e., one non-homophonic orthographic neighbor: 柜, */gui/*, with its character frequency of 44 per million). Thus, the character 炬 has a high type consistency value of $(1+4)/(1+5) = 0.83$ and a high token consistency value of $(12+98+74+16+1)/(12+98+74+16+1+44) = 0.82$. Phonograms with high type and token consistency values (e.g., 炬) can be referred to as high global congruence (consistency) characters, otherwise as low global congruence (consistency) characters.

Local mapping congruence, which captures "regularity" (a borrowing from alphabetic "rule"-based mapping), is the pronunciation match between a phonetic radical and its host character (hence, "local"). Thus, because the pronunciation of the character 炬, matches that of its phonetic radical 巨, the character is locally congruent. This radical-character congruence has been referred to as "regularity" (e.g., X. Zhou & Marslen-Wilson, 1999) and phonetic validity (e.g., Perfetti et al., 1992; S. Zhang et al., 1999). About 31% of phonograms share an identical pronunciation (including tones) with their radical, and thus have local mapping congruence.

Global and local congruence can diverge. For example, the character 钮 (*/niu/*) is locally incongruent because its phonetic radical 丑 (*/chou/*) has a different pronunciation; however, 钮 is a high global congruence character, because it is homophonic with most of its orthographic neighbors, 妞, 扭, 忸, 纽, all pronounced as */niu/*. In contrast, the character 呱 (*/gua/*) is locally congruent, containing a valid phonetic, 瓜 (*/gua/*), but is low in global congruence because its pronunciation is different from most of its orthographic neighbors, 孤 (*/gu/*), 弧 (*/hu/*), 狐 (*/hu/*). Thus, local and global congruence can be independently varied.

In their naming study that varied local and global congruence factorially within a single set of stimuli, L. Zhou and Perfetti (2021) concluded that global congruence plays an early and continuous role in character identification, as indicated by its effect on early (N170, P200), and mid-latency (N400) ERP components. Local congruence, which affected the frontal N400 (FN400) and late positive complex (LPC) only through an interaction with the global congruence, shows a minor role in character identification. (In terms of the traditional descriptors, consistency shows a greater effect than regularity in Chinese, as it does in English, Jared, 2002).

L. Zhou and Perfetti (2021) associated early components (N170 and P200) with the early stages of ortho-phonological processing, the mid-latency component (N400) with the lexical processing (including both phonological and semantic information) during character identification or perhaps post-lexically, and the LPC with preparations for the pronunciation sameness task (see Figure 1). In particular, high global congruence (consistency) led to less negative-going N170 and more positive-going P200 in comparison with low global congruence. These effects reflect stronger activation of a radical within a character of high global congruence and thus stronger phonological activation of the host character, relative to a character of low global congruence. The N400 effect, which was less negative-going for characters of high global congruence, reflects facilitated activation of lexical information (including orthographic, phonological, and semantic) due to a phonological congruence effect, that is, stronger phonological activation for characters high in global congruence. The LPC, which was affected jointly by global and local congruence, was interpreted as a post-lexical task-dependent process: Local congruence added to the effect of global congruence, creating a strong phonological memory that served the pronunciation sameness task. On this account, if access to meaning engages in the same (sublexical) radical-related phonological processing as naming does, mapping congruence would affect the phonological interference on ERP responses in meaning judgments in the same way as it does in naming, and with a greater role of global congruence than local congruence.

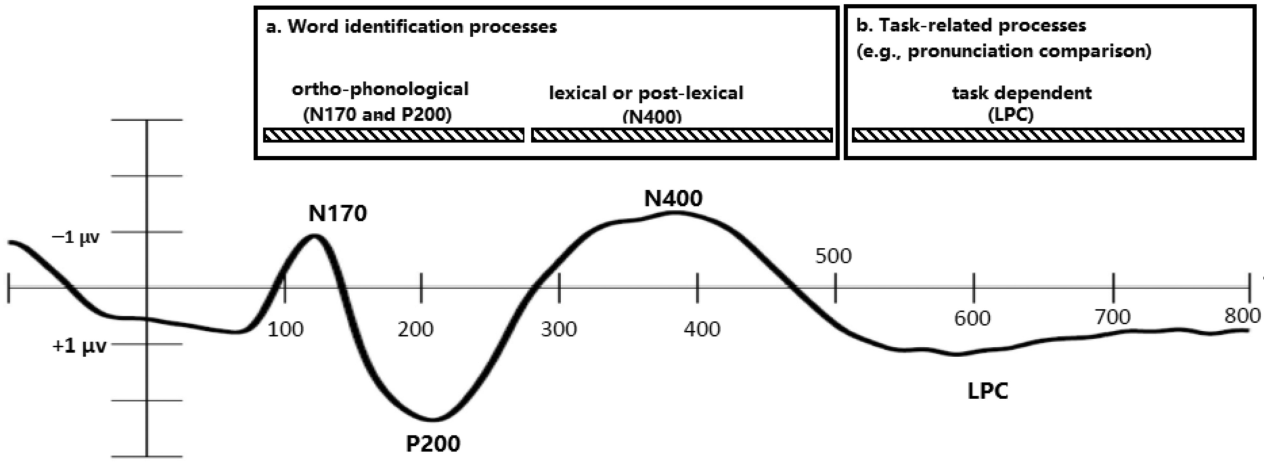
The Present Study

Our study asks whether the sublexical structures of characters responsible for local and global mapping congruence affect meaning processing, as they have been shown to do in both covert (L. Zhou & Perfetti, 2021) and overt (Lee et al., 2005) naming. A more general theoretical proposition is at stake, whether reading for meaning by-passes sublexical phonological processes, activating phonology only as part of post-lexical (character) process, which is the prediction of strong direct access view on meaning access (e.g., Taft & van Graan, 1998).

A variation on this issue is the location of reader-controlled strategic processing. If a reader can control the reading processes for meaning and for naming prior to word identification, then differences in early ortho-phonological processes should occur, depending on the task. The contrary view is that these early processes are the same for meaning judgment and naming tasks because they reflect strong (automatic) phonological associations that accompany the graphic form; task-dependent effects occur at a later phase. ERPs provide temporal information relevant to this issue. More specifically, if radical-related phonological processes are engaged as part of ortho-phonological phase of word identification without regard to task demands (meaning vs. phonology), then the mapping congruence should affect early and mid-latency ERPs in a meaning judgment task, as it did in L. Zhou and Perfetti (2021), and with a greater role of global congruence than local congruence. If the reader's task controls the early stages of identification, radical-related phonological effects might not emerge at all or emerge only in the late stages of meaning processing.

Our method follows the covert naming study of L. Zhou and Perfetti (2021) described above. We use this same factorial design in a meaning judgment task with both behavioral and ERP measures. We orthogonally manipulate global congruence (high vs. low) and local congruence (locally congruent vs. locally incongruent) on

Figure 1
ERP Effects Mapped Onto two Phases of Pronunciation Sameness Tasks Described in L. Zhou and Perfetti (2021)



Note. This figure shows the grand averaged ERP waveforms of all characters at C4 electrode clusters in L. Zhou and Perfetti (2021). Early components (N170 and P200), which reflect ortho-phonological processing, and the mid-latency component (N400), which reflects lexical or post-lexical processing, capture the first phase–word identification processes; the LPC captures the second phase, which involves task-related processes (see text for description).

the critical (second) character of two-character pairs that are sequentially presented for a judgment of their meaning similarity. On the assumptions that (a) meaning judgment task requires character identification and (b) the identification process activates sublexical orthographic structures and their character-level phonology, we expect an unfolding of ERP phonological interference effects that will be influenced by the mapping congruence factors that were found to affect covert naming in L. Zhou and Perfetti (2021). Thus, phonological interference effects should be observed for all characters as a result of character-level phonology and early ERP markers should be influenced by the mapping congruence of sublexical structures, especially the global congruence of the orthographic lexicon.

