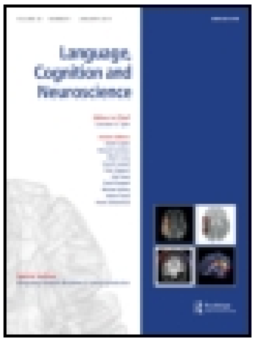

Language, Cognition and Neuroscience

ISSN: 2327-3798 (Print) 2327-3801 (Online) Journal homepage: http://www.tandfonline.com/loi/plcp21

Phonology contributes to writing: evidence from a masked priming task

Qingqing Qu, Markus F. Damian & Xingshan Li

LANGUAGE, COGNITION AND NEUROSCIENCE, 2015
http://dx.doi.org/10.1080/23273798.2015.1091086

Phonology contributes to writing: evidence from a masked priming task

Qingqing Qu[a], Markus F. Damian[b] and Xingshan Li[a]

[a]Key Laboratory of Behavioral Science, Chinese Academy of Sciences, Institute of Psychology, Beijing, People's Republic Of China; [b]School of Experimental Psychology, University of Bristol, Bristol, UK

ABSTRACT

Is written word production affected by phonological properties of target words? We report three experiments using masked priming to investigate this issue. Chinese was chosen as the target script because sound and spelling can be largely dissociated. Participants wrote down names of objects, and latencies were measured on a graphic tablet. Objects were preceded by masked prime words which were either phonologically and orthographically related (PO) to the picture name, phonologically related but orthographically unrelated (P), or unrelated. Priming effects were found for both types of related primes with prime exposure durations of 58 ms (Experiment 1) and 33 ms (Experiment 2), with PO priming larger than P priming. Priming disappeared in Experiment 3 when a manual semantic judgment was required instead of written naming, suggesting that facilitation in the earlier experiments originated at the orthographic output level. These findings strengthen the existing evidence for the involvement of phonology in written word production.

ARTICLE HISTORY
Received 22 July 2014
Accepted 30 August 2015

KEYWORDS
Handwriting; written production; orthography; masked priming paradigm; Chinese

In tasks which require the generation of an orthographic output code (e.g. handwriting, typing, texting, and spelling), how are orthographic representations planned? One possibility is that orthographic production is essentially based on "inner speech", that is, on sound-based codes. Early theorists (e.g. Geschwind, 1969; Luria, 1970) advocated a *phonological mediation* view, according to which access to orthography is possible only via prior retrieval of sound-based codes. This view is in line with the fact that spoken language precedes written production both ontogenetically and phylogenetically (e.g. Scinto, 1986) and it is also compatible with common spelling and typing errors such as homophone substitutions (e.g. there spelled as "their") and production of phonologically plausible non-words (e.g. dearth spelled as "dirth"; Aitchison & Todd, 1982). However, this view is no longer considered tenable, because neuropsychological studies have demonstrated a dissociation between spoken and written production. For instance, Bub and Kertesz (1982) reported a case study of a patient with acquired brain damage who was unable to name pictures orally because of a deficit at the level of the phonological lexicon (as indicated, e.g. by chance-level performance in rhyme judgments on picture names and printed words), yet was able to write down their names. Miceli, Benvegnù, Capasso, and Caramazza (1997) reported a case study of a patient who, when asked to name pictures in spoken and written form, produced consistent responses within each modality yet sometimes produced different spoken and written responses for the same picture (e.g. "brush" for written responses and "comb" for spoken responses). Such neuropsychological studies motivated the *orthographic autonomy* view (Rapp, Benzing, & Caramazza, 1997) according to which orthographic codes can be directly accessed from the semantic level, without necessary prior phonological mediation.

This account, however, does not exclude the possibility that in unimpaired individuals, orthographic production is affected by phonological codes. Indeed, orthographic encoding might be based on double input, from a direct route from semantics (as advocated by the orthographic autonomy view) and from an indirect route via phonology. To investigate this possibility, a rising number of empirical studies have focused on handwriting in healthy participants, and have investigated the relative contribution of phonological properties. The availability of inexpensive digital graphic tablets allows straightforward collection of written latencies, and hence experimental tasks which are well-established in research on spoken production can be adopted to the written domain. As will be shown below, the evidence concerning a potential role of phonology in orthographic production is somewhat mixed, with a substantial number of empirical findings supporting such a role, but also a range of reported null findings (see Table 1 for an overview).

CONTACT Qingqing Qu quqq@psych.ac.cn

Table 1. Overview of studies concerning the role of phonology in written word production.

Outcome	Study	Manipulation	Language	Sample size
Positive finding				
	Afonso and Álvarez (2011)	Implicit priming	Spanish	18 in Exp. 1 48 in Exp. 2
	Bonin, Méot, Lagarrigue, and Roux (2015)	Spelling to dictation	French	34
	Bonin et al. (2001)	Picture naming	French	36 in Exp. 3
	Damian and Qu (2013)	Stroop task	Chinese	37
	Damian et al. (2011)	Cross-modal long-lasting repetition priming	English	18
	Qu et al. (2011)	Picture-word interference	Chinese	30
	Qu et al. (2014)	Coloured picture naming	Chinese	26
	Zhang and Damian (2010)	Picture-word interference	English	30
	Zhang and Wang (2015)	Picture-word interference	Chinese	24
Null findings				
	Bonin et al. (1998)	Masked priming	French	27
	Bonin, Méot, Lagarrigue, and Roux (2015)	Written picture naming; copying of written words	French	34
	Roux and Bonin (2011)	Picture-picture interference	French	30 in Exp. 3
	Shen et al. (2013)	Implicit priming	English	20 in Exp. 4 & 5

For instance, in the "picture-word interference (PWI)" task, participants name objects while instructed to ignore distractor words presented simultaneously or in close temporal vicinity. One central finding in this literature is that form-related distractors (picture: cat; distractor: cap) tend to lead to faster object naming times than entirely unrelated distractors (picture: cat; distractor: top, e.g. Glaser & Düngelhoff, 1984; Lupker & Katz, 1981; Schriefers, Meyer, & Levelt, 1990; Starreveld & La Heij, 1995). Zhang and Damian (2010) used written rather than spoken responses in this task, and distractor words were chosen such that they were orthographically and phonologically related (PO; hand-sand), orthographically related but phonologically less related (P; hand-wand), or unrelated. They also varied the onset of the distractor relative to the target dimension (stimulus-onset asynchrony, or SOA), a common manipulation in the literature on PWI tasks which is believed to allow the distractor to tap into successive stages of target processing and hence yields information about the time course of the latter. Results showed priming restricted to the former condition only at an earlier SOA, and equivalent priming at later SOA. These findings suggest that at least at a relatively "early" stage of target processing, phonology modulates orthographic encoding.

Similar results were reported by Qu, Damian, Zhang, and Zhu (2011) with Chinese individuals. Because Chinese has a non-alphabetic orthographic system in which spelling and sound are largely dissociated, experiments which examine the two dimensions can be more easily constructed (more on this below). Qu et al. (2011) compared effects of distractors which were phonologically related (but orthographically unrelated) to the picture name to those which were orthographically and phonologically related. They found a similar degree of priming for both conditions at an "early" SOA of 0 ms. At a later SOA (+100 ms), facilitation emerged only for the orthographically and phonologically related condition, but no longer for the phonologically only related condition. As Zhang and Damian (2010) did, Qu et al. (2011) concluded that this pattern suggests a role of phonology in written picture naming, and furthermore that phonology might be particularly prominent at early stages of orthographic encoding. The latter (but not the former) part of this suggestion has very recently been called into question by Zhang and Wang (2015) who reported results from picture-word interference experiments, also conducted in Chinese, in which effects of orthographically related, phonologically related, or orthographically and phonologically related distractors were compared. Results showed independent effects of orthographic and phonological relatedness, but contrary to Qu et al. (2011), at "early" SOAs facilitation was exclusively based on orthographic relatedness whereas at a "later" stage, both orthographic and phonological relatedness contributed to priming. According to the authors, the early, exclusively orthographically based, priming reflects the direct route from meaning to orthography, whereas the later phonologically based priming indicates activation via the indirect phonologically based pathway. In combination, the available evidence highlights the role of phonological relatedness in picture-word interference tasks with written responses, although the results concerning the relative time course of orthographic and phonological variables are clearly complex and not fully resolved.

