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Balanced bilinguals favor lexical processing in their opaque language and conversion system in their shallow language

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ABSTRACT

Referred to as orthographic depth, the degree of consistency of grapheme/phoneme correspondences varies across languages from high in shallow orthographies to low in deep orthographies. The present study investigates the impact of orthographic depth on reading route by analyzing evoked potentials to words in a deep (French) and shallow (German) language presented to highly proficient bilinguals. ERP analyses to German and French words revealed significant topographic modulations 240–280 ms post-stimulus onset, indicative of distinct brain networks engaged in reading over this time window. Source estimations revealed that these effects stemmed from modulations of left insular, inferior frontal and dorsolateral regions (German > French) previously associated to phonological processing. Our results show that reading in a shallow language was associated to a stronger engagement of phonological pathways than reading in a deep language. Thus, the lexical pathways favored in word reading are reinforced by phonological networks more strongly in the shallow than deep orthography.

1. Introduction

Growing evidence suggests that neurocognitive processes involved in word recognition and reading vary depending on internal and external factors. In addition to age (e.g. Wu et al., 2014), language proficiency (e.g. Dehaene et al., 2010; Newman, Tremblay, Nichols, Neville, & Ullman, 2012) or other characteristics of the reader, word features including their regularity or lexicality have been demonstrated to modulate the brain networks involved in reading (e.g. Jobard, Crivello, & Tzourio-Mazoyer, 2003). Another factor having received much less attention is the orthographic depth, i.e. the consistency of grapheme/phoneme patterns of a language. However, a better understanding of the impact of orthographic depth on the underlying brain networks would be of particular interest since the consistency of grapheme/phoneme correspondences has been shown to critically influence literacy acquisition (e.g. Ellis & Hooper, 2001; Goswami, 1998; Lallier, Carreiras, Tainturier, Savill, & Thierry, 2013), reading performance (Seymour, Aro, & Erskine, 2003) and the emergence of language-related disorders such as dyslexia (Goswami, 1998; Paulesu et al., 2001; Wheat, Cornelissen, Frost, & Hansen, 2010).

The Dual Route Cascade Model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; for a review see Jobard et al., 2003) assumes that after letter identification, word reading processing may follow two pathways, differentiating in the way graphemes and phonemes are being mapped. The predominant (i.e. not exclusive) engagement of each pathway would depend on the degree of the regularity, lexicality and/or familiarity of the word being read. Both routes have been proposed to rely on common structures, such as the left occipito-temporal region, which has been found to be activated in both phonological (non-lexical; Binder, Medler, Desai, Conant, & Liebenthal, 2005; Kronbichler et al., 2004; Mechelli et al., 2004; Xu et al., 2001) and lexical processing (Binder et al., 2005; Fiebach, Friederici, Muller, & von Cramon, 2002; Ischebeck et al., 2004; Rissman, Eliassen, & Blumstein, 2003).

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Regular and unfamiliar word or non-word reading may preferentially rely on phonological pathways, where each grapheme is sequentially mapped to its corresponding phoneme. Neural correlates of phonological processing have most commonly been identified within superior temporal (Graves, Grabowski, Mehta, & Gupta, 2008; Jobard et al., 2003), supramarginal (Graves et al., 2008; Jobard et al., 2003; Roux et al., 2012), insular (Binder et al., 2005; Fiez, Balota, Raichle, & Petersen, 1999; Herbster, Mintun, Nebes, & Becker, 1997) and inferior frontal regions/pars opercularis; BA44; e.g. Jobard et al., 2003; Nixon, Lazarova, Hodinott-Hill, Gough, & Passingham, 2004; Binder et al., 2005).

In contrast, irregular and familiar word reading may preferentially involve lexical pathways, where phonological word forms are retrieved from memory structures, i.e. from orthographic and their corresponding phonological lexical entries. Lexico-sematic processing has most commonly been linked to bilateral inferior-middle temporal (Ischebeck et al., 2004; Jobard et al., 2003) and inferior frontal regions/pars triangularis; BA 45; Fiebach et al., 2002; Jobard et al., 2003; Binder et al., 2005; Rissman et al., 2003; Ischebeck et al., 2004).

The pathway involved in mapping graphemes to phonemes may not only be influenced by the regularity, lexicality and familiarity of a word but also by the orthographic depth of a language. The orthographic depth refers to the degree of consistency of grapheme/phoneme correspondences and varies across languages from high in shallow orthographies to low in deep orthographies. The Orthographic Depth Hypothesis (Katz & Feldman, 1983; revised by Katz & Frost, 1992) posits that reading shallow orthographies (e.g. German and Italian) with consistent grapheme to phoneme correspondences favors phonological pathways, whereas reading deep orthographies (e.g. French and English) with inconsistent grapheme to phoneme correspondences favors lexical pathways.

