A Phonetic Radical Account of the Phonology-to-Orthography Consistency Effect on Writing Chinese Characters: Evidence from a Chinese Dysgraphic Patient

Dustin Kai-Yan Lau[1]
Hong Kong Polytechnic University, Hong Kong

Karen Hau-Wan Ma[2]
United Christian Hospital, Hong Kong

[1] Correspondence to be address to Dustin Kai-Yan Lau, Department of Chinese and Bilingual Studies, Hong Kong Polytechnic University, Hong Kong SAR (email: dustin.lau@polyu.edu.hk). Telephone number: (852) 3400-3636

[2] Karen Hau-Wan Ma is affiliated to United Christian Hospital, Hospital Authority, Hong Kong SAR (email: mhw379@ha.org.hk). Postal address: Speech Therapy Department, United Christian Hospital, Hospital Authority, Hong Kong SAR. Telephone number: (852) 3949-4644

Abstract

This paper investigated the sublexical route in writing Chinese. Using a writing-to-dictation task, we compared the performance of neurotypical individuals in writing a set of 40 characters with homophones sharing different phonetic radicals, and another set of 40 characters with homophones sharing the same phonetic radicals. The first set was regarded as both syllable-to-character and syllable-to-radical inconsistent while the second set was considered syllable-to-radical consistent but syllable-to-character inconsistent. Results of error analysis showed that the participants demonstrated greater tendency to make errors with preserved phonetic radicals in the second set of stimuli. Furthermore, we conducted the same task on a Chinese brain-injured patient, WCY, with mild dyslexia and severe dysgraphia associated with mild impairment in the lexical semantic route of writing. Results showed that WCY demonstrated similar error pattern as the controls and he showed shorter writing time in the second set of stimuli. Altogether, the observations were taken as evidence to support our claim that there exists the syllable-to-phonetic radical route that governs the sublexical route of Chinese character writing.

Keywords: Phonology-to-orthography consistency, Chinese, writing, dysgraphia

Introduction

The dual route model of spelling (Ellis & Young, 1996) proposed two independent routes, the lexical and the nonlexical routes, in the writing process. According to the model, the lexical route allows retrieval of orthographic forms of words directly from the orthographic output lexicon, while the nonlexical route operates by assembling spellings based on sound-to-spelling conversion rules (Luzzi, Bartolini, Coccia, Provinciali, Piccirilli, & Snowden, 2003). By assuming parallel operation of the two routes, the dual route model explains how people spell different types of words including regular words, exception words and pseudowords. In general, operation of the lexical route allows correct spelling of exception words with irregular sound-to-spelling mappings, while operation of the nonlexical route allows correct spelling of pseudowords, which do not exist in one's lexicon. Finally, correct spelling of regular words with predictable sound-to-spelling mappings can be achieved by employing either the lexical or the nonlexical route.

The existence of the nonlexical route is usually supported by the occurrences of phonological spellings (e.g. their → *there*) in writing. While it is uncertain whether such errors may be a result of mis-identification of lexical items in the lexical route, more "homogeneous" phonological spelling errors were usually observed from certain patients with dysgraphia. For example, Hatfield and Patterson (1983) reported a patient with dysgraphia who produced phonologically plausible errors (that are pseudowords on their own) most of the time when writing regular and exception words. Since the errors were different from phonological errors typically observed in reading tasks, Hatfield and Patterson (1993) concluded that the patient was relying on the nonlexical route in writing, which is governed by phonology-to-orthography (P-O) consistency.

The sound-to-spelling rules, usually applied to segmented phonological units, such as onsets, rhymes and phonemes, and segmented orthographic units, such as letters and letter clusters (Ziegler, Stone & Jacob, 1997), are language specific. For example, the English word /maɪnd/, can be segmented into the onset /m/ and the rhyme /-aɪnd/. The rhyme /-aɪnd/ maps onto different words (e.g. MIND, BIND, KIND, BLIND) which all share the same spelling "-IND". Therefore the rhyme /-aɪnd/ is said to be P-O consistent in English. On the other hand, the rhyme /-eɪs/ in English maps onto different spellings, including "-ASE" as in CASE and VASE, and "-ACE" as in RACE and PLACE. Hence, the rhyme /-eɪs/ is considered P-O inconsistent in English. It has been documented that P-O consistency affects neurotypical individuals' writing. In a writing-to-dictation task, Peereman, Content, & Bonin (1998) observed that neurotypical individuals demonstrated faster response and higher accuracy in writing words that are P-O consistent compared to the inconsistent words. In this study, we examined the effect of P-O consistency on Chinese writing.

Chinese is a morpho-syllabic language where each basic orthographic unit, i.e. character, usually maps onto one morpheme and one syllable (Hoosain, 1992). For example, the character "手" corresponds to the syllable [sau2][1] and the morpheme <hand>. There exists a major group of Chinese characters called phonetic compounds, which contain radicals that give clues to phonology and meaning. For example, the character "鋅" [san1] <zinc> contains the semantic radical "金" <metal-related> that gives clues to meaning and the phonetic radical "辛" [san1] <suffering> that gives clues to phonology. Studies have reported that semantic and phonetic radicals are involved in reading phonetic compounds (e.g. Feldman & Siok, 1999; Lau, Leung, Liang & Lo, 2015; Law & Wong, 2005; Perfetti & Tan, 1998; Zhou & Marslen-Wilson, 1999). In general, it is agreed that the orthography-to-

[1] Since this study was conducted in Hong Kong where traditional Chinese characters and Cantonese were used, in this paper, phonetic transcriptions are represented in *jyutping,* a romanisation system developed by the Linguistic Society of Hong Kong.

phonology (O-P) mapping of phonetic radicals affects the accuracy and latency in reading phonetic compounds.

Most of the previous studies that investigated Chinese writing process involved the observations of errors produced by dysgraphic patients suffered from strokes who had normal writing abilities before the strokes. For example, Law, Yeung, Wong & Chiu (2005) tested a Chinese dysgraphic patient using tasks of writing-to-dictation and written-naming. They reported that the patient produced errors that involve substitutions, additions and deletions of strokes, phonetic radicals or semantic radicals. In another study, Law and Leung (2000) reported a Chinese dysgraphic patient who produced writing errors that involve substitutions of logographemes (stroke clusters in radicals that frequently occur in other characters, e.g. 十 and 又, in the radical 支 in Figure 1). In another study by Han, et al. (2007), another stroke patient produced similar errors of logographeme substitutions, deletions and transpositions. These authors concluded that strokes, logographemes and radicals are functional processing units in writing Chinese characters. It has been proposed that orthographic units with different sizes are organized in the orthographic representations at the same level in the mental lexicon and are all involved in the writing process (Law et al., 2005).

