Phonological Encoding in Word Naming and Word Typing

Jenn-Yeu Chen (psyjyc@mail.ncku.edu.tw)
Institute of Cognitive Science, National Cheng Kung University
1 University Road, Tainan City, Taiwan 701

Cheng-Yi Li (adamli100@gmail.com)
Institute of Cognitive Science, National Cheng Kung University
1 University Road, Tainan City, Taiwan 701

Abstract

The process of phonological encoding was investigated in primed word naming and word typing with Chinese monosyllabic words. The target words shared or did not share the onset consonants with the prime words. The stimulus onset asynchrony (SOA) was 100 ms or 300 ms. Typing required the participants to enter the phonetic letters of the target word, which correspond roughly to the onset and the rhyme of the word's syllable. Regardless of SOAs, response times were shorter in the related condition than in the unrelated condition (an onset priming effect) for word typing, but were similar for word naming. The results suggest that naming and typing in Chinese may involve somewhat different phonological encoding processes even though both tasks require accessing the phonological codes. It is hypothesized that phonological encoding in Chinese is syllable driven in word naming, but is segment driven in word typing.

Keywords: Naming, Typing; Phonological Encoding; Word Production.

Introduction

The organization of a production system, natural or artifactual, must be constrained by the kind of outputs it is designed to produce. The production system for a car is organized differently than the production system for an airplane. The production systems for different kinds of cars (sedan vs. truck) are probably also organized differently. For natural languages, it has been shown recently that the word form encoding component of the word production system is organized differently for different languages such as Dutch and Chinese. In the present study, we show that the process of phonological encoding in word production is also somewhat different for naming and typing within the same language, Chinese, even though both tasks involve accessing phonological codes.

The phonological codes of a word may contain the syllables (e.g., /seg/ and /ment/ for the word 'segment'), the individual segments (e.g., /s, ɛ, g, m, ə, n, t/) and the prosodic features (the stress pattern ˈσσ) of the word. Theories of word production vary in whether the syllables are hypothesized as stored and retrieved units (Dell, 1986; Ferrand, Segui, & Grainger, 1996; Santiago, MacKay, Palma, & Rho, 2000), or whether they are assembled online during phonological encoding (Levelt, Meyer, & Roelofs, 1999). According to the model proposed by Levelt and colleagues (the LMR model), phonological encoding starts with retrieving the segmental contents and the wordshape frame of the word to be produced. The segments are then assigned to the slots in the wordshape frame sequentially from left to right according to the phonotactic principles of the language. The result of this segment-to-frame association (called syllabification) is phonological syllables, which are fed to the next stage of processing for phonetic encoding and articulation. In this model (illustrated in Figure 3), the syllables are assembled products of phonological encoding. The model was solely based on empirical evidence from Indo-European languages such as English, Dutch, and German.

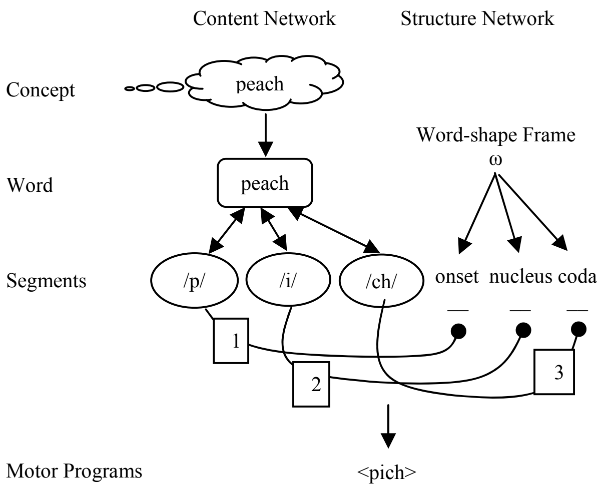

Figure 3: Production of an English CVC monosyllable for naming. Arrows signify activation. Button terminals signify assignment of contents to structures.

