Bilingualism: Language and Cognition

cambridge.org/bil

Monolingual and Bilingual Phonological Activation in Cantonese

Ming Yan[1,2,*], Yingyi Luo[3,*] and Jinger Pan[4]

[1]Department of Psychology, University of Macau, Macau; [2]Center for Cognitive and Brain Sciences, University of Macau, Macau; [3]Institute of Linguistics, Chinese Academy of Social Sciences, Beijing and [4]Department of Psychology, The Education University of Hong Kong, Hong Kong

Research Article

*Ming Yan and Yingyi Luo contributed equally to this work.

Cite this article: Yan M, Luo Y, Pan J (2023). Monolingual and Bilingual Phonological Activation in Cantonese. *Bilingualism: Language and Cognition* **26**, 751–761. https://doi.org/10.1017/S1366728923000123

Received: 18 April 2022
Revised: 22 November 2022
Accepted: 16 January 2023
First published online: 23 February 2023

Keywords:
Mandarin; Cantonese; bilingualism; phonology; eye movement

Address for correspondence:
Jinger Pan,
Department of Psychology,
The Education University of Hong Kong,
10 Lo Ping Road, New Territories,
Hong Kong
E-mail: jpan@eduhk.hk

Abstract

Previous research has provided evidence for cross-language phonological activation during visual word recognition. However, such findings mainly came from alphabetic languages, and readers' familiarity with the two scripts might differ. The present study aimed to test whether such cross-language phonological activation can be observed in Chinese, a logographic script, without the confounding factor of script familiarity as readers read the same script in different languages. Cantonese–Mandarin bilinguals were tested in an eye-tracking experiment in which they were instructed to read sentences silently. A target word in the sentence was replaced by either a homophone in both Cantonese and Mandarin, a homophone in Cantonese or in Mandarin only, or an unrelated character. The results showed that native Cantonese readers could activate phonological representations of L1 and L2 while reading Chinese sentences silently. However, the degree to which they relied on phonological decoding in L1 and L2 varied in the two languages.

Introduction

When reading sentences, information from different aspects of words becomes available during lexical access. Critically, sound-related properties of orthographic patterns are activated automatically for readers' lexical processing, even when reading silently. Much of the theoretical debate about this has been driven by language comparative research, especially between the reading of logographic scripts like Chinese and alphabetic scripts like English and German. According to the dual route model of word reading (e.g., Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), semantics can be accessed either directly from orthography or indirectly via phonological mediation. While phonological mediation is often found in English (van Orden, 1987), Chinese is well-known for its optimization of fast and direct access to meaning (Hoosain, 1991; Yan & Kliegl, 2023), as evident by early foveal (Chen & Shu, 2001; Zhou & Marslen-Wilson, 1999, 2000) and parafoveal lexical processing of semantics (Yan, Richter, Shu & Kliegl, 2009; Yan, Zhou, Shu & Kliegl, 2012) bypassing the mediation of phonology. As such, studies of Chinese reading are important not only to document language-specific aspects of reading but also to achieve universal reading principles. The present study tested late Cantonese–Mandarin bilinguals[1] who were native to Cantonese and spoke Mandarin as their second language (L2) in order to investigate how the two phonological representation systems contributed to lexical access during their silent reading of Chinese sentences. In the following, we first review prior works on phonological activation during reading employing the error disruption paradigm and the eye-tracking technique. We then focus on cross-language studies, which shed light on the mechanism of mapping multiple phonological representations on one written form in the lexicon. Finally, we elaborate on the characteristics of the two (spoken) languages involved, Cantonese and Mandarin.

The error disruption paradigm and eye-tracking experiments

One piece of evidence for the importance of phonology in sentence-reading comprehension has been illustrated with the error disruption paradigm (Doctor & Coltheart, 1980). In their study, the participants were presented with sentences containing certain typographic errors and were instructed to read silently and judge the meaningfulness of these sentences. It was noted that all the sentences should have been rated as meaningless due to the errors; the

[1]It is under debate among linguists whether Cantonese is considered a dialect of the Chinese language or a language of its own. Cantonese and Mandarin are generally not mutually intelligible in spoken forms. From this perspective, Cantonese can be treated as a language and thus Mandarin is considered a second language for native Cantonese speakers. On the other hand, the traditional criterion of mutual intelligibility is questionable (Chappell, 2001), mainly because among the native Cantonese population there is a high degree of mutual unintelligibility between subdivisions. In this paper, we refer to Cantonese as a language for the sake of simplicity, but remain neutral on the debate.

© The Author(s), 2023. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

participants, however, showed a higher likelihood of falsely accepting the sentences with homophonic errors as meaningful (e.g., "He ran *threw* the street" for "He ran *through* the street") than those containing unrecoverable words (e.g., "He ran *sew* the street"). This homophone recovery effect has been replicated in later studies (e.g., Coltheart, Avons & Trollope, 1990; Treiman, Freyd & Baron, 1983), suggesting that alphabetic readers achieve lexical access via phonological decoding.

Phonological activation has also been explored in a sentence-reading comprehension task with readers' eye movements recorded. Eye-tracking allows measurement of reading in a relatively natural scenario and provides psychologists with a powerful tool to understand implicit cognitive processing at high temporal and spatial resolutions. There is consistent evidence that not only phonemes but also detailed articulation-specific sub- and supra-phonemic features are used early during visual recognition of English words (Ashby & Clifton, 2005; Ashby, Treiman, Kessler & Rayner, 2006). A combination of the eye-tracking technique and the error-disruption paradigm provides more fine-grained measurements of lexical processing at the individual word level. The rationale for this paradigm is that erroneous substitutions that preserve critical linguistic features for readers to recover from should be less disruptive to reading than other non-recoverable substitutions. Specifically, as shown in previous studies, a longer fixation duration on a word indicates a greater processing effort and more difficulty in recovery (Inhoff & Topolski, 1992; Jared, Ashby, Agauas & Levy, 2016). These experiments provide evidence that phonology plays an important role in lexical activation during silent sentence reading (Daneman & Reingold, 1993; Rayner, Pollatsek & Binder, 1998).

Notably, the error disruption paradigm has revealed that the role of phonological decoding in lexical access varies as a function of reading skills. Doctor and Coltheart (1980) showed that the false-acceptance rate of sentences containing homophonic errors decreased with the increase of readers' ages. This finding is convergent with other evidence, suggesting that beginning readers are more likely to rely on phonological information than more skilled and advanced readers, who, in contrast, rely on a more direct and orthography-based procedure (Ehri, 1992; Frith, 1985; Harm & Seidenberg, 2004; Seymour, 1997). Similar eye-tracking evidence from the error disruption paradigm has been reported in Chinese (Zhou, Shu, Miller & Yan, 2018). Chinese children showed a recovery effect during their fixations on pre-target words caused by homophone targets, whereas this effect did not emerge in adults until they had accomplished lexical access, and it appeared only on post-target words. The results of their study, therefore, suggest that phonological decoding in lexical access is mediated by reading skill, even among readers of Chinese, a writing system in which the spelling-sound correspondence is rather opaque.

As children learn to read, they start learning to associate written characters/words with their oral vocabularies (Harm & Seidenberg, 2004). An interesting question to be asked, then, is how phonological routes would function if there were more than one spoken system involved. Would the predominant spoken system always activate due to the fact that it is used more often, or would the specific phonological system activated be situational-dependent? Before elaborating on this question, we review below cross-language evidence of phonological activation in a specific situation of processing cognates, where words have common meanings and forms in two languages.