Results from written forms of the classic Stroop task (Damian & Qu, 2013) also converge with the inference that phonological properties of responses are relevant when written words are produced. Other experimental tasks which have been employed to investigate the issue involve object naming with a manipulation of the object names' sound-to-spelling consistency (Bonin, Peereman, & Fayol, 2001) and cross-modal long-lasting repetition priming (Damian, Dorjee, & Stadthagen-Gonzalez, 2011). These studies lend some support to the claim that whereas orthographic representations can be directly accessed from semantics, phonological properties nevertheless influence writing.

At the same time, there are a number of reported null findings concerning a role of phonology in orthographic encoding (see bottom portion of Table 1). Bonin, Méot, Lagarrigue, and Roux (2015) directly compared various tasks which can be used to elicit written output (picture naming; copying of written words; and spelling-to-dictation). In a regression analysis, sound-to-spelling consistency did significantly affect latencies only in the spelling-to-dictation task, but not in the copying of written words, nor crucially in written picture naming. These results suggest that the involvement of a phonological route in orthographic encoding is strongly dependent on the specific task, and that the task which most obviously engages the semantics-to-orthographic route (written picture naming) might be unaffected by phonological variables such as PO consistency.

A further null finding was reported by Roux and Bonin (2011) who adopted the so-called "picture-picture priming" (PPP) task from the spoken to the written domain. In this task, two coloured line drawings are superimposed on each other, and participants are instructed to name one (cued by colour) and to ignore the other. The central finding (Morsella & Miozzo, 2002) is that if the names corresponding to the two objects are form-related (e.g. bell-bed), naming times are accelerated compared to an unrelated condition. This observation supports a "cascaded" view of form encoding in spoken word production because it implies that not only the name of the target, but also the name of the to-be-ignored object is retrieved. Roux and Bonin conducted a PPP experiment with French participants and written responses, and found a similar priming effect as previously reported with spoken responses. In further experiments, this priming effect was still found when object and distractor names started with the same letter, but with a different sound (cigar-camion) but it disappeared when both names had different initial letters but share the same sound (singe-ceinture). Evidently, cascading of activation from the conceptual to the graphemic level was restricted to the semantics-to-orthography link, but did not take place in the indirect route via phonology. However, Roux and Bonin always presented pictures and distractors simultaneously (i.e. with a stimulus-onset asynchrony of 0 ms). This opens the – as of yet untested – possibility that phonological effects might be found in the written PPP task under a different timing. Indeed, we (Qu, Li, & Damian, 2014) recently reported electroencephalogram (EEG) evidence that orthographic and phonological variables in written production might have distinct time courses: activation of phonological codes takes place earlier (by approximately 100 ms) than access to orthographic codes. On the other hand, as summarised earlier, Zhang and Wang (2015) suggested that phonology might be particularly relevant at a relatively late stage of orthographic encoding. Irrespective of which claim turns out to be true, the exact timing of the two dimensions in the picture-picture task might be crucial, hence further research is required to examine Roux and Bonin's null finding concerning phonological "cascaded" effects in written word production.

Two recent articles (Afonso & Álvarez, 2011; Shen, Damian, & Stadthagen-Gonzalez, 2013) reported experiments in which the popular "implicit priming" technique from the spoken literature was adopted to handwriting. In this task, participants memorise, prior to an experimental block, a small set of highly associated word pairs such as fruit-melon, iron-metal, and grass-meadow. During the subsequent block the first word of each pair is repeatedly visually presented in random order, and participants produce the second word of the pair. After completion of the block, participants are presented with a new set of words to learn, and the next experimental block begins. Critically, responses within a block are chosen such that they sometimes overlap with regard to form-related characteristics. In homogeneous blocks, responses might share word-initial segments whereas in heterogeneous blocks they do not. Across all blocks each response occurs in both contexts and hence acts as its own control. The basic finding, replicated in numerous studies, is that phonological word-initial overlap leads to a facilitation effect (Meyer, 1990, 1991) which is attributed to partial phonological planning possible in the homogeneous but not in the heterogeneous context. Afonso and Álvarez (2011) modified this technique to require written rather than spoken responses, and reported a similar facilitation effect with Spanish participants when responses overlapped in their word-initial properties (e.g. balada-baraja-banana-basura). Interestingly, priming was still found in a condition which included a word with different initial letter, but which despite the different spelling is still pronounced with an initial/b/ in Spanish (e.g. balada-baraja-banana-vacuna). This finding prima facie suggests that the implicit priming task in its form with written responses is indeed sensitive to phonological properties.

However, Shen et al. (2013) reported very similar experiments conducted in English, but with the opposite results: a priming effect based on graphemic overlap (e.g. camel-coffee-cushion) was maintained when words began with the same grapheme but a different sound (census-climate-candle) yet disappeared when words began with the same sound but with a different grapheme (kennel-coffee-cushion). Hence, implicit priming exclusively depended on whether word-initial graphemes were shared, but word-initial phonemic overlap was not sufficient to generate priming. These results directly contradict those reported by Afonso and Álvarez (2011), and it is of yet unclear why this is the case. Shen et al. (2013) took care, however, not to interpret their findings as evidence against the involvement of phonological codes in handwritten word production. Rather, they argued that the specific mechanism which underlies the implicit priming effect is evidently not sensitive to phonological properties. For the spoken version of this task, a "suspend-resume" principle has been postulated (Roelofs, 1997) according to which in a homogeneous context, spoken preparation can be carried out on the basis of fragments of information. The partially constructed mental representation is then buffered ("suspended") until the missing information becomes available, and resumed as soon as further information arrives. Applied to the written form of the implicit priming task, orthographic encoding ultimately requires the assembly of structured orthographic representations resulting in sequential motor patterns. In a homogeneous context, the initial grapheme can be prepared and buffered, and hence yields a response latency benefit. But having information about the initial sound would not be helpful because it would not allow partial construction of the orthographic code required for the response. Hence, no phonological priming effect is predicted. Again, the issue requires further research and the reason for the discrepancy between the two sets of results is not well understood. However, given Shen et al.'s (2013) argument outlined above concerning the locus of the effect, the available results from implicit priming tasks should not be interpreted as evidence against a role of phonology in written production.