A few neuroimaging studies have brought evidence for a modulation of brain activity by orthographic depth of the used language in word reading.

Using PET imaging, Paulesu et al. (2000) showed that native English readers rely more strongly on left posterior inferior temporal and anterior inferior frontal areas than native Italian readers, associated with lexical processes. By contrast, monolingual Italian readers showed stronger activity than English readers in left superior temporal areas, associated with phonological non-lexical processes. Investigating lexical decision in French–Arabic bilinguals (with Arabic being the relatively deep orthography), Simon, Bernard, Lalonde, and Rebai (2006) showed that the N320, a component associated with spelling-to-sound conversion (Ashby, Sanders, & Kingston, 2009; Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Carreiras, Perea, Vergara, & Pollatsek, 2009; Grainger, Kiyonaga, & Holcomb, 2006; Hauk, Davis, Ford, Pulvermuller, & Marslen-Wilson, 2006; Huang, Itoh, Suwazono, & Nakada, 2004; Proverbio, Vecchi, & Zani, 2004; Simon, Bernard, Largy, Lalonde, & Rebai, 2004; Simon et al., 2006), differentiated French and Arabic words. Similarly, Bar-Kochva and Breznitz (2012) showed larger event-related potential amplitudes to a deep (unpointed) than shallow (pointed) version of Hebrew script 340 ms after word-onset when they were presented to Hebrew bilinguals.

However, several methodological issues of the studies conducted so far on the impact of orthographic depth in word reading limit their interpretability. In studies applying between-subject designs, the observed effects could be related to inter-subject heterogeneity resulting from socio-cultural differences (Paulesu et al., 2000). Other studies used non-matched stimulus lists, e.g. by comparing pointed versus unpointed Hebrew scripts (Bar-Kochva & Breznitz, 2012), which may lead to confounds related to unbalanced familiarity and/or frequency across orthographic depth. Finally, bilingual EEG reading studies on the effect of orthographic depth (Bar-Kochva & Breznitz, 2012; Simon et al., 2006) did not perform analysis in the brain space, limiting conclusions about the brain pathways underlying the effects observed at the scalp.

In a recent study minimizing the confounds related to inter-subject heterogeneity and differences in stimuli lists, we found a modulation of the routine phonological non-lexical pathways engaged in pseudoword reading depending on the orthographic depth of language context (Buetler et al., 2014). The exact same pseudowords were presented to highly equi-proficient French–German bilinguals and the orthographic depth of PW reading was manipulated by embedding them among either a set of French (deep orthography) or German (shallow orthography) words. We showed that pseudoword reading in a shallow context relied more strongly on phonological frontal phonological pathways than reading in the deep orthographic context. In contrast, reading pseudowords in a deep orthographic context recruited less routine phonological pathways, reflected in a stronger engagement of visuo-attentional parietal areas in the deep than shallow orthographic context. These results were interpreted in terms of supporting a modulation of reading route by orthographic depth.

However, the utilization of pseudowords as target stimuli might have enhanced attentional demands and the differences we found might reflect controlled instead of automatic processing. In addition, the use of PWs as target stimuli likely reinforced assembled/phonological reading in both languages and may thus not reflect natural everyday reading, especially in the French context.

In the present study, we aimed at extending the findings on pseudoword reading to a more "natural" setting and to analyze the impact of orthographic depth on reading route selection in (French versus German) word reading. For this purpose, we focused on the EEG responses to the word stimuli presented to reinforce the linguistic context in Buetler et al. (2014), resulting in a French versus German word reading contrast. Investigating reading in highly equi-proficient (French–German) bilingual subjects allowed to minimize potential confounds arising from inter-subject comparisons. Bilingualism is an advantageous model to investigate the neural underpinnings of reading, since there is evidence for a certain degree of independency in word processing for each language context (Kovelman, Baker, & Petitto, 2008; Rodriguez-Fornells, Balaguer, & Munte, 2006; Soares & Grosjean, 1984). In addition, reference-independent electrical neuroimaging analysis and electrical source estimations (e.g. Lehmann, 1987; Tzovara, Murray, Michel, & De Lucia, 2012) were performed on event-related potentials to French and German word reading to investigate if the pathways engaged to map graphemes and phonemes are modulated by the orthographic depth of the language being read.

Reading highly familiar words will probably strengthen lexical processing independent of orthographic depth of the language. However, we predict that compared to the deep orthography, reading in the shallow orthography might rely more strongly on phonological networks. In turn, reading in deep orthography might more strongly recruit lexical pathways than reading in the shallow orthography. Thus, we expect a differential engagement of lexical versus phonological pathways between pre-lexical and semantic processing stages (~300 ms; e.g. Bentin et al., 1999; Grainger et al., 2006) when contrasting French versus German word reading.

2. Material and methods

The present study is based on a new analysis of data obtained by Buetler et al. (2014), in which the procedure and task are already detailed; we thus present only the main methodological