Assuming a similar architecture to the LMR model, Chen and colleagues (Chen, Dell, & Chen, 2002; O'Seaghdha, Chen & Chen, 2010) examined Mandarin Chinese recently but proposed that phonological encoding starts with retrieving the stored syllables of the word. The segmental contents and the syllable frame of each syllable are then retrieved for the same kind of segment-to-frame association process as in the LMR model. The difference between the LMR model (Figure 3) and the Chinese model (illustrated in Figure 4) can be characterized as the difference between segment-driven and syllable-driven processes. The difference, as we maintained previously, is due to the different design characteristics of the phonological systems in the respective languages. The English and the Dutch phonology emphasize words and segments (large number of syllable types, syllable boundaries are often ambiguous, segments may be resyllabified in a different context, syllables carry stress and are not equally weighted), whereas the Chinese phonology emphasize syllables (clear syllable boundaries, syllabification prohibited, simple syllable structures, small number of syllable types).

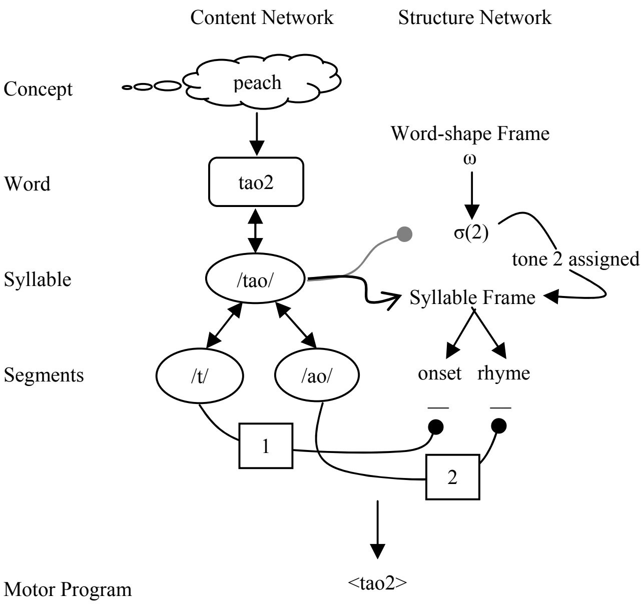

Figure 4: Production of a CV monosyllable in Mandarin for speaking. Arrows signify activation. Button terminals signify assignment of contents to structures. For simplicity, a rhyme is represented as a segment.

Typing is a production task which resembles speaking in many aspects except perhaps for the motor outputs. For speaking, the motor output involves moving several articulators simultaneously and sequentially in a highly coordinated fashion to produce syllable-sized gestures (MacNeilage, 1998). For typing, the motor output involves moving the fingers of both hands entirely discretely and sequentially (even though planning is done in parallel, Rumelhart & Norman, 1982; Salthouse, 1986). Both tasks, however, will need to access the phonological contents of a word, especially true in Chinese. The question we asked was whether the same kind of phonological encoding process operates in speaking and typing.

One hypothesis is that the same kind of phonological encoding process operates in speaking and typing. Although the motor outputs of typing are more discrete and sequential than those of speaking, the individual keystrokes may still be organized hierarchically into chunks of the word and the syllable sizes (Cooper, 1983). Accordingly, the entire process of producing a word would be identical in speaking and typing except that the specific motor muscles involved are different. Recent studies by Damian and colleagues (Zhang and Damian, in press; Shen and Damian, 2009) with English showed that writing accessed orthographic codes (graphemes) whereas speaking accessed phonological codes (phonemes or segments). However, writing involves a segment driven process just like speaking. In English, writing and typing are similar enough so that Damian and Shen's findings can be taken as the basis for the same-process hypothesis when speaking and typing are being compared. In Chinese, however, writing and speaking are distinctly different, and so are writing and typing (to be explained immediately). Therefore, hypothesizing about the phonological encoding processes in speaking and typing Chinese requires some explanation of the way Chinese characters are typed.

