The time course of speech production revisited: no early orthographic effect, even in Mandarin Chinese

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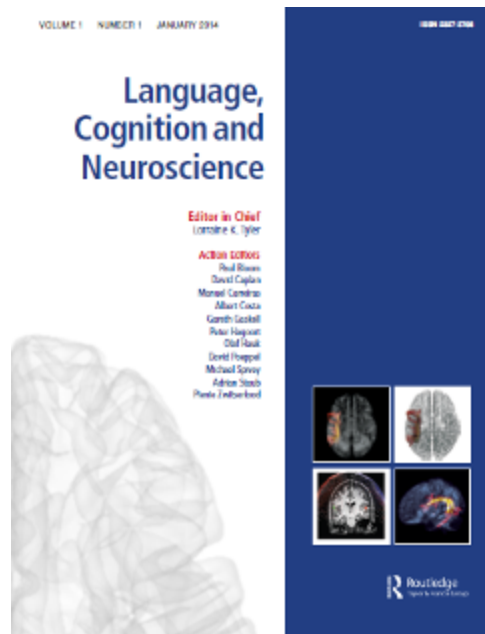# The Time Course of Speech Production Revisited: No Early Orthographic Effect, Even in Mandarin Chinese

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The Time Course of Speech Production Revisited: No Early Orthographic Effect, Even in

Mandarin Chinese

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1 **Abstract**

2 Most psycholinguistic models of speech production agree on an earlier semantic processing

3 stage and a later word-form encoding stage. Using a logographic language, Mandarin Chinese,

4 Zhang and Weekes (2009) reported an early effect of orthography in a picture-word-

5 interference study and suggested orthography affects speech production via a lexical-semantic

6 pathway at an early stage. This early orthographic effect without co-occurrence of phonological

7 effect, however, was not replicated (Zhao, La Heij, & Schiller, 2012). The present study aimed

8 to dissociate further the semantic and phonological representations from orthography by using

9 simplex Chinese characters. The results of Experiment 1 and 2 revealed an orthographic effect

10 but only at a similar point in time as the phonological effect, both of which followed the

11 semantic effect. Our results thus raise further doubts about the role of orthography at the

12 conceptual level of speech planning and lend new evidence to a two-step model of speech

13 production.

14 Keywords: language production, orthography, picture-word interference, Mandarin Chinese

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1   The time course of speech production revisited: No early orthographic effect, even in

2   Mandarin Chinese

1. Introduction

4   An important issue in psycholinguistic research is the extent to which psycholinguistic

5   models are capable of accounting for cross-linguistic differences. Models of speech production

6   generally recognize several major processing stages: conceptualization, lemma retrieval, word-

7   form encoding and articulation (e.g. Caramazza, 1997; Dell & O'Seaghdha, 1991, 1992; Levelt,

8   1989, 1992; the WEAVER++ model, Levelt, Roelofs, & Meyer, 1999a, b; Roelofs, 1992;

9   Roelofs & Meyer, 1998). Previous studies have reported that orthographic relatedness

10   modulates the speech production response latencies (Lupker, 1982; Posnansky & Rayner 1978;

11   Underwood & Briggs, 1984). It has also been suggested that the orthographic codes are

12   mandatorily activated in speech production based on the evidence that in the form-preparation

13   paradigm (Meyer, 1990), spelling inconsistency of the initial phoneme (e.g., *coffee* and *kennel*)

14   interrupts the facilitative effect caused by phonological overlap (e.g., /k/), compared to spelling

15   consistency (e.g., *coffee, camel, cushion;* Damian & Bowers, 2003; but see, e.g., Alario, Perre,

16   Castel, & Ziegler, 2007 as well as Schiller, 2007). However, models of speech production have

17   been mainly based on evidence from West Germanic languages, where orthographic and

18   phonological forms are less clearly distinguished. For instance, the WEAVER++ model

19   postulates a modality-neutral lemma representation where orthography is not specified (Levelt

20   et al., 1999a, b; Roelofs, 1992; Roelofs & Meyer, 1998). Alternatively, the Independent

21   Network model (Caramazza, 1997; Rapp & Caramazza, 2002) postulates a modality-specific

22   representation in language production with the semantic representation activating the

23   phonological representation of the lexicon in speech production and orthographic

24   representation in written word production. In other words, the Independent Network model

4

1 recognizes the role of the orthographic representation but posits that it only affects written word

2 production.

3   It is difficult to tease apart orthography and phonology in languages with alphabetic

4 scripts because the correspondence between grapheme and phoneme is relatively transparent,

5 with some showing very consistent mapping (as in Serbo-Croatian) but others relatively less

6 consistent mapping (as in English) (Katz & Frost, 1992). By contrast, logographic languages

7 show a highly arbitrary grapheme-to-phoneme correspondence. Take Mandarin Chinese as an

8 example; the basic unit of the writing system is a logographic character, and one character

9 usually corresponds to a syllable. The number of possible syllables in Mandarin Chinese is

10 limited, i.e., about 400 syllables excluding lexical tones or about 1,300 syllables including

11 tones (Duanmu, 2002). As a consequence, there is a large number of homophones, with the

12 result that orthography plays a crucial distinguishing role. It is therefore possible that in

13 logographic languages such as Mandarin Chinese orthography plays a different role in speech

14 production compared to languages with alphabetic scripts.

15   Attempts to address the separate roles of orthography and phonology in speech

16 production have been made in English (Damian & Bowers, 2009; Lupker, 1982; Posnansky &

17 Rayner, 1978) using the picture-word interference paradigm (e.g., Lupker, 1979; Rosinski,

18 Golinkoff, & Kukish, 1975). In this paradigm, participants are asked to name pictures while

19 ignoring superimposed distractor words. It is found that distractor words that belong to the

20 same semantic category as the target interfere with picture naming and phonologically-related

21 distractors facilitate picture naming (e.g., Starreveld, 2000; Starreveld & La Heij, 1995, 1996;

22 see Glaser, 1992; MacLeod, 1991 for a review of the paradigm). When the distractors are

23 related to the picture name both orthographically and phonologically, the facilitation effect is

24 stronger compared to pure phonological relatedness (e.g., Lupker, 1982; Posnansky & Rayner

25 1978; Underwood & Briggs, 1984). For instance, naming the picture of a *chair* was faster with

4

1   the distractor *air* (55 ms) or *bear* (23 ms), compared to an unrelated condition, from which the

2   facilitation effect was derived (32 ms) and attributed to orthographic overlap (Lupker, 1982).

3   However, Damian and Bowers (2009) found that 'extra' orthography alone did not modulate

4   the facilitation effect when distractors were presented in the auditory format instead of the

5   visual modality. Therefore, the presence of a pure orthographic effect in speech production has

6   remained unclear.

7   Two factors may have contributed to the discrepancy in the results of the studies based

8   on English stimuli. One factor is the limited number of word pairs that can dissociate

9   orthography and phonology in English (e.g. *bear – year*). The other factor is that the role of

10   orthography is often not examined independently but rather tested by a subtraction approach

11   (the effect of phonological and orthographic relatedness minus the effect of phonological

12   relatedness; e.g. Lupker, 1982; Posnansky & Rayner 1978; Underwood & Briggs, 1984).