Method

Participants

Sixty-three undergraduate students at the University of Pittsburgh with normal or corrected-to-normal vision were recruited to participate in one of two experiments. Thirty-three (15 males, M_{age} 19, range 18–22) participated in ERP experiments and 30 (17 males, M_{age} 20, range 18–22) in behavioral experiments. All participants grew up in Mainland China and were right-handed, native Mandarin speakers.

Materials

The materials were identical for behavioral and ERP experiments. The critical stimuli were 184 low-frequency (below 40 per million) critical characters, equally distributed in four groups (46 characters in each group, Table 1) defined by the orthogonal manipulation of global congruence (high vs. low) and local congruence (congruent vs. incongruent). All high global congruence characters have token consistency values greater than 0.5 and most (36 out of 46 characters in each group) of them have type consistency values greater than 0.45; all low global congruence characters have token consistency values less than 0.4 and type consistency values less than 0.45.

Locally congruent (regular) characters had the same syllabic pronunciation as their phonetic radicals (ignoring tonal differences). Locally incongruent (irregular) characters include those with no overlap in the pronounced syllables and those sharing only the consonant onset or the rhyme of the syllable. The four groups of critical characters were matched in character frequency, visual complexity (stroke number), phonetic combinability[2] (all no less than 4), and radical token frequency (Table 1).

Each critical character was paired with two types of preceding (first) characters (Table 1): homophone characters (e.g., 勇, /*yong*/, "*brave*"), which were homophonic (ignoring the tonal differences) with the (second) critical characters (e.g., 咏, /*yong*/, "*chant*") at the lexical level, and control characters (e.g., 卷, /*juan*/, "*roll*"), which were matched with the homophone character in character frequency, visual complexity, and character structure.[3] Neither the homophone nor the control character had any meaning or orthographic association with the critical character. In addition, characters with the highest token frequency among the homophonic characters were selected as the critical homophone characters. This is to ensure that participants know the pronunciations of the homophone characters.

In total, there were 552 character-pairs, including 368 critical character-pairs, which were unrelated semantically[4] and thus

[2] Phonetic combinability is the total number of characters containing the same phonetic radical as the host character.

[3] Character structure refers to the layout of radicals in complex characters (e.g., left-right, top-down) or the simple structure of a simple character.

[4] The meaning relation of 571 character pairs (including 368 critical character pairs and 203 semantically related character pairs) was rated in a questionnaire from 1 (*totally unrelated*) to 7 (*highly related*) by nine native Mandarin speakers (four males), who did not participate in either experiment. Critical character pairs had an average score below 4, whereas the filler character-pairs ($n = 184$) had high meaning relatedness values ($M = 6.4$,

Table 1
Sample Stimuli

	Critical characters			
Global congruence (consistency)	High consistency		Low consistency	
Local congruence ("regularity")	Congruent	Incongruent	Congruent	Incongruent
Sample critical character	咏 ***/yong/*** *chant*	崛 ***/jue/*** *rise abruptly*	怅 ***/chang/*** *disappointed*	贿 ***/hui/*** *bribe*
Frequency (per million)	8.6 (7.3)	9.0(8.9)	9.1(8.8)	8.4(8.4)
Range: min, max	0.8, 27.2	0.6, 30	0.5, 30.8	0.5,34.7
Visual complexity	10.4 (2.8)	11.3 (3.6)	10.1 (2.7)	10.2 (3.0)
Token consistency	0.79 (0.15)	0.78 (0.17)	0.08 (0.12)	0.08 (0.09)
Type consistency	0.56 (0.17)	0.53 (0.21)	0.24 (0.09)	0.21 (0.08)
Phonetic combinability	7.0 (2.6)	6.6 (2.6)	7.5 (2.7)	7.4 (2.5)
Phonetic radicals Phonetic radical				
Token Frequency	永 660.3 (1,019.9) 0.9,	屈 625.8 (1,101.8) 3.1, 6,	长 568.3 (740.6) 4.8,	有 855.3 (1,417.6) 8.6,
Range: min, max	4,702.9	315.5	2,866.3	8,159.0
Preceding character type				
Homophone				
Sample	勇 ***/yong/*** *brave*	绝 ***/jue/*** *desperate*	唱 ***/chang/*** *sing*	慧 ***/hui/*** *intelligent*
Frequency	125.8	290.1	136.2	64.5
Visual complexity	9	9	11	15
Semantic relatedness	1.25	1.24	1.27	1.37
Control				
Sample	卷 */juan/ roll*	修 */xiu/ repair*	绩 */ji/ achievement*	慰 */wei/ comfort*
Frequency	125.2	293.0	144.3	62.2
Visual complexity	8	9	11	15
Semantic relatedness	1.22	1.28	1.12	1.31

Note. All stimuli were chosen from a word frequency database from the Centre for Chinese Linguistics at Peking University and all psycholinguistic variables, including consistency values, were calculated on the basis of 5,200 characters by the authors. Visual complexity is the stroke number of the host character. Phonetic combinability is the total number of characters containing the same phonetic radical as the host character. Phonetic radical token frequency refers to the token frequency of radicals when standing alone as legal characters.

required "*no*" responses, and 184 semantically related character-pairs (with no overlap with any characters in the critical pairs), thus requiring "*yes*" responses. The meaning relations between characters in the semantically related filler pairs varied, including antonyms, synonyms, and category coordinates.[5] These filler character-pairs did not share any phonetic radicals with critical characters, so that participants would not encounter any orthographical neighbors of critical characters during the experiment.

Procedure

The procedure was the same for the behavioral and ERP experiments, except as noted below. Each trial started with a fixation cross displayed for 300 ms, followed by the first (preceding) character, either a homophone or a control character, for 140 ms. After a 360 ms blank, the second (critical) character appeared and remained on the screen for 1,500 ms. The inter-trial interval was 1,800–2,200 ms. Both characters were displayed in Song font in black against a gray background at the center of the screen. Participants were seated 60 cm from the screen (visual angle: 1.9°) in a dark shielded room. They were instructed to judge whether the two characters were semantically related. Thus, all critical character pairs (controls and homophones) required a "*no*" response, whereas filler character pairs required a "*yes*" response. The ERP experiment required a key press only for the "*yes*" responses to avoid motion interference with the ERPs on critical "*no*" trials. In the behavioral experiment, participants were instructed to make manual responses to indicate both "*yes*" and "*no*" responses.

Following 20 practice trials, participants completed 552 trials (368 critical trials and 184 fillers) in 11 blocks. Each block contained 32 critical trials (equally distributed across the eight conditions) and 16 filler trials, except the third to fourth blocks, which contained 40 critical trials and 20 filler trials. Thus, the ratio of critical ("*no*") trials to filler ("*yes*") trials in each block were 2 to 1. In each block, the first two trials were always fillers. Due to the within-subject design, each critical character, which was paired with two types of preceding characters, was presented twice throughout the experiment. To control order effects, critical characters in each group were randomly divided into two lists and the presentation order of critical characters on the two lists was counterbalanced for each participant. The repetition trials for each critical character were separated by at least 240 trials. Participants were allowed to take a break between blocks.