Chinese characters are logographs. Writing a Chinese character involves writing the strokes in a specific order and configuration. In contrast, the most commonly used methods of typing a Chinese character (*zhuyin* in Taiwan and *pinyin* in Mainland China) involve entering the phonetic letters of the word such as the onset consonant, the medial vowel, the rhyme, and the tone (for the *zhuyin* method), which bear no resemblance whatsoever with the strokes in writing. Nevertheless, what displays on the computer screen after phonetic typing is the orthographic form of the character. The phonological form is also shown, but only as an intermediate output before the typist hits the Enter key.

Given the way Chinese characters are typically typed (the phonetic typing method), it can be reasonably assumed that word typing might involve accessing the phonological codes of a word much like word speaking or naming. It can, then, be asked whether the same or different kinds of phonological encoding process underlie Chinese word naming and word typing.

Because previous studies have shown that speaking a word in Chinese is syllable driven, the same-process hypothesis predicts that typing a word in Chinese is also syllable driven. The contrasting hypothesis is that somewhat different kinds of phonological encoding process operate in speaking and typing. Because the individual keystrokes are organized discretely in typing, the process might emphasize the individual keystrokes, and, accordingly, the segments, more than the higher order units like the syllables. Support for the emphasis comes from analysis of typing errors, which, according to Norman and Rumelhart (1983), suggest that words are parsed into single-letter and two-letter units for execution. There may be two consequences of this emphasis. First, syllabification may not be necessary. Once the segmental contents of a word are retrieved, they are mapped to segment-sized motor programs for execution. This is different from speaking, where the initially retrieved segmental contents of a word are assembled back to syllables in order to be mapped to syllable-sized motor programs for execution. Second, the influence of higher-order units such as syllables and words may be weak because the end products are segments. In sum, the different-process hypothesis predicts that typing a word in

Chinese might be segment driven (illustrated in Figure 5), in contrast to the syllable driven process in speaking (Figure 4).

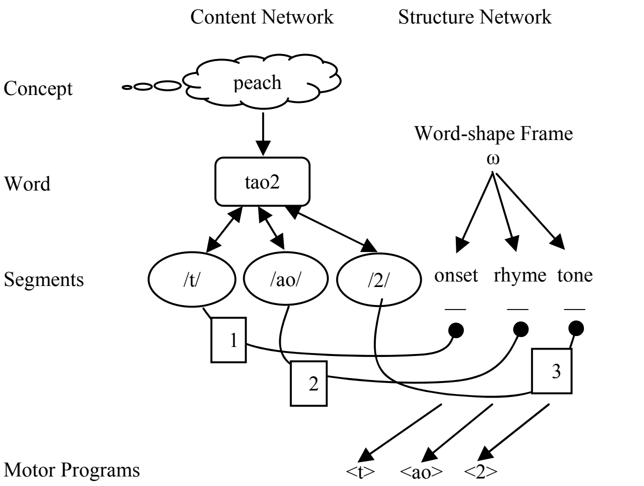

Figure 5: Production of a CV monosyllable in Mandarin for typing as modified from the speaking model of Figure 4 according to the prediction of the different-process hypothesis.

To test the hypotheses against each other, we employed a primed word naming task and a primed word typing task using Chinese monosyllabic words. Typing was performed with the zhuyin method. The target words shared or did not share the onset consonants with the prime words. We compared the onset priming effects (the difference in response times between the related and the unrelated conditions) between the two tasks. Because previous studies have observed no onset effect in Chinese speaking tasks (masked priming and implicit priming, Chen, Chen, & Dell, 2002; Chen, Lin, & Ferrand, 2003; O'Seaghdha, Chen, & Chen, 2010), the same-process hypothesis predicts no onset priming effects for either task, whereas the different-process hypothesis predicts no priming for the naming task but significant onset priming for the typing task.