Finally and most importantly for the current article, relevant evidence comes from a study reported by Bonin, Fayol, and Peereman (1998). Bonin et al. (1998) used a masked priming technique in which participants engaged in written object naming, and objects were preceded by briefly presented and masked non-words. Non-words were chosen such that they were (i) pseudohomophones of the target name (e.g. a picture of a tooth – DENT in French – preceded by the non-word DANT), (ii) orthographically related non-words (e.g. the prime DUNT), and (iii) control primes (e.g. DISE). English equivalents for this manipulation are the target picture girl, preceded either by GERL (pseudohomophone), GARL (orthographically related), or GONT (control). Across Bonin et al.'s (1998) stimulus set, pseudohomophones were 100% phonologically related (i.e. identical) to the target names, whereas orthographically related primes were 60% phonologically related, and control primes were 31% related. Pseudohomophones and orthographically related primes were both 76% orthographically related to the targets, whereas control primes were 27% related. This implies that the only difference between orthographically related and pseudohomophone primes were that the latter were more phonologically related than the former (they were equated in terms of orthographic relatedness). Primes were sandwiched between a forward mask presented for 500 ms, and the target pictures, and presented for a prime duration of 34 ms in Experiment 1. Relative to the control condition, pseudohomophones and orthographically related primes generated similar-sized priming effects (70 and 62 ms, respectively), suggesting an orthographic origin but no involvement of phonology (note that with the same materials, Ferrand, Grainger, & Segui, 1994, Experiment 2A, reported significant phonological priming in spoken picture naming, which suggests that in tasks such as naming which depend on phonological retrieval, the degree of phonological overlap relative to the control condition is sufficient to generate priming). Experiment 2 used the same prime duration but with a more effective forward mask, and showed very similar results (102 and 92 ms priming for the pseudohomophone and orthographic conditions, respectively). Finally, Experiment 3 used a slightly longer prime duration of 51 ms and again found similar priming effects for pseudohomophone and orthographic primes (81 and 104 ms, respectively). The authors concluded that "phonological codes are not a prerequisite for access to orthographic codes" (p. 324), which in our reading reflects the by now widely accepted theoretical account of "orthographic autonomy" (see beginning of section). Nevertheless it is curious why this technique failed to render phonological priming effects, given the mounting evidence supporting phonological involvement from other tasks (see above).

Manipulating phonological and orthographic overlap by holding one property constant while varying the other, as in the studies reported by Bonin et al. (1998), is not easy in alphabetic scripts. Even in languages with irregular spelling such as French and English, spelling and sound are strongly confounded, hence "pure" manipulations (i.e. orthographic overlap in the absence of phonological overlap or vice versa) are impossible. To specifically explore a contribution of phonology to orthographic production, it would be ideal to compare a critical condition in which primes share phonological properties with targets yet are orthographically unrelated, to a control condition with no overlap. In the experiments below, we revisited this issue by conducting experiments with Chinese participants. In written Chinese, spelling and sound are largely independent, and hence the two dimensions can be more cleanly dissociated. In the experiments below, we revisited this issue by conducting experiments with Chinese participants. In written Chinese, spelling and sound are largely independent, and hence the two dimensions can be more cleanly dissociated. For instance, word pairs can be selected which, although phonologically related (in this case, sharing the initial syllable plus tone), do not share any orthographic properties (鳄鱼, /e4yu2/, crocodile – 恶劣, /e4lie4/, terrible). This property allows for a clear manipulation of phonological and orthographic overlap. Using Chinese as target language is also interesting for other reasons, given the considerable dissimilarity between such non-alphabetic orthographic systems, and the alphabetic systems used in Western languages.

The studies reported below employed the same experimental paradigm as the one used by Bonin et al. (1998): prime words were presented very briefly and were masked. Under this procedure, participants are usually unable to identify the prime, thus excluding conscious processing of prime words and producing strategy-free lexical processing. Native Mandarin speakers wrote down the names of objects on a graphic tablet, and written naming latencies were recorded. Primes and pictures were either phonologically and orthographically related (they shared initial syllable plus tone, as well as an orthographic radical), only phonologically related (they shared initial syllable plus tone, but no radicals), or unrelated. Based on Bonin et al.'s (1998) finding, we expected that phonologically and orthographically related prime words would substantially facilitate written picture naming latencies. The central issue was whether priming would also emerge for the phonologically related but orthographically unrelated prime words. If so, this would further corroborate the claim that written word production is constrained by sound-based codes.

Experiment 1

Method

Participants

Sixteen students (8 males, age 19–26 years, mean age 22 years) from Beijing Forestry University and China Agricultural University participated in the experiment. All were native Mandarin Chinese speakers without dysgraphia and had normal or corrected-to-normal vision.

Materials

Twenty-two line drawings of common objects were selected as targets. All has disyllabic names. Each picture was paired with two form-related disyllabic prime words: (a) a phonologically and orthographically related (PO) word (i.e. a word that shared the initial syllable plus tone, as well as an orthographic radical, with the picture name, e.g. picture: 鳄鱼, /e4yu2/, *crocodile*; prime: 愕然, /e4ran2/, *stunned*); (b) a phonologically related, but orthographically unrelated (P) word (i.e. a word that shared the initial syllable but no radicals with the picture name (e.g. 鳄鱼, /e4yu2/, crocodile – 恶劣, /e4lie4/, terrible). Across these two relatedness conditions, prime words were statistically matched on number of strokes and lexical frequency (mean frequency: 5.6 per million). Pictures and primes were then recombined within each relatedness condition to form two baseline conditions in which orthographic or phonological overlap was avoided (e.g. 鳄鱼, /e4yu2/, crocodile – 阳光, /yang2guang1/, sunshine). Semantic and associative prime picture-word relationships were avoided in all conditions (see Appendix for the full list of materials).

Design

The experimental design included relatedness (related vs. unrelated) and type of relatedness (PO vs. P) as within-participants factors. Each of the 22 target pictures was presented to each participant under each level of relatedness and type of relatedness, resulting in 88 trials. Each combination was repeated twice, resulting in a total of 176 trials. A pseudorandom order was generated using Mix (van Casteren & Davis, 2006), with the constraint that neither targets nor prime words were repeated on consecutive trials.

Procedure

The experiment was run using DMDX (Forster & Forster, 2003) from an IBM-compatible computer on a 17-in. monitor. Prime words were presented in 18-point Song font; prime words and pictures were displayed at the bottom of the screen in order to reduce participants' head and eye movements as they wrote the picture names. Response latencies (the interval between picture onset and initial contact of the pen with the tablet) were recorded within each response period using an Intuos4 graphic tablet and inking pen (Wacom, Kazo-shi, Japan). A sheet of paper was attached to the tablet, and participants wrote down their responses, which allowed us to identify naming errors following the experiment.

Participants were tested individually. They were first instructed to hold the pen slightly above the corresponding line to get ready for writing down the responses so that initiation of the response would not require an arm movement; neither should they drop the pen on the sheet before identifying responses. Subsequently, they were asked to familiarise themselves with the experimental stimuli by looking at all 22 pictures, which were presented in reduced size on the computer screen, with the name for each picture printed underneath it. In a first practice block, all 22 target pictures were successively presented, and participants wrote down their names. In a second practice block, 10 target pictures were presented preceded by unrelated prime words. Then, two experimental blocks of 88 trials each were presented.

In the vast literature on masked priming, prime presentation durations of 50–60 ms are typical (e.g. Forster & Davis, 1984; Perfetti & Tan, 1998; Shen & Forster, 1999). In Experiment 1, we adopted a form of the task in which primes were presented for 58 ms, and forward and backward masked. On each trial, participants saw a sequence consisting of a forward pattern mask (※※) for 500 ms, a prime word presented in 18-point Song font that remained visible for 7 screen refresh cycles (approx. 58 ms, refresh rate: 120 Hz), a backward pattern mask (※※) for 2 refresh cycles (approx. 17 ms), and the target picture presented for 2000 ms. The intertrial interval was 1000 ms. Each testing session lasted approximately 40 min.

Results and discussion

Response latencies for incorrect responses (5.6%) were excluded from analysis, and latencies faster than 200 ms or slower than 1800 ms (0.2%) were discarded as outliers. Mean written latencies for each experimental condition are shown in Table 2. The results were analysed using a linear mixed-effects model (Baayen, Davidson, & Bates, 2008; Bates, 2005). Model fitting was carried out by initially specifying a model that only included the random factors (participants and items) which was then enriched by subsequently adding the fixed factor relatedness, followed by type of relatedness, and finally the interaction between the two factors. The best-fitting model was defined to be the most complex model that significantly improved the fit over the previous model. The best-fitting model included relatedness, $\chi^2(1, N = 2652) = 30.90$, $p < .001$, reflecting the fact that response latencies were 31 ms faster on related trials (659 ms) than on unrelated trials (691 ms), type of relatedness, $\chi^2(1, N = 2652) = 5.55$, $p = .018$, and the interaction between relatedness and type of relatedness, $\chi^2(1, N = 2652) = 4.40$, $p = .036$. The significant interaction reflects the fact that priming in the PO condition (45 ms) was substantially greater than in the P condition (17 ms). Planned comparisons that assessed the effects of relatedness for each type of relatedness separately showed significant facilitation in the PO condition, $\chi^2(1, N = 1317) = 29.72$, $p < .001$, and the *P* condition, $\chi^2(1, N = 1335) = 6.30$, $p = .012$.