Comparatively, studies that explore the effect of P-O consistency on Chinese character writing are very limited. In a large-scale study involving the writing-to-dictation task, Han, Song and Bi (2012) studied the effect of P-O consistency on Chinese character writing. They measured the P-O consistency of Chinese based on the mapping between syllables and the corresponding orthographic characters, including the number of homophones of each character and the ratio of frequency of occurrence of each character to the sum of frequencies of its family of homophones. They reported that the syllable-to-character consistency measures predicted the participants' performance in the writing-to-dictation task.

While the study by Han et al. (2012) confirms the effect of P-O consistency on writing performance, their measure of P-O consistency might not be comprehensive enough. There is no doubt that syllables were selected as the units in the phonological representations, because segmental units in the Chinese phonological system do not give clues to orthographic units. The major concern is the grain-size of the units selected in the orthographic representations. As mentioned, previous studies have documented the involvement of phonetic radicals in the processing of Chinese characters. Hence, it is possible, in reading, for syllables in the phonological representations to receive activations from phonetic radicals in the orthographic representations. Likewise, it should also be possible for phonetic radicals in the orthographic representations to receive activations from syllables in the writing process. Therefore, we suggest that there should be two different measures to capture the mapping variations from phonology to orthography in Chinese. In Measure 1, the P-O consistency is determined based on the count of homophonic characters at the lexical level. In other words, the more characters a syllable is associated with, the less consistent it is. For example, there is a total of four characters associated with the syllable [bun6]: 伴 <partner>, 畔 <side>, 胖 <fat> and 叛 <betray>. So, the syllable [bun6] has inconsistent mapping with orthographic forms at lexical level in Measure 1. In Measure 2, the P-O consistency is defined based on the count of number of phonetic radicals a syllable is associated with. Using the above example, the same phonetic radical 半 is shared among all four characters 伴, 畔, 胖 and 叛. Hence, using Measure 2, the syllable [bun6] consistently maps on the phonetic radical 半 at the sublexical level. On the other hand, the syllable [gei6] is associated with four different characters: 忌 <avoid>, 妓 <prostitute>, 技 <skill>, and 伎 <trick>. The syllable [gei6], therefore, should be considered inconsistent in

Measure 1. Furthermore, since the syllable maps onto different phonetic radicals (i.e. 己 and 支) at the sublexical level, it should also be considered inconsistent in Measure 2.

Taking a more refined approach to measure P-O consistency, we identified stimuli of three different levels of P-O consistency: (a) characters with no homophones, (b) characters with homophones that are associated with more than three phonetic radicals, and (c) characters with at least two homophones, all sharing the same phonetic radicals. The first type is consistent in Measure 1 and Measure 2[2], the second type is inconsistent in both measures, and the last one is inconsistent in Measure 1 but consistent in Measure 2.

Figure 1(i) depicts the processes involved in the writing-to-dictation of a Category (a) stimulus, 變 [bin3] <change. Upon auditory presentation, the identified syllable [bin3] in the phonological representations, will send activation to the associated semantic features in the semantic system which will then access the corresponding orthographic unit 變 at the character level of the orthographic representations. At the same time, the orthographic unit 變 will also receive activation from the syllable [bin3] directly. In this case, both phonological and semantic units converge on the target character 變. The same, however, does not apply to Category (b) stimuli. As can be seen in Figure 1(ii), because there exist other characters sharing the same syllable [gei6], activations from the identified syllable will flow not only to the target orthographic unit 忌 but also to other orthographic units, 伎, 技 and 技, at the character level. Competition among these orthographic units are expected,

---

[2] This only applies to phonetic compounds with no homophones. About one third of the characters without homophones in Chinese are non-phonetic compounds, i.e. characters without phonetic and semantic radicals that give clues to sound and meaning, according to The Hong Kong Corpus of Chinese NewsPaper (Leung & Lau, 2010). Therefore, it is not always possible to define the syllable-to-radical consistency of characters in Category (a).

hence, retrieval of the target orthographic unit will be less efficient compared to that of Category (a) stimuli with comparable frequencies. Similarly, as illustrated in Figure 1(iii), because there exist other characters sharing the same syllable [bun6], activations from the identified syllable will flow to the target orthographic unit 胖 as well as other orthographic units, 伴, 畔 and 叛, at the character level. Hence, writing-to-dictation of Category (c) stimuli will also be slower than Category (a) stimuli due to the competition among the associated orthographic units at the character level. Furthermore, if P-O consistency in Chinese is modulated only by syllable-to-character consistency (Measure 1), latencies of retrieval of Category (c) stimuli should be comparable with that of Category (b) stimuli matched for character frequencies. Besides, given that the competitions, which only exist at the character level in this case, are similar, the types and distributions of writing errors produced by people when writing these two categories of stimuli should also be comparable.

Insert Figure 1 about here

However, we propose that there are subtle differences between the processes of Category (b) and Category (c) stimuli if syllable-to-radical consistency (Measure 2) affects writing. As illustrated in the shaded part in Figure 1(ii), because the orthographic units at the character level that are associated with the target syllable [gei6] are linked to two different orthographic units, 己 and 支, at the radical level, competitions exist at both character level and radical level which will both affect the writing process. On the other hand, such competition at the radical level should be absent in the case of Category (c) stimuli. Instead, as illustrated in the shaded part in Figure 1(iii), because the target and competing units at the character level are all linked to the same unit 半 at the radical level, a facilitative effect from syllable-to-radical consistency is expected for Category (c) stimuli in comparison with Category (b) stimuli. Therefore, if P-O consistency in Chinese is modulated by both syllable-to-character consistency (Measure 1) and syllable-to-radical consistency (Measure 2), writing-to-dictation of Category (c) stimuli should be slightly faster than that of Category (b) stimuli matched for character frequencies. Furthermore, in the case that character frequencies are low, given that all associated characters of Category (c) stimuli converge on the same phonetic radical, it is expected that there will be higher chance for people to choose one of the associated characters as substitute. The chance for people to make similar errors upon writing Category (b) stimuli should be lower as the associated phonetic radicals do not agree with each other.