13   Damian and Bowers (2009) pointed out that one of the limitations of using English words as

14   stimuli is that the distractors in the orthographically unrelated condition are only

15   orthographically "less similar". Consequently, this might have "underestimated the potential

16   contribution of spelling" (Damian & Bowers, 2009, p. 595).

17   Mandarin Chinese provides an ideal testing ground to tease apart the role of orthography

18   and phonology in speech production. As we mentioned earlier, it has a logographic writing

19   system that can help to dissociate phonology and orthography. Each syllable in Mandarin

20   Chinese contains segmental information and a lexical tone, and is represented by a single

21   character that comprises one or more sub-elements, known as 'radicals'. A semantic radical is

22   a sub-element of a Chinese character that conveys semantic information, while a phonetic

23   radical conveys phonological information. For example, 锤 (*chui2*, 'hammer') (here *chui* is the

24   alphabetic or 'pinyin' transcription of the Mandarin syllable, and *2* indicates Lexical Tone 2)

25   is a complex character where the left part is a semantic radical 钅 indicating that the meaning

1   denoted by the character is related to metal, and the right part is the phonetic radical 垂 (*chui2*)

2   suggesting the pronunication of the character 锤 (*chui2*). Some characters, however, contain

3   only one element (henceforth 'simplex' characters). For example, 羊 (*yang2*, 'sheep') is a

4   simplex character which cannot be decomposed into sub-parts. Thus, there are Chinese

5   characters which do not provide phonological or semantic information and therefore provide

6   an opportunity to tease apart orthographic, phonological, and semantic information. This

7   provides a great opportunity for us to manipulate the (un)relatedness of orthographic and

8   phonological information. For example, simplex 羊 (*yang2*, 'sheep') and 央 (*yang1*, 'center')

9   are only phonologically related (i.e. overlapping at the segmental level *yang* although differing

10   in lexical tones), while 羊 (*yang2*, 'sheep') and 半 (*ban4*, 'half') are orthographically related

11   but have no phonological overlap (i.e. neither in segment nor in tone). None of the characters

12   (i.e., 羊, 央, 半) are related semantically.

13   Independent orthographic and phonological facilitation effects have been reported in

14   studies using Mandarin Chinese stimuli (Bi, Xu, & Caramazza, 2009; Zhang, Chen, Weekes,

15   & Yang, 2009; Zhang & Weekes, 2009; Zhao, La Heij, & Schiller, 2012). In the picture-word

16   interference paradigm, it is well-established that if the visually presented distractor is

17   semantically related to the target, it exerts an inhibition effect. That is, the semantic

18   representation of the distractor is firstly activated and then inhibits the picture naming process

19   (see, e.g., La Heij, 1988; Levelt et al., 1999a; 1999b; Roelofs, 2003; but see also, e.g.,

20   Finkbeiner & Caramazza, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Mahon, Costa,

21   Peterson, Vargas, & Caramazza, 2007; Miozzo & Caramazza, 2003 for accounts of the

22   semantic effect). If the distractor is phonologically related to the target, however, there would

23   be a facilitation effect. That is, the phonological representation of the target is primed by the

24   distractor (e.g., Perfetti & Tan, 1998; Zhou & Marslen-Wilson, 1999a; Zhou, Shu, Bi, & Shi,

25   1999) and therefore shortens the naming latency of the target picture. In addition, upon seeing

1   the distractor, the visual input of the distractor has been reported to activate the orthographic

2   representations of its orthographic neighbors that are visually similar (McClelland &

3   Rumelhart, 1981, cf. Bi et al., 2009). Such a visual similarity effect has been observed when

4   the distractor is orthographically related to the character of the target picture name. Specifically,

5   the orthographic representation of the target is activated and the activated orthographic code

6   produces a facilitative effect on picture naming, reflected by shorter naming latencies with an

7   orthographically related distractor relative to an unrelated one (Bi et al., 2009; Zhang et al.,

8   2009; Zhang & Weekes, 2009; Zhao et al., 2012).

9   The central issue here is when and how the orthographic representation that is activated

10   by the visual cues in processing the visual words then affects speech production. To tap into

11   this issue, previous studies have manipulated the stimulus onset asynchrony (SOA) but yielded

12   mixed results regarding the temporal locus of the orthographic effect (Zhang et al., 2009; Zhang

13   & Weekes, 2009; Zhao et al., 2012). For example, Zhang and colleagues (Zhang et al., 2009;

14   Zhang & Weekes, 2009) reported orthographic effects with the negative SOAs (-150 ms and -

15   100 ms) without co-occurrence of any phonological effect, which led them to claim that sharing

16   orthography might activate the target concept via the lexical-semantic pathway (Link A in

17   Figure 1) and facilitate the target name retrieval at an earlier stage compared to the

18   phonological effect. However, Zhao et al. (2012), failed to replicate the findings in any of the

19   negative SOA conditions (-150 ms in Experiment 1; -150 ms and -75 ms in Experiment 2).

20   Instead, their results demonstrated that orthographically and phonologically related distractors

21   both facilitated picture naming at a similar stage (i.e. with SOA = 0 ms in Experiment 1 and no

22   interaction between relatedness (two levels: orthographic or phonological) and SOA in

23   Experiment 2). Furthermore, based on the null effect of orthographic relatedness on picture

24   naming and picture categorization in their third experiment, Zhao and colleagues (Zhao et al.,

25   2012) excluded the scenario of orthographic facilitation at the early, conceptual stage. Taken

1   together, they suggested that the orthographic facilitation effect should be attributed to the

2   word-form encoding stage of speech production.

3   The discrepancy in the findings of Zhao and colleagues (Zhao et al., 2012) and Zhang

4   and colleagues (Zhang et al., 2009; Zhang & Weekes, 2009) could be attributed to their

5   differences in experimental design. In Zhao et al. (2012), semantic relatedness was not

6   manipulated. In other words, only orthographically (or phonologically) related conditions were

7   compared to orthographically (or phonologically) unrelated conditions. It is possible that

8   orthographic relatedness affects speech production via the interaction with the semantic

9   representation. The experimental design of Zhao et al. (2012), however, does not allow testing

10   this possibility.

11   ## insert Figure 1 about here ##

12   The crucial issue is thus to clarify whether orthography affects speech production by

13   interacting with the semantic representation of the target word. The goal of Experiment 1 of

14   the present study was therefore two-fold. First, we were interested in resolving the controversial

15   empirical findings and planned to to confirm whether orthography affects speech production

16   via a lexical-semantic pathway independent of the phonological effect. Second, we were

17   interested in whether orthography affects speech production by interacting with semantics. To

18   this end, we improved the design in Zhao et al. (2012) and employed a full factorial design

19   including all four possible conditions of semantic and orthographic overlap: semantically and

20   orthographically related, semantically related but orthographically unrelated, orthographically

21   related but semantically unrelated, and unrelated. We used the picture-word interference

22   paradigm with SOAs ranging from negative to positive values to cover the process before and

23   after the activation of the target lemma, respectively (see Schriefers et al., 1990; Zhang &

24   Weekes, 2009; Zhao et al., 2012). A more refined increment (75 ms) was employed (instead of

25   100 ms as in Zhang & Weekes, 2009) to increase the sensitivity of detecting the hypothesized

1   effects. If orthography facilitates speech production at the conceptual level, as claimed in

2   Zhang and Weekes (2009), we would expect an orthographic effect at negative SOAs, possibly

3   with the same temporal locus as that of the semantic effect (Zhang & Weekes, 2009) or showing

4   interaction with the semantic effect.