Table 2. Experiment 1–3: Mean response latencies as a function of relatedness and type of relatedness.

Experiment (prime duration)	PO_R	U	Effect	P_R	U	Effect
Experiment 1 (58 ms)	646	691	+45**	672	689	+17*
Experiment 2 (33 ms)	703	752	+49**	731	758	+27**
Experiment 3 (33 ms)	513	514	+1	518	516	−2

Notes: PO_R, phonologically and orthographically related condition; P_R, only phonologically related condition; U, unrelated condition.
$^{**}p < .01$.
$^{*}p < .05$.

A parallel analysis was conducted on the errors, but a binomial family was used because of the binary nature of the responses (Jaeger, 2008). Adding relatedness, and the interaction between relatedness and type of response did not significantly improve the fit, Wald *Z*s < 1.47, *p*s ≥ .141. Adding type of relatedness marginally improved the fit, Wald $Z = 1.656$, $p = .098$. Planned comparisons showed no effect of relatedness in the PO and P conditions, Wald *Z*s < 1.20, *p*s ≥ .23.

In summary, Experiment 1 showed a reliable facilitation effect when prime words and picture names were both phonologically and orthographically related, which replicates the finding in Bonin et al. (1998). More relevant to the purpose of the study is the observation that prime words that were phonologically related but orthographically unrelated to the picture names also facilitated written word production. This finding contrasts with the null phonological effect reported in Bonin et al. (1998). Our finding that phonologically and orthographically related prime words produced greater priming than only phonologically related prime words indicates that orthographic overlap produced an additional benefit beyond phonological relatedness. Nevertheless, the "pure" phonological priming effect strongly suggests that phonological codes contribute to written word priming in this task.

As outlined in the Introduction, we chose a prime duration of 58 ms based on previous studies using masked priming tasks. It is possible that under this prime duration, participants might consciously perceive some of the prime words. Therefore, in Experiment 2, we shortened the prime duration to 33 ms in order to further reduce the visibility of the prime words. A secondary goal was to ensure that the phonological priming effect shown in the first experiment could be reliably replicated.

Experiment 2

Method

Participants

Sixteen participants (8 males, age 19–24 years, mean age 21 years) from the same population as Experiment 1 participated in this experiment. All were native Mandarin Chinese speakers without dysgraphia and had normal or corrected-to-normal vision. None of them had participated in the first experiment.

Materials, design, and procedure

These were identical to Experiment 1, except that the prime duration was reduced to four refresh cycles of the computer screen or 33 ms.

Results and discussion

The same exclusion criteria as in Experiment 1 were applied. In Experiment 2, 5.8% of the trials were incorrect responses, 1.3% of the data were outliers (see Table 2 for mean latencies for each condition). As in Experiment 1, the results were analysed using a linear mixed-effects model. The best-fitting model included relatedness, $\chi^2(1, N = 2614) = 32.91$, $p < .001$, reflecting that response latencies were 38 ms faster on related trials (717 ms) than on unrelated trials (755 ms), and type of relatedness, $\chi^2(1, N = 2614) = 5.15$, $p = .023$. The interaction between relatedness and type of relatedness marginally improved the fit, $\chi^2(1, N = 2614) = 2.88$, $p = .090$, reflecting a trend towards priming in the PO condition (49 ms) being greater than in the P condition (27 ms). Planned comparisons that assessed the effects of relatedness for each type of relatedness separately showed significant facilitation in the PO condition, $\chi^2(1, N = 1293) = 28.06$, $p < .001$, and the *P* condition, $\chi^2(1, N = 1321) = 8.34$, $p = .004$.

A parallel analysis was conducted on the errors, using a binomial family. Adding relatedness, and the interaction between relatedness and type of response did not significantly improve the fit, Wald *Z*s < 1.00, *p*s ≥ .401. Adding type of relatedness significantly improved the fit, Wald $Z = 2.02$, $p = .043$. Planned comparisons showed no effect of relatedness in the PO and P conditions, Wald *Z*s < 1.00, *p*s ≥ .505.

In summary, using a shorter prime duration of 33 ms, Experiment 2 replicated the findings observed in Experiment 1. Both types of prime words produced reliable priming effects, and using a shorter prime duration did not reduce the size of the effects. Moreover, the fact that phonologically and orthographically related prime words produced numerically larger priming than only phonologically related prime words (although only marginally so in the second experiment) indicates that beyond "pure" phonologically based priming, orthographic overlap generated an additional benefit.

Experiment 3

Could it be that the phonological priming effects observed in Experiment 1 and 2 do not reflect processing of an indirect semantics-phonology-orthography route (as we have so far assumed), but rather arose during distractor input processing and acting at the semantic level? According to this scenario, target objects may mandatorily activate corresponding phonological codes, even in tasks that do not require naming (see, e.g. Allopenna, Magnuson, & Tanenhaus, 1998). Processing of written words (such as the primes in the current experiment) is likely to result in rapid phonological encoding (e.g. Van Orden, 1987). If there is a feedback link from phonology to semantics, feedback might be stronger when prime and picture are form-related than when they are unrelated; hence, priming from phonologically related prime words could arise at the semantic level, and not at the orthographic level, as so far has been assumed.

If so, facilitation from phonologically related primes should arise even in tasks that do not require access to a lexical component (plus subsequent orthographic encoding) at all, but that rather necessitate only perceptual processing and conceptual access for the target object. To test this possibility, we conducted a further experiment which was identical in most aspects to Experiment 2, but in which written picture naming was replaced by a manual decision task involving semantic processes ("Is the object human-made or not?"). If the semantic hypothesis is true, the phonological priming effects observed in Experiment 1 and 2 should also be found in the manual decision task in Experiment 3.

Method

Participants

Sixteen participants from the same population as Experiment 1 and 2 participated in this experiment. All were native Mandarin Chinese speakers without dysgraphia and had normal or corrected-to-normal vision. None of them had participated in Experiment 1 and 2.

Materials, design, and procedure

These were identical to Experiment 2 (prime duration: 33 ms), except that two additional natural filler targets were included to equalise the number of human-made and natural targets (12 of each). The two filler targets were paired with unrelated prime words. Participants were asked to press the "F" key on the computer keyboard when an object was human-made, and the "J" key when it was natural. Each testing session lasted approximately 15 min.

Results and discussion

Response latencies for incorrect responses (1.6%) were excluded from analysis, and latencies faster than 200 ms or slower than 800 ms (4.4%) were discarded as outliers (see Table 2 for mean latencies for each condition). Analyses using linear mixed-effects models showed that the best-fitting model only included random effects of participants and items. Inclusion of relatedness, type of relatedness, and the interaction between relatedness and type of relatedness did not improve the fit, χ^2s(1, $N = 2{,}692) < 1$, $ps > .347$. Planned comparisons were conducted to assess the effects of relatedness for each type of relatedness separately. Results showed that response latencies for the PO condition did not differ significantly from the corresponding unrelated condition (related: 513 ms; unrelated: 514 ms), $\chi^2(1, N = 1{,}343) < 1$, $p = .582$, and neither did the P condition (related: 518 ms; unrelated: 516 ms), $\chi^2(1, N = 1{,}349) < 1$, $p = .443$.

