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Abstract

Employing the implicit priming task, we examined whether Chinese words that shared the initial onset consonant could be typed, using the phonetic-based method (called zhuyin), with faster response times than words that did not share the initial onset consonant. We also examined the effect of sharing the initial tonal syllable. A significant onset preparation effect and a significant syllable preparation effect were both observed. The latter was found to vary linearly with the number of segments in the syllable. The slope of 63 ms was similar to the 70-ms onset effect, suggesting that the syllable effect was segment-based. The results contrasted with the lack of an onset effect previously reported for speaking, and were interpreted as supporting the Output Constraint Hypothesis which states that the kind of outputs a production system is designed to produce (speaking vs. typing) can flexibly and adaptively alter the way the system is organized and operates.

Keywords: Chinese; Typing; Speaking; Phonological Encoding; Word-Form Encoding

Introduction

With the popularization of computers and internet, typing has become a new form of communication that may someday dominate our social life. It is, therefore, of interest to study the cognitive processes involved in typing, in particular, how typing as a language production activity may differ from speaking. Past research has studied typing more as a skilled motor activity during transcription (Shaffer, 1975; Sternberg et al., 1978; Rumelhart & Norman, 1982; Norman & Rumelhart, 1983; Salthouse, 1986; Crump & Logan, 2010a, 2010b) than as a language production activity.

In a spoken language production model (e.g., Dell, 1986; MacKay, 1987; Levelt et al., 1999), word form encoding refers to the hierarchically organized processes that translate the semantic/syntactic representation of a word into its phonological and phonetic forms. The processes involve retrieving the structural frame and the phonemic segments of a word, followed by assigning, in a sequential order, the segments to their categorized slots in the frame. An issue under much debate concerns the units that make up the stored phonological representation of a word and drive the phonological encoding process. In some models, they contain the syllables (e.g, Dell, 1986; MacKay, 1987), while in others they do not (e.g., Levelt et al., 1999). Prevailing evidence from Indo-European languages suggests that the units are the segments (e.g., Meyer, 1990, 1991; Roelofs & Meyer, 1998; Roelofs, 1999; Schiller, 1998, 2004; Schiller & Costa, 2006). But in Mandarin Chinese, they appear to be the syllables (J.-Y. Chen et al., 2002; J.-Y. Chen et al., 2003; T.-M. Chen et al., 2007; O'Seaghdha et al., 2010). The varying units of a word's stored phonological representation in different languages may have something to do with the rhythmic structures of the languages (Cutler et al., 1986; Otake et al., 1996).

The units may also vary with different kinds of outputs targeted by different production tasks within the same language, e.g., typing as opposed to speaking. Mandarin Chinese provides an excellent testing bed for evaluating this hypothesis. A popular method of typing in Chinese uses the phonetic alphabet called zhuyin in Taiwan and pinyin in China. For example, to type the character 潔 ('clean', jie2) in zhuyin, the onset consonant j, the medial glide i, the rhyme e, and the tone 2 are typed on a keyboard sequentially, followed by the selection among a list of homophones. To this extent, zhuyin typing requires accessing the phonological codes of the character, much like speaking. Employing a traditional (unmasked) priming task and comparing naming with zhuyin typing, our previous study (Chen & Li, 2011) investigated whether syllable onset priming was absent in naming, which would be consistent with our findings for speaking (J.-Y. Chen et al., 2002; J.-Y. Chen et al., 2009; O'Seaghdha et al., 2010), but might be present in zhuyin typing.

A possible reason for predicting onset priming in zhuyin typing is that the output of zhuyin typing consists of discrete manual keystrokes that correspond to the onset, medial, rhyme and tone of a syllable. This is different from the output of naming (and speaking), which consists of syllable-sized articulatory gestures. That is, the different output characteristics constrain the way a word is planned during speaking and typing. Indeed, Berg (2002) observed that slips of the key resembled slips of the pen, but not slips of the tongue. He suggested that 'speaking is characterized by a hierarchical strategy of activation while typewriting is subject to the so-called staircase strategy of serialization in which activation is a function of linear distance' (p.185). Although such a prediction seems obvious and only expected, there are reasons to predict otherwise too. Studying handwriting, Kandel and colleagues (Kandel et al., 2006; Lambert et al., 2007; Alverez et al., 2009) found that interletter intervals were longer between syllables than within syllables and that the number of syllables of a word modulated the time course of handwriting production, indicating that word syllable structure constrains motor production both in French and Spanish. Given that very similar processes are believed to underlie typing and writing (Berg, 2002), it is reasonable to assume that syllables are also essential units of processing in typing. Direct evidence for this assumption has also been reported (Nottbusch et al., 2005). The results from primed naming and primed zhuyin typing showed significant onset priming for zhuyin typing but not for naming, supporting the hypothesis that the units of the stored phonological representation of a word vary with different kinds of outputs targeted by different production tasks within the same language. We will refer to this hypothesis as the Output Constraint Hypothesis (OCH).