Nevertheless, given that writing-to-dictation of Chinese is dominantly modulated by the lexical-semantic pathway (Han et al., 2012), it is expected that detecting the subtle difference in writing accuracy and latency of the two categories of stimuli with matched character frequencies in a writing-to-dictation task is very difficult if not impossible. To detect the potential difference in the processing of the two categories of characters, we propose to compare the errors produced when people write these two categories of stimuli in a writing-to-dictation task. It is expected that if P-O consistency of Chinese is modulated by both Measure 1 and Measure 2, due to the stronger syllable-to-radical relations of the Category (c) stimuli, their phonetic radicals in a writing-to-dictation task should be less prone to error in the written output compared to that of Category (b) stimuli.

In short, by comparing writing-to-dictation performance using Category (b) and Category (c) stimuli, the role of the phonetic radical in writing can be examined. In the current study, the errors produced by a group of neurotypical individuals upon writing the two categories of stimuli were compared to confirm our proposal that P-O consistency of Chinese is modulated by both Measure 1 and Measure 2. Furthermore, we reported a

Chinese patient with dysgraphia associated with an impaired lexical-semantic route in writing. His writing performance provided a window for the investigation of the sublexical route of writing Chinese. His different performance in writing-to-dictation on the two sets of stimuli was reported. Since the sublexical route should be more involved in the processing of low frequency items (e.g. Hatfield & Patterson, 1993; Rapp, Epstein, & Tainturier, 2003), detailed analysis of the errors that WCY made in writing the low frequency characters was further conducted. Based on his different performance in writing the two categories of stimuli, we propose that there exists a sublexical syllable-to-radical route for writing in Chinese. To our knowledge, this is the first study that reports this sublexical syllable-to-radical route for Chinese character writing.

Method

Participants

The patient. WCY, a 57-year old right-handed male speaker of Cantonese, suffered from a left hemisphere stroke 7 months before the study was conducted. According to the medical referral, he was diagnosed as having atrial fibrillation, cerebral embolism and left cortical infarct. His educational level was university bachelor's degree and his premorbid occupation was an accountant. Initial assessment using the Cantonese version of the Western Aphasia Battery (CAB) (Yiu, 1992) revealed an AQ score of 93.5, leading to a diagnosis of mild anomic aphasia. No visual, hearing, or motor impairment is reported.

Control participants. A total of 24 normal participants (12 males and 12 females; mean age = 54 years, age range = 47-66 years), were recruited as the controls. All of them were native Cantonese speakers with no reports of reading and writing problems. Their education level ranged from post-secondary to master degree. They reported normal vision and hearing abilities.

Materials and tasks

Comprehensive assessment. A follow-up assessment was conducted after WCY was referred to us for a detailed assessment of his reading and writing problem, using the stimuli set used in Law, et al. (2005). The following tasks were included: (1) oral and written naming using black-and-white drawings taken from Snodgrass and Vanderwart picture set (1980), (2) disyllabic word reading aloud, (3) auditory and written homophone identification with semantic, tonal, orthographically similar and phonologically similar distractors, (4) written lexical decision task, (5) spoken word-picture matching and written word-picture matching tasks, each with a semantic and an unrelated distractor for each item (6) a synonym judgment task, and (7) non-verbal semantic tests including the Birmingham Object Recognition Battery (BORB) Test 7 (Minimal feature view task), Test 8 (Foreshortened view task), Test 10 (Object decision task) and Test 12 (Association match task) (Riddoch & Humphreys, 1993) and the Pyramid and Palm Trees Test (PPTT) (Howard & Patterson, 1992).

Writing-to-dictation task. A writing-to-dictation task was carried out to examine the effect of phonology-to-orthography consistency in Chinese writing. Both WCY and the control participants were assessed using this task. A total of 80 characters were used in a 2 (P-O consistency) X 2 (frequency) design. Hence, there were 20 items in each of the sub-category. P-O consistency of the stimuli were categorized into two levels: characters with homophones that are associated with more than three phonetic radicals, and characters with at least two homophones, all sharing the same phonetic radicals. Character frequencies and stroke numbers were matched across the two categories. Information regarding the stimuli in different categories was summarized in Table 1. For each target character, a disyllabic word context was provided (chosen by using the first or most common word entries obtained from the Chinese dictionary) to avoid confusion, because on average each Chinese character shares the same syllable with about three other characters. For example, for the character 淹 [jim1]

<flood>, 淹沒 [jim1 mut6] <drown> was used as the word context. A similar example in English would be "the word *brake* as in *handbrake*". During the test, the experimenter first presented the word context and then specified which syllable corresponded to the target character, "「淹沒」嘅「淹」字" "the character *flood* in the word *flood-sink* <drown>,". Accuracies and errors made by the control participants were recorded. As for WCY, he was instructed to write using a stylus on an Android tablet that recorded the elapsed time each time the stylus touched / left the tablet screen as well as the final written output. Accuracies and errors made as well as the total writing time of each item, measured as the time difference between the onset of the first stroke and the offset of the last stroke of each character response, were recorded.

Insert Table 1 about here

Results

Comprehensive assessment

Table 2 summarized the WCY's performance in each of the tasks in the comprehensive assessment. WCY demonstrated high accuracies in auditory (126/126) and written (122/126) word-picture matching tasks, suggesting that he had intact spoken and written comprehension of object names. He demonstrated fair performance (47/60) in the spoken synonym judgement task. Furthermore, mild impairment was also observed in his performance in the nonverbal semantic task. For instance, in BORB test 10, he only scored 24 which is 1.36 SD lower than norm. These suggested a mild impairment in his semantic system.