A parallel analysis conducted on the errors, using a binomial family, showed that adding relatedness, and type of relatedness did not significantly improve the fit, Wald Zs < 1.00, $ps \geq .772$. Adding the interaction between relatedness and type of response significantly improved the fit, Wald $Z = 2.27$, $p = .023$. Planned comparisons showed no reliable effect of relatedness in the PO and P conditions, Wald Zs < 1.76, $ps \geq .079$.

In summary, the priming effects observed in Experiment 1 and 2 vanished in the manual response task in Experiment 3. Hence, it is unlikely that the phonologically based effects observed in the two earlier experiments can be attributed to a phonology-to-semantics feedback link, and hence the inference is strengthened that such effects reflect an indirect processing route from semantics to phonology which feeds activation onward to the orthographic level.

General discussion

As highlighted in the Introduction, current consensus is that the codes required for orthographic output tasks such as handwriting can be generated via a direct link from semantics to orthography. At the same time, a growing number of recent studies provide support for the view that phonological properties also influence handwriting, via an indirect semantics-phonology-orthography pathway. However, a small number of studies have generated null effects when phonological properties were manipulated. Here, we tackled results from a masked priming procedure reported by Bonin et al. (1998), and we used native speakers of a language with a non-alphabetic script (Mandarin Chinese) because here, sound and spelling are more easily dissociated. We used a masked priming paradigm in which prime words were presented very briefly (58 and 33 ms in Experiment 1 and 2, respectively) and were covered by forward and backward masks. Using the masked priming paradigm with such relatively short prime durations, participants should have little opportunity to develop processing strategies which might have affected the results from other tasks such as picture-word interference, PPP, and implicit priming. We manipulated form overlap between prime words and picture names, such that they were phonologically and orthographically related (i.e. they shared initial syllable and tone, plus an orthographic radical), only phonologically related but orthographically unrelated (they shared initial syllable and tone, but no radical) or were completely unrelated. The results showed that both types of related prime words facilitated written word production, with a more substantial priming effect for phonologically and orthographically related primes compared to only phonologically related ones. These results indicate that both phonological information and orthographic information constrain written word production. Moreover, these priming effects vanished when written responses were replaced by manual decision response in Experiment 3, which suggests that the effects indeed arise from the orthographic output level.

Whereas we believe that our results provide fairly strong evidence for a role of phonology in handwritten word production, we find it difficult to resolve the discrepancy with the earlier findings reported by Bonin et al. (1998). This is mainly because of the procedural differences between the two studies. To reiterate, the critical finding in Bonin et al. (1998) came from similar-sized priming effects generated by pseudohomophones of the target name and from orthographically related, but phonologically less related (~60% shared phonemes) non-word primes. By contrast, we used word primes (necessarily so in a non-alphabetic system such as Chinese) but formed a "pure" phonological condition (prime and target shared the initial syllable plus tone, but were orthographically entirely unrelated). The fact that this manipulation generated priming shows that at least for Chinese word primes and Chinese characters as responses, there is a clear and unambiguous phonological contribution to handwritten production. Nevertheless, we acknowledge that further research might be required to render the two sets of results more directly comparable, to the extent possible. There is also a possibility (discussed by Bonin et al., 1998, p. 323) that the priming shown for pseudohomophones and orthographically related non-words in their experiments might have arisen from different loci: because pseudohomophones correspond to lexical entries in the phonological lexicon, these might have primed picture naming latencies via a phonological pathway; by contrast, the orthographically related non-words might have primed target naming via sublexical orthographic overlap. If so, the pseudohomophone priming effect by itself could reflect activation in the phonological pathway, contrary to Bonin et al.'s (1998) inferences. Bonin et al. (1998) mount a number of arguments why this scenario is unlikely; nevertheless we find the formation of a "pure" phonological relatedness condition as in our current study on balance a more powerful source of evidence.

Could the null finding of phonological influences in Bonin et al. (1998) and our positive finding be reconciled via postulating cross-linguistic (or rather, cross-script) differences in the target languages? It is clearly the case that alphabetic and non-alphabetic systems have important differences in the way they represent orthographic information. Most importantly, alphabetic systems implement a tight coupling between speech sounds and orthographic symbols, whereas non-alphabetic systems do not. However, on balance we feel that the stronger correspondence between spelling and sound in alphabetic languages would predict the opposite pattern than what was found, that is, a *stronger* influence of phonology in alphabetic languages.

The present study also provides some insight into the unique nature of non-alphabetic scripts. In contrast to alphabetic languages, written Chinese implements a logographic orthographic system, with the orthographic system of Chinese broadly described by the following levels: words, characters, radicals, and strokes (an additional coding level of "logographemes", intermediate between radicals and strokes, has been postulated, e.g. Han, Zhang, Shu, & Bi, 2007; Law & Leung, 2000). It is commonly assumed that there is a sublexical representational level for radicals, with results from a number of empirical studies supporting this assumption. For instance, Zhou and Marslen-Wilson (1999) asked Chinese participants to name target words, and obtained a priming effect when prime words were semantically related to phonetic radicals of the target words, even though prime words were semantically unrelated to the whole target words. The role of radicals has also been underscored in a number of neuropsychological studies. For instance, Law (1994, 2004) and Law and Caramazza (1995) analysed writing errors made by a group of Cantonese dysgraphic patients and observed numerous errors at the radical level (i.e. radical replacement, deletion, or insertion). In the present study, we found that an overlapping orthographic radical between prime words and object name induced a facilitation effect beyond the one generated by phonological overlap. This further underscores the psychological reality of the representational level of radicals in Chinese individuals.

Moreover, the findings provide support for a strong non-modular view according to which subsystems of language act in a non-modular fashion and all the various subsystems become activated in language task, even if a particular subsystem is irrelevant. For instance, a growing amount of research suggests an involvement of orthographic codes in speech perception (e.g. Hallé, Chéreau, & Segui, 2000), despite the fact that access to the spelling of words would appear to be superfluous in an auditory task. Similarly, in visual word recognition, strong evidence suggests that phonological codes are a rapidly accessed from orthographic codes (e.g. Stone, Vanhoy, & Van Orden, 1997). The present study provides further insights into modular/non-modular accounts, and our inference that phonology constrains orthographic output process is consistent with the prediction of non-modular views.

Our experiments used a masking procedure in which primes were presented very briefly, and were forward and backward masked. We assumed that this masking prevents stimuli from being consciously seen, but we did not conduct tests of prime visibility. The prime duration used in our first experiment (58 ms) is fairly representative of numerous masked priming studies in alphabetic (e.g. Adelman et al., 2014; Forster & Davis, 1984) and non-alphabetic languages (Chen, Lin, & Ferrand, 2003; Shen & Forster, 1999; Verdonschot, Lai, Chen, Tamaoka, & Schiller, 2015; Xia & Andrews, 2015; You, Zhang, & Verdonschot, 2012). In our second experiment, we used a prime duration (33 ms) which was considerably shorter than the one conventionally used. The resulting priming effect was unaffected by the reduction in prime duration (Experiment 1: 33 ms; Experiment 2: 38 ms). In fact, the size of the phonological priming effect which is the main point of interest was numerically *larger* with the reduced prime duration of Experiment 2 (27 ms) than with the longer prime duration in Experiment 1 (17 ms). This makes it seem unlikely that primes were insufficiently masked to prevent visibility. Moreover, the fact that shorter primes evoke numerically stronger priming tells us that it is less prime duration per se which is relevant (otherwise we would have predicted the opposite pattern) but rather the timing between respective prime and target onset.