In addition to manipulating phonological overlap, we also manipulated orthographic overlap such that the prime and the target words shared or did not share the first radical. With an unmasked priming procedure and stimulus onset asynchronies of varying lengths, previous studies showed that an orthographic overlap would produce positive (43 ms), negative (57 and 85 ms) or no (115 ms) priming in a word naming task (Perfetti & Tan 1998). According to one explanation, negative priming is due to form-related competition whereby the episodic memory trace of the prime is reactivated by the shared orthographic form in the target and competes with the target for phonological encoding (O'Seaghdha & Marin, 2000). If the level of competition is lexical, both the same-process hypothesis and the different-process hypothesis predict similar negative priming for naming and typing. If the level of competition is phonological, the same-process hypothesis predicts similar negative priming for the two tasks, while the different-process hypothesis predicts greater negative priming for naming than for typing (assuming syllable competition is greater than segment competition) or similar negative priming for naming and typing (assuming syllable competition is no greater than segment competition). Due to the uncertainties about the level of competition, the extent of competition, and the effect of SOA, the orthographic manipulation was included more for an explorative purpose than for testing the present hypotheses.

Method

Participants

Twenty-six native Mandarin Chinese speakers were recruited for the typing task and twenty-two for the naming task. They were students from National Cheng Kung University and the surrounding universities. The participants for the typing task were all habitual zhuyin typists with an average typing speed of 62.7 characters per min. All the participants had normal or corrected-to-normal vision and they were paid for participation.

Design and Materials

Thirty characters served as targets. Each was paired with four types of prime characters according to whether it shared the onset consonant or the first radical with the prime. An example is given in Table 1. The frequencies and the stroke numbers were matched among the four types of primes. There were a total of 120 pairs, which were randomly ordered for each participant. The experiment included one between-subjects factor (typing method) and three within-subjects factors (phonological relatedness, orthographic relatedness, and stimulus onset asynchrony), each with two levels. The SOA was either 100 or 300 ms. For each of the four types of prime-target pairs, half was presented with 100-ms SOA and the other half with 300 ms. The half which was presented with 100-ms SOA for half of the participants was presented with 300-ms SOA for the other half of the participants, and vice versa.

Table 1: An example of the prime-target pairs as a function of phonological and orthographic relatedness between the primes and the targets. The mean frequencies and the mean stroke numbers of the prime characters (standard deviations in parentheses) are also given.

		+Onset	-Onset
+Radical	Characters	梯- 桃	概-桃
	Pinyins	ti1-tao2	gai4-tao2
	Mean frequency	224 (34)	258 (119)
	Mean strokes	11.6 (2.8)	10.9 (3.6)
-Radical	Characters	泰-桃	棄-桃
	Pinyins	tai4-tao2	qi4-tao2
	Mean frequency	238(87)	276 (112)
	Mean strokes	11.9 (3.5)	12.4 (3.4)

Apparatus and Procedure

The experiment was programmed in Visual Basic for the typing task and in E-Prime for the naming task. Both were run on a personal computer (Intel® Core™2 Quad CPU, Q6600@2.40GHz) with a 20-inch LED screen (32bits, 1400x1050 pixels, 8-ms refresh rate), a standard keyboard, and a microphone. For the typing task, the experiment began with a familiarization phase, followed by a practice block of six trials and the experiment block of 120 trials. To ensure the participants knew the exact phonetic letters of each character used in the experiment, all of the characters (120 primes and 30 targets) were shown one at a time in a random order. The participants had to type in the correct phonetic letters of each character. If a mistake was made, the correct answer was offered. All of the incorrectly-answered characters were presented again at the end of the list. The procedure was repeated until no characters were incorrectly typed.

A trial for the practice and the experimental blocks consisted of a fixation cross appearing at the center of the computer screen for 1 sec. The prime character appeared in the Ximing font for 100 or 300 ms, followed immediately by the target character in the Biaokai font. Each character subtended about 2˚visual angle horizontally and vertically from a viewing distance of 50 cm. The participants were asked to type in the phonetic letters of the target character as quickly and accurately as possible. The response time was recorded and measured to the accuracy of millisecond from the onset of the target character to the first keystroke of the typing response. Response accuracy was also recorded.

All of the participants completed the typing task before coming back a month later for the naming task. For the naming task, exactly the same procedure was employed, except that the participants were asked to name the characters out loud. The response time was registered at the onset of the participants' vocal response.