Regarding his language expression, his score in the oral naming task (80%) was lower than normal subjects (average = 93%) reported by Law (2007), which is consistent with his diagnosis of mild anomic aphasia in the CAB results. There is significant difference between his performance in oral (174/217) and written (94/217) naming tasks with the same set of stimuli, Chi Square test, $X^2(1) = 291.8$, $p < .001$), showing relatively more impaired performance in the written modality. He produced mostly semantic errors in oral naming and mostly orthographic substitution errors involving logographeme in written naming (Table 3). Nevertheless, his close-to-perfect performance in the reading aloud task (100%), the written lexical decision task (97%) and the written homophone identification task (97%), suggested that the orthographic input lexicon was largely preserved. In short, WCY was suffering from mild anomia, mild dyslexia and more severe dysgraphia associated with mild semantic impairment.

Insert Table 2 about here

Insert Table 3 about here

Writing-to-dictation task

Table 4 summarizes the accuracies of the control participants in each of the categories. The results of a 2 (P-O consistency) x 2 (Frequency) ANOVA showed no significant main effect of P-O consistency but the main effect of frequency was significant *(p<.001)*. The interaction effect was not significant. In general, the control participants showed higher accuracy in writing high frequency characters.

Insert Table 3 about here

Table 5 summarized the accuracies of WCY in each of the categories in the writing-to-dictation task. Accuracy differences among the two different P-O consistency was not significant (Category b: 13/40, Category c: 18/40). Instead, accuracy was affected much more by frequency (high frequency: 27/40, low frequency: 4/40), $X^2(1) = 17.06$, $p < .01$). He demonstrated comparable performances in writing the high frequency characters as the controls. But his performance in writing the low frequency characters was much worse. On the other hand, results of t-test showed that the observed longer total writing time of Category (b) stimuli than that of Category (c) stimuli after controlling for stroke number as covariate was marginally significant [t(29) = 3.778, MSE = 22.49, $p = .051$].

Insert Table 5 about here

Error analyses

The errors made by the control participants are summarized in Table 6. Results of Chi-square test show that the distribution of errors across the two categories of stimuli were different ($X^2(7) = 91.32$, $p < .001$). Post-hoc analysis was conducted based on Cox & Key (1993)'s pairwise comparison method by comparing the difference between chi-square values, i.e. $\Delta(X^2)$, of each error type. Detailed calculations are given in Appendix A. Results indicated that the $\Delta(X^2)$ between errors with substitution of homophones containing shared phonetic radicals with the targets (e.g. 棲 [cai1] <stay> → 淒 [cai1] <miserable>) and other error types are all larger than the critical value 10.83 of $\alpha = 0.001$ and one degree of freedom. This indicates that the difference in distribution of errors between Category (b) and Category (c) stimuli was mainly due to more errors involving substitutions of homophones containing shared phonetic radicals with the targets in Category (c).

Insert Table 6 about here

Altogether, WCY made 36 errors in the 40 low frequency trials. A summary of his writing errors is given in Table 7.

Insert Table 7 about here

Results of Chi-square test showed that the distribution of errors made by WCY across the two categories of stimuli were different ($X^2(8) = 17.68$, $p < .01$). A closer look at the comparison revealed that more errors with preserved phonetic radicals in Category (c) stimuli [6/18 in Category (c) vs 1/18 in Category (b)), and more errors with substitutions of phonetic radicals sharing the same syllables with the target in Category (b) stimuli [3/18 in Category (b) vs 0/18 in Category (c)] were observed.

Discussion

The overall comparable writing-to-dictation accuracies across the two different categories of stimuli observed from the control participants did not inform us much about how P-O consistency in Chinese affects writing. Given that Chinese is a deep orthography, such observation is within our expectations that the P-O consistency showed less effect on writing-to-dictation (Bonin, Barry, Méot & Chalard, 2004; Han, Song & Bi, 2012). According to Han et al. (2012), there exists interaction between the lexical semantic route and the phonology-to-orthography conversion route in writing Chinese. With a weaker effect from the P-O consistency on Chinese writing, one may expect that the writing accuracy should be largely affected by the lexical semantic route. Given that the two different categories of stimuli used in the current study were matched on character frequencies, it is not surprising that the writing-to-dictation accuracies across the two different categories were comparable.

In spite of the insignificant difference in accuracy measure, the subtle difference between the two categories was evident in latency measure, i.e. the marginally significant difference between the total writing time of Category (b) stimuli and that of Category (c) stimuli observed in WCY's writing. The longer total writing time of Category (b) stimuli than that of Category (c) stimuli is consistent with our predictions that syllable-to-radical consistency affects Chinese character writing. Referring to Figure 1, if P-O consistency in Chinese is modulated only by syllable-to-character consistency, latencies of retrieval of Category (b) stimuli and that of Category (c) stimuli should be comparable. To explain the longer total writing time of Category (b) stimuli, the difference in syllable-to-radical consistency between the two categories of stimuli is essential. As illustrated in Figure 1, competitions of orthographic units occur at both character and radical levels in the processing of Category (b) stimuli, while competitions of orthographic units occur only at character level in the processing of Category (c) stimuli. This explains why the processing time of Category (c) stimuli was slightly faster in WCY's writing. Therefore, WCY's longer total writing time of Category (b) than Category (c) stimuli confirms our claim that P-O consistency in Chinese is also modulated by syllable-to-radical consistency. It is noteworthy that the total writing time obtained from WCY's writing was traditionally considered a reflection of the peripheral processing instead of central processing of writing (Ellis & Yong, 1996). The longer total writing time of Category (b) stimuli observed from WCY, therefore, is consistent with the growing body of literature which suggested that central processing of writing is not fully completed before the initiation of the peripheral processing (e.g. Roux, McKeeff, Grosjacques, Afonso, & Kandel, 2013).

Results of the analyses of errors made by the control participants and those made by WCY were consistent with our predictions, which further supported our claim of the significance of syllable-to-radical consistency in Chinese character writing. Results from the control participants showed that they made more errors with substitutions of homophones that shared the same phonetic radicals with the targets in Category (C) stimuli. If P-O consistency in Chinese is modulated only by syllable-to-character consistency, one should expect equal number of homophone substitutions in the two categories of stimuli. Therefore, the more substitutions of homophone that shared the same phonetic radicals with the targets observed in Category (c) stimuli should be attributed to the more consistent syllable-to-radical mappings of Category (c) stimuli. When an individual is required to write a character belonging to Category (c), referring to Figure 1(iii), the issue that all associated characters converge on the same phonetic radical probably prompted the individual to select one of the activated characters as substitute, particularly when the target character is of low frequency, during the writing-to-dictation task. On the other hand, in the case that the target character belongs to Category (b), it should be easier for the individual to reject the other associated characters because the multiple phonetic radicals activated do not agree with each other. Instead, the individual may choose to give no response in the particular trial, which was what we observed as the most dominant error type given by the control participants in response to low frequency trials belonging to Category (b). Once again, the errors made by the control participants further substantiated our claim regarding the significance of syllable-to-radical consistency in Chinese character writing.