In the present study, the OCH was tested further with the implicit priming task. The implicit priming task (also known as the form preparation task) has been used extensively in investigating the word form encoding processes in spoken production (Meyer, 1990). The task requires the participants to learn a set of prompt-target word pairs during the learning phase. During the testing phase, the prompt words are shown one at a time and the participants have to say the corresponding target words as responses. The target words are arranged in a homogeneous context such that they share the initial portion of their phonological forms (e.g., the onset consonant). In a heterogeneous context, the same target words are re-arranged such that they no longer share the initial portion of the phonological forms. Response latencies tend to be shorter when the target words are produced, upon the presentation of the prompt words, in the homogeneous context than in the heterogeneous context. The response benefit is attributed to the suspension-resumption mechanism in the production system, according to which the system prepares a word from left to right in an incremental fashion, and it can prepare the word as far to the right as the left portion is known. The system suspends the operation when everything that is known has been prepared, and resumes operation as soon as information about the rest of the word is received. It is assumed that the portion that can be prepared by the system represents the unit of word form encoding during spoken production (Roelofs, 1997a, 1997b). Sufficient evidence has indicated that this unit must be the size of a syllable in Mandarin Chinese, but can be a phonemic segment in English and Dutch.

Because previous studies in Mandarin Chinese have already consistently documented no onset preparation effect with an implicit priming task in speaking (Chen, Chen, &Dell, 2002; O'Seaghdha, Chen, & Chen, 2010), the present study examined typing only, but contrasted the findings with those reported for speaking base on the same materials. The OCH predicts that the onset segment of a Chinese word can be prepared during zhuyin typing, i.e., an onset preparation effect is predicted in an implicit priming task of zhuyin typing.

In addition to the syllable onset, the full syllable was also examined. If phonological encoding in zhuyin typing is segment-driven as predicted by the OCH, a syllable preparation effect that is a function of the number of segments in a syllable should be observed.

Method

Participants

Sixteen native Mandarin Chinese speakers from the student body of National Cheng Kung University were recruited for the onset experiment, and another sixteen for the syllable experiment. They were all native and habitual zhuyin typists, i.e., they learned the zhuyin typing when they first learned typing and have been typing in zhuyin ever since. All the participants had normal or corrected-to-normal vision and they were paid for participation.

Apparatus and Materials

The experiment was programmed in DMDX (Forster & Forster, 2003) and 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) and a standard keyboard that included marks of the zhuyin letters.

The stimulus materials for the onset experiment were disyllabic words taken out of Experiment 5 of J.-Y. Chen et al. (2002). They consisted of four sets of prompt-target word pairs, with four pairs in each set. The prompt and the target in a pair bore clear semantic or associative relationship such that they could be learned easily. The target words were chosen such that they shared the same onset consonant of the first syllable in a set. Across the four sets, four different onset consonants were used (m, d, sh, l). These formed the homogeneous sets (see Set 1-4 in Table 1). The same target words were reshuffled to form the four heterogeneous sets such that within a set the target words no longer shared the onset consonant (see Set 5-8 in Table 1). The arrangement of the stimulus materials was identical to that of J.-Y. Chen et al. (2002) Experiment 5.

The stimulus materials for the syllable experiment were disyllabic words taken out of Experiment 3 of T.-M. Chen & J.-Y. Chen (2006) (see Table 2), and arranged in the same way. The target words in a homogeneous set shared the first tonal syllables.

Table 1: Target words arranged as homogeneous sets (1-4) and heterogeneous sets (5-8) for the onset experiment.

		Homogeneous			
	Set	1	2	3	4
Heterogeneous	5	mo1-cai3 摸彩 draw lots	da1-ing4 答應 promise	shu1-fa3 書法 caligraphy	luo1-suo1 囉唆 nagging
	6	ma2-que4 麻雀 sparrow	de2-kuo2 德國 Germany	shi2-yan4 實驗 experiment	li2-ge1 驪歌 farewell song
	7	mu3-dan1 牡丹 peony	du3-buo2 賭博 gambling	she3-qi4 捨棄 abandon	la3-ba1 喇叭 horn
	8	mi4-yue4 蜜月 honeymoon	di4-yu4 地獄 hell	shou4-ruo4 瘦弱 weak	lu4-shi1 律師 lawyer

Table 2: Target words arranged as homogeneous sets (1-4) and heterogeneous sets (5-8) for the syllable experiment.