Results

Typing

Errors were infrequent (less than 6%) and were not analyzed. Response times (RT) for the correct trials were analyzed using a linear mixed model (Statistical Analytic System, the PROC MIXED procedure) with subjects and items as random-effect variables and phonological relatedness, orthographic relatedness and SOA as fixed-effect variables. The mean RTs as a function of phonological relatedness, orthographic relatedness and SOA are plotted in Figure 1. The most notable effects in the figure are that of SOA and that of phonological relatedness. Response times were faster under 300-ms SOA than under 100-ms SOA: $F(1, 2895) = 62.4$, $p < .0001$. Response times were also faster when the prime and the target shared the onset consonant than when they did not (a positive onset priming effect of 30 ms): $F(1, 2895) = 35.3$, $p < .0001$. Response times were somewhat slower when the prime and the target shared the first radical than when they did not (a negative orthographic priming effect of 9.5 ms): $F(1, 2895) = 4.2$, $p < .05$. None of the interactions were significant, p's > .2.

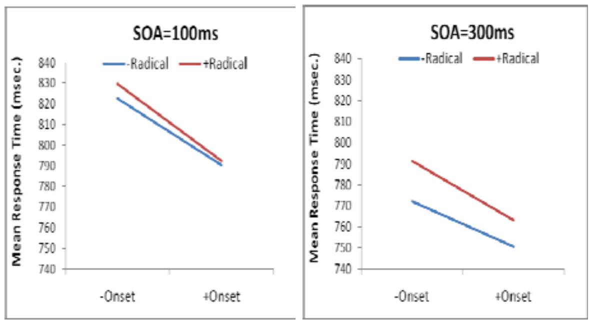

Figure 1: Mean RTs as a function of phonological relatedness, orthographic relatedness, and SOA from the typing task.

Naming

Errors were less than 2%. Response times were similarly analyzed as they were for typing. The mean RTs as a function of phonological relatedness, orthographic relatedness and SOA are plotted in Figure 2. The only significant effect in the figure is that of SOA. Response times were faster under 300-ms SOA than under 100-ms SOA: $F(1, 2516) = 323.9$, $p < .0001$. Response times were somewhat slower when the prime and the target shared the first radical than when they did not (a negative orthographic priming effect of 5.6 ms), but the effect fell short of the conventional level of significance, $p = .134$. None of the other effects were significant, p's ranging from . 454 to .932.

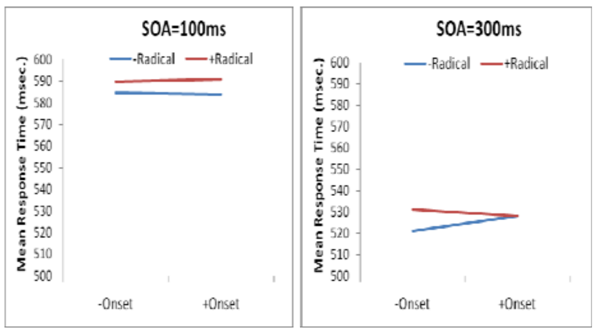

Figure 2: Mean RTs as a function of phonological relatedness, orthographic relatedness, and SOA from the naming task.

Combined Analysis

When the data from both tasks were included in the analysis with task as an additional fixed-effect variable, the results revealed significant main effects for all fixed-effect variables: $F(1, 5440) = 68.3$, $p < .0001$ for task, $F(1, 5440) = 259.3$, $p < .0001$ for SOA, $F(1, 5440) = 21.5$, $p < .0001$ for phonological relatedness, and $F(1, 5440) = 5.9$, $p < .02$

for orthographic relatedness. Importantly, the task x phonological relatedness interaction was significant: $F(1, 5440) = 23.5$, $p < .0001$, confirming the different findings in the separate analyses. The task x orthographic relatedness interaction was not significant, $F < 1$, confirming the similar findings in the separate analyses. The only remaining significant effect was that of task x SOA. All of the other effects were nonsignificant, *p*'s ranging from .262 to .997.

Discussion

Single word naming and typing in Chinese both involve accessing the phonological codes of the word, but the motor outputs are different. Does word typing involve the same or different phonological encoding processes from word naming? Using an unmasked priming procedure and manipulating phonological and orthographic overlaps between the prime and the target characters, we observed significant positive onset (phonological) priming in the typing task, but no priming in the naming task. At the same time, we also observed significant and comparable negative radical (orthographic) priming in both tasks.