Following the experiments, participants performed a transcription task to assess their knowledge of pronunciation of the experimental characters, which were relatively low frequency (less than 40 per million). They wrote in Pinyin the pronunciation of each of 184 critical characters and 107 preceding characters, presented in random order. For each participant, only characters correctly transcribed were included in behavioral and ERP data analyses.

EEG Recording

A 128-electrode Geodesic sensor net with Ag/AgCl electrodes (Electrical Geodesics, Inc., Eugene, OR, USA) recorded EEGs at a sampling rate of 1,000 Hz with impedances kept below 40 kΩ.

$SD = 1.2$). Paired t-tests confirmed that the character pairs in the homophone and control trials did not differ significantly from each other in meaning relation for any of the four groups of critical characters (all $ps > .5$).

[5] Category coordinates refer to character pairs (e.g., 狗 and 猫: dog and cat) belonging to the same semantic category (e.g., animals).

Data Analyses

For the pronunciation transcription task, accuracy data were analyzed with mixed-effect logistic regression, using the maximum likelihood (ML) estimation. For each participant, characters that were marked as unknown or transcribed incorrectly in the pronunciation transcription task were excluded from analysis in the behavioral and ERP meaning judgment tasks. Mixed-effect linear regressions were applied to decision times data, recorded from the appearance of critical characters; mixed-effect logistic regression modeling was applied to the trimmed accuracy data (excluding unknown and wrong items) of critical trials in the meaning judgment task. For all mixed-effect modeling, the final model was obtained by using the likelihood-ratio test in comparing a model with fixed effects of global (high vs. low) and local (congruent vs. incongruent) mapping congruence and their interaction, with nested simple models. The contrasts of dummy variables were set as 0.5 and −0.5 so that a one-unit change reflected the main effect of each factor. Random effects of both subjects and items were included.

The EEG data were recomputed offline against averaged reference across the whole scalp, and band-passed at 0.5–30 Hz. ERPs were computed for correct trials after ocular artifact rejection. Each epoch was 1,100 ms, including a 100 ms baseline interval prior to the critical character onset. Based on global field power and previous research, mean amplitudes across four time windows (130–190 ms, 190–280 ms, 300–500 ms, and 500–700 ms) were calculated, corresponding to the N170, P200, N400, and LPC, respectively. These mean amplitudes were analyzed with a five-way ANOVA with global congruence (high vs. low), local congruence (congruent vs. incongruent), trial type (homophone vs. control trial), laterality (left, midline, right), and region as within-subject factors. The planned testing regions were as follows: The N170 at parietal (P3/Pz/P4) and occipital (O1/Oz/O2) regions, the P200 amplitude at frontal (F3/Fz/F4) and central (C3/Cz/C4) regions, the N400 amplitude at central and parietal regions, and LPC at frontal, central, and parietal regions. The Greenhouse–Geisser correction was applied to all repeated-measures with more than one degree of freedom. Because the main focus was the phonological interference effect, defined by the contrast of trial type (homophone vs. control trials), only effects related to the factor of trial type were reported. Any three-way interactions containing the factors of trial type and global congruence were followed by separate analyses at the high and low global congruence levels. Any two-way interactions were followed by simple main effect analyses and overall pair-wise comparisons across all electrodes with Bonferroni adjustment.

Results

Pronunciation Transcription Accuracy

On average, participants transcribed more accurately (+9%) pronunciations of characters with high global congruence ($M = 90\%$) than those with low global congruence ($M = 81\%$). The final mixed logit model (Table 2) showed that global congruence had a significant effect ($p < .05$) on the logits of correct pronunciation transcriptions after the variances associated with subjects and items were simultaneously controlled for. However, the effect of local congruence ($p > .1$) was not significant in the final mixed logit model, although on average, participants transcribed more accurately (+3%) the pronunciations of locally congruent characters ($M = 87\%$) than locally incongruent characters ($M = 84\%$).

Behavioral Phonological Interference Effects

On average, participants responded more slowly (+17 ms) to homophone trials than to control trials in giving "*no*" responses. This phonological interference effect on decision times was confirmed by the significant effect of trial type in the final linear mixed-effect model (Table 2). The average phonological interference effect was smallest for characters that are low in global congruence and locally incongruent (irregular low-consistency, +12 ms), and quite close for the other three groups of characters: high global congruence, locally congruent (regular high-consistency, +19 ms), high global congruence and locally incongruent (irregular high-consistency, +16 ms), and low global congruence and locally congruent (regular low-consistency, +19 cm). Neither global nor local congruence showed a significant effect in the final linear mixed-effect model on decision times (see Table 2). The accuracy of judging these semantically unrelated trials approached ceiling: 94% for homophone trials and 95% for control trials and the final mixed logit model on accuracy showed no phonological interference effect.

Phonological Interference Effects on ERP Components

Phonological interference effects were observed across the ERP recording: homophone trials elicited less negative N170, more positive P200, less negative N400, and more positive LPC than control trials. Moreover, these phonological interference effects (trial type: homophone vs. control) were dynamically affected by critical characters' global (consistency) and local congruence (regularity).

N170 (130–190 ms)

The N170 showed phonological interference, but only for high global congruence, locally incongruent characters (i.e., irregular high-consistency): Homophone trials were less negative (+0.333 μv) in posterior regions than control trials for these characters. Trial type interacted with global congruence and laterality (for ANOVA, see Table 3). For characters of high global congruence, homophone trials induced a less negative (+0.235 μv) N170 than control trials in the right hemisphere ($p < .05$) posterior region, but not in the midline ($p > .1$) nor in left hemisphere ($p > .1$). No effect of trial type was observed when the critical characters were of low global congruence. Trial type also interacted with global and local congruence. Only when the critical characters were locally incongruent but of high global congruence did homophone trials produce less negative (+0.333 μv, $p < .05$) N170 in comparison with control trials (Figure 2).

P200 (190–280 ms)

The P200 showed phonological interference, but only for characters of high global congruence: Homophone trials were more positive than control trials for these characters in the right frontal-central regions. Trial type interacted with laterality and global congruence (for ANOVA, see Table 3). Only when the critical characters were of high global congruence did homophone trials produce more positive (+0.260 μv) P200 in comparison with control

Table 2
Final Mixed-Effect Models

Predictor	Coefficient	*SE*	Wald *Z*	*p*-Value
(a) Pronunciation transcription accuracy				
Logit of correct transcription ~ 1 + Local congruence + Global congruence +(1|Subject) + (1|Item)				
Intercept	2.97	0.18	16.26	**<.001**
Local congruence	−0.34	0.31	−1.10	.27
Global congruence	0.69	0.31	2.21	**<.05**
(b) Accuracy of meaning judgment task				
Logit of correct judgment ~ 1 + Local congruence + Global congruence + Trial type +(1|Subject) + (1|Item)				
Intercept	3.47	0.20	17.62	**<.001**
Local congruence	−0.20	0.15	−1.32	.19
Global congruence	−0.02	0.15	−0.15	.88
Trial type	0.12	0.09	1.26	.21
(c) Decision times of meaning judgment task				
RTs ~ 1 + Local congruence*Global congruence + Probe condition + (1|Subject) + (1|Item)				
Intercept	652.98	20.56	31.76	**<.001**
Local congruence	3.30	6.48	0.51	.61
Global congruence	−4.44	6.48	−0.69	.49
Local *Global congruence	4.54	12.95	0.35	.73
Trial type	−18.14	3.92	−4.63	**<.001**

Note. SE = standard error; RT = reaction time. Bold values show that the effect is significant

trials (Figure 2); this trial type effect was significant in the right ($p < .05$) hemisphere frontal-central regions only, not in the midline ($p > .1$) or in left ($p > .1$) hemisphere frontal-central regions. No effect of trial type was observed when the critical characters were low global congruence.