		Homogeneous			
	Set	1	2	3	4
Heterogeneous	5	xi1-gua1 西瓜 watermelon	hong2-shui3 洪水 flood	jia1-fa3 加法 addition	yi4-wen2 軼聞 anecdote
	6	xi1-fan4 稀飯 porridge	hong2-guan1 宏觀 macroscopic	jia1-bin1 嘉賓 honored guests	yi4-wei4 異味 peculiar smell
	7	xi1-guan3 吸管 straw	hong2-mo2 虹膜 iris	jia1-shi4 家事 household duty	yi4-ren2 藝人 entertainer
	8	xi1-shui3 溪水 stream	hong2-bao1 紅包 cash gift	jia1-yao2 佳餚 delicacy	yi4-chu4 益處 benefit

Design and Procedure

The design and the procedure were identical to the experiments where we took the materials from. Each pair in a set was repeated four times (the Repetition factor) so that there were 16 pairs and they appeared in a random order within a block. Half of the participants received the homogeneous sets first and the other half received the heterogeneous sets first (the Sequence factor). The participants went through the round of homogeneous and heterogeneous sets (the Context factor) three times (the Round factor) and in the same sequence. The type of onset consonants or syllables constituted another factor (Onset). The Sequence factor was a between-subjects factor while the rest were within-subjects factors.

During the learning phase, the participants were shown the four pairs of words in a set. They learned the association between the two words in each pair until they had memorized the pairs well. Then the target words were cued one at a time by their associated prompt words. When the participants succeeded in reporting the target words correctly without hesitation, they proceeded to the testing phase. Otherwise, they repeated the learning phase.

During the testing phase, each trial began with a 1000-Hz warning tone and two short dashed lines flanking a blank space at the center of the screen. The tone and the dashed lines appeared for 200 ms. The prompt word appeared in the previously flanked space 600 ms later. The prompt word stayed on the screen for 150 ms. Another 1850 ms elapsed before the trial ended. The participants were told to type in zhuyin the target word upon seeing the prompt word, as quickly and accurately as possible. The participants entered the zhuyin letters in the English input mode. Accordingly, no homophonous characters were shown for selection after the zhuyin letters of a character have been entered. Response latencies were measured, to the accuracy of milliseconds, from the presentation of the prompt word to the striking of the first zhuyin letter. If no response was initiated within 2000 ms of the presentation of the prompt word, a feedback tone of 500 Hz was sounded for 200 ms. The next trial began after another 200 ms. A practice session containing four trials was given before the experiment began. The participants were seated 60 cm from the screen. Each character measured 1.6 cm in height and 1.1 cm in width at that viewing distance.

Results

Onset Experiment

Error rates were 2% in the homogeneous condition and 4% in the heterogeneous condition. Response times ranged from 374 to 1946 ms for the homogeneous trials (mean: 825, SD: 190), and ranged from 354 to 1988 ms for the heterogeneous trials (mean: 894, SD: 195). No apparent outliers were noted. All response times (RTs) for the correct trials were then analyzed using a linear mixed model (Statistical Analytic System, the PROC MIXED procedure) with subjects and items as random-effect variables and context, sequence, round, repetition as fixed-effect variables. Most notable in the analysis was the significant main effect of context: $F(1, 14) = 33.67$, $p < .0001$. The mean RT was 824 ms in the homogeneous context and 894 ms in the heterogeneous context. The difference represents an onset preparation effect of 70 ms. The context effect varied with sequence: $F(1, 1465) = 4.92$, $p < .03$, being greater when the heterogeneous sets appeared first than when the homogeneous sets appeared first. The context by sequence interaction also varied with round: $F(2, 1465) = 8.46$, $p < .0005$. The three-way interaction is manifested as the context effect displaying an increasing trend when the homogeneous trials were done first and a decreasing trend when the heterogeneous trials were done first (see Table 2). The remaining effects are not enumerated here because they were either non-significant (p's > .06) if they involved the context factor, or significant but did not involve the context factor. Table 3 summarizes the results by presenting the mean RTs as a function of context, round, and sequence.