5   As we noted earlier, in Mandarin Chinese, simplex characters and complex characters

6   have distinctive structural properties. So we used complex characters in Experiment 1 to test

7   possible interactions between semantic and orthography, but we designed Experiment 2 with

8   only simplex-character stimuli. The design with simplex characters only is also a novelty of

9   the present study, which promises to help further disentangle orthographic effect from that of

10   semantic and phonological effects. This is because in complex characters (e.g., 猫, *mao1*, 'cat';

11   see Figure 2), the semantic radical (i.e., the left part of the character; in this case, 犭) may allow

12   activation from orthography to semantics and the phonetic radical (i.e., the right part of the

13   character; in this case, 苗, *miao2*, 'sprout') may allow activation from orthography to

14   phonology (苗, *miao2*, and the target 猫, *mao1* have the same rhyme *ao*). All existing studies,

15   due to the lack of control in their stimuli, could not rule out such activations. In our study, by

16   using only simplex characters, we made sure that there are no such semantic/phonological

17   radicals that may allow activation from orthography to semantics or phonology. In this way,

18   we excluded possible grapheme-to-phoneme route (Link C in Figure 1) and were able to zoom

19   into the orthographic effect as well as semantic and phonological effects on speech production

20   without having to worry about their possible overlaps. The time course of these independent

21   effects can then be more clearly teased apart when we examine the inhibition and facilitation

22   patterns in picture naming.

23   ## insert Figure 2 about here ##

24   **Experiment 1**

25   **2. Methods**

2.1. Participants

Twenty native Mandarin speakers (5 male; average age = 27.4 years; SD = 2.41 years) studying in the Netherlands (within one year after arrival) were paid for their participation. All participants signed a letter of informed consent, had normal or corrected-to-normal vision and none had any language impairments.

2.2 Materials and design

Twenty black-and-white line drawings from the International Picture Naming Project (Bates et al., 2003) and Snodgrass and Vanderwart (1980) databases, or drawn similarly, corresponding to complex character names in Mandarin Chinese (either monosyllabic N = 7 or disyllabic N = 13) were selected as target pictures. Each picture was presented with four types of monosyllabic distractors: a) semantically and orthographically related (S+O+); b) semantically related but orthographically unrelated (S+O-); c) orthographically related but semantically unrelated (S-O+); d) semantically and orthographically unrelated (S-O-). Ten other pictures corresponding to monosyllabic or disyllabic names were selected from the same databases to serve as fillers.

All the distractors were phonologically unrelated to the targets. The distractors in the four conditions were comparable in terms of word frequency, $F(3, 76) < 1$ (calculated with the log frequency of words in the SUBTLEX-CH database; Cai & Brysbaert, 2010) and visual complexity (number of strokes), $F(3, 76) = 1.655$, $p > 0.05$. Orthographic relatedness was operationalized by overlapping in one radical of the characters (e.g., 猫, *mao1*, 'cat' and 狗, *gou3*, 'dog' which overlap in the radical 犭). Please note that the one-radical overlap applied to both monosyllabic and disyllabic target words, so the amount of overlap slightly varied within the orthographically-related condition due to limitations in the available stimuli given the other criteria. Fourteen native Mandarin speakers rated the semantic relatedness of word pairs with one distractor word and its corresponding target word on a 1-7 scale, with a higher

1   score indicating stronger relatedness. The average rating scores per participant were then

2   submitted to Wilcoxon Signed-Rank tests. The rating scores differed significantly between

3   semantically related and unrelated word pairs, $Z = -3.9$, $p < 0.0001$. The semantic relatedness

4   did not differ between S+O+ and S+O-, $Z = -1.9$, $p > 0.05$ or between S-O+ and S-O-, $Z = -1.4$,

5   $p > 0.05$.

6   The design included two factors: Distractor Type (S+O+, S+O-, S-O+, S-O-) and SOA

7   (-150 ms, -75 ms, 0 ms, and 75 ms). Each participant received 30 pictures × 4 Distractor Types

8   × 4 SOAs = 480 trials in total in a pseudo-randomized order such that the same picture did not

9   re-occur within three consecutive trials. The trials were blocked by SOA. The sequence of the

10 blocks was counterbalanced across participants.

11 **2.3.** *Apparatus and procedure*

12 Before the experiment, there was a familiarization and practice session. The participants

13 were first shown all the pictures with their names underneath, and were then asked to name the

14 pictures without their names presented. Incorrect answers were corrected.

15 Each trial in the experimental sessions consisted of: a fixation (300 ms); a blank screen

16 (200 ms); the first stimulus which was either the target picture (350 by 350 pixels) or the

17 distractor depending on the SOA (Arial Unicode MS, 48 point size); followed by the second

18 stimulus (again either target picture or distractor). The stimuli lasted until the voice-key was

19 triggered or a 2 s limit was exceeded, followed by another blank screen (500 ms). There was a

20 self-paced pause between every two blocks.

21 The stimuli were presented using the software E-prime 2.0 and reaction times were

22 recorded online by a voice-key connected with a PST serial response box. Incorrectly triggered

23 voice-key responses were corrected manually using the program CheckVocal (Protopapas,

24 2007). Errors were firstly manually coded on-line and then double-checked based on the voice

25 recordings.

2.4. *Statistical analysis*

The statistical analysis was conducted using the 'lmer4' package (Bates, Maechler, Bolker, & Walker, 2014) using a mixed effect model structure (see, Janssen, Hernández-Cabrera, Van der Meij, & Barber, 2015, for a similar approach). The initial statistical model was built with three fixed predictors: semantic relatedness, orthographic relatedness and SOA. The naming latencies showed a skewed distribution and were therefore log-transformed (base 10). The log-transformed naming latencies (6,107 data points) were submitted to the mixed-effects modeling in R (version 3.1.0; R Core Team, 2014) as the dependent variable. We further entered two-way interactions between distractor type (semantic and orthographic relatedness) and SOA, two random intercepts (participant and target picture), and the random slopes of fixed predictors by participant. The model failed to converge, so the least variable random slope (the random slope of orthographic relatedness by participant; judged by its lowest variance value in the model summary) was removed. ~~The model summary showed a significant effect of semantic relatedness, coefficient estimate = 0.026, SE = 0.009, *t* = 2.90, *p* = 0.004, indicating slower responses in the semantically related than the unrelated condition. The linear regression model also showed significant differences between the reference level (SOA = -150 ms) and other levels of SOA, coefficient estimates > 0.033, SEs < 0.019, *t* values > 2.05, *p* values < 0.05. Since we are not interested in the pairwise comparison of difference SOAs, we did not run further posthoc analyses on the SOA effects. The effect of orthographic relatedness in the initial model did not reach significance, coefficient estimate = 0.007, SE = 0.009, *t* = 0.78, *p* = 0.435. The interaction between orthographic relatedness and SOA was significant when comparing orthographic relatedness at SOA = 75 ms to the reference level (orthographically unrelated at SOA = - 150 ms), coefficient estimate = -0.020, SE = 0.011, *t* = 1.79, *p* = 0.037 (one-tail; based on Zhang et al., 2009; Zhang & Weekes, 2009; Zhao et al., 2012).~~ The data were then divided into four subsets per SOA. Separate models were built with semantic