Cross-language phonological activation in bilinguals

Many studies on cross-language phonological activation focused on bilinguals' lexical access of translation equivalents (i.e., cognates) that share meaning and form properties. Evidence from alphabetic languages has revealed a priming effect for cognates during the processing of word lists, even when the two languages are cross-scripted (English-Hebrew: Gollan, Forster & Frost, 1997; Korean-English: Kim & Davis, 2003; Japanese–English: Nakayama, Sears, Hino & Lupker, 2012), suggesting that lexical phonology is cross-linguistically integrated and represented for bilinguals (Dijkstra & Van Heuven, 2002; Dijkstra, Wahl, Buytenhuijs, Van Halem, Al-Jibouri, De Korte & Rekké, 2019). Specifically, Nakayama, Verdonschot, Sears, and Lupker (2014) accented the influence of phonological similarity between L1 (Japanese) primes and L2 (English) targets with Japanese–English cognates. They found that phonologically similar cognates were responded to more rapidly than were dissimilar ones.

However, as far as Chinese, the logographic script, is concerned, the role of phonology in cognate processing becomes somewhat unclear and inconsistent. On the one hand, for late Chinese–English bilinguals, Chinese words can phonologically prime English targets that are similar in pronunciation (e.g., Zhou, Chen, Yang & Dunlap, 2010). On the other hand, priming effects have been found not to differ between phonologically similar and dissimilar Chinese–Japanese cognate word pairs among late bilinguals, suggesting little phonological facilitation effect (Liu, Lupker & Nakayama, 2022; Liu, Wanner-Kawahara & Nakayama, 2019). These results may hint at a late role of phonology in Chinese lexical access.

The Chinese language and phonological activation

Chinese is known for its logographic nature. The basic writing units, characters, are disconnected square-shaped units occupying the same horizontal and vertical extents irrespective of visual complexity. Importantly, one character usually maps to one morpheme when combining with other character(s) to form a word or a phrase. Different from the alphabetic languages, the character's pronunciation, which is monosyllabic with a lexical tone, is not obtained transparently from its visual form. Visually similar Chinese characters can have fundamentally different pronunciations.

Chinese has variations in the written and spoken forms, as it is a language with a long history and has undergone development in different areas. Relevant to this study, in Macau, Chinese characters are written in accordance with Traditional Chinese (as opposed to Simplified Chinese, which is used in Mainland China). While the majority of the population speaks Cantonese in Macau, the numbers of Mandarin-speaking people are increasing nowadays. Although Cantonese and Mandarin share a largely common vocabulary, they are mutually unintelligible in the spoken forms, because the characters have different pronunciations in the two languages. As such, bilingualism in Cantonese and Mandarin utilizes one script in writing and two phonological systems in speaking. On the other hand, a huge amount of words in Cantonese and Mandarin languages, although differing in the degree of phonological similarity, share common meanings, orthographies and even syntactic functions. In this sense, these words can be considered as cognates from the bilingual perspective, just like Chinese–Japanese cognates.

It should be noted that, despite the similar phonological hierarchy of Cantonese and Mandarin, there are nine lexical tone

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

categories and 700 meaningful syllables in Cantonese while there are five tone categories and 400 meaningful syllables in Mandarin (Tsou, 1976). Given that there are over 50,000 Chinese characters in total, with about 8,000 commonly used ones (Shen & Bear, 2000), there are many homophones in both languages. Importantly, unlike English words, Chinese homophones can be visually dissimilar. For instance, 施氏食獅史, a group of five visually distinct Mandarin homophones with an identical pronunciation of /shi/, means "the story of Mr. Shi eating lions". Similarly in Cantonese, 余與汝遇於雨, with all characters pronounced as /jyu/, it translates as "I encountered you on a rainy day". The feature of high homophone density offers a unique opportunity to explore phonological processing independent of orthographic overlap. An interesting phenomenon to note is that a pair of homophones in Mandarin can be either homophonic or non-homophonic in Cantonese and vice versa (Chu & Taft, 2010), which allows an orthogonal manipulation of homophony in the two languages using a within-item design. For instance, the character 習 (Mandarin: /xi2/ and Cantonese: /zaap6/) has a Mandarin-only homophone 席 (Mandarin: /xi2/ and Cantonese: /zik6/) and a Cantonese-only homophone 雜 (Mandarin: /za2/ and Cantonese: /zaap6/). In the present study, we made use of this phenomenon to test cross-language phonological processing independent of visual similarity among native Cantonese readers who spoke Mandarin as L2.

Studies of Chinese reading suggest that phonological activation occurs during lexical access. Isolated character/word recognition involves activation of phonological properties (Tan & Perfetti, 1997, 1999), although such homophonic priming effects have been demonstrated mainly under long stimulus onset asynchrony (SOA) and thus may hint at a relatively late phonological process in Chinese (Chen & Shu, 2001; Zhou & Marslen-Wilson, 1999, 2000; Zhou, Marslen-Wilson, Taft & Shu, 1999). Considering the unique properties of Chinese, the question also arises about the degree to which detailed phonological features are activated during visual word recognition. For instance, variety-specific tonal characteristics can affect processing during silent reading in Chinese, leading to shorter viewing durations and fewer refixations on neutral-tone words than on full-tone words (Yan, Luo & Inhoff, 2014). In a later study, Luo, Yan, Yan, Zhou and Inhoff (2016) further recorded electrophysiological activities and showed that, in comparison to full-tone words, neutral-tone words elicited smaller N100 (i.e., a negative going potential that peaks around 100 ms after stimulus onset) and anterior N250 amplitudes and a larger N400 amplitude. Testing a different tone-change phenomenon in Chinese with native Mandarin speakers, Pan, Zhang, Huang, and Yan (2021a) reported that sandhi-tone target words elicited longer viewing durations than base-tone target words when the words were infrequent, suggesting a more direct lexical access route for frequent words and a more phonology-based route for infrequent ones.

Previous studies of phonological activation during the silent reading of Chinese sentences focused almost exclusively on Mandarin, with the majority using the Simplified Chinese script. Therefore, little is known about the role of phonology in Cantonese written in Traditional Chinese script. The most relevant study was conducted by Lam, Perfetti, and Bell (1991). They measured Cantonese–Mandarin bilinguals' reaction times in a homophone judgment task. Four types of critical words, homophones in both languages, in Cantonese-only, in Mandarin-only, and in neither language, were presented. They found that the participants were slower in responding to word pairs that differed in their homophone status in either language. Although the study made an important step towards understanding the effect of L2 phonology on L1 lexical access, there are a few methodological considerations to be made. First, the results were based on small samples of participants and items, when evaluated according to the current standard. There were only 16 native Cantonese participants and only 30 items for each of the four experimental conditions. Second, a between-item experimental design was adopted, in which each condition had a different word list. Consequently, the study suffered from possibly uncontrolled confounding factors, reducing its reliability. Third, the homophone judgement task was rather explicit, encouraging readers' effortful activation of phonological representations. Fourth, their critical comparison of Mandarin homophone pairs that were either homophonic or non-homophonic in Cantonese was based on "yes" responses versus "no" responses, because the participants had to make different responses to these two groups of word pairs when judging Cantonese pronunciation. Finally, the readers' reaction times in the task were quite long. Therefore, the results only hinted at a late processing stage of phonology in lexical access. However, this study nevertheless provided us with a direction to study cross-language phonological activation with homophones in Cantonese and Mandarin.

The role of phonology during Chinese sentence reading has also been examined using the error disruption paradigm. A study by Wong and Chen (1999) is another rare example that focused on Cantonese phonology. They manipulated the type of erroneous first character within a two-character target word (i.e., visually similar, homophonic, and unrelated substitution characters) and found a recovery effect from the visually similar substitutions in first-fixation duration (FFD; duration of the first fixation on a word irrespective of the number of fixations) and gaze duration (GD; the cumulative duration of all fixations during the first-pass reading of the word). However, no homophone recovery effect was found in either of these two fixation measures. Arguably, experimental effects that emerge in FFD are assumed to take place in an earlier temporal stage than those that appear only in GD when a target word is re-fixated on. Likewise, effects shown only in second-pass reading measures such as total reading time (TRT, sum of all fixations on a word, including regressive fixations) reflect a late processing stage (Inhoff, 1984; Inhoff & Radach, 1998). In this sense, the results from Wong and Chen (1999) agree with previous studies of Chinese isolated word recognition and suggest that phonological activation may show up late. Two recent eye-tracking experiments focusing on Mandarin homophones (Pan, Laubrock & Yan, 2021b; Pan, Yan, Laubrock & Shu, 2019) did not find evidence for early homophone recovery in FFD or GD, either. Such an effect only emerged in TRT, supporting the view of late phonological activation in Chinese. Perhaps the disparity in the roles of phonology in Chinese and English has been best captured by Feng, Miller, Shu, and Zhang (2001), in a cross-language study. They compared how skilled English and Chinese readers rely on word shape and phonology for lexical recovery during silent sentence reading. Their English readers showed an early phonological recovery effect, whereas the Chinese readers only had a late effect.