There are two possibilities as to how syllable-to-radical consistency works. The first possibility is that the radicals, e.g. 半 in Figure 1(iii), received activations from the target syllable, [bun6] in this example, via the corresponding characters, i.e. 胖, 伴, 畔, and 叛 in this example. The second possibility is that a direct link connects the radical 半 with the syllable [bun6], i.e. the grey arrow in Figure 1(iii), was established across time because of the strong syllable-to-characters-to-radical linkage. Given that these two possibilities are all consistent with the above observations, it may be difficult to determine which one, or both, of them better represents the sublexical route of writing Chinese simply based on the analysis of errors produced by the control participants. Instead, examining the errors produced by WCY may provide some insights.

Results showed a large difference between WCY's accuracies on high and low frequency characters. This probably indicated damage to stored representations in the orthographic output lexicon (Basso, 2003). Together with the mild impairment observed in the BORB and the PPTT tests, it is hypothesized that WCY is suffering from an impaired lexical semantic route of writing. Therefore, WCY's writing performance, especially on low frequency items, offered a good platform for the investigation of the sublexical route of writing Chinese. Although the floor effect he achieved in writing the low frequency characters makes accuracy comparisons among the two categories of stimuli impossible, the fact that he made only very few errors with no response allows an insightful error analysis.

First of all, the large number of non-characters in response to the writing-to-dictation task is consistent with previous reports of acquired dysgraphia in Chinese (e.g. Han, Zhang, Shu & Bi, 2007; Law & Leung, 2000; Law & Or, 2001; Law, et al., 2005; Law & Wong, 2005). Besides, WCY's tendency to combine and/or substitute logographemes to form non-characters in response to the writing-to-dictation task is consistent with previous reports that suggested logographemes as the functional processing units in writing Chinese (Han et al., 2007; Law & Leung, 2000).

Before looking into the specific errors WCY made in different categories, it is important to note that among all 53 errors, 32 of them were produced with left-right configurations. Among these 32 trials, he deliberately wrote the phonetic radicals on the right side before adding the semantic radicals on the left side in 18 of them. In a post-assessment interview, he also explained that it was because he found 'writing the phonetic radicals is much easier' for him. This observation further strengthened our claim that WCY relied heavily on the sublexical route of writing.

To investigate how P-O consistency affect the sublexical route of writing Chinese, the errors WCY made in each P-O consistency category were compared. The comparable number of errors WCY made in each category allows fairer comparisons in the error analyses. The significantly different distributions of errors between Category (b) and Category (c) suggested that the syllable-to-radical consistency plays a significant role in sublexical route of writing Chinese. The comparatively more errors with preserved phonetic radicals in Category (c) stimuli is consistent with our prediction that syllable-to-radical consistency affects Chinese writing. Such phonetic-radical-advantage observed in Category (c) is probably a result of stronger P-O consistency between syllables and phonetic radicals of this category. Referring to Figure 1, since WCY suffered from severe lexical deficits, retrieval of target orthographic units at the lexical level via activations from semantic system or directly from the target syllables should be difficult if not impossible. Hence, retrieval of phonetic radicals via the syllable-to-character-to-radical pathway may not be possible. Therefore, we propose that those errors with preserved phonetic radicals in WCY's writing were probably generated from the direct linkage between syllables and radicals.

On the other hand, in the case of Category (b) stimuli, because of the inconsistent syllable-to-character-to-radical mappings, weaker linkage between syllables and phonetic radicals, illustrated by the dotted grey arrows in Figure 1(ii), would be resulted. The weaker direct linkage between syllables and radicals explains why the phonetic radicals in Category (b) stimuli were less preserved in WCY's writing The weaker syllable-to-radical linkage together with the deficits in the lexical pathway might have also prompted WCY to produce errors with substitution of phonetic radicals sharing the same syllables as the target (e.g. 侖 → 粦 as in 倫 /leon4/ [moral] → 鄰 /leon4/ [neighbor]) in this category. Finally, WCY's dominant errors with combinations of unrelated logographemes in this category were probably also resulted from the weak syllable-to-radical linkage together with the deficits in the lexical pathway. Given that both the lexical and sublexical pathways were providing low/no support for him to retrieve relevant orthographic units, combining unrelated logographemes appeared to be the only possible responses he could give in response to the requirements of the writing-to-dictation task.

Limitations and Future studies

The direct link between syllable and phonetic radicals depicted in Figure 1(i) was only derived based on the assumption that similar strong syllable-to-character-to-radical mappings in Category (a) stimuli should exist as in the case of Category (c) stimuli. Given that a large proportion of Category (a) stimuli are non-phonetic compounds (Leung & Lau, 2010), future studies that involves two subtypes, phonetic compounds (e.g. “冷” [laang5] <cold>, “怕” [paa3] <afraid>) vs non-phonetic compounds (e.g. “北” [bak1] <north>， “弄” [lung6] <manipulate>), of Category (a) stimuli will be needed to confirm our claim.

Conclusions

The current study examined the P-O consistency effect on Chinese character writing by observing the writing performance of a patient suffering from dysgraphic characterized by an impairment in the lexical semantic route of writing. His performances in writing characters with homophones sharing different phonetic radicals, and characters with homophones with shared phonetic radicals were compared. Results showed that WCY spent longer time in writing the former type of stimuli than the latter type. Results of the error analyses showed that both the patient and the control participants showed greater tendency for making errors with preserved phonetic radicals when writing the latter set of stimuli. These findings were argued to be evidence to support that phonetic radicals play a significant role in the sublexical route of Chinese writing. Our findings support the claim in previous reports that phonology-to-orthography conversion plays a role in Chinese writing (Han, et al., 2012). In addition to the syllable-to-character consistency measures of the P-O consistency reported in Han, et al. (2012), the current work highlights that syllable-to-phonetic radical consistency measures should also be part of the phonology-to-orthography conversion route that governs, particularly the sublexical route of, Chinese character writing.