N400 (300–500 ms)

The N400 showed phonological interference: Homophone trials were less negative than control trials in the midline and right hemisphere, central-parietal regions (Figure 2), but this phonological interference was stronger for high global congruence characters relative to low global congruence characters. The main effect of trial type, the two-way interaction between trial type and global congruence, and that between trial type and laterality were significant (for ANOVA, see Table 3). When the critical characters were of high global congruence, the phonological interference effect of a reduced N400 (+0.702 μv) was significant in both midline ($p < .001$) and right hemisphere ($p < .001$) central parietal regions, but not in the left hemisphere ($p > .1$). However, when the critical

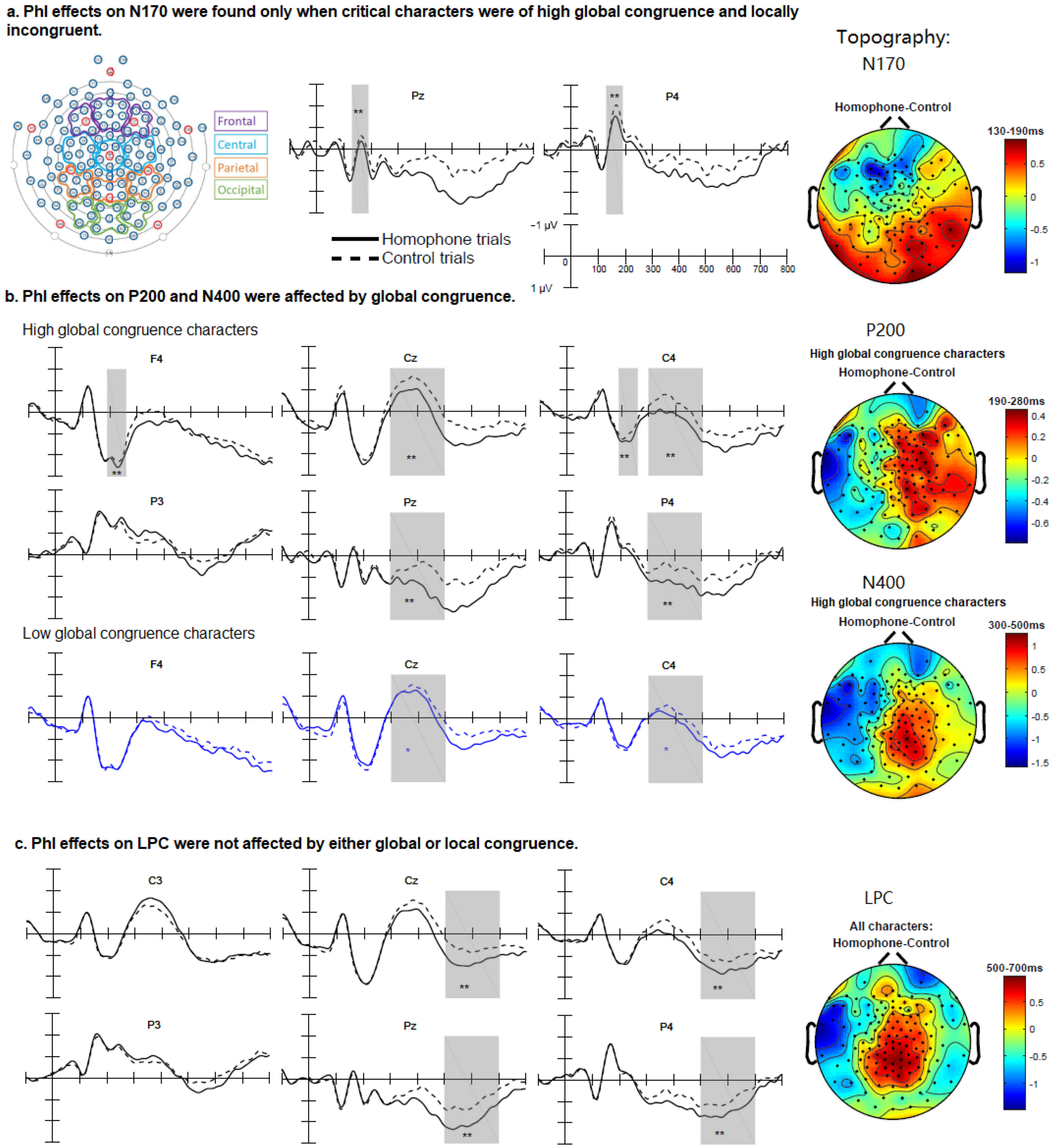
Table 3
Results of Five-Way Repeated Measure ANOVA for All ERP Components (Only Main Effects and Interactions Involving Trial Type Are Shown)

N170	**Trial type × Global congruence × Local congruence:** $F(1, 64) = 4.24$, $p < .05$
	High global congruence: Local congruence × Trial type: $F(1, 64) = 5.42$, $p < .05$
	Trial type effect: locally congruent: $p > .1$, locally incongruent: $p < .025$
	Low global congruence: Local congruence × Trial type: $p > .1$
	Trial type × Global congruence × Laterality: $F(1.7, 60) = 3.40$, $p < .05$
	High global congruence: Laterality × Trial type: $F(1, 64) = 5.24$, $p < .05$
	Trial type effect: Left: $p > .1$, midline: $p > .1$, right: $.025 < p < .05$
	Low global congruence: Laterality × Trial type: $p > .1$
P200	**Trial type × Global congruence × Laterality:** $F(1.6, 49.6) = 3.66$, $p < .05$
	High global congruence: Laterality × Trial type: $F(1.5, 47.2) = 4.44$, $p < .05$
	Left: $p = .189$, midline: $p = .174$, right: $p < .025$
	Low global congruence: Laterality × Trial type: $p > .1$
N400	**Trial type:** $F(1, 32) = 12.83$, $p < .05$
	Trial type × Global congruence: $F(1, 32) = 5.15$, $p < .05$
	Trial type × Laterality: $F(1.4, 43.4) = 20.08$, $p < .001$
	Trial type × Global congruence × Laterality: $F(1.9, 59.24) = 4.66$, $p < .05$
	High global congruence: Trial type effect: Left: $p > .1$, midline: $p < .001$, right: $p < .001$
	Low global congruence: Trial type effect: Left: $p = .18$, midline: $p = .12$, right: $p = .059$
LPC	**Trial type:** $F(1, 32) = 15.87$, $p < .001$
	Trial type × Laterality: $F(1.3, 40.84) = 9.66$, $p < .05$
	Trial type effect: Left: $p > .1$, Midline: $p < .001$, Right: $p < .05$
	Trial type × Region : $F(1.3, 41.42) = 7.02$, $p < .05$
	Trial type effect: Frontal: $p > .1$ Central: $p < .05$, Parietal: $p < .001$

Note. ANOVA = analysis of variance; ERP = event-related potentials.