The present study

As reviewed above, the identical written form of Chinese is mapped to several very different spoken systems, of which the most widely used are Cantonese and Mandarin. Research on

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

Cantonese–Mandarin homophones offers a unique opportunity to understand phonological representation among bilingual readers, free of confounding caused by script familiarity, because the same written forms of target words and sentences are used in both. We aimed to incorporate the research ideas reviewed above to explore how L1 and L2 phonological knowledge is used during late Cantonese–Mandarin bilinguals' silent reading of Chinese sentences. We adopted a natural reading comprehension task with the error disruption paradigm, in which no explicit response was required to study readers' implicit phonological activation. To activate their specific phonological representations for L1 or L2 processing, our participants were required to read aloud a paragraph in either Cantonese or Mandarin (i.e., the primed language) before they read the experimental sentences for eye-movement recording. In addition, a within-item design was chosen, in which each target word was paired with substitutions under different conditions, to achieve a better experimental control. The manipulation of homophones of dual-language and single-language allowed us to examine if the lexical access of a word is facilitated with strengthened phonological cues from both languages for bilinguals. Finally, for more reliable results, we used larger samples of participants and items than were used in previous related studies.

Our predictions were clear, as follows. First, based on previous studies (Pan et al., 2019, 2021b; Wong & Chen, 1999), we hypothesized that phonological information is processed in a relatively late stage in Chinese word recognition. Therefore, we expected an overall late homophone recovery effect in Chinese. Second, we hypothesized that different prime languages would activate different language modes, leading to different reliance on phonological decoding for lexical access. As a rule of thumb, skilled Chinese readers are known to have a more direct lexical access than less-skilled readers. Therefore, since our participants were late bilinguals living in an L1-dominant environment, after being primed for L1 and as skilled readers of Cantonese, they were expected to show relatively less phonology-based recovery. In contrast, when primed for L2, our participants were expected to behave as less-skilled readers of Mandarin and thus to rely more on phonological decoding. As a result, we anticipated that L2 phonology activation would be more likely to appear when the readers were primed for their L2 mode, resulting in an overall stronger phonological activation when primed in L2 than in L1. Note that the phonological activation during the L2 mode likely involves both L1 and L2 representations (Oppenheim, Wu & Thierry, 2018).

Method

Participants

Sixty-five participants, with a mean age of 20.9 years ($SD = 2.7$, 40 females), were tested in the eye-tracking experiment. To ensure their language dominance, we carefully chose local students who had undertaken their education in Macau (where Cantonese is the official and the most-used language) since primary school. Two independent samples, of 30 and 40 participants, were recruited for norming studies for target-word predictability and plausibility, respectively. All participants were university students with normal or corrected-to-normal vision and were native Chinese readers of traditional characters and Cantonese speakers. All experimental procedures were reviewed and approved by the Human Research Ethics Committee of the Education University of Hong Kong (No.2017-2018-0195) and approved by the Ethics Committee of the Department of Psychology, University of Macau (SONA-2020-05). The participants gave their written informed consent prior to the experiment, which conformed to the tenets of the Declaration of Helsinki.

The participants filled out a brief adapted version of the language-history questionnaire created by Li, Sepanski, and Zhao (2006). All participants were born in native Cantonese-speaking families. They all indicated that they spoke Cantonese with their mothers and all but two with their fathers. All participants used Cantonese as their daily communication language and therefore were not asked to report their L1 language proficiency. The participants reported late acquisition Mandarin ($M_{\text{age of acquisition}} = 6.6$, $SD = 2.6$) and had learned it officially for an average of 14.3 years ($SD = 3.3$). Their self-evaluations of their Mandarin language skills indicated high proficiencies in reading ($M = 5.7$, $SD = 1.1$), writing ($M = 5.4$, $SD = 1.2$), oral communication ($M = 5.0$, $SD = 1.4$) and listening ($M = 5.3$, $SD = 1.3$), all rated on 7-point scales.

Design and materials

We adopted a 2×5 two factorial within-subject and within-item design. The first factor was LANGUAGE MODE. We collected the participants' eye movements in two testing sessions; each session started with their reading aloud a short passage in Cantonese or Mandarin to activate their respective phonological modes. The second factor was SUBSTITUTION TYPE. Each target character was paired with three different homophonic characters and an unrelated one. The three homophone conditions were bilingual homophone (C+M+), Cantonese-only homophone (C+M-) and Mandarin-only homophone (C-M+). In the identical (no substitution) condition, the participants saw the correct target character itself and in the baseline condition they saw an unrelated character (C-M-). Therefore, 10 different reading lists were created and each participant silently read two of them containing two different sets of sentences, with one list in a pre-activated language mode of Cantonese and the other one in Mandarin.

We selected 75 quintuplets of critical characters for the identical, C+M+, C+M-, C-M+ and C-M- substitutions. The critical characters were embedded in the position of the first character in two-character target words. Therefore, only the correct target character formed real words with the following character. The substitution characters were matched strictly for frequency [$F(4, 296) = 1.304$, $p = .269$; RIH-CUHK, 2001] and number of strokes [$F(4, 296) = .412$, $p = .800$; Table 1]. For each set of the critical characters, two target words and two different sentence frames were constructed, resulting in a total of 150 experimental sentences. Pre-target and target word regions, which were always two characters in length, were never among the first or last three words in the sentences. The target-preceding sentence frames, including the pre-target words, were constructed to be non-predictive for different types of substitution characters, in order to minimize top-down processing. In the cloze test for predictability, each participant was presented with a half set of the sentence frames up to the pre-target words and asked to complete the sentences. As expected, the non-identical substitution characters were equally unpredictable [$F(3, 447) = 1.60$, $p = .189$]. In addition, we conducted a plausibility rating using a 5-point Likert scale (1 = not plausible at all and 5 = highly plausible). The participants

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

Table 1. Substitution Character Properties

	Type of Substitution				
	Identical	Bilingual	Cantonese	Mandarin	Unrelated
Example	效	孝	拷	笑	眷
Can. Pronunciation (Jyutping)	haau	haau	haau	siu	gyun
Man. Pronunciation (Pinyin)	xiao	xiao	kao	xiao	juan
Log Frequency	3.16 (0.79)	3.01 (0.73)	2.94 (0.75)	2.90 (0.70)	3.02 (0.69)
N. strokes	10.8 (3.6)	11.4 (3.5)	11.5 (3.9)	11.1 (4.8)	10.9 (4.2)
Plausibility	4.01 (.56)	2.38 (.51)	2.39 (.46)	2.38 (.48)	2.30 (.40)
Predictability	.49 (1.24)	.03 (.23)	.00 (.00)	.00 (.00)	.01 (.08)

An example set of critical characters with their pronunciations in Cantonese provided in Jyutping (formally known as the Linguistic Society of Hong Kong Cantonese Romanization Scheme, a Romanization system for Cantonese) and pronunciations in Mandarin provided in Pinyin. See the example sentence in Figure 1 in which the example substitution characters here were embedded. Means (and standard deviations in parentheses) of log-transformed character frequency (number of occurrences per million), number of strokes (count), plausibility rating (5-point scale) and predictability (percentage) of the substitution are shown.

were presented with sentence frames up to and including the substitutions and were asked to rate how the sentences would end meaningfully. Plausibility did not cause the non-identical substitutions to differ significantly [$F(3, 447) = 1.249$, $p = .291$].