As outlined in the Introduction, this inference broadly agrees with previous studies which also suggested that the exact timing is critical (Qu et al., 2011; Zhang & Damian, 2010; Zhang & Wang, 2015). Qu et al. (2014) recently reported EEG evidence suggesting that orthographic and phonological variables in written production have distinct time courses: activation of phonological codes takes place earlier (approximately 100 ms) than access to orthographic codes. Note that this inference conflicts with the one drawn from the results reported by Zhang and Wang (2015), which had suggested an early phase of orthographic access, followed by a later stage in which phonology is relevant. Clearly, more evidence is needed to resolve this issue. However, in combination the available evidence supports the claim that phonological codes play a role in written production. At the same time, it would be questionable to draw strong inferences from the size of such a phonological effect (or indeed, from its absence under specific circumstances) because the effect is evidently sensitive to timing. As we argued in the Introduction, this might, for instance, account for Roux and Bonin's (2011) failure to obtain phonologically based priming in their picture-picture-priming methodology; we predict that with a different timing between the onset of the two pictures, phonologically based priming would emerge even in that paradigm.

Our results add to a growing body of evidence supporting the claim that phonology plays an important role in written production. Yet, given that a direct route from semantics to orthographic output is now almost universally accepted, how exactly does phonology contribute to graphemic encoding? Existing models of handwritten production, both for Western (e.g. Bonin et al., 2001, 2015; van Galen, 1991; Kandel, Peereman, Grosjacques, & Fayol, 2011) and non-Western languages (e.g. Chen & Cherng, 2013) are not computationally specific, and oftentimes do not include a phonological route. By contrast, the model advocated by Bonin and colleagues stipulates parallel activation of both orthography and phonology from semantic input, as well as a sublexical phonology-to-orthography route which could account for phonological effects in written tasks. A schema which represents this idea is shown in the left hand side of Figure 1. To render these assumptions more computationally explicit, one could expand the dual-route connectionist model of spelling (rather than writing) introduced by Houghton and Zorzi (2003). This model accounts for how sound is transferred into (alphabetic) spelling, via a sublexical route which learns correspondences between sound and spelling via Parallel Distributed Processing (PDP) principles, and an additional lexical route (essentially, an orthographic output lexicon). The model successfully accounts for a range of empirical findings from the literature on spelling. In our current article, by contrast, we deal with semantically driven orthographic production, rather than with sound-to-spelling conversion. One could extend Houghton and Zorzi's model by adding a semantic layer, and implementing a situation in which activation emanating at the semantic layer spreads simultaneously towards both an orthographic and a phonological lexicon (perhaps with stronger/faster activation of phonology than orthography; see Qu et al., 2014; but see Zhang & Wang, 2015), and activation further cascades from phonology to orthography via a lexical or sublexical route (if Bonin et al., 2001, are correct, the latter is more relevant than the former, hence the question mark next to the lexical route in the Figure 1). In this way, phonologically overlapping primes might pre-activate units at the graphemic encoding layer, resulting in observable priming effects.

An additional complexity in accounting specifically for the current results is that in Chinese, the lexical/sublexical distinction present in alphabetic orthographic systems is much less clear: most words are compounds of multiple characters, yet most characters themselves are morphemes and hence carry meaning. There is no grapheme/phoneme-sized sublexical conversion route in Chinese; the main correspondence is between characters and spoken syllables. In the current article, overlap in the critical condition (P) was defined as prime and target sharing the initial syllable (incl. tone). The fact that priming arises from this granularity underscores the importance of a direct link between spoken syllables and written characters. A corresponding schema is shown on the right hand side of Figure 1. A computationally explicit model would have to rely primarily on this link in order to account for the phonological priming effects in our experiments.

The inference that handwritten word production is constrained by phonology might need to be qualified in various ways. First, written picture naming might differ substantially from writing under more realistic (real-life) conditions such as note taking, etc., and perhaps effects of phonology which emerge in the former activity are absent in the latter.[1] Second, participants in our study were University students, and these might not necessarily constitute a representative sample. It is certainly true that students can be expected to have above-average exposure to orthographic codes, and perhaps this influences the found phonological effects. It is our intuition, however, that the relation between proficiency and the role of phonology should be negative: strong orthographic skills should involve *less* phonological involvement in the writing task. Future studies should explicitly investigate a potential

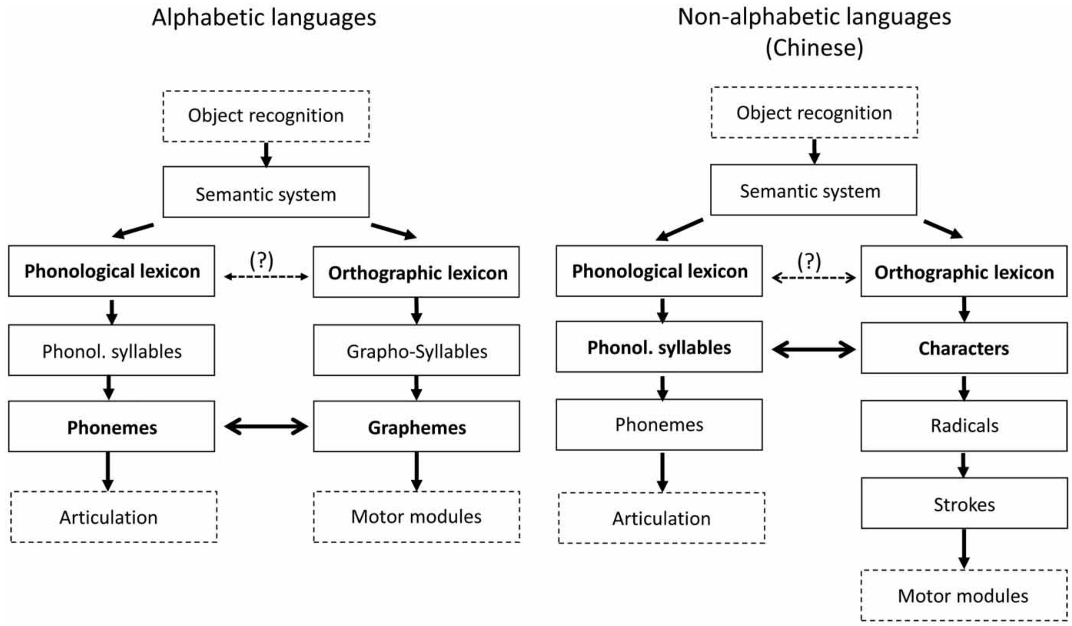

Figure 1. Possible architecture of word production in alphabetic (left panel) and non-alphabetic (right panel) languages. In both panels, the left side corresponds to spoken word production, and the right side to written production.

role of writing proficiency. Third, written production might be subject to "strategic" effects which reflect the specific demand characteristics of a given experimental task, rather than a general property of the cognitive domain. This is possible, although in the current study, participants were likely unaware of the primes' presence so strategies were presumably less relevant than they are in alternative experimental paradigms. Finally, the role of phonology might depend on the method which is used to elicit a written response. As described in the Introduction, Bonin et al. (2015) found that sound-to-spelling consistency (reflecting the influence of phonology) reliably affected latencies in a spelling-to-dictation task, but not in written picture naming or immediate copying tasks. Overall, we acknowledge that more research is required to explore which factors constrain the involvement of phonology in written production.

A growing body of recent research suggests that the processes involved in preparation of a handwriting movement (central processing) cascade into the motor processes during movement execution (peripheral processing). For instance, Kandel, Álvarez, and Vallée (2006) asked participants to copy French words in uppercase letters on a digital tablet, and found that interletter intervals were longer at syllabic boundaries than within syllables. From these findings, one might predict that the phonological priming effect found in our studies emerges not only in writing latencies, but also in properties of writing execution, such as writing duration for radicals, or inter-radical intervals. To our knowledge, no such work yet exists, likely because compared to alphabetic languages in which interletter intervals can be measured relatively easily, the temporal-spatial dynamics in non-alphabetic scripts such as Chinese are more complex. Future research should tackle this issue by investigating the dynamics of Chinese writing execution, in addition to examining onset latencies.