Figure 2

Grand Average ERP Waveforms Showing Phonological Interference (PhI) Effects on Different ERP Components



Note. (Panel A) Phonological interference (PhI) effect on N170 in the posterior region was observed only when critical characters were of high global congruence and locally incongruent. (Panel B) PhI effect on P200 in the right frontal and central regions (F4, C4) was found only when critical characters were of high global congruence; PhI effect on N400 in the midline, right hemisphere central and parietal regions (Cz, C4, Pz, P4) was more prominent in high global congruence characters (statistically significant) than in low global congruence characters (marginal significant). (Panel C) PhI effect on LPC in the midline, right hemisphere central and parietal regions (Cz, C4, Pz, P4) was not affected by either global or local congruence of critical characters. (The highlighted windows in gray are averaged time windows of different ERP components. Mark of "**" indicates statistically significant and "*" indicates marginally significant.) See the online article for the color version of this figure.

characters were of low global congruence, the phonological interference effect of a reduced N400 (+0.249 μv) was marginally significant in the right hemisphere ($.05 < p < .1$) central parietal regions only, but not in the midline ($p > .1$) and left hemisphere ($p > .1$).

LPC (500–700 ms)

The LPC showed phonological interference: Homophone trials were less negative than control trials (Figure 2)—this phonological interference was affected by neither global nor local congruence. The main effect of trial type and its two-way interactions with region and with laterality was significant (for ANOVA, see Table 3). Homophone trials elicited more positive (+0.469 μv) LPC than control trials in the midline ($p < .001$), right hemisphere ($p < .05$), central ($p < .001$), and parietal ($p < .001$) regions. This trial-type effect was affected by neither global nor local congruence of critical characters.

Summary

The behavioral results show a significant phonological interference effect on decision times: Homophone trials took longer than control trials to respond "*no*." This phonological interference effect was not affected by the mapping congruence of critical characters. However, ERP results show a fine-grain time course of phonological interference effects that begin early with orthographic processing (N170) and persist throughout the recording interval: Homophone trials, compared with control trials, showed a less negative N170, a more positive P200, a less negative N400 and a more positive LPC than control trials. Equally important, the ERPs show evidence for early effects of mapping congruence on phonological interference: The N170 effect was restricted to characters of high global congruence but locally incongruent; the P200 effect was restricted to characters of high global congruence only; the N400 effect was observed more widely across regions for high global congruence than low global congruence characters. Finally, although the LPC showed phonological interference effect (greater LPC for homophones than controls), this interference was not affected by either global or local congruence.

Discussion

The pattern of behavioral and ERP results supports the assumptions that reading characters for their meaning (a) activates character phonology and (b) this phonological activation involves sublexical structures, just as it does in reading words to pronounce them.

Several key results support these conclusions. First, with the same factorial design of global congruence (high vs. low) and local congruence (congruent vs. incongruent) as the covert naming study of L. Zhou and Perfetti (2021), we found phonological interference in decision times (i.e., longer decision times to homophone trials than to control trials), replicating previous behavioral results (Perfetti & Zhang, 1995). Second, this behavioral effect was not influenced by either the local or global congruence of critical characters, consistent with S. Zhang et al. (1999).

Third, however, ERP results showed a time-dependent dynamic role of mapping congruence in phonological interference. Consistent with ERP responses in covert naming (L. Zhou & Perfetti, 2021), phonological interference on early and mid-latency ERP components (N170, P200, and N400) was modulated by the mapping congruence—especially global congruence—of critical characters. Finally, more in line with decision times, the LPC showed phonological interference, but without any influence of global congruence or local congruence. These results suggest two phases of phonological processes in the meaning judgment task: The first phase is character identification, which involves radical-related phonological process just as in naming tasks; the second phase is meaning comparison, which is associated with the final output phonology of the character.

Finally, we note that in our experiments, when determining mapping congruence and homophone character pairs we have ignored lexical tone, which further differentiates syllable-level phonology. However, we observed strong homophone effects based only on the syllable; these effects could be stronger for homophones with identical syllable plus tone. Below we discuss further each of the more important results.

The Behavioral Phonological Interference Effect, Not Affected by the Mapping Congruence

The behavioral data for meaning judgments showed a reliable (although small), overall phonological interference effect in decision times: Participants responded more slowly (+17 ms) to homophone trials than to control trials. We note these homophone effects are smaller than those observed by S. Zhang et al. (1999) with the same paradigm. It is possible that these smaller effects reflect a response bias that led to faster responses and less systematic variance to "*no*" items because of the imbalanced probabilities of "*yes*" and "*no*" items. Our "*no*" items were twice as likely as "*yes*" items, a contrast with the balanced probabilities in S. Zhang et al. (1999). Interestingly, consistent with S. Zhang et al. (1999), who reported a null effect of local congruence, neither local nor global congruence was significant in the behavioral phonological interference effect in the present study.

The Temporal Dynamics of Phonological Interference, Influenced by the Mapping Congruence

ERP results showed that homophone trials elicited reduced (i.e., less negative) N170, enhanced (i.e., more positive) P200, reduced (i.e., less negative) N400, and enhanced (i.e., more positive) LPC in comparison with control trials. However, these phonological interference effects were dynamically affected by mapping congruence of critical characters. Notably, the phonological interference effects on early and mid-latency ERP components (N170, P200, and N400) were sensitive to mapping congruence: They showed the same pattern of global and local congruence effects reported in the covert naming study (L. Zhou & Perfetti, 2021), where high global congruence led to reduced N170, enhanced P200, and reduced N400 relative to low global congruence. This suggests that the course of character identification that leads to a meaning outcome is the same as that for a naming outcome, initiated by orthographic encoding of lexical and sublexical structures that activate associated phonology and meaning. The next sections consider these ERP effects in more detail.

Early Components: N170 and P200

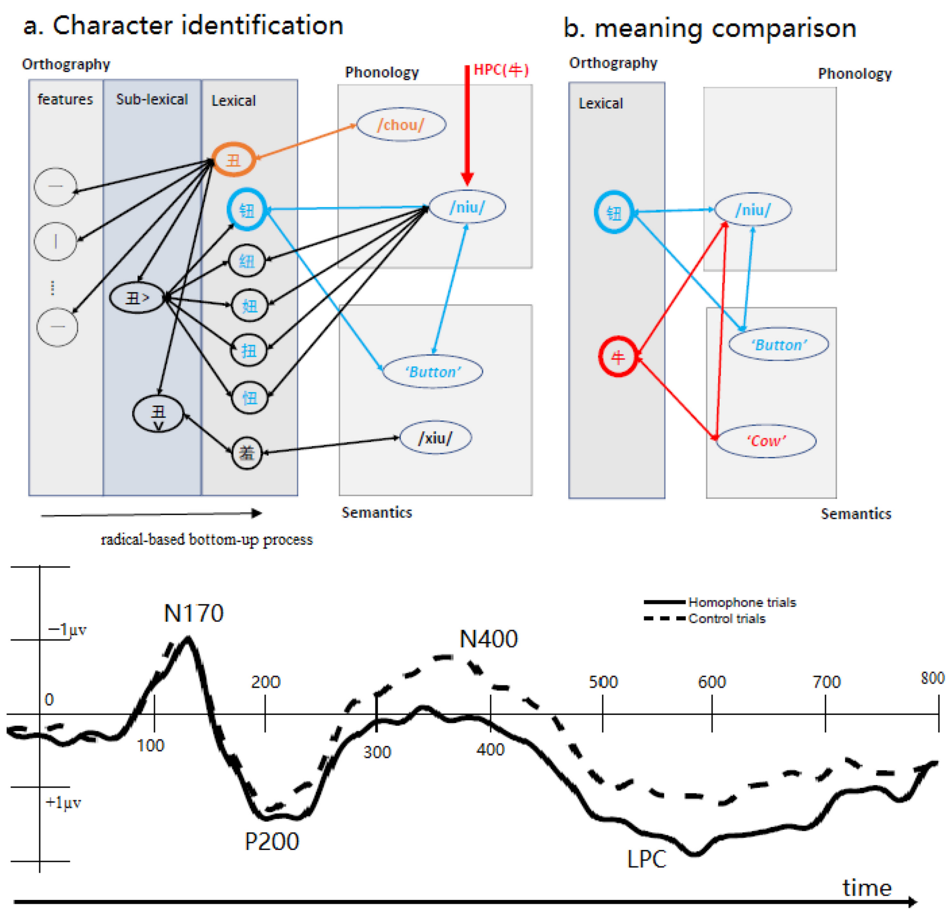
Our study is the first to find a lexical-level phonological interference effect on the N170 and to find that this interference on both the N170 and the P200 is affected by mapping congruence. Homophone trials produced a less negative N170 in posterior regions and a more positive P200 in right hemisphere frontal central regions. An effect of global congruence was present across both time windows and, at N170, was more prominent in locally incongruent (irregular) characters than locally congruent (regular) characters. The P200 effect is consistent with Chen et al. (2007) and Q. Zhang et al. (2009), both of which observed an enhanced P200 phonological interference effect in low-frequency characters; however, this P200 effect was not found in Liu et al. (2003) and L. Zhou et al. (2014).