Apparatus

The participants' eye movements were recorded with an Eyelink Desktop system running at a sampling rate of 1000 Hz. Each sentence was presented in a single line on a 24-inch Dell E2416H monitor (resolution: 1920 x 1080 pixels; frame rate: 60 Hz) using the Song font. The participants were seated 65 cm from the monitor and were tested individually with their heads placed on a chin-and-forehead rest. Each character subtended 0.9° of visual angle. All recordings and calibrations were done monocularly based on the right eye; viewing was binocular.

Procedure

The experiment was completed in two testing sessions. The participants were first instructed to read a short passage aloud, in either Cantonese or Mandarin, to activate their respective LANGUAGE MODES, after which their eye movements during sentence reading were collected. The second session followed the same procedure and tested the other language mode. The order of the two sessions was counterbalanced across the participants.

Before eye-movement data collection started, the participant's gaze position was calibrated with a 9-point grid (maximum errors < 0.5°). Prior to each sentence, an additional calibration was performed if a participant's gaze was not detected on the initial fixation-point. Fixation on the initial fixation-point initiated presentation of the next sentence, with its first character occupying the fixation-point. The participants were instructed to read the sentences silently for comprehension, then fixate on a point in the lower right corner of the monitor, and finally press a keyboard button to signal completion of a trial. We used a silent sentence-reading comprehension task to test implicit phonological activation. The participants were also told that there might be typographical errors in the sentences and that they should try to ignore them and understand the sentence meaning. They received 12 practice trials before reading the experimental sentences. We randomly selected 48 experimental sentences (32% of all sentences), each to be followed by an easy yes-no comprehension question, to encourage the participants' engagement with the reading task. Data from three participants with accuracy lower than 70% were discarded from the analysis. The remaining 62 participants, on average, answered 85.4% of the questions correctly ($SD = 4.9\%$ and range: 75% to 95%).



Fig. 1. A set of example sentences with the target word (效益, *efficiency*) replaced by different types of substitutions. The target word regions are highlighted with a gray background only for illustrative purposes and were presented normally during the experiment. The target sentence translates as: *They need to work on improving efficiency*.

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

Data analysis

Fixations were determined with an algorithm for saccade-detection (Engbert & Kliegl, 2003). For fixation-duration analyses, we screened our data at several levels, as described below. Overall, 450 (4.8%) trials were removed due to participants' blinks, coughing or body movements during reading, or to tracker errors. In total, 516 target words (6.7% of all fixated target words) with FFDs shorter than 60 ms or longer than 800 ms, or GDs longer than 1000 ms, or TRTs longer than 1600 ms were removed. Additionally, using an a priori criterion (Briihl & Inhoff, 1995), 325 target words (4.2% of all fixated target words) with regressions from them were discarded because they may reflect incomplete lexical processing. The remaining 4899 observations were largely distributed evenly across the conditions.

Estimates were based on (general) linear mixed models (GLMMs/LMMs) using the lme4 package (Version 1.1-23; Bates, Maechler, Bolker & Walker, 2015) in the R environment (Version 3.6.3; R Development Core Team, 2020). The dependent variables were viewing duration measures explained earlier for LMMs, as well as skipping probability (SP, the probability of a word not being fixated on during first-pass reading) and refixation probability (RP, the probability of a word receiving multiple fixations during first-pass reading) for GLMMs. Language mode, substitution type, and their interactions were the fixed effects (i.e., independent variables) in the (G)LMMs. We specified a sum contrast for language mode and a treatment-contrast with the unrelated condition as a reference baseline for substitution type. The first level of the treatment-contrast was between the no-substitution condition and the unrelated condition and indicated an effect of word legality. Analogously, the other three levels of the contrast between the three homophone substitution conditions and the unrelated condition reflected effects of bilingual, Cantonese and Mandarin homophony, respectively. We reported parsimonious LMMs for successful convergence (Bates, Kliegl, Vasishth & Baayen, 2015; Matuschek, Kliegl, Vasishth, Baayen & Bates, 2017). Additionally, we calculated *p*-values using the *lmerTest* package (Version 3.1-2; Kuznetsova, Brockhoff & Christensen, 2017). The dependent variables of viewing duration measures were log-transformed in the LMMs (Kliegl, Masson & Richter, 2010). Analyses for untransformed and log-transformed durations yielded the same patterns of significance.

Results

Overall, the readers skipped the target regions more often ($b = 0.368$, $SE = 0.100$, $z = 3.685$, $p < .001$) and refixated on them less often ($b = -0.964$, $SE = 0.112$, $z = -8.619$, $p < .001$) in the no-substitution condition than in the baseline condition. There were no statistically significant differences between the two reading modes, or between the homophone substitution conditions and the unrelated condition in skipping or refixation probabilities (p-values > .1; Table 2). Our traditional-Chinese readers spent less time processing the target region when the correct word was presented (FFD: $b = -0.132$, $SE = 0.014$, $t = -9.095$, $p < 0.001$; GD: $b = -0.271$, $SE = 0.022$, $t = -12.403$, $p < 0.001$ and TRT: $b = -0.367$, $SE = 0.024$, $t = -15.577$, $p < 0.001$). As expected, the identical condition did not introduce any interruption and led to a shorter time than other types of substitutions, indicating that our data were reliable. More relevant to the core research question of the present study, the participants fixated on the bilingual homophones (C+M+) more briefly over the baseline (C-M-; FFD: $b = -0.034$, $SE = 0.015$, $t = -2.328$, $p = 0.020$ and TRT: $b = -0.099$, $SE = 0.019$, $t = -5.206$, $p < 0.001$, with a marginal significant effect in GD: $b = -0.035$, $SE = 0.020$, $t = -1.754$, $p = 0.080$). The main effect of L1 phonological recovery from Cantonese homophones (C+M-) appeared only in TRT ($b = -0.053$, $SE = 0.019$, $t = -2.809$, $p = 0.005$). In contrast, there was no reliable main effect of L2 phonological recovery ($p > 0.1$).

In addition to the main effects reported above, we also observed significant interactions in TRT between language mode and bilingual homophony (C+M+; $b = 0.080$, $SE = 0.040$, $t = 2.031$, $p = 0.042$), between language mode and Cantonese homophony (C+M-; $b = 0.097$, $SE = 0.039$, $t = 2.483$, $p = 0.013$),

Table 2. Target Region Condition Means

	Type of Substitution				
	Identical	Bilingual	Cantonese	Mandarin	Unrelated
Cantonese					
SP	17 (15)	13 (14)	14 (15)	13 (11)	13 (14)
RP	17 (15)	32 (24)	31 (25)	32 (25)	32 (26)
FFD	271 (52)	293 (56)	313 (61)	296 (70)	302 (67)
GD	318 (77)	394 (112)	412 (117)	407 (110)	412 (115)
TRT	340 (101)	434 (131)	461 (145)	469 (148)	475 (156)
Mandarin					
SP	16 (14)	13 (14)	13 (13)	13 (11)	12 (12)
RP	16 (14)	29 (24)	28 (23)	32 (25)	31 (24)
FFD	268 (55)	303 (59)	300 (62)	315 (71)	303 (67)
GD	309 (67)	390 (102)	399 (121)	412 (124)	409 (121)
TRT	335 (81)	432 (115)	444 (147)	459 (142)	498 (170)

Means (and standard deviations in parentheses) for skipping probability (SP) and refixation probability (RP) in percent, first-fixation duration (FFD), single-fixation duration (SFD), gaze duration (GD), and total reading time (TRT) in ms. Values are computed across participant means.