1 relatedness and orthographic relatedness as the fixed predictors, the random intercepts: the

2 participant and target picture, and the random slopes of fixed predictors by participant. The

3 interaction between semantic relatedness and orthographic relatedness was also tested but

4 model comparisons showed no significance at any SOA (based on the criteria of AIC

5 differences < 2 and *p*-values > 0.05). Thus, the final models included the fixed effects of

6 semantic relatedness and orthographic relatedness, the random intercepts of participant and

7 target picture, the random slopes of semantic relatedness and orthographic relatedness by

8 participants   (Liner   mixed   effects   model   syntax:

9 lmer(logrt~S+O+(1+S|Subject)+(1+O|Subject)+(1|Item))). The *p*-values of the final models

10 were obtained using the 'pbkrtest' package (Halekoh & Højsgaard, 2014).

11

12 **3. Results and discussion**

13 ## insert Table 1 and Figure 3 about here ##

14 Errors (3.41% of all 6,400 data points; including incorrect and disfluent responses) and

15 outliers (1.17%; shorter than 300 ms and longer than 1,300 ms) were excluded from further

16 analysis. Error rates were very low and thus considered not informative enough for further

17 statistical analysis.

18 ## insert Table 2 about here ##

19 The ~~model~~ summary of the initial model showed a significant effect of semantic

20 relatedness, ~~coefficient estimate~~β = 0.026, ~~SE = 0.009~~, *t* = 2.90, *p* = 0.004, indicating slower

21 responses in the semantically related than the unrelated condition. The linear regression model

22 also showed significant differences between the reference level (SOA = -150 ms) and other

23 levels of SOA, ~~coefficient estimate~~βs > 0.033~~, SEs < 0.019~~, *t*~~-values~~ > 2.05, *p*~~-values~~ < 0.05.

24 Since we are not interested in the pairwise comparison of difference SOAs, we did not run

25 further posthoc analyses on the SOA effects. The effect of orthographic relatedness in the initial

14

1 model did not reach significance, ~~coefficient estimate~~β = 0.007, ~~SE = 0.009,~~ t = 0.78, p = 0.435.

2 The interaction between orthographic relatedness and SOA was significant when comparing

3 orthographic relatedness at SOA = 75 ms to the reference level (orthographically unrelated at

4 SOA = - 150 ms), ~~coefficient estimate~~β = -0.020, ~~SE = 0.011,~~ t = 1.79, p = 0.037 (one-tail;

5 based on Zhang et al., 2009; Zhang & Weekes, 2009; Zhao et al., 2012).

6 The final models showed ~~W~~when SOA was -150 ms, -75 ms or 0 ms, there was a

7 significant effect of semantic interference (+15 ms, +16 ms and +20 ms, respectively; please

8 see Tables 1 and 2). As shown in Figure 3, naming latencies with semantically related

9 distractors were significantly longer than those with semantically unrelated distractors (see,

10 e.g., La Heij, 1988; Levelt et al., 1999a; 1999b; Roelofs, 2003; but see also, e.g. Finkbeiner &

11 Caramazza, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Mahon, Costa, Peterson, Vargas,

12 & Caramazza, 2007; Miozzo & Caramazza, 2003 for accounts of the semantic effect). There

13 was a significant effect of orthographic facilitation when SOA was 75 ms (difference of -13

14 ms). The semantic effect did not reach significance at SOA of 75 ms.

15 The semantic interference effect was shown at negative SOAs. This result is compatible

16 with previous research using the picture-word interference paradigm in both alphabetic and

17 logographic languages (e.g. Lupker, 1982; Zhang & Weekes, 2009; Zhang et al., 2009).

18 Critically, we did not observe an early orthographic effect or any significant interaction

19 between orthographic relatedness and semantic relatedness at negative SOAs. Instead, the

20 orthographic effect was only demonstrated at the positive SOA (i.e., 75 ms, see Tables 1 and

21 2), suggesting that orthographic relatedness only affected the picture naming process after

22 lemma retrieval, possibly at the word-form processing stage. This result did not confirm the

23 necessity to reconstruct the speech production model regarding the orthographic effect, as

24 suggested by Zhang and Weekes (2009).

14

1   It is worth noting that the significant semantic and orthographic effects have distinctive

2   temporal loci without any overlap at the specified SOAs (see Figure 3). That is, the semantic

3   interference effect was only found at negative SOAs and orthographic facilitation at positive

4   SOAs. This pattern is similar to the pattern of results in Schriefers et al. (1990), suggesting a

5   two-step model of speech production that distinguishes meaning and form processing (but see

6   e.g. Dell, Schwartz, Martin, Saffran, & Gagnon, 1997 for an interactive two-step model).

7   Furthermore, the magnitudes of the semantic interference and orthographic facilitation

8   was comparable to Zhang and Weekes (2009) but smaller than Zhao et al. (2012). In contrast

9   to Zhang and Weekes (2009), there was only a numerical difference between the

10   orthographically related and the unrelated conditions at negative SOAs (-10 ms at SOA -75 ms

11   and -4 ms at SOA 0 ms). Moreover, the size of the orthographic facilitation effect obtained at

12   SOA 75 ms was relatively small (-13 ms) with a *p*-value of 0.035. There is a possibility that

13   the current design is not sensitive enough to obtain a robust orthographic effect. For instance,

14   the orthographic relatedness represented by sharing one radical (e.g. 碗, *wan3,* 'bowl' and 矿,

15   *kuang4,* 'mine' share the radical 石, *shi2,* 'stone') may not be salient enough to facilitate picture

16   naming. However, increasing evidence has been found to support the decomposition of the

17   Chinese characters involved in reading (e.g., Ding, Peng & Taft, 2004; Feldman & Siok, 1999;

18   Qu, Damian, Zhang, & Zhu, 2011; Zhou & Marslen-Wilson, 1999b; Yeh & Li, 2004; but see,

19   e.g., Cheng, 1981; Tzeng, Hung, Cotton, & Wang, 1979; Yu, Feng, Cao, & Li, 1990 for a

20   holistic view).

21   Experiment 2 was therefore designed to tap into the time course of the orthographic

22   effect using simplex characters with orthographic relatedness implemented as overlapping in

23   larger portions (e.g., 兔, *tu4,* 'rabbit' and 免, *mian3*, 'exemption'). As explained earlier, in

24   complex characters, the semantic radical or phonetic radical (comprising the orthographic form

25   of the character) usually indicates the semantic category or the phonological form of the

1   character. Thus, another advantage of using simplex characters is that we can avoid implicit

2   confounding effects of orthography and phonology or semantic information.

3

4   **Experiment 2**

5   **4. Methods**

6   *4.1. Participants*

7   Sixty-eight native Mandarin speakers (30 male; average age = 21.6 years; SD = 2.19

8   years) living in Beijing, China were paid for their participation in the experiment. All

9   participants signed a letter of informed consent, had normal or corrected-to-normal vision and

10   none had any language impairments. Following a Latin Square design, there was an increase

11   in sample size in Experiment 2. The sixty-eight native Mandarin speakers were randomly

12   distributed across four groups.