In conclusion, our experiments document phonologically based priming effects in a masked priming task with written responses. Previously reported null findings in similar studies should not be taken as evidence against the claim that orthographic word production is influenced by phonological properties.

Acknowledgement

We acknowledge Wenyu Li for help in data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Scientific Foundation of Institute of Psychology, Chinese Academy of Sciences [grant number Y3CX132005], and the National Natural Science Foundation of China [grant number 31400967] to the first author.

Note

1. Note, however, that Tainturier and Rapp (2001) made the prediction that for the writing of multiple words, the role

of phonology might be *more* pronounced than in single word written production. Due to the slow execution speed of handwritten output, buffering and rehearsal of constituents in phonological short-term memory is required for production of longer written utterances. Indeed, patients with preserved writing skills but difficulties in accessing phonology tend to produce "agrammatic" written utterances (e.g. Bub & Kertesz, 1982), which is in line with the idea that phonological buffering plays an important role in multi-word written generation.

References

Adelman, J. S., Johnson, R. L., McCormick, S. F., McKague, M., Kinoshita, S., Bowers, J. S., … Davis, C. J. (2014). A behavioral database for masked form priming. *Behavior Research Methods*, *46*, 1052–1067.

Afonso, O., & Álvarez, C. J. (2011). Phonological effects in handwriting production: Evidence from the implicit priming paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*, 1474–1483.

Aitchison, J., & Todd, P. (1982). Slips of the mind and slips of the pen. In B. N. Chir & W. von Raffler-Engel (Eds.), *Language and cognitive styles: Patterns of neurolingusitic and psycholinguistic development* (pp. 180–194). Lisse: Swets and Zeitlinger.

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language*, *38*, 419–439.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*, 390–412.

Bates, D. (2005). Fitting linear mixed models in R. *R News*, *5*(1), Article no. 5. Retrieved from http://ftp.cs.pu.edu.tw/network/CRAN/doc/Rnews/Rnews_2005-1.pdf

Bonin, P., Fayol, M., & Peereman, R. (1998). Masked form priming in writing words from pictures: Evidence for direct retrieval of orthographic codes. *Acta Psychologica*, *99*, 311–328.

Bonin, P., Méot, A., Lagarrigue, A., & Roux, S. (2015). Written object naming, spelling to dictation, and immediate copying: Different tasks, different pathways? *The Quarterly Journal of Experimental Psychology*, *68*, 1268–1294.

Bonin, P., Peereman, R., & Fayol, M. (2001). Do phonological codes constrain the selection of orthographic codes in written picture naming? *Journal of Memory and Language*, *45*, 688–720.

Bub, D., & Kertesz, A. (1982). Evidence for lexicographic processing in a patient with preserved written over oral single word naming. *Brain*, *105*, 697–717.

van Casteren, M., & Davis, M. H. (2006). Mix: A program for pseudorandomization. *Behaviour Research Methods*, *38*, 584–589.

Chen, J. Y., & Cherng, R. J. (2013). The proximate unit in Chinese handwritten character production. *Frontiers in Psychology*, *4*, Article no. 517. doi:10.3389/fpsyg.2013.00517

Chen, J. Y., Lin, W. C., & Ferrand, L. (2003). Masked priming of the syllable in Mandarin Chinese speech production. *Chinese Journal of Psychology*, *45*, 107–120.

Damian, M. F., Dorjee, D., & Stadthagen-Gonzalez, H. (2011). Long-term repetition priming in spoken and written word production: Evidence for a contribution of phonology to handwriting. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*, 813–826.

Damian, M. F., & Qu, Q. Q. (2013). Is handwriting constrained by phonology? Evidence from Stroop tasks with written responses and Chinese characters. *Frontiers in Psychology*, *4*, Article no. 765. doi:10.3389/fpsyg.2013.00765

Ferrand, L., Grainger, J., & Segui, J. (1994). A study of masked form priming in picture and word naming. *Memory & Cognition*, *22*, 431–441.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 680–698.

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments and Computers*, *35*, 116–124.

van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science*, *10*, 165–191.

Geschwind, N. (1969). Problems in the anatomical understanding of the aphasias. In A. L. Benton (Ed.), *Contributions to clinical neuropsychology* (pp. 107–128). Chicago, IL: Aldine.

Glaser, W. R., & Düngelhof, F. J. (1984). The time course of picture-interference. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 640–654.

Hallé, P. A., Chéreau, C., & Segui, J. (2000). Where is the /b/ in "absurde" [apsyrd]? It is in French listeners' minds. *Journal of Memory & Language*, *43*, 618–639.

Han, Z., Zhang, Y., Shu, H., & Bi, Y. (2007). The orthographic buffer in writing Chinese characters: Evidence from a dysgraphic patient. *Cognitive Neuropsychology*, *24*, 341–350.

Houghton, G., & Zorzi, M. (2003). Normal and impaired spelling in a connectionist dual-route architecture. *Cognitive Neuropsychology*, *20*, 115–162.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards Logit Mixed Models. *Journal of Memory and Language*, *59*, 434–446.

Kandel, S., Álvarez, C. J., & Vallée, N. (2006). Syllables as processing units in handwriting production. *Journal of Experimental Psychology Human Perception and Performance*, *32*, 18–31.

Kandel, S., Peereman, R., Grosjacques, G., & Fayol, M. (2011). For a psycholinguistic model of handwriting production: Testing the syllable-bigram controversy. *Journal of Experimental Psychology: Human Perception and Performance*, *37*, 1310–1322.

Law, S. P. (1994). The structure of orthographic representations of Chinese characters: From the perspective of the cognitive neuropsychological approach. *Bulletin of Institute of History and Philology*, *65*, 81–130.

Law, S. P. (2004). Writing errors of a Cantonese dysgraphic patient and their theoretical implications. *Neurocase*, *10*, 132–140.

Law, S. P., & Caramazza, A. (1995). Cognitive processes in writing Chinese characters: Basic issues and some preliminary data. In B. de Gelder & J. Morais (Eds.), *Speech and reading: A comparative approach* (pp. 143–190). Hove: Psychology Press.

Law, S. P., & Leung, M. T. (2000). Structural representations of characters in Chinese writing: Evidence from a case of acquired dysgraphia. *Psychologia*, *43*, 67–83.

Lupker, S. J., & Katz, A. N. (1981). Input, decision, and response factors in picture-word interference. *Journal of Experimental Psychology: Human Learning and Memory*, *7*, 269–282.

Luria, A. R. (1970). *Traumatic aphasia: Its syndromes, psychology, and treatment*. The Hague: Mouton.

Meyer, A. S. (1990). The time course of phonological encoding in language production: The encoding of successive syllables of a word. *Journal of Memory and Language*, *29*, 524–545.

Meyer, A. S. (1991). The time course of phonological encoding in language production: Phonological encoding inside a syllable. *Journal of Memory and Language*, *30*, 69–89.

Miceli, G., Benvegnù, B., Capasso, R., & Caramazza, A. (1997). The independence of phonological and orthographic lexical forms: Evidence from aphasia. *Cognitive Neuropsychology*, *14*, 35–69.

Morsella, E., & Miozzo, M. (2002). Evidence for a cascade model of lexical access in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 555–563.

van Orden, G. C. (1987). A rows is a rose: Spelling, sound, and reading. *Memory & Cognition*, *15*, 181–198.

Perfetti, C. A., & Tan, L. H. (1998). The time course of graphic, phonological, and semantic activation in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 101–118.

Qu, Q. Q., Damian, M. F., Zhang, Q., & Zhu, X. B. (2011). Phonology contributes to writing: Evidence from written word production in a nonalphabetic script. *Psychological Science*, *22*, 1107–1112.