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

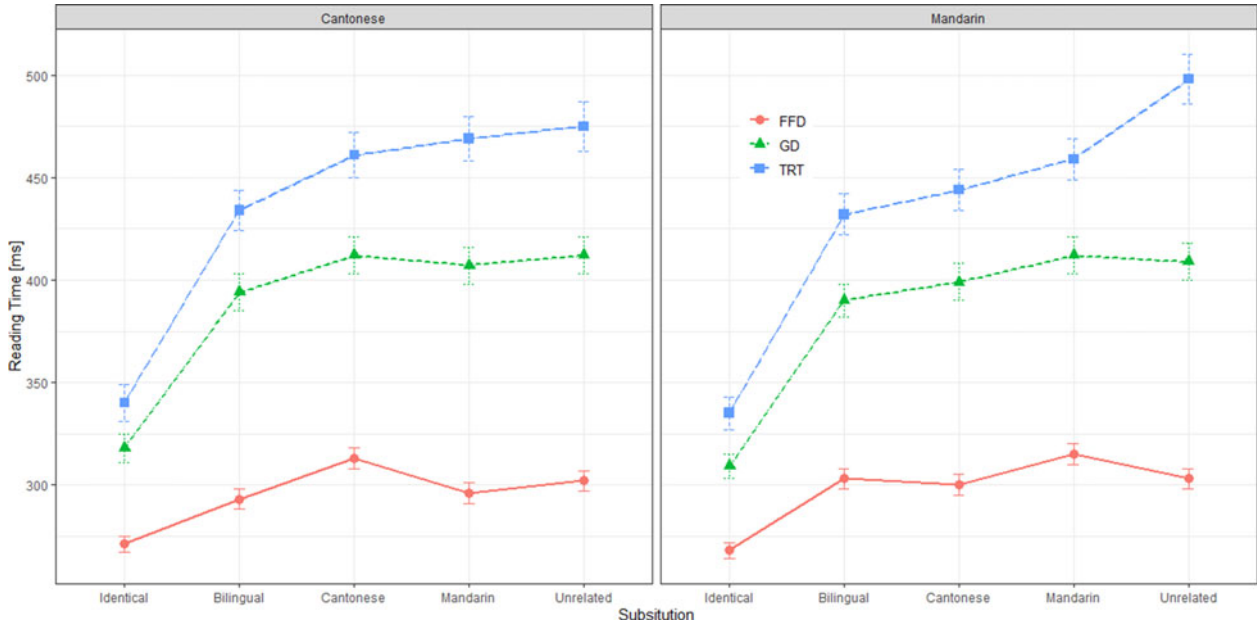


Fig. 2. Means and standard errors of first-fixation (FFD), gaze duration (GD), and total reading time (TRT) for Cantonese reading mode (left panel) and Mandarin reading mode (right panel). Error bars indicate one standard error. Plots were generated with the remef package (version 0.6.10; Hohenstein & Kliegl, 2015) and the ggplot2 package (version 2.1.0; Wickham, 2009).

and a marginally significant interaction between language mode and Mandarin homophony (C-M+; $b = 0.065$, $SE = 0.039$, $t = 1.679$, $p = 0.093$). Figure 2 shows that, in general, in TRT our readers exhibited stronger homophone recovery effects in their L2 (Mandarin) mode (C+M+: $b = -0.137$, $SE = 0.030$, $t = -4.572$, $p < 0.001$; C+M-: $b = -0.100$, $SE = 0.028$, $t = -3.626$, $p < 0.001$; C-M+: $b = -0.056$, $SE = 0.027$, $t = -2.056$, $p = 0.040$) than in their L1 (Cantonese) mode, where the only significant, although weaker, effect was found in the C+M+ condition ($b = -0.064$, $SE = 0.028$, $t = -2.309$, $p = 0.021$). In contrast, the interaction between language mode and the contrast between the no-substitution and baseline conditions were non-significant ($p > 0.1$), indicating a language mode-independent effect of word legality.

Discussion

The present study explored how native Cantonese readers make use of phonological information for lexical recovery during the reading of traditional Chinese sentences. Up to now Cantonese readers' phonological processing in L1 and L2 modes remains largely unknown from the existing literature. The use of eye-tracking methodology during online sentence reading allows us to understand lexical processing in a more natural scenario as compared to many previous studies that adopted isolated word recognition tasks. Additionally, thanks to high temporal and spatial resolutions, eye-tracking indices provide more fine-grained measurements to capture moment-to-moment cognitive processes. One novel contribution of the present study is that readers give different priorities to phonological processing in different language modes, even during the silent reading of Chinese. Reflected by an interaction between bilingual homophony and language mode, the readers showed more phonological-based recovery when their L2 (Mandarin) mode was pre-activated than when L1 (Cantonese) was, suggesting that they may generally rely more on phonological cues in attempting to recover from lexical errors when reading in their L2 mode. In contrast, the readers may employ a more direct lexical access route in their native language mode. In addition, a phonological recovery effect from the L2 homophone was discovered only in the L2 mode, indicating that the readers had a higher degree of activation of the Mandarin phonological coding system after reading aloud a short passage in the language. Interestingly, such a language mode pre-activation procedure seemed to introduce a long-lasting effect through the whole testing session. Finally, effective recovery from L1 homophone was observed with even more salient benefits in the readers' L2 mode, implying robust phonological activation of readers' L1 phonological representation overriding their current language mode. Below we focus our discussion on three interrelated aspects of psycholinguistic research to provide implications for lexical access in Chinese, bilingualism and second language learning.

Our results agree with several previously established critical findings. Chinese reading studies have consistently shown activation of phonological knowledge during visual word recognition (e.g., Tan & Perfetti, 1997). The present study also showed that phonology is among the most important aspects of lexical access in reading Chinese. Overall, the present study has unveiled phonological activation in a relatively natural reading task in which readers comprehend sentences that may or may not contain errors, and it appeared mainly in a late processing measurement of eye movement as reflected by TRT. Chinese is considered a logographic script, optimized for semantics but less so for phonology (Hoosain, 1991). Although lexical access in Chinese involves activation of orthography, phonology and semantics just like in alphabetic scripts (Zhou et al., 1999), most of the experimental evidence from both isolated priming paradigms (Chen & Shu, 2001; Zhou & Marslen-Wilson, 1999, 2000) and sentence reading paradigms (Pan, Yan & Yeh, 2022; Tsai, Kliegl & Yan, 2012; Yan et al., 2009) generally favors a direct lexical access route for Chinese adults. For instance, Yan et al. (2009) reported, in Simplified Chinese, a larger semantic than phonological priming effect from parafoveally presented priming

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

characters. A similar pattern has been reported during horizontal (Tsai et al., 2012) and vertical reading (Pan et al., 2022) in Traditional Chinese. Nevertheless, activation of phonological information in Chinese reading may shift to an earlier temporal stage due to specific task demands. Isolated character-naming experiments showed that phonological codes of Chinese characters can be activated early during character identification when explicit naming is involved (Pollatsek, Tan & Rayner, 2000; Shen & Forster, 1999; Zhou & Marslen-Wilson, 2000). During sentence reading, Pan, Laubrock, and Yan (2016) examined how Chinese readers adjusted their relative weighting of phonological and semantic information processing when reading silently and aloud. They found that these readers showed earlier and stronger phonological activation in oral reading than in silent reading and attributed the effect to an articulatory demand of phonological production when reading aloud. In contrast, semantic activation is robust and independent of task. According to the empirical evidence reviewed above that, Chinese readers can adjust their processing priorities flexibly and put more weight on phonology when required by the current task. In the present study, our participants, who were late bilinguals living in an L1-dominant environment, clearly demonstrated more reliance on phonological decoding in their non-dominant L2 mode. From this perspective, the present study has provided a novel piece of evidence for Chinese readers' enhanced phonological activation in their non-dominant spoken language mode.