13   *4.2 Materials and design*

14   Twenty target pictures were selected from the same sources as in Experiment 1. The

15   target pictures in Experiment 2 corresponded to monosyllabic simplex names in Mandarin

16   Chinese (i.e. written using non-decomposable, simplex characters). Each picture was presented

17   with four different types of superimposed monosyllabic distractors: a) semantically related but

18   orthographically and phonologically unrelated (S+O-P-); b) orthographically related but

19   semantically and phonologically unrelated (S-O+P-); c) phonologically related but

20   semantically and orthographically unrelated (S-O-P+); d) semantically, orthographically and

21   phonologically unrelated (S-O-P-).

22   The distractors in the four conditions, as well as the names of the target pictures, were

23   comparable in terms of word frequency, $F(4, 95) < 1$ (calculated with the log frequency of

24   words in the SUBTLEX-CH database; Cai & Brysbaert, 2010) and visual complexity (number

25   of strokes), $F(4, 95) = 1.421$, $p > .20$. Moreover, two separate online surveys were carried out

1   to ensure the semantically related distractors were not orthographically related to the targets

2   and vice versa. In each survey, 40 native speakers of Mandarin were asked to rate the semantic

3   or orthographic relatedness of word pairs on a 1-7 scale, with the higher score indicating

4   stronger relatedness. Rating scores were first transformed to z-scores per participant, and then

5   submitted to the Friedman test. There were statistically significant differences in the rating

6   scores for orthographic and semantic relatedness among the four conditions, $\chi^2(3) = 71.167$, p

7   < 0.001 and $\chi^2(3) = 67.774$, $p < 0.001$, respectively. Post-hoc analyses using Wilcoxon Signed-

8   Rank tests were conducted with Bonferroni correction. The results showed respectively that

9   orthographically related stimuli were rated as significantly more orthographically related, and

10   semantically related stimuli were rated as significantly more semantically related compared to

11   the other three conditions, p-values < 0.001. Phonological relatedness was represented by

12   overlapping the segmental information of syllable pairs (e.g. 羊, *yang*, 'sheep' and 央, *yang*,

13   'center'). Twenty other pictures corresponding to monosyllabic names were selected from the

14   same databases to serve as fillers.

15   The design included two factors: Distractor Type and SOA (-150 ms, -75 ms, 0 ms and

16   75 ms) as in Experiment 1. In total, there were 16 combinations of the two factors. The 16

17   conditions were assigned to four groups of participants based on the Latin-square method, with

18   17 participants per group. In this way, each group of participants was presented with four

19   different combinations of distractor type and SOA, and each saw all the pictures, distractor

20   types and SOAs. In total, each participant received 160 trials (4 blocks by 40 trials).

21   **4.3. *Apparatus and procedure***

22   The apparatus and procedure were the same as in Experiment 1.

23   **4.4. *Statistical analysis***

24   The initial model was built using the 'lmer4' package (Bates et al., 2014) with two fixed

25   factors: distractor type and SOA, the interaction between distractor type and SOA, and one

1   random intercept: target pictures. The naming latencies showed a skewed distribution and were

2   therefore log-transformed. The log-transformed naming latencies (5,253 data points) were

3   submitted to the mixed-effects modelling in R (version 3.1.0; R Core Team, 2014) as the

4   dependent variable. Since the experiment adopted a between-participants design, the intercept

5   of the participant was correlated with the fixed factors and thus was not entirely random. ~~The~~

6   ~~model summary showed a significant effect of semantic relatedness, coefficient estimate =~~

7   ~~0.051, SE = 0.015, t = 3.35, p < 0.001, indicating slower responses on the semantically related~~

8   ~~than unrelated trials. The linear regression model also showed signicant differences between~~

9   ~~the reference level (SOA = -150 ms) and two other levels (SOA = 0 ms and SOA = 75 ms),~~

10   ~~coefficient estimates > 0.045, SEs < 0.015, t values > 2.98, p values < 0.003. Since we are not~~

11   ~~interested in the pairwise comparison of different SOAs, we did not run further posthoc~~

12   ~~analyses on the SOA effects. The effects of orthographic and phonological relatedness in the~~

13   ~~initial model did not reach significance, coefficient estimate = -0.018, SE = 0.015, t = -1.18, p~~

14   ~~= 0.237 and coefficient estimate = -0.008, SE = 0.015, t = -0.54, p = 0.593, respectively. The~~

15   ~~model showed significant interactions between distractor type and SOA at several lower level~~

16   ~~contrasts, coefficient estimates > 0.038, SEs < 0.022, t values > 1.78, p values < 0.038 (one-~~

17   ~~tail; based on Zhang et al., 2009; Zhang & Weekes, 2009; Zhao et al., 2012).~~ The data were

18   then divided into four subsets per SOA. Separate models were built with the distractor type as

19   the fixed predictor and random intercept for target picture (Liner mixed effects model syntax:

20   lmer(logrt~Distractor+(1|Item))). The adjusted p-values were obtained with the Bonferroni

21   method using the 'multcomp' package (Hothorn, Bretz, & Westfall, 2008).

22

23   **5. Results and discussion**

24   Following the criteria used in Experiment 1, errors (2.61% of all 5,440 data points;

25   including incorrect and disfluent responses) and outliers (0.83%; shorter than 300 ms and

1   longer than 1,300 ms) were excluded from further analysis. Error rates were very low and thus

2   considered not informative enough for further statistical analysis.

3   ## insert Table 3 and 4 about here ##

4   The ~~model~~ summary of the initial model showed a significant effect of semantic

5   relatedness, ~~coefficient estimate~~β = 0.051, ~~SE = 0.015,~~ t = 3.35, p < 0.001, indicating slower

6   responses on the semantically related than unrelated trials. The linear regression model also

7   showed signicant differences between the reference level (SOA = -150 ms) and two other levels

8   (SOA = 0 ms and SOA = 75 ms), ~~coefficient estimate~~βs > 0.045, ~~SEs < 0.015,~~ t ~~values~~ > 2.98,

9   p ~~values~~ < 0.003. Since we are not interested in the pairwise comparison of different SOAs, we

10   did not run further posthoc analyses on the SOA effects. The effects of orthographic and

11   phonological relatedness in the initial model did not reach significance, ~~coefficient estimate~~β

12   = -0.018, ~~SE = 0.015,~~ t = -1.18, p = 0.237 and ~~coefficient estimate~~β = -0.008, ~~SE = 0.015,~~ t = -

13   0.54, p = 0.593, respectively. The model showed significant interactions between distractor

14   type and SOA at several lower level contrasts, ~~coefficient estimate~~βs > 0.038, ~~SEs < 0.022,~~ t

15   ~~values~~ > 1.78, p ~~values~~ < 0.038 (one-tail; based on Zhang et al., 2009; Zhang & Weekes, 2009;

16   Zhao et al., 2012).

17   As shown in Table 3 and 4, the final models showed that when SOA was -150 ms, there

18   was a significant effect of semantic interference (+37 ms). Naming latencies with semantically

19   related distractors were significantly longer than those with semantically unrelated distractors

20   (see Figure 4). When SOA was -75 ms, there was again a significant effect of semantic

21   interference (+24 ms). The orthographic effect and phonological effect did not reach

22   significance at negative SOAs, p-values > 0.05. These results are in line with the results of

23   Experiment 1.

24   ## insert Figure 4 about here ##

1   When SOA was 0 ms, there was a significant effect of orthographic facilitation (-38

2 ms), and a significant effect of phonological facilitation (-26 ms). When SOA was 75 ms, there

3 was again significant effects of orthographic facilitation (-37 ms) and phonological facilitation

4 (-42 ms). The semantic effects did not reach significance at SOAs 0 or 75 ms (see Tables 3 and

5 4).