(words)

Reference

Basso, A. (2003). *Aphasia and its therapy*. N.Y.: Oxford University Press.

Bonin, P., Barry, C., Méot, A., & Chalard, M. (2004). The influence of age of acquisition in word reading and other tasks: A never ending story? *Journal of Memory and Language, 50*, 456–476.

Chen, H. C., Vaid, J., & Wu, J. T. (2009). Homophone density and phonological frequency in Chinese word recognition. *Language and cognitive processes*, *24*(7-8), 967-982.

Coltheart, M. (2001). Assumptions and methods in cognitive neuropsychology. The handbook of cognitive neuropsychology: What deficits reveal about the human mind, 3-21.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological review*, 108(1), 204.

Cox, M.K., & Key, C.H. (1993). Post-hoc pairwise comparisons for the chi-square test of homogeneity of proportions. *Educational and Psychological Measurement, 53,* 951-962.

Ellis, A. W., & Young, A.W. (2013). Human cognitive neuropsychology: A textbook with readings. Psychology Press.

Feldman, L. B., & Siok, W. W. (1999). Semantic radicals contribute to the visual identification of Chinese characters. *Journal of Memory and Language*, *40*(4), 559-576.

Han, Z., Song, P., Bi, Y. (2012). Cognitive mechanism of writing to dictation of logographic characters. *Applied Psycholinguistics, 33,* 517-537.

Han, Z., Zhang, Y., Shu, H., & Bi, Y. (2007). The orthographic buffer in writing Chinese characters: Evidence from a dysgraphic patient. *Cognitive neuropsychology,* 24(4), 431-450.

Howard, D., & Patterson, K. E. (1992). *The Pyramids and Palm Trees Test: A test of semantic access from words and pictures*. Thames Valley Test Company.

Jared, D., McRae, K., & Seidenberg, M. S. (1990). The basis of consistency effects in word naming. *Journal of memory and language*, *29*(6), 687-715.

Lau, D.K.-Y., Leung, M.T., Liang, Y., & Lo, C.M.J. (2015). Predicting the naming of regular-, irregular- and non-phonetic compounds in Chinese. *Clinical Linguistics & Phonetics, 29(8-10)*, 776-792.

Law, S. P. (2007). A test battery for Chinese aphasia. *Accessed February*, *22*, 2015.

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

Law, S.P. & Or, B. (2001) A Case Study of Acquired Dyslexia and Dysgraphia in Cantonese: Evidence for Nonsemantic Pathways for Reading and Writing Chinese, *Cognitive Neuropsychology, 18(8)*, 729-748

Law, S. P., Yeung, O., Wong, W., & Chiu, K. M. (2005). Processing of semantic radicals in writing Chinese characters: Data from a Chinese dysgraphic patient. *Cognitive*

Neuropsychology, 22(7), 0885-903.

Law, S.P. & Wong, R. (2005) A model-driven treatment of a Cantonesespeaking dyslexic patient with impairment to the semantic and nonsemantic pathways, *Cognitive Neuropsychology, 22(1)*, 95-110.

Laxon, V., Masterson, J., & Coltheart, V. (1991). Some bodies are easier to read: The effect of consistency and regularity on children's reading. *The Quarterly Journal of Experimental Psychology*, *43*(4), 793-824.

Lee, C. Y., Hsu, C. H., Chang, Y. N., Chen, W. F., & Chao, P. C. (2015). The feedback consistency effect in Chinese character recognition: Evidence from a psycholinguistic norm. *Language and Linguistics*, 16(4), 535-554.

Leung, M.T. & Lau, D.K.Y. (2010). The Hong Kong Corpus of Chinese NewsPapers. The University of Hong Kong. [Unpublished database].

Luzzi, S., Bartolini, M., Coccia, M., Provinciali, L., Piccirilli, M., & Snowden, J. S. (2003). Surface dysgraphia in a regular orthography: Apostrophe use by an Italian writer. *Neurocase, 9*, 285– 296.

Peereman, R., Content, A., & Bonin, P. (1998). Is perception a two-way street? The case of feedback consistency in visual word recognition. *Journal of Memory and language*, 39(2), 151-174.

Rapp, B., Epstein, C., & Tainturier, M.J. (2003). The integration of information across lexical and sublexical processes in spelling. *Cognitive Neuropsychology, 19(1),* 1-29.

Riddoch, M. J., & Humphreys, G. W. (1993). *Birmingham object recognition battery*. Lawrence Erlbaum Associates.

Roux, S., McKeeff, T.J., Grosjacques, G., Afonso, O., & Kandel, S. (2013). The interaction between central and peripheral processes in handwriting production. *Cognition, 127(2),* 235-241.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological review*, 96(4), 523.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of experimental psychology: Human learning and memory*, 6(2), 174.

Stone, G. O., Vanhoy, M., & Van Orden, G. C. (1997). Perception is a two-way street: Feedforward and feedback phonology in visual word recognition. *Journal of Memory and language, 36(3)*, 337-359.

Taft, M., Liu, Y., & Zhu, X. (1999). Morphemic processing in reading Chinese. In J. Wang, A. W. Inhoff, & H.-C. Chen (Eds), *Reading Chinese script: A cognitive analysis*, 91-113.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General, 124(2),* 107.

Yiu, E. M. (1992). Linguistic assessment of Chinese-speaking aphasics: Development of a Cantonese aphasia battery. *Journal of Neurolinguistics*,*7*(4), 379-424.

Zhou, X., & Marslen-Wilson, W. (2000). Lexical representations of compound words: Cross-linguistic evidence. *Psychologia, 43*, 47-66.

Ziegler, J. C., Montant, M., & Jacobs, A. M. (1997). The feedback consistency effect in lexical decision and naming. *Journal of Memory and Language*, 37(4), 533-554.

Ziegler, J. C., Stone, G. O., & Jacobs, A. M. (1997). What is the pronunciation for-ough and the spelling for/u/? A database for computing feedforward and feedback consistency in English. *Behavior Research Methods*, *29*(4), 600-618.

Ziegler, J. C., Tan, L. H., Perry, C., & Montant, M. (2000). Phonology matters: The phonological frequency effect in written Chinese. *Psychological science*, *11*(3), 234-238.