Table 3: Mean RTs (SEs in the parentheses) as a function of context, round, and sequence for the onset experiment.

Sequence	Round	Homo-geneous Context	Hetero-geneous Context	Prepara-tion Effect
Homo-geneous First	1	909 (18)	932 (24)	23
	2	824 (20)	875 (18)	51
	3	789 (18)	848 (19)	59
	Overall	**841 (12)**	**885 (12)**	**44**
Hetero-geneous First	1	835 (20)	964 (17)	129
	2	787 (19)	876 (18)	89
	3	796 (22)	866 (19)	70
	Overall	**806 (12)**	**902 (11)**	**96**

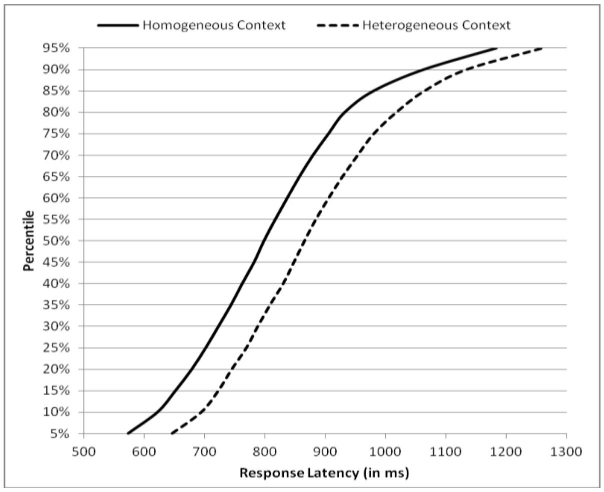

Figure 1: Cumulative response latency distributions for the homogeneous context and the heterogeneous context for the onset experiment.

Although the participants were told to complete all key presses without hesitation or pauses once a response was initiated, it is possible that the homogenous context might have encouraged a strategic behavior in them to start the first key press without having planned for the subsequent keys. If this was the case, the duration of a response should be longer in the homogeneous context than in the heterogeneous context. Unfortunately, response durations were not available to rule out this possibility. However, we plotted cumulative response latency distributions for the two conditions, following Damian and Stadthagen-Gonzalez (2009). As Figure 1 shows, the differences between the two distributions are relatively uniform across the entire spectrum of response latencies, suggesting that the strategy of immaturely starting responses on homogeneous trials was not used by our participants. The similar distributions of the two conditions also rule out the possibility that participants were able to locate the first key and initiate a response on homogeneous trials sooner than on heterogeneous trials, where the first keys were different and took time to locate.

Syllable Experiment

Error rates were 2% in the homogeneous condition and 5% in the heterogeneous condition. Response times less than 250 ms were excluded, making up 0.8% of all trials, before they were subject to the same kind of analysis as in the onset experiment. The context effect was significant, with the homogeneous RTs being 255 ms faster, on the average, than the heterogeneous RTs (620 ms vs. 875 ms): $F(1, 14) = 69.98$, $p < .0001$. The context effect did not vary with sequence ($p > .8$), but it increased significantly across rounds ($p < .01$). The three-way interaction involving context was not significant, $p > .19$. Table 4 summarizes the results of the syllable experiment.

The cumulative distribution plot of Figure 2 shows no clear evidence of strategic responding for the homogeneous trials. To examine if the syllable preparation effect increased with the number of segments in the syllable (tone being counted as a segment), a by-item linear regression analysis was performed, which revealed a slope of 63ms. This is fairly close to the 70 ms onset preparation effect.

Table 4: Mean RTs (SEs in the parentheses) as a function of context, round, and sequence for the syllable experiment.

Sequence	Round	Homo-geneous Context	Hetero-geneous Context	Prepara-tion Effect
Homo-geneous First	1	669 (29)	906 (17)	237
	2	591 (29)	870 (16)	279
	3	584 (32)	858 (14)	274
	Overall	**615 (18)**	**878 (9)**	**263**
Hetero-geneous First	1	678 (13)	916 (12)	238
	2	619 (18)	857 (10)	238
	3	577 (19)	842 (12)	265
	Overall	**625 (11)**	**872 (7)**	**247**