6   In summary, using solely simplex characters, we did not observe any orthographic

7 effect with negative SOAs, indicating that the early orthographic effect shown in Zhang and

8 Weekes (2009) may not be reliably obtained. Instead, both orthographic and phonological

9 effects were found at positive SOAs, replicating results in Zhao et al. (2012). Furthermore, the

10 magnitudes of orthographic and phonological facilitation were comparable to Zhao et al. (2012),

11 i.e. 37 ms and 38 ms after excluding stimuli with phonetic radicals.

12

13 **6. General discussion**

14   Using two experiments, the present study made use of Chinese, a language with

15 logographic scripts, to tease apart the orthographic and phonological representations and test

16 the independent orthographic and phonological effects in spoken word production. The

17 previous literature (e.g., Zhang et al., 2009; Zhang & Weekes, 2009; Zhao et al., 2012) debated

18 on the time course of the orthographic effect about whether the orthographic relatedness

19 facilitates the conceptual identification of target pictures. Our study revisited this topic and

20 found evidence against this claim. One of the contributions of our study beyond the previous

21 literature is that we tested if there was an interaction between the orthographic representation

22 and semantic representation in picture naming with visual cues, which was not tested in Zhao

23 et al. (2012). Neither an early orthographic effect nor an interaction with semantic relatedness

24 was observed in Experiment 1. One novelty of our study is that we utilized the simplex Chinese

25 characters in Experiment 2 to avoid any semantic and phonetic radicals and to further tease

1 apart the semantic, phonological and orthographic processing. Again, no early orthographic

2 effect was observed in Experiment 2.

3   In contrast to the results of Experiment 1, at SOA 0 ms, the semantic interference effect

4 did not reach significance in Experiment 2 (see Figure 4). In the previous literature, the

5 presence and absence of semantic effects at SOA = 0 have both been reported (e.g., present in

6 Zhao et al., 2012 and absent in Schriefers et al., 1990). One possibility for such discrepancy in

7 our two experiments could be the difference in distractor frequencies between Experiment 1

8 and 2. The distractor frequency (calculated by taking the log frequency of words in the

9 SUBTLEX-CH database; Cai & Brysbaert, 2010) is lower in Experiment 1 (mean = 2.49) than

10 in Experiment 2 (mean = 3.64), $p < 0.0001$. It has been shown that lower-frequency distractors

11 produce stronger interference at the lexical selection stage (Miozzo & Caramazza, 2003). The

12 difference in distractor frequency may also explain the faster average naming latencies and

13 lower error rates in Experiment 2 than in Experiment 1, as due to the less interference during

14 lexical selection in Experiment 2. Although Miozzo and Caramazza offered a very plausible

15 explanation for the varying semantic effects in Experiments 1 and 2, we cannot exclude other

16 possibilities that may have contributed to the finding.

17   Although both the orthographic effect and the phonological effect were significant at

18 the same SOA conditions, we still observed minor differences in their effect sizes. For instance,

19 Experiment 2 revealed that when SOA was 0 ms, the orthographic effect ($p = 0.0002$) was

20 stronger than the phonological effect ($p = 0.0307$), which is in line with previous findings in

21 English (e.g. Lupker, 1982; Posnansky & Rayner, 1978) and Chinese (Bi et al., 2009). It has

22 been questioned to compare directly the effect sizes of orthographic relatedness and

23 phonological relatedness, partially because the degree of overlap between orthographically

24 related pairs (visual similarity) and phonologically related pairs (differing in tone) hardly

25 allows such a direct comparison (see Bi et al., 2009). Nevertheless, distractors in the current

1 study were presented visually, and phonological relatedness relies on the activation of the

2 orthographic level (Link B in Figure 1). In other words, orthographic relatedness may play a

3 more critical role when the distractor is presented visually than it does when it is presented

4 auditorily (see, e.g., Damian & Martin, 1999; Starreveld, 2000), and thus it is not surprising to

5 observe a stronger orthographic than phonological effect.

6 It is worth noting that the distinctive temporal loci of the semantic, orthographic and

7 phonological effects without any overlap in Experiment 2 were similar to the pattern of results

8 found in Experiment 1, which has also been shown for Dutch in Schriefers et al. (1990), where

9 the semantic interference effect was only found at negative SOAs and phonological facilitation

10 at positive SOAs. In both experiments of the present study, the significance of semantic and

11 orthographic effects did not overlap at any SOA. Since both orthographic and phonological

12 effects were significant at SOA = 0 ms and SOA = 75 ms in Experiment 2, later than when the

13 semantic effect was observed, what we can conclude is that both orthographic and phonological

14 effects take place after the conceptual level. This is consistent with the predictions of the

15 WEAVER++ model in that semantic and word-form processing are localized at disinctive

16 layers and the activation flows in a discrete manner. Nevertheless, our results do not rule out

17 the possibility that the word form processing level of representation may affect an earlier

18 lexical selection level through feedback connections (Dell & O'Seaghdha, 1992). Additional

19 research using high temporal resolution measurements such as electrophysiological studies are

20 preferable to settle this debate.

21

22 **7. Conclusion**

23 With two behavioral experiments, the present study shows no early orthographic effect,

24 even in a logographic language like Mandarin Chinese where the orthography is characterized

25 by opaque symbol-to-sound mappings. The results run counter to the proposal that orthography

affects speech production at an early, conceptual level (Zhang & Weekes, 2009). Rather, the

orthographic effects were found at similar temporal loci to the phonological effects, as

predicted by most speech production models (e.g. Dell & O'Seaghdha, 1992; Levelt et al.,

1999a, b; Roelofs, 1992; Roelofs & Meyer, 1998). The results therefore lend further support to

a two-step model of speech production in Mandarin Chinese which distinguishes between

meaning and form processing.

8. Acknowledgement

9. Declaration of interest statement

The authors declare that the research was conducted in the absence of any commercial

or financial relationships that could be construed as a potential conflict of interest.

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1   Appendix A. Stimuli used in Experiment 1: Target picture names and distractors.