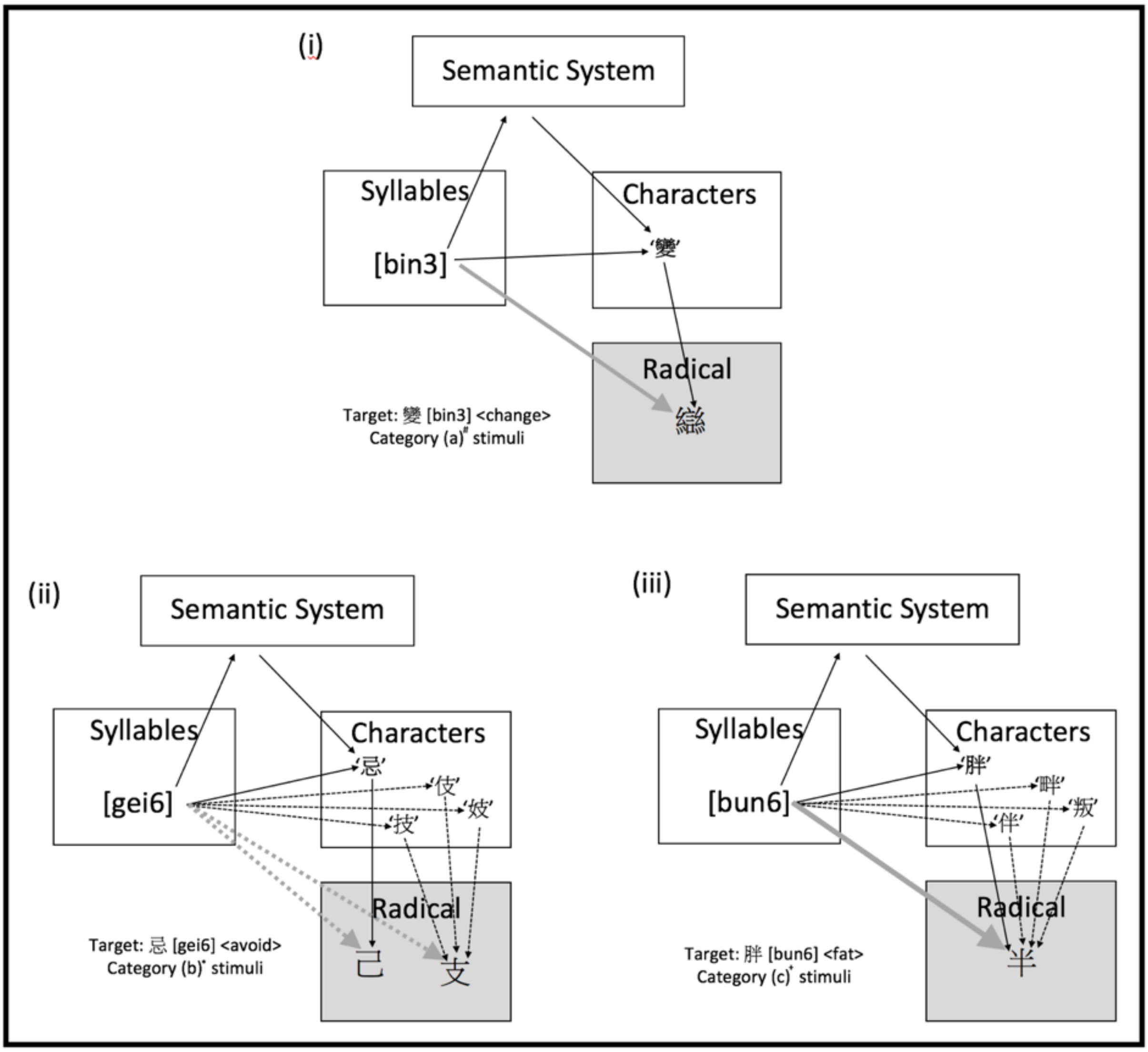

Figure 1. Different processes involved in writing-to-dictation of characters of different P-O consistencies. "→" represents activation related to the target, and "···>" denotes activation of neighbours.

[#] Category (a) stimuli: Characters with no homophones

[*] Category (b) stimuli: Characters with homophones that are associated with more than three phonetic radicals

[+] Category (c) stimuli: Characters with at least two homophones, all sharing the same phonetic radicals

Table 1.
Means and standard deviations of character frequency, number of strokes, number of shared phonetic radicals and number of homophones of the two categories of stimuli.

Frequency Category	High		Low	
P-O consistency category[#]	(b)	(c)	(b)	(c)
Frequency (in million)[*]				
Mean	319.19	448.97	35.86	30.40
Standard Deviation	235.48	412.56	19.31	19.13
Number of strokes				
Mean	11.8	12.65	12.5	12.9
Standard Deviation	4.60	3.12	4.54	3.16
Number of shared phonetic radicals				
Mean	4.85	1	3.65	1
Standard Deviation	1.09	0	0.75	0
Number of homophones				
Mean	6.1	3.1	3.6	2.75
Standard Deviation	2.81	1.12	1.43	0.72

[#] Category (b): characters with homophones that are associated with more than three phonetic radicals; Category (c): characters with at least two homophones, all sharing the same phonetic radical

[*] Measures of character frequencies, number of homophones and number of shared phonetic radicals were obtained from The Hong Kong Corpus of Chinese NewsPapers (Leung & Lau, 2010).

Table 2. WCY's performance in the comprehensive assessment

Task	**Correct rate**
Naming	
Oral naming	174/217 (80%)
Written naming	94/217 (43%)
Reading aloud of single words	120/120 (100%)
Homophone identification	
Auditory homophone identification	63/65 (97%)
Written homophone identification	62/65 (95%)
Written lexical decision task	62/64 (97%)
Word-picture matching task	
Spoken word-picture matching task	126/126 (100%)
Written word-picture matching task	122/126 (97%)
Synonym judgment task	47/60 (78%)
Non-verbal semantic tests	
BORB[*] (Test 7)	24/25 (96%)
BORB (Test 8)	25/25 (100%)
BORB (Test 10)	24/32 (75%)
BORB (Test 12)	23/23 (100%)
PPTT[#]	25/28 (89%)

[*] Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993)
[#] Pyramid and Palm Trees Test (Howard & Patterson, 1992)

Table 3. Distributions of WCY's errors in the oral and written naming tasks.