The fact that the phonological interference at the N170 was modulated by global congruence implicates the role of the character lexicon in influencing the effect of the phonetic radical. Whether a character has the same pronunciation as other characters containing the same radical affects the early stages of ortho-phonological processing. Consistent with the account of L. Zhou and Perfetti (2021) for naming, high global congruence among characters in the same orthographic neighborhood, produce stronger activation of the radical in the target character. The prior presentation of a homophone character (e.g., 牛, /niu/, in Figure 3A) further boosts the identification process of the critical character through its orthographic neighborhood, when this neighborhood has high phonological mapping congruence. The N170 effect may further reflect the activation of the phonetic radical's pronunciation, which is dissociable from the host characters' pronunciation within locally incongruent characters but not within locally congruent characters, making it more prominent for locally incongruent characters that are of high global congruence.

The phonological interference effect at P200 is also dependent on global congruence, in agreement with results of the covert naming study (L. Zhou & Perfetti, 2021). The explanation of the naming result, where there was no preceding character to pre-active pronunciation of the critical character, also applies here: The P200 reflects stronger phonological activation of the single syllable that applies to the entire orthographic neighborhood for characters with high global congruence. In the present study, a further boost to this pronunciation comes from the preceding homophone.

Figure 3

Phonology is Activated Across two Phases in Meaning Judgment Task



Note. (1) The top panel illustrates the two phases of meaning judgment task with the interactive framework of character identification described in L. Zhou and Perfetti (2021): (Panel A) character identification and (Panel B) meaning comparison. (2) The bottom panel shows grand averaged ERP waveforms of homophone (solid line) and control (dashed line) trials with high global congruence characters at C4, where significant Phonological Interference (PhI) effects on P200, N400, and LPC were observed. (3) PhI effects on different ERP components are associated with different phases of meaning judgment tasks (see discussion). See the online article for the color version of this figure.

The Mid-Latency Component: N400

Consistent with all previous studies (Chen et al., 2007; Liu et al., 2003; Q. Zhang et al., 2009; L. Zhou et al., 2014), homophone trials elicited a reduced (i.e., less negative) N400 compared with control trials in midline and right hemisphere, central parietal regions. However, the present study is the first to find that the strength of this phonological interference effect on the N400 is associated with global congruence (consistency). The N400 phonological interference effect is stronger and more widely distributed across regions in characters of high global congruence (+0.702 μv, in the midline and in right hemisphere central-parietal regions) than in characters of low global congruence (+0.249 μv, in right hemisphere central-parietal regions only). The original discovery of the N400 phonological interference effect was interpreted as a congruence effect (Liu et al., 2003), in which the phonological activation of the critical character matches the pronunciation of the preceding character. This phonological congruence in homophone trials may facilitate lexical processing (including phonological and semantic information) of critical characters. This explanation of the N400 phonological effect remains the most likely. Although the N400 is usually associated with meaning congruence, it can also reflect congruence along other dimensions that match task demands, memory, or expectancy (e.g., Federmeier, 2007).

The Late Component: LPC

Homophone trials produced an enhanced LPC compared with control trials in the midline and right central parietal regions. This phonological interference effect was independent of the global and local congruence of critical characters, thus reflective of character-level phonology that has stabilized following the radical-related processes associated with mapping congruence. This interpretation aligns with research on visual conflict tasks (e.g., Stroop or flanker), which finds an enhanced posterior LPC for incongruent trials than congruent trials (Coderre et al., 2011; McKay et al., 2017).

Beyond the stabilizing of phonology is a final process of meaning comparison required by the task. Part of this process lies outside the reading system in the resolution of conflicting signals sent by a homophone trial. The phonology signal for the two characters is "same"; the meaning signal is "different." Resolution of the conflict, and thus successful meaning comparison requires the suppression of the task-irrelevant, congruent phonological information, which interferes with making a "*no*" response that the meaning of the character pairs is unrelated. This process is likely to be reflected in the greater LPC positivity for homophone trials.

Phonology is Activated Across Two Phases in the Meaning Judgment Task

We have highlighted two important patterns: The time-course of phonological interference begins in early ERP components associated with ortho-phonological processing and is sustained through a late positivity associated with post-lexical level phonology and task-specific processes. The mapping congruence effect emerges early but is not observed in the late positivity. The combination of these patterns suggests that phonological interference arises across two phases: The first phase is engaged by radical-related ortho-phonological processes that are sensitive to mapping congruence. The second phase involves the overall output phonology of the character and its effect on a comparison process.

The first phase, character identification, can be described by the interactive framework of L. Zhou and Perfetti (2021), which is based on Taft's account (2006) of the functional orthographic structure of Chinese. As shown in Figure 3A, character (e.g., 钮) identification includes both whole-character and radical-related processes. Activation of the phonetic radical (e.g., 丑>) spreads to the orthographic neighborhood (e.g., 忸, 妞, 扭, 纽) defined by this phonetic radical. The activation of high-frequency orthographic neighbors sharing the same pronunciation with the host character supports the character's phonology, whereas activation of those with different pronunciations generates competition. The net effect of these supporting and interfering patterns determines the effect of global congruence (for details, see L. Zhou & Perfetti, 2021).

Consider a meaning judgment trial: The meaning of the first character must be retrieved and held briefly in memory so that it can be compared with the second character. This meaning is part of an identification process that has activated the orthographic, phonological, and semantic constituents of the character (Perfetti et al., 2005). This assumption contrasts with one that allows phonology to be suppressed when meaning is the task goal. Thus, the pronunciation, as well as the meaning of the character, has been activated when the second (critical) character appears. On a homophone trial (but not on a control trial), the same identification process of critical characters, targeted on meaning but activating phonology as well, produces a pronunciation that is the same as the first character. This leads to the second phase, in which the meanings are compared to make the relatedness decision. Because on the critical trials, the meanings are not related, the decision requires a not-related ("*no*") response, but the phonological information shared by the two characters produces conflicting sameness ("*yes*"), adding time to decisions for homophone trials and producing a late LPC shift in the ERPs.