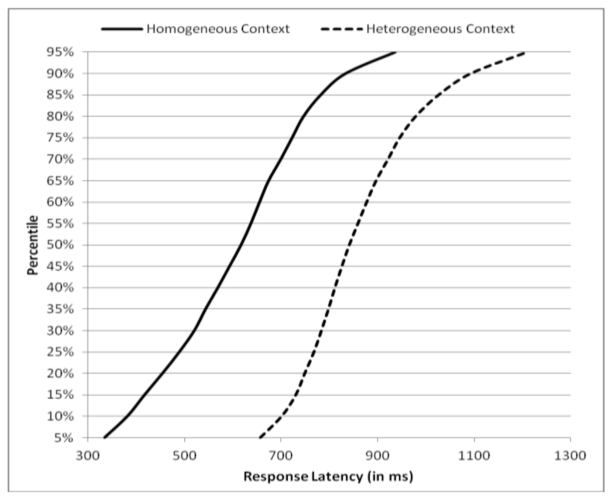

Figure 2: Cumulative response latency distributions for the homogeneous context and the heterogeneous context for the syllable experiment.

Discussion

Employing the implicit priming task, a widely used tool for studying word form encoding in spoken production, we examined whether words that shared the initial onset consonant could be typed with faster response times than words that did not share the initial onset consonant. The result of the experiment was clear. There was a significant and sizeable onset preparation effect when words to be typed shared the initial onset consonant (70 ms). This contrasted interestingly with the small and non-significant onset effect observed in our previous work when the task was speaking (J.-Y. Chen et al., 2002, Experiment 5 with the same material: -1 ms; O'Seaghdha et al., 2010, Experiments 1-4 and 7 with different materials: 3, -6, 3, 4, 2 ms). We also observed a large tonal syllable preparation effect which varied with the number of segments in the syllable. The slope of 63 ms was similar to the 70 ms onset preparation effect, suggesting that the syllable preparation effect was likely segment-based. This also contrasted interestingly with the syllable preparation effect previously observed for speaking, which could be more unambiguously attributed to the syllable. Together, these results extended the previous findings of significant onset priming for typing (30 ms) but no significant onset priming for naming (-5.6 ms) when an unmasked priming task was employed (Chen & Li, 2011).

Speaking a Chinese word and typing it in zhuyin take the same input for processing, i.e., the concept of the word. They also require retrieving the same phonological representation of the word. However, the two tasks have different goals, aiming at different outputs. The findings of the present study as well as the earlier one (Chen & Li, 2011) suggest that the form of the output can constrain the internal organization/mechanism of the production system. Speaking, aiming at syllable-sized gestures, requires a syllable-driven word form encoding process. Typing, aiming at segment-sized gestures, involves segment-sized word form encoding process. Thus, all production systems are not organized in the same way. The kind of outputs a production system is designed to produce can flexibly and adaptively alter the way the system is organized and operates.

It has been suggested that the traditional priming paradigm and the implicit priming paradigm tap different levels of word form encoding process (Levelt et al., 1999; Cholin, Schiller, & Levelt, 2004). Traditional priming works to pre-activate the segments of a word, facilitating its phonological encoding process. Its effect takes place at the early stage of phonological encoding. Implicit priming is said to work at this early stage of phonological encoding as well as at the later stages of phonological encoding and phonetic encoding (i.e., online syllabification and possibly accessing the mental syllabary). Because onset priming in zhuyin typing was observed with both the explicit priming paradigm and the implicit priming paradigm, it may be concluded that the production system respects the form of its output and gets ready for that form at the stage as early as the beginning of the word form encoding process.

One caveat against the above conclusion is that typing is typically much slower than speaking, indicating low automaticity, and this is perhaps the reason that typing is less hierarchically organized than speaking (Berg, 2002). Future work will investigate this with professional typists.

The output constraint is not unique to the production system only, but finds an analog in the perception system too, where it is the input that constrains how the perception system is organized and operates. For example, research has shown that the structural and functional basis of word recognition and reading varies between an alphabetic writing system like English and a logographic writing system like Chinese (Perfetti, Liu, & Tan, 2005; Tan, Spinks, Eden, Perfetti, & Siok, 2005; Tzeng & Hung, 1981; Kuo, Yeh, Duann, Wu et al., 2001; Kuo, Yeh, Lee, Wu et al., 2003; Siok, Niu, Jin, Perfetti, & Tan, 2008; Siok, Perfetti, Jin, & Tan, 2004).

When building a model of language processing, a universal one is always preferred. But, even a universal model needs to incorporate flexible parameters and constraints to accommodate the variations across languages and tasks. One source of such constraints might be sought from the input and output a particular language system is designed to process. This view carries the Gibsonian tradition of emphasizing the role of environment in perception (Gibson, 1986), but extends it to production.

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