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Mouse tracking traces the "Camrbidge Unievrsity" effects in monolingual and bilingual minds

Yu-Cheng Lin [a,*], Pei-Ying Lin [b]

[a] Department of Psychological Science, University of Texas — Rio Grande Valley, USA
[b] Department of Educational Psychology and Special Education, University of Saskatchewan, Canada

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ABSTRACT

Previous monolingual studies have consistently suggested that there was flexibility of letter position encoding in different alphabetic writing systems. This robust letter transposition was named the "Cambridge University" effect. However, to date whether the orthographic neighborhood and cross-language script similarity would modulate the magnitude of the Cambridge University effect during the second-language word recognition in bilingual minds was unknown. We address this question using a mouse-tracking experimental paradigm to trace the internal lexical matching processes underlying the lexical access. Our linear mixed effects models and growth curve analyses revealed that a low orthographic neighborhood can trigger a large magnitude of the Cambridge University effect for monolinguals and bilinguals on their hand trajectories. We also found that different-script bilinguals (Chinese-English bilinguals) exhibited a greater Cambridge University effect than similar-script bilinguals (Spanish-English bilinguals) and English monolinguals. The findings offer compelling evidence that a human lexical match criterion of recognition system can be modified by neighborhood density and cross-language script similarity of readers.

1. Introduction

In 2003, there was a widely spread claim termed the "Cambridge University" effect in the scientific community, suggesting that readers can easily recognize jumbled letters within a non-word like a real word without any processing difficulty based on a finding from a research team of the Cambridge University. Although the internet meme is a hoax, in recent decades it has motivated many cognitive researchers to explore the transposed-letter effect during visual word recognition in alphabetic languages (e.g., Perea & Carreiras, 2006a, 2006b, in Spanish; Rayner, White, Johnson, & Liversedge, 2006, in English; Schoonbaert & Grainger, 2004, in French). Basically, human word recognition processing is involved in identifying the best word match from the large number of similar looking word neighbors. It is commonly said that the orthographic neighborhood size (*NS*) refers to a set of words differing from a target word by just a single letter, preserving the other letters and their positions (Coltheart, Davelaar, Jonasson, & Besner, 1977; Perea & Rosa, 2000). For example, the orthographic neighbors of RANK consist of all of the other words such as TANK, RACK, and RANG. Thus, the orthographic neighborhood size is three. In a broad sense, the definition of the *NS* can be also defined to include RNAK, which creates a transposed-letter non-word neighbor by swapping internal two letter positions (A and N) within the word RANK (Davis, 2012). Earlier studies (e.g., Chambers, 1979; O'Connor & Forster, 1981) have showed that the non-word transposition neighbors are relatively difficult to be rejected in a lexical decision task compared to their orthographic non-word controls (e.g., the RPOK was created by replacing adjacent letters A and N with random letters like P as well as O). For example, Chambers (1979) found that participants categorized the transposed-letter non-word neighbors (RNAK) to a non-word category more slowly than orthographic non-word controls (RPOK) around 100 ms difference. This result reflected the idea that the transposed-letter non-word neighbor activated the orthographic representations from its base word (RANK) and thus might incur a processing speed cost while rejecting the near-word as the real word.

This delayed processing of visual lexical access is also named the "transposed-letter" (TL) effect in current literature. This robust effect has also been repeatedly found in previous studies using various experimental paradigms such as masked priming and single-word lexical decision paradigms (see Lin, Bangert, & Schwartz, 2015, with mouse-tracking lexical decision paradigm; Perea & Lupker, 2003, 2004; Perea, Rosa, & Gómez, 2005, with masked priming paradigm). For example, Perea and Lupker (2003) used a masked priming lexical decision paradigm to examine the transposed-letter priming effects in native speakers of English. They reported that transposed-letter non-words (e.g., jugde — JUDGE) facilitated the processing speed of target word recognition compared to orthographic controls where two different letters are replaced (e.g., jupre — JUDGE). Again, this finding has provided

* Corresponding author at: 1201 West University Drive, Department of Psychological Science, The University of Texas — Rio Grande Valley, Edinburg, TX 78539, United States.
E-mail address: yucheng.lin@utrgv.edu (Y.-C. Lin).

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support for the view that there was flexibility in letter position encoding during visual word recognition and this has been reported in later studies (e.g., Perea & Lupker, 2004; Vergara-Martínez, Perea, Gomez, & Swaab, 2013).

Although the nature of the transposed-letter effect has been widely investigated by previous researchers, far too little attention has been paid to how the orthographic similarity affects the reading performance when the transposed-letter non-words are processed during visual word recognition in bilingual speakers. "A lack of such evidence for the transposed-letter effect in bilinguals would under-estimate many significant differences between lexical processing for monolinguals and bilinguals" (e.g., the cross-language lexical activation in orthographic neighborhood; see Lin et al., 2015, p. 367 for the concern). In fact, the cross-language orthographic activation and script similarity might modulate the magnitude of the transposed-letter effect during bilingual word recognition. In order to fill the knowledge gap, we address this important issue in the current study.

One of the theoretical models that discussed the effects of orthographic neighborhood size on monolingual lexical access is the lexical tuning hypothesis. This intriguing hypothesis was initiated by Forster (Forster, 1987, 1989, the entry-opening search model; Forster & Davis, 1984) and was subsequently proposed by Castles and colleagues (Castles, Davis, & Letcher, 1999; Castles, Davis, Cavalot, & Forster, 2007). In this hypothesis, Castles et al. (2007) argued that the magnitude of the transposed-letter effect of the word was affected by its orthographic neighborhood size (namely, the neighborhood density). They proposed that the visual word recognition system in skilled readers of English precisely tuned the match criterion to meet the increasing demands of discriminating a target from a great number of its orthographic neighbors (the high *NS* words) that fall in a dense lexical space. However, their match criterion was coarsely tuned by the decreasing demands of discriminating between the target word and its smaller number of orthographic neighbors (the low *NS* words). Previous studies have tested this hypothesis and provided empirical evidence that supported the idea that transposed-letter effects are modulated by orthographic neighborhood density. For example, Kinoshita, Castles, and Davis (2009) examined how the effects of transposed-letter priming can be modulated by neighborhood density in a lexical decision task (used in Experiment 1), and found that a greater magnitude of transposed-letter priming effects for low *NS* words than high *NS* words.