Figure 3A and B illustrates these identification and comparison phases captured during the presentation of the second character. The identification phase, which may be facilitated by the pre-activation of its phonological representation (Figure 3A), includes phonological activation that is dependent on radical-character mapping congruence and is reflected in early and mid-latency ERP components. The second phase, reflected in the LPC, which showed a phonological interference that was not affected by mapping congruence, captured a stabilized character-level phonological output that was no longer influenced by how the phonology was computed. As the final stage, the conflict between the character's phonological output and its meaning output is resolved so that a meaning comparison is made (Figure 3B).

Greater Role of Global Than Local Congruence in Influencing the Timing of Phonological Interference

As in the covert naming study (L. Zhou & Perfetti, 2021), the present study with the meaning judgment task shows that global mapping congruence plays a greater role than local congruence in affecting phonological interferences, suggesting that the ortho-phonological processes of word identification during naming and meaning judgments tasks are much the same.

The general role of mapping congruence across tasks has implications for the timing of phonological interference. The original ERP study of Liu et al. (2003) showed an effect in the N400, reflective of lexical (character) level phonology, rather than an effect on earlier components reflective of ortho-phonological processing. Although Chen et al. (2007) and Q. Zhang et al. (2009) suggested that this timing difference was due to uncontrolled frequency effects, L. Zhou et al. (2014) still found an effect only on N400 with low-frequency characters. However, these low-frequency characters in L. Zhou et al. (2014) are all locally incongruent. The present study shows that the earliness of phonological interference on ERPs is affected by the mapping congruence: Effects on the N170 were observed only in high global congruence and locally incongruent characters; effects on the P200 were observed only in high global congruence characters.

The reason why mapping congruence matters for the timing of phonological interference is straightforward: The emergence of phonological interference depends on the activation speed and strength of lexical phonology, which in turn depends on the mapping congruence of a character with its orthographic neighborhood (global congruence) and with its phonetic radical (local congruence). Thus, for characters that are low in both global and local congruence (i.e., irregular low-consistency), the magnitude of phonological interference was smallest (+12 ms), concurring with null phonological interference on early ERPs. The radical-related phonological processes, modulated by the mapping congruence, affect lexical phonological computation during character identification in both naming and meaning tasks, by virtue of influencing the speed and strength of lexical phonological activation.

Comparing Phonological Processes in Naming and Meaning Tasks

Global congruence (consistency) effects are more prominent than local congruence (regularity) effects whether the reader's goal is to retrieve pronunciation (L. Zhou & Perfetti, 2021) or meaning (present study). Figure 4 summarizes the time-line of mapping congruence effects in the two studies. In the present study, global congruence effects emerged at the N170, P200, and N400, whereas local congruence showed an effect only at the N170 and only through an interaction with global congruence. In the covert naming study, effects of global congruence were on N170, P200, and central-parietal N400 responses, whereas local congruence affected the frontal N400 and LPC only through an interaction with global congruence. These results lend further support to the conclusion of L. Zhou and Perfetti (2021) that global congruence plays a greater role than local congruence during character identification; local congruence adds to the effect of global congruence in a time window that is influenced by task.

The prominence of global congruence is also observed in the results of pronunciation transcription task in both the present study and the covert naming study after the ERP experiments: Global congruence, but not local congruence, affected the accuracy of a separate task–transcribing character pronunciations. The prominence of global congruence across tasks implies that the overall structure of the orthographic neighborhood, rather than only the radical itself within the character, is functional during an identification process, whatever use is made of the output of that process.

Task effects are not entirely absent, however, across the two studies. First, the timing of the interaction of global and local congruence seems to differ (Figure 4), being later in covert naming (FN400 and LPC), and earlier in meaning judgments (N170). The earlier effect in meaning may arise from the presentation of a preceding character. When this character is a homophone, the phonological activation of the critical character is accelerated, including feedback to the radical from the orthographic neighborhood.

Second, the mapping congruence effect on the LPC response is different across the two studies. The LPC in the covert naming study was affected jointly by global and local congruence, whereas in the present study, it was affected by neither global nor local congruence. The topography of LPC effect also differs in the two studies. In the covert naming study, the greater LPC effect, as a result of high global congruence relative to low global congruence in characters that were locally congruent, was localized in the left-hemisphere recording sites, whereas in the current study, the greater LPC in homophone character pairs than in control character pairs was localized in the midline, right hemisphere, central-parietal regions, which are typical locations for the LPC. If the LPC is sensitive to task demands, the general explanation for the interaction of global and local congruence in naming study may lie in the procedure of the covert naming task, which requires the reader to maintain the first-presented (critical) character's pronunciation in mind long enough to decide whether the second character has the same pronunciation. This may allow the combination of local and global congruence, which provides the strongest possible phonological output for the naming task, to show its effect. This is consistent with the observation that the LPC can reflect perceived memory strength (Brezis et al., 2017). The location of this interaction in left-hemisphere sites might reflect a left-hemisphere phonological memory source, although this is only a possibility in the absence of source localization.

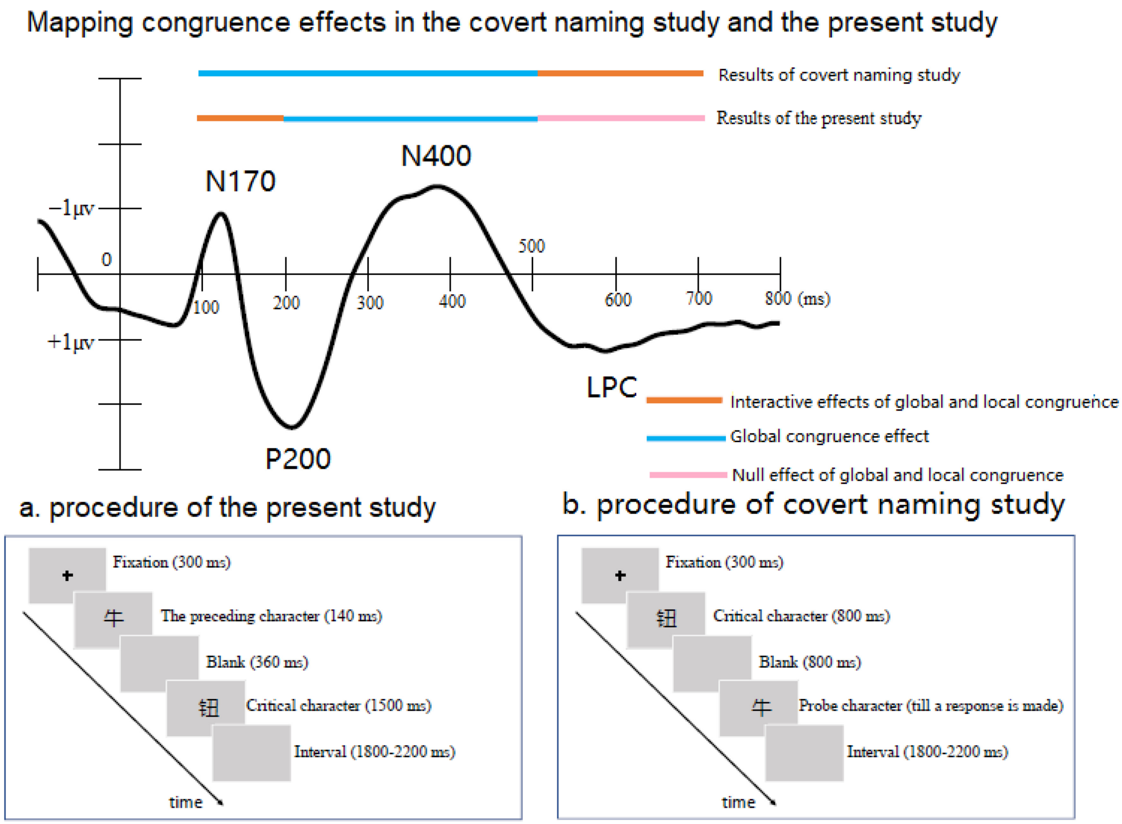
Thus, we have different interpretations for the LPC effect in meaning and pronunciation tasks. In covert naming, the greater LPC (localized in the left hemisphere) for characters that are high in both global and local congruence (regular high-consistency) reflects a stronger phonological activation maintained in memory, which supports performance on the pronunciation sameness task; in meaning judgments, by contrast, the greater LPC for homophone trials reflects a resolution of the conflict between a ("*yes*") sameness signal from pronunciation and a ("*no*") not-related signal from meaning. Other research also shows that the LPC is affected by the demands of the task on phonology. For example, Fisher-Baum et al. (2014) reported that local congruence (regularity) of English words affected the LPC in a delayed naming task through an interaction with word frequency, but not in a proper name detection task.