This study also took the first step to explore native Cantonese readers' L1 (Cantonese) and L2 (Mandarin) phonological activation during online reading of sentences written in traditional Chinese. The results add to our knowledge of cross-language phonological activation of cognates in bilinguals. In their influential work on bilingual visual word recognition, Dijkstra, Van Heuven and their colleagues proposed the Bilingual Interactive Activation model (BIA: Dijkstra & Van Heuven, 1998; Van Heuven, Dijkstra & Grainger, 1998; BIA+: Dijkstra & Van Heuven, 2002; Multilink: Dijkstra et al., 2019), arguing for an integrated lexicon and a language non-selective lexical access in comprehension. Specifically, co-activated orthography and shared semantics of the cognates – that is, resonance between orthographic and semantic representations – directly and indirectly activate their linked phonological representations. In line with this model, besides word comprehension, naming and translation tasks, the results from the present study among late bilinguals further demonstrate that multiple phonological representations of words in different languages can be activated automatically during natural sentence reading. Specifically, our results also generally agree with previous findings that late bilinguals automatically activate L1 knowledge when they are not using it (Oppenheim et al., 2018). Given the high degree of visual similarity between Chinese and Japanese Kanji and the large number of cognates in these two languages, it is of great theoretical and practical importance to explore bilingual phonological representation and activation among Chinese–Japanese bilingual readers.

Moreover, the activation asymmetry of the phonological-engaged route in Chinese reading can be taken as a form of task-dependent adjustment in bilinguals. Prior works have captured several types of asymmetries in the influence between L1 and L2. For instance, some studies reported enhanced cross-language cognate facilitation effects for L1 prime words over L2 prime words (Gollan et al., 1997; Nakayama et al., 2012; Voga & Grainger, 2007) and shorter production latencies in L2-to-L1 translation than in L1-to-L2 translation (see Kroll, van Hell, Tokowicz & Green, 2010 for a review; but Christoffels, De Groot & Kroll, 2006). In the current study, as our participants were late L2 learners, such an asymmetry also contributed to the different recovery effects observed. Additionally, the existing literature has shown a task-dependent effect of phonology, that Chinese readers process phonological information more efficiently when reading sentences aloud (Pan et al., 2016, 2019, 2021b) and in naming or production tasks (Liu et al., 2022). Dijkstra et al. (2019) recruited a task/decision system in their computational model, which explains these facts as the system's capability to check and tune the degree of orthographic, phonological, or semantic activation, depending on the task and stimulus list at hand. It is possible that Cantonese speakers do not rely heavily on orthographic-phonological connections when reading in their native language, like all Chinese readers do. They nevertheless may set a different parameter for the phonological activation threshold when they are in an L2 Mandarin mode, in which they are not as efficient as in their L1 Cantonese mode.

Although our findings suggest that activation of both L1 and L2 phonology mainly happens in a late temporal stage, it is worth noting that a weak yet significant early recovery effect of the bilingual homophone, as reflected by FFD, was observed in the L1 reading mode. We tend to interpret this as reflecting an extra benefit in retrieving the correct word caused by the double overlap of phonological representations, an approach of "walking on two legs". A follow-up study on this topic is needed to confirm this speculation. For instance, the gaze-contingent boundary paradigm (Rayner, 1975) adopts a priming logic and has been considered a "gold standard" to measure lexical access during sentence reading. Indeed, the paradigm has been used widely to explore the types and their priorities in lexical processing in a number of orthographies, especially in Chinese.

From a practical perspective, the comparison between Cantonese and Mandarin in the present study provides a reference for educational policy makers and classroom teachers with regard to Mandarin education in Cantonese-speaking areas. Our results suggest that, for bilinguals, the procedure of reading a passage aloud in a language introduces a long-lasting and effective activation of its phonological representation. Therefore, school teachers may consider focusing instruction on their students' oral reading of the target language as early as possible, preferably within the very first few minutes of the lesson, for a better learning effect.

As a limitation, the conclusion from the present study is restricted to the lexical processing of foveated character/words. However, studies of perceptual span (i.e., the effective area of vision during sentence reading; McConkie & Rayner, 1975) have shown that Chinese readers can obtain useful information from up to four upcoming characters beyond the current fixation (e.g., Inhoff & Liu, 1998; Yan, Li, Su, Cao & Pan, 2020; Yan, Zhou, Shu & Kliegl, 2015). In other words, lexical processing typically starts parafoveally before a word is fixated on. To understand bilingual phonological activation in an earlier (i.e., parafoveal) processing stage in sentence reading, it would be desirable to use a more sensitive experimental paradigm such as the gaze-contingent boundary paradigm (Rayner, 1975). Following earlier work on parafoveal phonological processing in English (Chace, Rayner & Well, 2005; Pollatsek, Lesch, Morris & Rayner, 1992) and in Chinese (e.g., Liu, Inhoff, Ye & Wu, 2002; Tsai, Lee, Tzeng, Hung & Yen, 2004), future studies are needed to determine early phonological access among native Cantonese readers. In addition, the current study tested native Cantonese speakers

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

who had been living in a Cantonese-dominant environment and learned Mandarin as L2 at their school age. As proficiency and dominance are important factors modulating cross-language activation (Costa, Pannunzi, Deco & Pickering, 2017), future studies are needed to investigate how bilingual phonological activation is affected by other factors such as language proficiency and age of acquisition.

To conclude, the present results consolidate our current understanding about the language-universal importance of the phonological code, even in the logographic Chinese writing system. More generally, from a perspective of bilingual cognition, the results provide novel evidence for a notion that the human mind can adapt flexibly to the current language environment and access lexical information accordingly.

Acknowledgements. This research was supported by a Multi-Year Research Grant from the University of Macau (MYRG2020-00120-FSS), by a FDCT grant from the Macao Science and Technology Development Fund (Project code: 0015/2021/ITP), by the CASS Innovation Program, and by the Research Grants Council of Hong Kong Special Administrative Region, China (EdUHK ECS 28606818). The authors thank Yuqi Hao for her efforts during data collection.

References

Ashby, J and Clifton, C Jr. (2005). The prosodic property of lexical stress affects eye movements during silent reading. *Cognition* **96**, B89–B100. https://doi.org/10.1016/j.cognition.2004.12.006

Ashby, J, Treiman, R, Kessler, B and Rayner, K (2006). Vowel processing during silent reading: Evidence from eye movements. *Journal of Experimental Psychology: Learning, Memory, & Cognition* **32**, 416–424. https://doi.org/10.1037/0278-7393.32.2.416

Bates, D, Kliegl, R, Vasishth, S and Baayen, RH (2015). Parsimonious mixed models. *arXiv*: 1506.04967 [stat.ME]. https://doi.org/10.48550/arXiv.1506.04967

Bates, D, Maechler, M, Bolker, B and Walker, S (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* **67**, 1–48. https://doi.org/10.18637/jss.v067.i01

Briihl, D and Inhoff, AW (1995). Integrating information across fixations during reading: The use of orthographic bodies and of exterior letters. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **21**, 55–67. https://doi.org/10.1037/0278-7393.21.1.55

Chace, KH, Rayner, K and Well, AD (2005). Eye movements and phonological parafoveal preview: Effects of reading skill. *Canadian Journal of Experimental Psychology* **59**, 209–217. https://doi.org/10.1037/h0087476

Chappell, H (2001). Synchrony and diachrony of Sinitic languages: A brief history of Chinese dialects. In H Chappell (Ed.), *Sinitic grammar: Synchronic and diachronic perspectives*. Oxford University Press, pp. 3–28.

Chen, HC and Shu, H (2001). Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. *Psychonomic Bulletin & Review* **8**, 511–518. https://doi.org/10.3758/BF03196186

Christoffels, IK, De Groot, AMB and Kroll, JF (2006). Memory and language skills in simultaneous interpreters: The role of expertise and language proficiency. *Journal of Memory and Language* **54**, 324–345. https://doi.org/10.1016/j.jml.2005.12.004

Chu, PCK and Taft, M (2010). The mental representation of second language phonological lexicons: Implications from the recognition of Mandarin mispronounced words by Cantonese and Mandarin speakers. *Paper presented at the Annual Research Forum of the Linguistic Society of Hong Kong, Hong Kong, December 4*.