Experiment 1				
	Distractor type			
	Semantically related		Semantically unrelated	
Target Picture	Orthogra-phically related	Orthogra-phically unrelated	Orthogra-phically related	Orthogra-phically unrelated
猩猩 xing1xing1 *gorilla*	狮 shi1 *lion*	鹅 e2 *goose*	独 du2 *alone*	柯 ke1 *a name*
吉他 ji2ta1 *guitar*	鼓 gu3 *drum*	琴 qin2 *piano*	喜 xi3 *favor*	知 zhi1 *knowledge*
桌 zhuo1zi0 *table*	床 chuang2 *bed*	窗 chuang1 *window*	杭 hang2 *a place name*	答 da2 *answer*
梨 li2 *pear*	杏 xing4 *apricot*	蕉 jiao1 *banana*	枪 qiang1 *gun*	缸 gang1 *jar*
椅子 yi3zi0 *chair*	柜 gui4 *closet*	凳 deng4 *stool*	构 gou4 *structure*	硫 liu2 *sulfur*
猫 mao1 *cat*	狗 gou3 *dog*	鹰 ying1 *owl*	犹 you2 *alike*	核 he2 *core*
碗 wan3 *bowl*	碟 die2 *plate*	盘 pan2 *plate*	矿 kuang4 *mine*	伯 bo2 *uncle*
胳膊 ge1bo0 *arm*	肚 du4 *belly*	头 tou2 *head*	服 fu2 *clothes*	权 quan2 *power*
腿 tui3 *leg*	脚 jiao3 *foot*	手 shou3 *hand*	朕 zhen4 *I (used by the emperor)*	钢 gang1 *steel*
花 hua1 *flower*	草 cao3 *grass*	叶 ye4 *leave*	艺 yi4 *art*	券 quan4 *coupon*
苹果 ping2guo3 *apple*	莓 mei2 *berry*	桔 ju2 *orange*	苍 cang1 *grey*	弧 hu2 *arc*
萝卜 luo2bo0 *radish*	葱 cong1 *onion*	姜 jiang1 *ginger*	节 jie2 *festival*	京 jing1

				a place name
蘑菇 mo2gu1 *mushroom*	菜 cai4 *vegetable*	豆 dou4 *bean*	苏 su1 *a name*	库 ku4 *garage*
虾 xia1 *shrimp*	蜂 feng1 *bee*	鸡 ji1 *chicken*	虹 hong2 *rainbow*	福 fu2 *bless*
蜻蜓 qing1ting2 *dragonfly*	蛾 e2 *moth*	豹 bao4 *leopard*	蚀 shi2 *ellipse*	模 mo2 *model*
蝎子 xie1zi0 *scorpion*	蟒 mang3 *python*	鸭 ya1 *duck*	褐 he4 *brown*	境 jing4 *place*
钉子 ding1zi0 *nail*	锤 chui2 *hammer*	斧 fu3 *axe*	钟 zhong1 *clock*	件 jian4 *piece*
锅 guo1 *pot*	铲 chan3 *spatula*	壶 hu2 *kettle*	铃 ling2 *bell*	地 di4 *ground*
饺子 jiao3zi0 *dumplings*	饼 bing3 *pastry*	面 mian4 *noodle*	馆 guan3 *place*	岛 dao3 *island*
骆驼 luo4tuo0 *camel*	驹 ju1 *horse*	鲑 gui1 *salmon*	骗 pian4 *lie*	坪 ping2 *grassland*

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1   Appendix B. Stimuli used in Experiment 2: Target picture names and distractors.

Experiment 2				
	Distractor type			
Target Picture	Semantically related	Phonologically related	Orthographically related	Unrelated
虫 chong2 *bug*	龟 gui1 *turtle*	充 **chong1** *charge*	史 shi3 *history*	末 mo4 *end*
勺 shao2 *spoon*	叉 cha1 *fork*	少 **shao3** *few*	句 ju4 *sentence*	川 chuan1 *river*
矛 mao2 *spear*	盾 dun4 *shield*	毛 **mao2** *fur*	予 yu3 *I*	井 jing3 *well*
山 shan1 *mountain*	谷 gu3 *valley*	闪 **shan3** *blink*	凶 xiong1 *bad luck*	瓦 wa3 *tile*
书 shu1 *book*	本 ben3 *(note)book*	术 **shu4** *skill*	韦 wei2 *a family name*	月 yue4 *month*
牙 ya2 *tooth*	口 kou3 *mouth*	亚 **ya4** *Asia*	才 cai2 *talent*	日 ri4 *sun*
鱼 yu2 *fish*	龙 long2 *dragon*	与 **yu3** *and*	角 jiao3 *corner*	七 qi1 *seven*
尺 chi3 *ruler*	寸 cun4 *inch*	赤 **chi4** *red*	户 hu4 *household*	辛 xin1 *a name*
虎 hu3 *tiger*	牛 niu2 *bull*	乎 **hu1** *a particle*	虔 qian2 *sincere*	巾 jin1 *towel*
耳 er3 *ear*	头 tou2 *head*	儿 **er2** *son*	其 qi2 *its*	久 jiu3 *long*
石 shi2 *stone*	土 tu3 *sand*	式 **shi4** *pattern*	右 you4 *right*	六 liu4 *six*
目 mu4 *eye*	鼻 bi2 *nose*	母 **mu3** *mother*	且 qie3 *and*	文 wen2 *text*
刀 dao1 *knife*	匕 bi3 *dagger*	导 **dao3** *guide*	力 li4 *power*	卜 bu3 *a name*

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风 feng1 *wind*	雨 yu3 *rain*	丰 **feng1** *a family name*	冈 gang1 *hill*	卢 lu2 *a family name*
人 ren2 *man*	工 gong1 *worker*	刃 **ren4** *knife edge*	八 ba1 *eight*	瓜 gua1 *melon*
手 shou3 *hand*	足 zu2 *foot*	兽 **shou4** *animal*	于 yu2 *at*	巴 ba1 *a name*
鼠 shu3 *mouse*	鸟 niao3 *bird*	束 **shu4** *bundle*	昆 kun1 *a name*	币 bi4 *money*
田 tian2 *farm*	农 nong2 *agriculture*	天 **tian1** *sky*	甲 jia3 *first*	气 qi4 *gas*
兔 tu4 *rabbit*	犬 quan3 *dog*	凸 **tu1** *convex*	免 mian3 *exemption*	厂 chang3 *factory*
羊 yang2 *sheep*	马 ma3 *horse*	央 **yang1** *center*	半 ban4 *half*	五 wu3 *five*

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1   Table 1

2   *The average naming latencies (in ms), standard deviations and percentage errors (in*

3   *parentheses) for each condition in Experiment 1.*

Distractor type	SOA (ms)			
	-150	-75	0	75
Semantically and orthographically related	708±76 (2.0)	719±69 (2.2)	744±71 (1.3)	730±73 (2.5)
Semantically related	713±75 (2.2)	738±70 (2.0)	749±83 (2.2)	750±71 (3.4)
Orthographically related	698±69 (1.7)	712±61 (1.9)	724±79 (2.7)	725±72 (1.6)
Unrelated	692±85 (1.9)	713±62 (1.7)	728±76 (3.0)	733±68 (1.9)

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2 Table 2

3 *The results summary: coefficient estimates, standard errors (SE), t-values and p-values for the*

4 *effect of distractor type in each SOA condition in Experiment 1. (significance codes: 0 '***'*