Implications for the Role of Phonology During Reading

We conclude by suggesting the broader implications of the present study and that of L. Zhou and Perfetti (2021) for the role of phonology in reading. Consistent with the Universal Phonological Principle (Perfetti et al., 1992) and with prior research in Chinese reading, phonological activation during character reading occurs in meaning tasks as well as naming tasks. More important, our studies are the first to report very early and continuous phonological effects (indexed by the mapping congruence effects on the N170, P200, and N400 components) in both naming and meaning judgment tasks, demonstrating the earliness of phonological activation in the morpho-syllabic writing system. The early ortho-phonological effects were quite similar (in the timing of ERP components and patterns of ERP effects) in naming and meaning judgment tasks,

Figure 4

Comparisons Between the Covert Naming Study and the Present Study



Note. (1) The top panel illustrates mapping congruence effects on different ERP components (N170, P200, N400, and LPC) observed in covert naming (L. Zhou & Perfetti, 2021) and in the meaning judgments of the present study. The ERP waveforms are the grand average of all critical trials (including homophone and control trials for all targets). Global congruence shows a continuous effect across early and mid-latency ERP components (N170, P200, and N400) in both naming and meaning judgments; local congruence shows an effect only in interaction with global congruence, early in the present meaning judgment study, late at the LPC in naming. (2) The bottom panel illustrates the procedures of the covert naming study and the present study. See the online article for the color version of this figure.

suggesting that sublexical phonological processing is an inherent part of word identification, not dependent on task demands. Thus, a general implication is that phonology is intrinsic to orthographic processing, and not easily affected by strategic control.

This view appears to contrast with the proposal of Frost (1998), which argues that although phonology is always activated, its level depends on the demands of the task and the writing system. Thus, lexical access in deep orthography may engage a relatively impoverished phonological representation. On this account, the lexical access of the irregular word PINT engages a phonological representation that does not necessarily involve the activation of the vowel /aɪ/ inside PINT. This argument is mainly based on behavioral research in alphabetic languages showing inconsistent effects of mapping congruence (regularity or consistency) in tasks (e.g., lexical decision task in Seidenberg et al., 1984, and semantic categorization task in Taft & van Graan, 1998) that do not require phonology. However, behavioral measures can fail to detect the range of processes that underlie an overt response. The present study found a null effect of mapping congruence on reading times but early and sustained effects across 500 ms of ERP indicators. It is undoubtedly correct that both writing systems and task demands influence word identification processes including its phonological aspects. However, it also seems that adding research using passive measures of temporal dynamics to the picture can confirm a more robust role for ortho-phonological mapping. Echoing Halderman et al. (2012), our ERP studies suggest that a stronger phonological theory is needed, one that accommodates very early and continuous effects of phonology even in the morpho-syllabic writing system in both naming (L. Zhou & Perfetti, 2021) and meaning judgment. We suggest that the early (pre-pronunciation) phase of ortho-phonological processing is much the same whether the output of this processing requires meaning or pronunciations.

Nevertheless, it is worth noting that how the writing system structures its graphic units affects the details of phonological processes. The mapping congruence of Chinese characters, which results from the orthographic structure of characters, is not the same as that of an alphabetic word (for details, see L. Zhou & Perfetti, 2021). More important, the normal framing of "phonological mediation" in reading alphabetic language, which implies the assembly of phonemes, does not apply to Chinese reading (see also Tan &

Perfetti, 1997). The sublexical pathway of character identification is through the orthographic neighbors that contain the same phonetic radical. Thus, the sublexical pathway in Chinese is lexically based.

In the framing of lexical constituency model (Perfetti et al., 2005), orthography, phonology, and semantics are three interconnected constituents of word identity. Character identification occurs threshold style, with activation of all constituents co-occurring to converge on a unique identity, a specific syllabic morpheme. As observed in the present study, the very early processes involving the phonetic radical activate orthographic and phonological information that accumulates to the threshold of character identification. For complex characters, semantic radicals may activate semantic information that also serves character identification. On this possibility, the concept of mapping congruence is further generalized to ortho-semantic processes based on the connections of a character (e.g., 斛) to meaning features of ortho-semantic neighbors (e.g., 斜, 斟, 料) sharing the same semantic radical (e.g., 斗). Skilled readers can learn the statistical distributions of orthography-to-semantics mappings over years of reading experience, leading to a significant role for global orthography-to-semantics mapping congruence in character identification. Our framing of global mapping congruence, as reflected in networks of both ortho-phonology and ortho-semantics, aligns well with theories that use distributed representations to explain meaning processing of multi-morpheme words (e.g., Plaut, 1996; Stevens & Plaut, 2022).

Finally, the demonstrated phonological effects in Chinese character identification literature are syllable-based, whereas the phonological effects of alphabetic word identification involve various grain sizes, including phonemes, rimes, and syllables. This reflects the contrast of the writing systems; specifically, Chinese characters encode syllables rather than phonemes. However, this does not mean Chinese readers are unaware of sub-syllabic segments. Beginning readers of Chinese are taught the sub-syllabic segments (i.e., the consonants and vowels within each syllable) by learning a phonetic or alphabetic pinyin script.[6]

Conclusion

The present study demonstrates phonological activation during the earliest ortho-phonological stage of Chinese character identification and, further finds that this early stage involves sublexical structures whose effects are most robustly realized through ortho-phonological neighborhoods that provide global congruence. This phonological activation occurs in a meaning judgment task that would be well-served if phonology could be suppressed. We conclude that global ortho-phonological mapping congruence of the read character with its orthographic neighborhood plays a more prominent role in identification than the local congruence between a character and its sublexical unit (a radical) whether the character is read for meaning or for naming. Local congruence adds to the effect of global congruence at certain time window that is dependent on the task. At the most general level, we suggest that the earliest phase of ortho-phonological processing is automatic and not dependent on whether the task requires meaning or pronunciation.

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[6] Before learning Chinese characters, knowledge of the subsyllabic segments (i.e., the consonant and vowels) are taught to children, in mainland China through the alphabetic pinyin script and in Taiwan through a phonetic script; however, in Hong Kong, Chinese characters are taught by rote learning (Ziegler & Goswami, 2005).

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