Coltheart, M, Rastle, K, Perry, C, Langdon, R and Ziegler, J (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review* **108**, 204–256. https://doi.org/10.1037/0033-295X.108.1.204

Coltheart, V, Avons, SE and Trollope, J (1990). Articulatory suppression and phonological codes in reading for meaning. *The Quarterly Journal of Experimental Psychology Section A* **42**, 375–399. https://doi.org/10.1080/14640749008401227

Costa, A, Pannunzi, M, Deco, G and Pickering, MJ (2017). Do bilinguals alter lexical structure? Response to Oppenheim, Wu, and Thierry (2018). *Cognitive Science* **43**, e12707. https://doi.org/10.1111/cogs.12707

Daneman, M and Reingold, E (1993). What eye fixations tell us about phonological recoding during reading. *Canadian Journal of Experimental Psychology* **47**, 153–178. https://doi.org/10.1037/h0078818

Dijkstra, A and Van Heuven, WJB (1998). The BIA-model and bilingual word recognition. In J Grainger and A Jacobs (Eds.), *Localist connectionist approaches to human cognition*. Lawrence Erlbaum Associates, pp. 189–225.

Dijkstra, A and Van Heuven, WJB (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition* **5**, 175–197. https://doi.org/10.1017/S1366728902003012

Dijkstra, T, Wahl, A, Buytenhuijs, F, Van Halem, N, Al-Jibouri, Z, De Korte, M and Rekké, S (2019). Multilink: A computational model for bilingual word recognition and word translation. *Bilingualism: Language and Cognition* **22**, 657–679. https://doi.org/10.1017/S1366728918000287

Doctor, EA and Coltheart, M (1980). Children's use of phonological encoding when reading for meaning. *Memory & Cognition* **8**, 195–209. https://doi.org/10.3758/BF03197607

Ehri, L (1992). Reconceptualizing the development of sight word reading and its relationship to recoding. In P Gough, L Ehri and R Treiman (Eds.), *Reading acquisition*. Lawrence Erlbaum Associates, pp. 107–143.

Engbert, R and Kliegl, R (2003). Microsaccades uncover the orientation of covert attention. *Vision Research* **43**, 1035–1045. https://doi.org/10.1016/S0042-6989(03)00084-1

Feng, G, Miller, K, Shu, H and Zhang, H (2001). Rowed to recovery: The use of phonological and orthographic information in reading Chinese and English. *Journal of Experimental Psychology: Learning, Memory, & Cognition* **27**, 1079–1100. https://doi.org/10.1037/0278-7393.27.4.1079

Frith, U (1985). Beneath the surface of developmental dyslexia. In KE Patterson, JC Marshall and M Coltheart (Eds.), *Surface dyslexia*. Lawrence Erlbaum Associates, pp. 301–330.

Gollan, TH, Forster, KI and Frost, R (1997). Translation priming with different scripts: Masked priming with cognates and noncognates in Hebrew–English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **23**, 1122–1139. https://doi.org/10.1037/0278-7393.23.5.1122

Harm, MW and Seidenberg, MS (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review* **111**, 662–720. https://doi.org/10.1037/0033-295X.111.3.662

Hoosain, R (1991). *Psycholinguistic implications for linguistic relativity: A case study of Chinese*. Hillsdale, NJ: LEA.

Inhoff, AW (1984). Two stages of word processing during eye fixations in the reading of prose. *Journal of Verbal Learning and Verbal Behavior* **23**, 612–624. https://doi.org/10.1016/S0022-5371(84)90382-7

Inhoff, AW and Liu, W (1998). The perceptual span and oculomotor activity during the reading of Chinese sentences. *Journal of Experimental Psychology. Human Perception and Performance* **24**, 20–34. https://doi.org/10.1037/0096-1523.24.1.20

Inhoff, AW and Radach, R (1998). Definition and computation of oculomotor measures in the study of cognitive processes. In G Underwood (Ed.), *Eye guidance in reading and scene perception*. Elsevier Science, pp.29–53. https://doi.org/10.1016/B978-008043361-5/50003-1

Inhoff, AW and Topolski, R (1992). Lack of semantic activation from unattended text during passage reading. *Bulletin of the Psychnomic Society* **30**, 365–366. https://doi.org/10.3758/BF03334090

Jared, D, Ashby, J, Agauas, SJ and Levy, BA (2016). Phonological activation of word meanings in grade 5 readers. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **42**, 524–541. https://doi.org/10.1037/xlm0000184

Kim, J and Davis, C (2003). Task effects in masked cross-script translation and phonological priming. *Journal of Memory and Language* **49**, 489–499. https://doi.org/10.1016/S0749-596X(03)00093-7

Kliegl, R, Masson, MEJ and Richter, EM (2010). A linear mixed model analysis of masked repetition priming. *Visual Cognition* **18**, 655–681. https://doi.org/10.1080/13506280902986058

Kroll, JF, van Hell, JG, Tokowicz, N and Green, DW (2010). The Revised Hierarchical Model: A critical review and assessment. *Bilingualism: Language and Cognition* **13**, 373–381. https://doi.org/10.1017/S136672891000009X

Kuznetsova, A, Brockhoff, PB and Christensen, RHB (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software* **82**, 26. https://doi.org/10.18637/jss.v082.i13

Lam, ASL, Perfetti, CA and Bell, L (1991). Automatic phonetic transfer in bidialectal reading. *Applied Psycholinguistics* **12**, 299–311. https://doi.org/10.1017/S0142716400009243

Li, P, Sepanski, S and Zhao, X (2006). Language history questionnaire: A web-based interface for bilingual research. *Behavior Research Methods* **38**, 202–210. https://doi.org/10.3758/bf03192770

Liu, C, Lupker, SJ and Nakayama, M (2022). Masked cognate priming effects with Chinese–Japanese bilinguals: Still no phonological facilitation for cognates with different scripts. *Studies in Language Sciences: Journal of the Japanese Society for Language Sciences* **20**, 1–8. https://doi.org/10.34609/sls.20.1_1

Liu, C, Wanner-Kawahara, J and Nakayama, M (2019). Visual word recognition in L2 Japanese for Chinese–Japanese bilinguals: Does phonological similarity modulate cognate priming effects in a naming task? *Proceedings of the Japanese Society for Language Sciences* **2019**, 51–54.

Liu, W, Inhoff, AW, Ye, Y and Wu, C (2002). Use of parafoveally visible characters during the reading of Chinese sentences. *Journal of Experimental Psychology: Human Perception and Performance* **28**, 1213–1227. https://doi.org/10.1037/0096-1523.28.5.1213

Luo, Y, Yan, M, Yan, S, Zhou, X and Inhoff, AW (2016). Syllabic tone articulation influences the identification and use of words during Chinese sentence reading: Evidence from ERP and eye movement recordings. *Cognitive, Affective, & Behavioral Neuroscience* **16**, 72–92. https://doi.org/10.3758/s13415-015-0368-1

Matuschek, H, Kliegl, R, Vasishth, S, Baayen, H and Bates, D (2017). Balancing Type I error and power in linear mixed models. *Journal of Memory and Language* **94**, 305–315. https://doi.org/10.1016/j.jml.2017.01.001

McConkie, GW and Rayner, K (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics* **17**, 578–586. https://doi.org/10.3758/BF03203972

Nakayama, M, Sears, CR, Hino, Y and Lupker, SJ (2012). Cross-script phonological priming for Japanese-English bilinguals: Evidence for integrated phonological representations. *Language and Cognitive Processes* **27**, 1563–1583. https://doi.org/10.1080/01690965.2011.606669

Nakayama, M, Verdonschot, RG, Sears, CR and Lupker, SJ (2014). The masked cognate translation priming effect for different-script bilinguals is modulated by the phonological similarity of cognate words: Further support for the phonological account. *Journal of Cognitive Psychology* **26**, 714–724. https://doi.org/10.1080/20445911.2014.953167