	Oral naming
Semantic errors	20
(e.g. 士多啤梨 [strawberry] → 車厘子 [cherry])	
Circumlocution errors	12
(e.g. 搖椅 [rocking chair] → 郁嘅凳 [chair that 'moves']	
No response	11
Total	43
	Written naming
Semantic errors	15
(e.g. 鹿 [deer] → 羊 [sheep])	
Errors with logographeme substitutions	72
(e.g. 椅[snake] → )	
Errors with preserved phonetic radicals	21*
(e.g. 交通燈 [traffic light] → 交通撜)	
Errors with character omissions	12
(e.g. 蒼蠅 [fly] → 蒼)	
No response	3
Total	123

* A total of 16 of the target words belong to Category (c) and the rest belong to Category (b).

Table 4. Mean Scores and standard deviations of control subjects (n=20) in the writing-to-dictation task

	Category (b)		**Category (c)**	
	HF (n=20)	LF (n=20)	HF (n=20)	LF (n=20)
Accuracy	18.0 (1.47)	13.5 (3.74)	19.0 (1.40)	15.0 (2.96)

Table 5. WCY's performance in the writing to dictation task

Accuracy	**Category (b)**	**Category (c)**
High frequency	11/20	16/20
Low frequency	2/20	2/20
Latency+		
Mean total writing time (seconds)	6.91	5.68
Upper bound (95% confidence level)	7.79	6.59
Lower bound (95% confidence level)	6.03	4.70

+Only data from accurate items were included. Because there remained too few items in the low frequency categories, the two frequency categories were combined in the latency analysis.

Table 6. Distribution of control participants' errors in the writing-to-dictation task

Errors of low frequency items	**Category (b)**	**Category (c)**
Logographeme substitution	9	0
(e.g. 描 [sketch] → 扌苗)		
Substitution of homophones containing		
shared phonetic radicals with targets	19	82
(e.g. 棲 [stay] → 淒 [miserable])		
different phonetic radicals from targets	5	0
(e.g. 犯 [crime] → 飯 [rice])		
Errors with preserved semantic radicals	10	1
(e.g. 賄 [bribe] → 敗 [lose])		
Morphological error	2	0
(e.g. 疾 [disease] → 病 [sick])		
Semantic error	2	0
(e.g. 趨 [to follow] → 返 [to get back])		
Unrelated character substitution	5	1
(e.g. 蟬 [cicada] → 筆 [pen])		
No response	73	35

Table 7. Distribution of WCY's errors in the writing-to-dictation task

Errors of low frequency items	**Category (b)**	**Category (c)**
Logographeme substitution	1 (5.56%)	3 (16.67%)
e.g. 描 [miu4] 'to draw'→  (non-word)		
Errors with preserved phonetic radicals	1 (5.56%)	6 (33.33%)
e.g. 燈 [dang1] 'light' → 僜 (non-word)		
Errors with preserved semantic radicals	0 (0%)	2 (11.11%)
e.g. 爺 [je4] 'grandfather' →  (non-word)		
Substitution of phonetic radical sharing the syllable	3 (16.67%)	0 (0%)
e.g. 趨 /ceoi1/ [to follow]→  (non-word)		
Morphological error	2 (11.11%)	0 (0%)
e.g. 疾 [zat6] 'disease'→ 病 [beng6] 'sick'		
Semantic error	2 (11.11%)	0 (0%)
e.g. 趨 [ceoi1] 'to follow' → 返 [faan2] 'to get back'		
Mixed error	1 (5.56%)	3 (16.67%)
e.g. 棲 [cai1] 'stay'→ 弓息 (The phonetic radical 息 came from the morphologically complex word 棲息 [cai1 sik1] 'rest')		
Combinations of unrelated logographemes	7 (38.89%)	2 (11.11%)
e.g. 剔 /tik1/ [pick]→  (non-word)		
No response	1 (5.56%)	2 (11.11%)
Total number of errors	18	18

Appendix A.

Contingency table for the control participants' errors of low frequency items in the writing-to-dictation task is given below

Errors of low frequency items	**Category (b)**			**Category (c)**		
	o_{ij}	e_{ij}	X^2_{ij}	o_{ij}	e_{ij}	X^2_{ij}
(1) Logographeme substitution	9	4.83	3.60	0	4.17	4.17
(e.g. 描 [sketch] → 扌苗)						
Substitution of homophones containing						
(2) shared phonetic radicals with targets	19	54.18	22.85	82	46.82	26.44
(e.g. 棲 [stay] → 淒 [miserable])						
(3) different phonetic radicals from targets	5	2.68	2.00	0	2.32	2.32
(e.g. 犯 [crime] → 飯 [rice])						
(4) Errors with preserved semantic radicals	10	5.90	2.85	1	5.10	3.29
(e.g. 賄 [bribe] → 敗 [lose])						
(5) Morphological error	2	1.07	0.80	0	0.93	0.93
(e.g. 疾 [disease] → 病 [sick])						
(6) Semantic error	2	1.07	0.80	0	0.93	0.93
(e.g. 趨 [to follow] → 返 [to get back])						
(7) Unrelated character substitution	5	3.22	0.99	1	2.78	1.14
(e.g. 蟬 [cicada] → 筆 [pen])						

(8) No response	73	52.04	8.44	35	44.96	9.77

Pairwise comparisons:

(2) vs (1); $\Delta(X^2) = 26.44 – 4.17 = 22.27$*

(2) vs (3); $\Delta(X^2) = 26.44 – 2.32 = 24.12$*

(2) vs (4); $\Delta(X^2) = 26.44 – 3.29 = 23.15$*

(2) vs (5); $\Delta(X^2) = 26.44 – 0.93 = 25.51$*

(2) vs (6); $\Delta(X^2) = 26.44 – 0.92 = 25.51$*

(2) vs (7); $\Delta(X^2) = 26.44 – 1.14 = 25.30$*

(2) vs (8); $\Delta(X^2) = 26.44 – 9.77 = 16.67$*

* Critical value of $\alpha = 0.001$ and one degree of freedom = 10.83