5 *0.001 '**' 0.01 '*' 0.05 "." 0.1 "" 1)*

SOA (ms)	Distractor Type	Coefficient Estimate	SE	*t* Value	*p* Value
-150	Intercept	6.527	.029	224.347	
	Semantic relatedness	.020	.008	2.597	.014*
	Orthographic relatedness	.002	.008	.196	.846
-75	Intercept	6.560	.024	275.689	
	Semantic relatedness	.021	.008	2.476	.018*
	Orthographic relatedness	-.014	.009	-1.591	.121
0	Intercept	6.576	.028	236.362	
	Semantic relatedness	.026	.008	3.169	.003**
	Orthographic relatedness	-.010	.009	-1.056	.299
75	Intercept	6.583	.026	256.912	
	Semantic relatedness	.016	.008	1.946	.061
	Orthographic relatedness	-.019	.009	-2.208	.035*

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1   Table 3

2   *The average naming latencies (in ms), standard deviations and percentage errors (in*

3   *parentheses) for each condition in Experiment 2.*

Distractor type	SOA (ms)			
	-150	-75	0	75
Semantically related	657±59 (1.5)	656±60 (2.9)	653±69 (2.6)	588±107 (1.3)
Orthographically related	610±55 (1.7)	621±96 (0.9)	615±67 (0.9)	528±79 (0.6)
Phonologically related	616±71 (0.7)	627±51 (1.1)	627±66 (1.3)	523±59 (1.7)
Unrelated	620±53 (0.9)	632±64 (1.3)	653±71 (1.1)	565±53 (1.1)

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1   Table 4

2   *The results summary: coefficient estimates, standard errors (SE), t-values and p-values for the*

3   *effect of distractor type in each SOA condition in Experiment 2. (significance codes: 0 '***'*

4   *0.001 '**' 0.01 '*' 0.05 ".".0.1 "" 1)*

| SOA (ms)	Distractor Type	Coefficient Estimate	SE	t Value	p Value
-150	Intercept	6.416	.018	350.2	
	Semantic relatedness	.051	.013	3.8	< .001***
	Orthographic relatedness	-.018	.013	-1.3	.537
	Phonological relatedness	-.008	.013	-0.6	1.000
-75	Intercept	6.433	.018	352.2	
	Semantic relatedness	.035	.014	2.6	0.032*
	Orthographic relatedness	-.021	.014	-1.6	.351
	Phonological relatedness	-.006	.014	-0.4	1.000
0	Intercept	6.461	.018	363.0	
	Semantic relatedness	.001	.014	-0.1	1.000
	Orthographic relatedness	-.056	.015	-3.9	< 0.001***
	Phonological relatedness	-.037	0.014	-2.6	0.031*
75	Intercept	6.309	.022	287.64	
	Semantic relatedness	.024	.019	1.2	.657
	Orthographic relatedness	-.077	.019	-4.1	< 0.001***
	Phonological relatedness	-.071	.019	-3.7	< 0.001***

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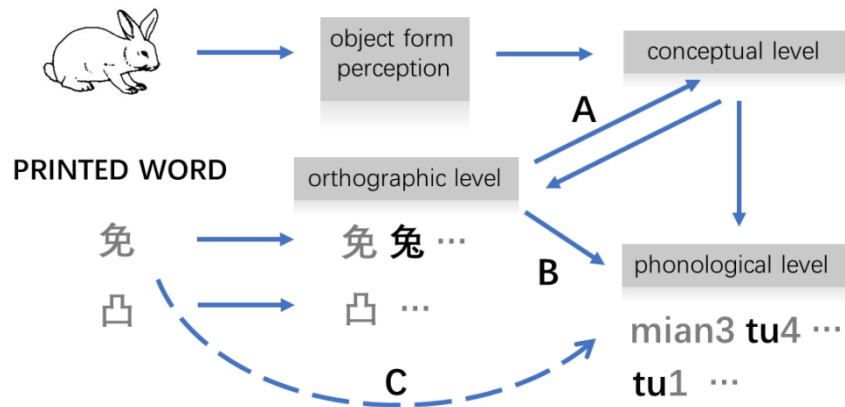
Figure 1. The model of overt picture naming with distractors in Chinese (adapted from Bi et al., 2009 and Zhao et al., 2012). Link C was drawn as the grapheme-to-phoneme GPC route and graphed as a dashed line because the sub-lexical GPC route was ruled out in our study.

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猫 *mao1* cat

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semantic
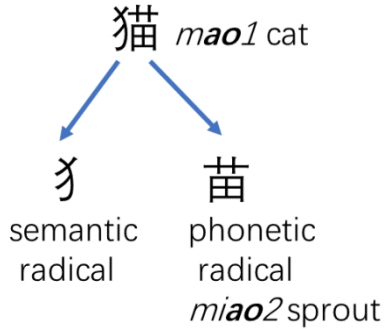radical

苗
phonetic
radical
miao2 sprout

Figure 2. Illustration of an example of complex characters with semantic and phonetic radicals.
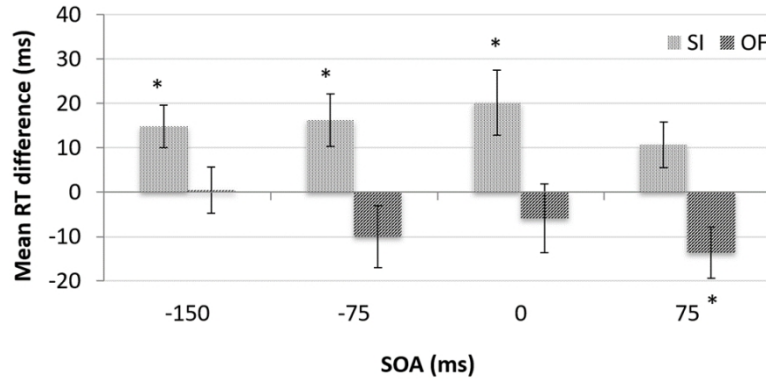
Figure 3. The main effects of semantic and orthographic distractors on picture naming latencies in Experiment 1 shown in reaction time differences across all participants. SI = semantic interference; OF = orthographic facilitation. The error bars represent standard errors of the means.

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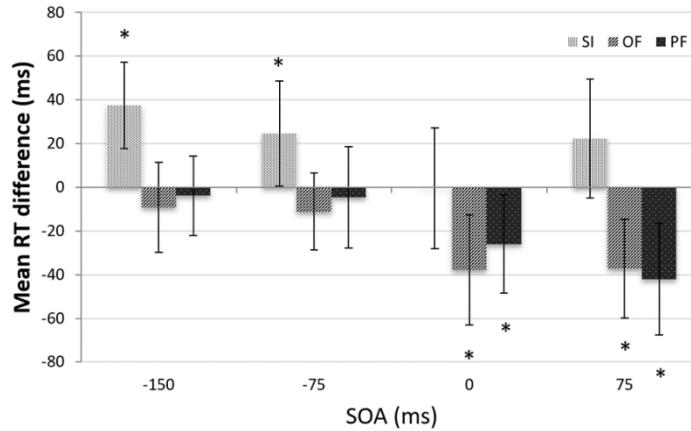11
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Figure 4. The main effects of semantic, orthographic and phonological distractors on picture naming in Experiment 2 shown in mean reaction time differences across all participants. SI = semantic interference; OF = orthographic facilitation; PF = phonological facilitation. The error bars represent standard errors of the means.

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