Oppenheim, G, Wu, YJ and Thierry, G (2018). Found in translation: Late bilinguals do automatically activate their native language when they are not using it. *Cognitive Science* **42**, 1700–1713. https://doi.org/10.1111/cogs.12618

Pan, J, Laubrock, J and Yan, M (2016). Parafoveal processing in silent and oral reading: Reading mode influences the relative weighting of phonological and semantic information in Chinese. *Journal of Experimental Psychology: Learning, Memory and Cognition* **42**, 1257–1273. https://doi.org/10.1037/xlm0000242

Pan, J, Laubrock, J and Yan, M (2021b). Phonological consistency effects in Chinese sentence reading. *Scientific Studies of Reading* **25**, 335–350. https://doi.org/10.1080/10888438.2020.1789146

Pan, J, Yan, M, Laubrock, J and Shu, H (2019). Lexical and sublexical phonological effects in Chinese silent and oral reading. *Scientific Studies of Reading* **23**, 403–418. https://doi.org/10.1080/10888438.2019.1583232

Pan, J, Yan, M and Yeh, S.-L. (2022). Accessing semantic information from above: Parafoveal processing during the reading of vertically presented sentences in traditional Chinese. *Cognitive Science* **46**, e13104. https://doi.org/10.1111/cogs.13104

Pan, J, Zhang, C, Huang, X and Yan, M (2021a). Sandhi-tone words prolong fixation duration during silent sentence reading in Chinese. *Reading & Writing: An Interdisciplinary Journal* **34**, 841–857. https://doi.org/10.1007/s11145-020-10093-7

Pollatsek, A, Lesch, M, Morris, RK and Rayner, K (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception and Performance* **18**, 148–162. https://doi.org/10.1037/0096-1523.18.1.148

Pollatsek, A, Tan, LH and Rayner, K (2000). The role of phonological codes in integrating information across saccadic eye movements in Chinese character identification. *Journal of Experimental Psychology: Human Perception and Performance* **26**, 607–633. https://doi.org/10.1037/0096-1523.26.2.607

Rayner, K (1975). The perceptual span and peripheral cues during reading. *Cognitive Psychology* **7**, 65–81. https://doi.org/10.1016/0010-0285(75)90005-5

Rayner, K, Pollatsek, A and Binder, KS (1998). Phonological codes and eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **24**, 476–497. https://doi.org/10.1037/0278-7393.24.2.476

R Development Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

RIH-CUHK. (2001). Chinese character frequency statistics for Hong Kong, mainland China and Taiwan: A trans-regional, diachronic survey. http://humanum.arts.cuhk.edu.hk/Lexis/chifreq/

Seymour, PHK (1997). Foundations of orthographic development. In CA Perfetti, L Rieben and M Fayol (Eds.), *Learning to spell: Research, theory, and practice across languages*. Erlbaum, pp. 319–337.

Shen, D and Forster, KI (1999). Masked phonological priming in reading Chinese words depends on the task. *Language and Cognitive Processes* **14**, 429–459. https://doi.org/10.1080/016909699386149

Shen, HH and Bear, DR (2000). Development of orthographic skills in Chinese children. *Reading & Writing* **13**, 197–236. https://doi.org/10.1023/A:1026484207650

Tan, LH and Perfetti, CA (1997). Visual Chinese character recognition: Does phonological information mediate access to meaning? *Journal of Memory and Language* **37**, 41–57. https://doi.org/10.1006/jmla.1997.2508

Tan, LH and Perfetti, CA (1999). Phonological activation in visual identification of Chinese two-character words. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **25**, 382–393. https://doi.org/10.1037/0278-7393.25.2.382

Treiman, R, Freyd, JJ and Baron, J (1983). Phonological recording and use of spelling-sound rules in reading of sentences. *Journal of verbal Learning and Verbal Behavior* **22**, 682–700. https://doi.org/10.1016/S0022-5371(83)90405-X

Tsai, J.-L., Kliegl, R and Yan, M (2012). Parafoveal semantic information extraction in traditional Chinese reading. *Acta Psychologica* **141**, 17–23. https://doi.org/10.1016/j.actpsy.2012.06.004

Tsai, J.-L., Lee, C.-Y., Tzeng, OJL, Hung, DL and Yen, N.-S. (2004). Use of phonological codes for Chinese characters: Evidence from processing of parafoveal preview when reading sentences. *Brain and Language* **91**, 235–244. https://doi.org/10.1016/j.bandl.2004.02.005

Tsou, BK (1976). Homophony and internal change in Chinese. *Computational Analysis of Asian & African Languages* **3**, 67–86.

Van Heuven, WJB, Dijkstra, A and Grainger, J (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language* **39**, 458–483. https://doi.org/10.1006/jmla.1998.2584

Van Orden, GC (1987). A rows is a rose: Spelling, sound, and reading. *Memory & Cognition* **15**, 181–198. https://doi.org/10.3758/BF03197716

Voga, M and Grainger, J (2007). Cognate status and cross-script translation priming. *Memory & Cognition* **35**, 938–952. https://doi.org/10.3758/BF03193467

Wong, KFE and Chen, HC (1999). Orthographic and phonological processing in reading Chinese text: Evidence from eye fixations. *Language and Cognitive Processes* **14**, 461–480. https://doi.org/10.1080/016909699386158

Yan, M and Kliegl, R (2023). Timelines of feature activation in Chinese and alphabetic script. Behavioral and Brain Sciences.

Yan, M, Li, H, Su, Y, Cao, Y and Pan, J (2020). The perceptual span and individual differences among Chinese children. *Scientific Studies of Reading* **24**, 520–530. https://doi.org/10.1080/10888438.2020.1713789

Yan, M, Luo, Y and Inhoff, AW (2014). Syllable articulation influences foveal and parafoveal processing of words during the silent reading of Chinese

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press

sentences. *Journal of Memory and Language* **75**, 93–103. https://doi.org/10.1016/j.jml.2014.05.007

Yan, M, Richter, EM, Shu, H and Kliegl, R (2009). Chinese readers extract semantic information from parafoveal words during reading. *Psychonomic Bulletin & Review* **16**, 561–566. https://doi.org/10.3758/PBR.16.3.561

Yan, M, Zhou, W, Shu, H and Kliegl, R (2012). Lexical and sub-lexical semantic preview benefits in Chinese reading. *Journal of Experimental Psychology: Learning, Memory and Cognition* **38**, 1069–1075. https://doi.org/10.1037/a0026935

Yan, M, Zhou, W, Shu, H and Kliegl, R (2015). Perceptual span depends on font size during the reading of Chinese sentences. *Journal of Experimental Psychology: Learning, Memory and Cognition* **41**, 209–219. https://doi.org/10.1037/a0038097

Zhou, H, Chen, B, Yang, M and Dunlap, S (2010). Language nonselective access to phonological representations: Evidence from Chinese–English bilinguals. *The Quarterly Journal of Experimental Psychology* **63**, 2051–2066. https://doi.org/10.1080/17470211003718705

Zhou, X and Marslen-Wilson, W (1999). Phonology, orthography, and semantic activation in reading Chinese. *Journal of Memory and Language* **41**, 579–606. https://doi.org/10.1006/jmla.1999.2663

Zhou, X and Marslen-Wilson, W (2000). The relative time course of semantic and phonological activation in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **26**, 1245–1265. https://doi.org/10.1037/0278-7393.26.5.1245

Zhou, X, Marslen-Wilson, W, Taft, M and Shu, H (1999). Morphology, orthography, and phonology in reading Chinese. *Language and Cognitive Processes* **14**, 525–565. https://doi.org/10.1080/016909699386185

Zhou, W, Shu, H, Miller, K and Yan, M (2018). Reliance on orthography and phonology in reading of Chinese: A developmental study. *Journal of Research in Reading* **41**, 370–391. https://doi.org/10.1111/1467-9817.12111

https://doi.org/10.1017/S1366728923000123 Published online by Cambridge University Press