The orthographic priming effects were similar in the naming and the typing tasks. It is important to note that these effects did not vary with phonological relatedness. That is, whether the prime and the target shared the onset consonant did not affect the orthographic priming effect. This could suggest (1) lexical competition whereby the reactivated prime word competed with the target word for phonological encoding, or (2) phonological competition whereby the phonological contents of the prime and the target competed for selection. It is not possible for the present study to determine whether the observed orthographic priming was due to lexical or phonological competition, and whether phonological competition between syllables is equivalent in magnitude to that between segments. As a result, the similar orthographic priming effects are interesting, but uninformative for testing our hypotheses. The following discussion will focus on the different phonological priming effects.

The different phonological priming effects observed in word naming and word typing suggest that the two types of tasks likely involve somewhat different phonological encoding processes, but an alternative account needs to be considered first. The alternative account would argue that the segmental effect in word typing occurred at the stage of motor output. That is, knowing ahead of time the first segment of a word allowed the participants to prepare the motor act of typing that segment, or even to start typing before they had retrieved the response word. Either possibility is highly unlikely because the prime-target SOAs were too short (100 and 300 ms) to allow the processing of the prime to proceed to the motor stage in time to benefit the production of the target at that level. The finding that onset priming in word typing did not vary with SOAs also helps to rule out these possibilities.

The different phonological priming effects can be explained by postulating two different models for word naming and word typing. Figure 3 illustrates a production model for speaking a monosyllabic Chinese word proposed previously (O'Seaghdha, Chen, & Chen, 2010). The model is applicable to a word naming task if we focus on the production phase of naming and also ignore the concept level. In the model, syllables are retrieved as chunks. The segmental contents and the syllable frame are separately spelled out, followed by the sequential assignment of the individual segments to the categorized slots in the frame. The result of this phonological encoding process is a syllable-sized motor program for articulation. Figure 4 illustrates the same model modified for typing. In this model, tone is assumed to be one of the segmental contents of a syllable and is assigned last; there is no explicit syllable level; and the sequential assignment of the individual segments to their categorized slots leads to several segment-sized motor programs, rather than one syllable-sized motor program.

The segment-sized output characterizes an important feature of the typing model and distinguishes it from the naming model. In fact, it also contrasts with the naming model hypothesized for Germanic languages (Roelofs, 1997; Levelt, Meyer, & Roelofs, 1999). The different characteristics of the outputs for typing and naming serve to constrain the processing at earlier stages differently. Specifically, the syllable-sized output for naming prescribes that phonological encoding address the syllable, whereas the segment-sized output for typing prescribes that it address the segment in the planning process. The segment-addressing system gives rise to the onset priming effect observed in the typing task, whereas the syllable-addressing system produces no onset priming in the naming task.

To summarize, the results of the present study, as far as the onset priming effects go, support the hypothesis that somewhat different phonological encoding processes are involved in speaking and typing. The process is syllable-driven in speaking, but segment-driven in typing. And this is due to the different natures of the outputs the two tasks aim to produce.

In our previous work (Chen, Chen, & Dell, 2002; Chen, Lin, & Ferrand, 2003; O'Seaghdha, Chen & Chen, 2010), we emphasized and investigated cross-linguistic differences in the design characteristics of Chinese and English/Dutch (with respect to the phonological system) and how the processing mechanisms of phonological encoding differ accordingly. In the present study, we highlighted another important factor that might modulate the processing mechanism *within the same language*. The idea that the specific form of the output must in some way drive the form of the intermediate representations in a production system should surprise no one. The input of a production system can differ greatly from the output. Given that production is a process that translates a specific input to a specific output, the final form of the output (the goal state of the production system) must require that the intermediate representations approach that form, or else production would fail. This idea is consistent with any system that is adaptive and goal-directed.