According to this lexical tuning hypothesis, one might expect that the tight match criterion of the visual recognition system in the dense lexical space might produce a small magnitude of transposed-letter encoding due to a stronger strength of lexical competition. On the contrary, the loose match criterion in the sparse lexical space should generate a larger magnitude of transposed-letter encoding during word processing. In our view, the processing of lexical selection can be easily understood by a metaphor of annual job-hunting in a highly competitive job market of cognitive psychology. More job applicants can lead to stricter screening and selection criteria developed by the hiring committee to ensure the best candidate has an "excellent fit" for the department and school. The committee on the other hand might revisit and loosen their criteria for a small number of applicants when the strength of competition in the faculty search becomes weaker. Using this metaphor, we argue that the orthographic neighborhood density (similar to the number of job applicants) should play a critical role in modulating the magnitude of transposed-letter effects during monolingual and bilingual visual word recognition. In other words, if the visual word recognition system did modify its match criterion, we should observe that the orthographic neighborhood density (size) determines the magnitude of transposed-letter effect during visual word recognition. This is, there would be a larger magnitude of the transposed-letter effect for the low orthographic neighborhood size words than high orthographic neighborhood size words in a lexical decision task.

Although the lexical tuning hypothesis was built based on the first language readers, it can offer clear predictions about how the orthographic density influences the letter position encoding during visual word recognition in second language readers. While there have been a few studies examining transposed-letter priming for bilingual readers (Perea, Abu Mallouh, García-Orza, & Carreiras, 2011, with Spanish-Arabic bilinguals; Witzel, Qiao, & Forster, 2011, with Japanese-English bilinguals), these studies have either focused on the impact of different levels of second language knowledge or prior reading experiences with special types of text directions (i.e., horizontal and vertical texts) on the degree of observed transposed-letter priming. As far we know, the effects of orthographic neighborhood size on the transposed-letter effect have not been investigated in previous studies with bilingual speakers. In the current study, we therefore aimed to investigate the impact of orthographic similarity effect on the transposed-letter encoding during English word recognition in native and second language learners.

In addition, no studies have examined the influence of cross-linguistic orthographic similarity (i.e., similar and different scripts) on the magnitude of the transposed-letter effect in bilingual speakers. The present research is the first study to investigate this issue across different groups of bilingual speakers (Chinese-English and Spanish-English bilinguals). According to the lexical tuning hypothesis, Chinese-English bilingual's visual recognition systems were expected to be coarsely tuned and tending to tolerate a greater degree of uncertainty of letter position encoding during visual word recognition due to a smaller number of orthographic neighbors in their written lexicons of English. It seems plausible that Chinese-English bilinguals' written vocabularies sizes are small and that their words have sparse orthographic neighborhoods. The lower demands of word discrimination should lead to a loose lexical match criterion, allowing a larger magnitude of transposed-letter effect while recognizing English words. In contrast, Spanish-English bilinguals and English monolinguals have a mature visual word recognition system and rich lexicons. Many word neighbors were densely distributed in their lexical space and are available in the well-developed lexicons. Thus, their visual recognition systems must precisely tune the match criterion to select the best matching candidate from the larger number of numerous lexical neighbors. If the word recognition systems indeed tuned in this strict way, we should observe a smaller magnitude of transposed-letter effect (i.e., a less flexible letter position encoding) in both Spanish-English bilingual and English monolingual speakers.

Furthermore, we hypothesized that there should be a similar degree of transposed-letter effect between Spanish-English bilingual and English monolingual groups. Although previous studies (e.g., Bialystok & Luk, 2012) indicated that bilingual adults had smaller vocabulary sizes than their monolingual peers, we would not expect that there was a larger transposed-letter effect in Spanish-English bilinguals than English monolinguals. Due to a non-selective view of bilingual lexical access,[1] one of previous studies (e.g., van Heuven, Dijkstra, & Grainger, 1998) reported that bilinguals (e.g., Spanish-English bilinguals) read target words (e.g., buzz) and not only activate the orthographic neighbors (e.g., fuzz) from the target language (e.g., English) that is currently used but also activate the orthographic neighbors (e.g., buzo) from the non-target language (e.g., Spanish). The richness of cross-language orthographic neighbors would narrowly tune Spanish-English bilinguals' match criteria in their visual recognition systems. The abundant number

[1] The cross-language lexical activation in bilingual speakers has been supported by the cognate facilitation effect (e.g., the Spanish-English cognate word 'piano-piano' has a higher degree of cross-linguistic overlap in orthographic and semantic representations that is faster and more accurate relative to controls 'pencil-lápiz'). The reliable effect has been repeatedly reported in a variety of experimental paradigms (e.g., de Groot, Borgwaldt, Bos, & van den Eijnden, 2002, a word naming; Van Hell & Dijkstra, 2002, a lexical decision task) and bilinguals with two similar-scripts (Spanish-English: Schwartz, Kroll, & Diaz, 2007) or different-scripts (Hebrew-English: Gollan, Forster, & Frost, 1997; Korean-English: Kim & Davis, 2003; Japnaese-English: Nakayama, Sears, Hino, & Lupker, 2012).