Qu, Q. Q., Li, X., & Damian, M. F. (2014, July). *An electrophysiological analysis of the time course of phonological and orthographic encoding in written word production*. Poster presented at the International Workshop on Language Production, Geneva.

Rapp, B., Benzing, L., & Caramazza, A. (1997). The autonomy of lexical orthography. *Cognitive Neuropsychology*, *14*, 71–104.

Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition*, *64*, 249–284.

Roux, S., & Bonin, P. (2011). Cascaded processing in written naming: Evidence from the picture-picture interference paradigm. *Language and Cognitive Processes*, *27*, 734–769.

Schriefers, H., Meyer, A. S., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, *29*, 86–102.

Scinto, L. F. (1986). *Written language and psychological development*. New York, NY: Academic Press.

Shen, D., & Forster, K. I. (1999). Masked phonological priming in reading Chinese words depends on the task. *Language and Cognitive Processes*, *14*, 429–459.

Shen, X. R., Damian, M. F., & Stadthagen-Gonzalez, H. (2013). Abstract graphemic representations support preparation of handwritten responses. *Journal of Memory and Language*, *68*, 69–84.

Starreveld, P. A., & La Heij, W. (1995). Semantic interference, orthographic facilitation and their interaction in naming tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 686–698.

Stone, G. O., Vanhoy, M. D., & Van Orden, G. C. (1997). Perception is a two-way street: Feedforward and feedback phonology in visual word recognition. *Journal of Memory and Language*, *36*, 337–359.

Tainturier, M. J., & Rapp, B. (2001). The spelling process. In B. Rapp (Ed.), *The handbook of cognitive neuropsychology: What deficits reveal about the human mind* (pp. 263–289). Philadelphia: Psychology Press.

Verdonschot, R. G., Lai, J., Chen, F., Tamaoka, K., & Schiller, N. O. (2015). Constructing initial phonology in Mandarin Chinese: Syllabic or subsyllabic? A masked priming investigation. *Japanese Psychological Research*, *57*, 61–68.

Xia, V., & Andrews, S. (2015). Masked translation priming asymmetry in Chinese-English bilinguals: Making sense of the Sense Model. *The Quarterly Journal of Experimental Psychology*, *68*, 294–325.

You, W., Zhang, Q., & Verdonschot, R. G. (2012). Masked syllable priming effects in word and picture naming in Chinese. *PloS One*, *7*, e46595.

Zhang, Q., & Damian, M. (2010). Impact of phonology on the generation of handwritten responses: Evidence from picture-word interference tasks. *Memory & Cognition*, *38*, 519–528.

Zhang, Q., & Wang, C. (2015). Phonology is not accessed earlier than orthography in Chinese written production: Evidence for the orthography autonomy hypothesis. *Frontiers in Psychology*, *6*, Article no. 448. doi:10.3389/fpsyg.2015.00448

Zhou, X., & Marslen-Wilson, W. (1999). The nature of sublexical processing in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 819–837.

Appendix. Stimuli used in experiments

	Condition			
Target picture	PO_R	PO_U	P_R	P_U
鳄鱼, crocodile, /e4yu2/	愕然, stunned, /e4ran2/	磅礴, boundless, /pang2bo2/	恶劣, terrible, /e4lie4/	阳光, sunshine, /yang2guang1/
铃铛, bell, /ling2dang/	羚羊, antelope, /ling2yang2/	疏忽, neglect, /shu1hu1/	灵感, inspiration, /ling2gan3/	恶劣, terrible, /e4lie4/
蝴蝶, butterfly, /hu2die2/	湖水, lakewater, /hu2shui3/	愕然, stunned, /e4ran2/	弧形, curve, /hu2xing2/	落伍, out of date, /luo4wu3/
骆驼, camel, /luo4tuo/	洛阳, Luoyang(place name), /luo4yang2/	釜山, Busan, /fu3shan1/	落伍, out of date, /luo4wu3/	缸盖, crock, /gang1gai4/
樱桃, cherry, /ying1tao2/	缨子, tassel, /ying1zi/	腊月, December in lunar, /la4yue4/	英俊, handsome, /ying1jun4/	弧形, curve,/hu2xing2/
梳子, comb, / shu1zi/	疏忽, neglect, /shu1hu1/	境界, boundary, /jing4jie4/	叔叔, uncle, /shu1shu/	凝视, gaze, /ning2shi4/
沙发, sofa, /sha1fa1/	纱布, gauze, /sha1bu4/	羚羊, antelope, /ling2yang2/	杀手, killer, /sha1shou3/	静止,motionless, /jing4zhi3/
猩猩, gorilla, /xing1xing/	惺忪, sleepy, /xing1song1/	湖水, lake water, /hu2shui3/	兴盛, prosperous, /xing1cheng4/	辣椒, pepper, /la4jiao1/
袋鼠, kangaroo, /dai4shu3/	贷款, loan, /dai4kuan3/	纲要, outline, /gang1yao4/	怠慢, slight, /dai4man4/	氢气, hydrogen, /qing1qi4/
柠檬, lemon, /ning2meng2/	狞笑, fleer, /ning2xiao4/	蛟龙, flood dragon, /jiao1long2/	凝视, gaze, /ning2shi4/	叔叔, uncle, /shu1shu/
钢笔, pen, /gang1bi3/	纲要, outline, /gang1yao4/	箩筐, basket, /luo2kuang1/	缸盖, crock, /gang1gai4/	螺旋, helix, /luo2xuan1/
鸵鸟, ostrich, /tuo2niao3/	驼背, hunchback, /tuo2bei4/	惺忪, sleepy, /xing1song1/	驮马, packhorse, /tuo2ma3/	骄傲, pride, /jiao1ao4/
斧子, axe, /fu3zi/	釜山, Buson, /fu3shan1/	狞笑, fleer, /ning2xiao4/	辅导, tutorship, /fu3dao3/	庞大, hugeness, /pang2da4/
蜡烛, candle, /la4zhu2/	腊月, December in lunar, /la4yue4/	佯装, pretend, /yang2zhuang1/	辣椒, pepper, /la4jiao1/	英俊, handsome, /ying1jun4/
萝卜, carrot, /luo2bo/	箩筐, basket, /luo2kuang1/	纱布, gauze, /sha1bu4/	螺旋, helix, /luo2xuan1/	杀手, killer, /sha1shou3/
烟囱, chimney, /yan1cong1/	咽喉, throat, /yan1hou2/	贷款, loan, /dai4kuan3/	淹没, submerge, /yan1mo4/	灵感, inspiration, /ling2gan3/
螃蟹, crab, /pang2xie1/	磅礴, boundless, /pang2bo2/	缨子, tassel, /ying1zi/	庞大, hugeness, /pang2da4/	兴盛, prosperous, /xing1cheng4/
蜻蜓,dragonfly, /qing1ting2/	清澈, limpid, /qing1che4/	洛阳, Luoyang, /luo4yang2/	氢气, hydrogen, /qing1qi4/	怠慢, slight, /dai4man4/
镜子, mirror, /jing4zi/	境界, boundary, /jing4jie4/	咽喉, throat, /yan1hou2/	静止, motionless, /jing4zhi3/	淹没, submerge, /yan1mo4/
洋葱, onion, /yang2cong1/	佯装, pretend, /yang2zhuang1/	清澈, limpid, /qing1che4/	阳光, sunshine, /yang2guang1/	辅导, tutorship, /fu3dao3/
胶囊, capsule, /jiao1nang2/	蛟龙, flood dragon, /jiao1long2/	倚靠, lean, /yi1kao4/	骄傲, pride, /jiao1ao4/	已经, already, /yi3jing1/
椅子, chair, /yi3zi/	倚靠, lean, /yi1kao4/	驼背, hunchback, /tuo2bei4/	已经, already, /yi3jing1/	驮马, packhorse, /tuo2ma3/