The hypothesis that the forms of the internal representations are constrained by the form of the output in a production system is consistent with previous models that postulate different modality-specific lexicons for speaking and writing, based on neuropsychological evidence (Ellis & Young, 1988; Caramazza, 1997). It is also consistent with the theoretical concept of embodiment in cognition (Lakoff & Johnson, 1999; Clark & Chalmers, 1998).

Many issues remain and further work awaits researchers. Convergent evidence is needed from other production tasks and procedures (e.g., word naming and picture naming with masked primes, the form preparation task). The difference between word typing in Chinese and word naming in English deserves investigations. Even though both involve segment-driven processes, they may be motivated differently. As mentioned earlier, the well-cited model of word production for English/Dutch assumes syllable-sized outputs. If the assumption is valid, the segment-driven process of phonological encoding must find a different motivation in the English/Dutch speaking system than that in the Chinese typing system. On the other hand, it could be that the assumption has been false. The hypothesis also bears a broader implication for understanding the cognitive system in general.

Finally, word typing (or typewriting) used to be a special skill of a small group of professionals. As a result, research on typewriting has been sparse. With the increasing popularity of computer word processing, typewriting has become a common skill of literacy like handwriting. As a production task, it is time for the production researchers to begin investigating this new technologically-driven skill of the digital age in order to understand its similarities and differences from the speaking task.

Acknowledgments

This work was supported by the NSC96-2413-H-006-004-MY2 grant.

References

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology*, *14*, 177-208.

Chen, J.-Y., Chen, T.-M., & Dell, G. S. (2002). Word-form encoding in Mandarin Chinese as assessed by the implicit priming task. *Journal of Memory and Language*, *46*, 751-781.

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.

Clark, A. and Chalmers, D. (1998). The extended mind. *Analysis*, 58, 7-19.

Cooper, W. E., (1983). Introduction. In W.E. Cooper (Ed.), *Cognitive aspects of skilled typewriting* (pp. 1-38). New York: Springer-Verlag.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, *93*, 283-321.

Ellis, A. W., & Young, A. W. (1988). *Human cognitive neuropsychology*. Hove, UK: LEA.

Ferrand, L., Segui, J., & Grainger, J. (1996). Masked priming of word and picture naming: The role of syllabic units. *Journal of Memory and Language*, *35*, 708-723.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought.* New York, NY: Basic Books.

Levelt, W. J. M, Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75.

MacNeilage, P. F. (1998). The frame/content theory of evolution of speech production. *Behavioral and Brain Sciences*, *21*, 499-546.

Norman, D. A., & Rumelhart, D. E. (1983). Studies of typing from the LNR Research Group. In W.E. Cooper (Ed.), *Cognitive aspects of skilled typewriting* (pp. 45-65). New York: Springer-Verlag.

O'Seaghdha, P. G., Chen, J.-Y., & Chen, T.-M. (2010). Proximate units in word production: phonological encoding begins with syllables in Mandarin Chinese but with segments in English. *Cognition*, *115*, 282-302.

O'Seaghdha, P. G. & Marin, J. W. (2000). Phonological competition and cooperation in form-related priming: Sequential and nonsequential processes in word production. *Journal of Experimental Psychology: Human Perception & Performance*, *26*, 57-73.

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,* 1–18.

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

Rumelhart, D. E., & Norman, D. A. (1982). Simulating a skilled typist: A study of skilled cognitive-motor performance. *Cognitive Science*, *6*, 1-36.

Salthouse, T. A. (1986). Perceptual cognitive, and motoric aspects of transcription typing. *Psychological Bulletin*, *99*, 303-319.

Santiago, J., MacKay, D. G., Palma, A., & Rho, C. (2000). Sequential activation processes in producing words and syllables: Evidence from picture naming. *Language and Cognitive Processes*, *15*, 1–44.

Shen, X., & Damian, M. F. (2009). Role of phonology in handwritten word production. Poster presented at the 15th Annual Conference on Architectures and Mechanisms for Language Processing (AMLaP), 7-9 September, Barcelona.

Zhang, Q., & Damian, M. F. (in press). Impact of phonology on the generation of handwritten responses: Evdience from picture-word interference tasks. *Memory & Cognition*.