Est. 1841 | YORK ST JOHN UNIVERSITY

Orthographic transparency modulates the grain size of orthographic processing: Behavioral and ERP evidence from bilingualism.

Marie Lallier[a,b,*], Manuel Carreiras[b,c], Marie-Josèphe Tainturier[a], Nicola Savill[a], and Guillaume Thierry[a]

[a]School of Psychology, Adeilad Brigantia, Penrallt Road, Gwynedd, LL57 2AS, Bangor, UK

[b]Basque Center on Cognition, Brain and Language, Paseo Mikeletegi 69, Donostia-San Sebastian, Spain

[c]Ikerbasque, Basque foundation for Science, Alameda Urquijo, 36-5, Plaza Bizkaia, 48011 Bilbao Bizkaia, Spain

***Correspondence:**

Marie LALLIER, PhD

Basque Center on Cognition Brain and Language

Paseo Mikeletegi 69, Planta, 2

20009 San Sebastián - Donostia, Spain

E-mail: **m.lallier@bcbl.eu**

Abstract

Grapheme-to-phoneme mapping regularity is thought to determine the grain size of orthographic information extracted whilst encoding letter strings. Here we tested whether learning to read in two languages differing in their orthographic transparency yields different strategies used for encoding letter-strings as compared to learning to read in one (opaque) language only. Sixteen English monolingual and 16 early Welsh-English bilingual readers undergoing event-related brain potentials (ERPs) recordings were asked to report whether or not a target letter displayed at fixation was present in either a nonword (consonant string) or an English word presented immediately before. In word and nonword probe trials, behavioural performance were overall unaffected by target letter position in the probe, suggesting similarly orthographic encoding in the two groups. By contrast, the amplitude of ERPs locked to the target letters (P3b, 340-570ms post target onset, and a late frontal positive component 600-1000ms post target onset) were differently modulated by the position of the target letter in words and nonwords between bilinguals and monolinguals. P3b results show that bilinguals who learnt to read simultaneously in an opaque and a transparent orthographies encoded orthographic information presented to the right of fixation more poorly than monolinguals. On the opposite, only monolinguals exhibited a position effect on the late positive component for both words and nonwords, interpreted as a sign of better re-evaluation of their responses. The present study shed light on how orthographic transparency constrains grain size and visual strategies underlying letter-string encoding, and how those constraints are influenced by bilingualism.

Keywords: bilingualism, reading, orthographic processing grain size, visual attention span, orthographic transparency

1. Introduction

Identifying generic cognitive factors underlying normal and atypical reading acquisition is an active area of research (Share, 2008). In particular, orthographic transparency is assumed to affect reading acquisition (e.g., Goswami et al., 1998; Seymour et al. 2003) since transparent languages (e.g., Italian, Welsh) entail highly consistent relations between graphemes and phonemes, whereas opaque languages (e.g., English) entail multiple correspondences between a given grapheme and speech sounds. Several theoretical frameworks have attempted to account for the impact of orthographic transparency on reading acquisition (e.g., Frost, 1994; Frost et al., 1987; Wydell and Butterworth, 1999). Amongst them, the psycholinguistic grain size theory (PGST) proposes that the size of the units upon which lexical representations are built is inversely proportional to the regularity of grapheme-to-phoneme correspondences (Ziegler and Goswami, 2005). In transparent orthographies, phonological regularity characterizes small orthographic units (i.e., graphemes) and prompts sub-lexical decoding strategies. By contrast, in opaque orthographies, the availability of larger orthographic units (e.g., grapheme clusters, syllables, or morphemes), which are phonologically more regular than smaller ones, encourages lexical, whole-word reading processing. Whilst this assumption fits well dual route models of reading (e.g., Coltheart et al., 2001), the PGST proposes that grain size gradually varies, i.e., that there is a continuum in reading procedures rather than two dichotomous pathways.

PGST has been supported by studies of item length effects, which are thought to index a serial procedure. Indeed, readers of transparent orthographies are sensitive to item length (Spinelli et al., 2005; Wydell et al., 2003) to a greater extent than readers of opaque orthographies (Ziegler et al., 2001; Ellis et al., 2004). In the same vein, Lima and Castro (2010) showed that length effects in readers of Portuguese, a mildly opaque language, vary according to task demands reflecting a reading strategy continuum according to the degree of orthographic transparency. Additional evidence for the PGST comes from cross-linguistic studies of reading errors (Ellis et al., 2004; Wimmer and Goswami, 1994) showing that readers of opaque languages are more prone to produce errors visually similar to word targets (e.g., “complete” for “computer”) than readers of transparent languages. Such errors suggest that readers of opaque orthographies rely more on whole-word lexical knowledge. By contrast, readers of transparent languages tend to mispronounce target words as nonwords (e.g., “canera” for “camera”), suggesting greater reliance on grapheme-to-phoneme conversion.

However, comparing reading strategies between countries may be confounded by methodological, cultural and environmental differences. Ellis and Hooper (2001; see also Spencer and Hanley, 2003) conducted a study comparing reading performance between a group of Welsh-English bilingual children learning to read in (transparent) Welsh, and monolingual English children. Importantly, all children lived in Wales where schools have either Welsh or English as the language of instruction, so that similar teaching schemes and methods were used. Length effects and errors observed in the two groups were in line with the previous cross-linguistic studies indicating that, during reading acquisition, the use of different strategies determined by the degree of orthographic transparency may differentially shape neural populations underlying reading as well as the extent to which these populations are recruited in reading, as suggested by cross-linguistic imaging studies in monolingual adults (Fiez, 2000; Paulesu et al., 2000).

In bilingual participants, fMRI and ERP studies have shown different patterns of activation between reading in L1 and reading in L2, whilst the two languages always varied in the extent to which grapheme-to-phoneme conversion and lexical processes are involved (Liu and Perfetti, 2003; Meschyan and Hernandez, 2006; Simon, et al., 2006). Some studies have however demonstrated a high level of interactivity between L1 and L2 in bilinguals, which does not support the idea of separate functional systems (e.g., Abutalebi, 2008; Perani and Abutalebi, 2005) but rather continuous parallel activation of the two languages (Kroll and De Groot, 2005; Perea, et al., 2008; Thierry and Wu, 2007). In the same vein, orthographic transparency of L1 has been shown to influence L2 reading (see Perfetti and Dunlap, 2008, for a review). For example, Wang et al. (2003) compared readers of Korean, an alphabetic language prompting sub-lexical processing, and readers of Chinese, a logographic language involving holistic reading, on their implicit reading performance in L2 (English). Results showed that Korean-English and Chinese-English bilinguals rely preferentially on phonological and orthographic information, respectively. It is however noteworthy that L1 and L2 were either totally different (Chinese-English) or visually dissimilar (Korean-English), and that striking perceptual differences between scripts may play a role in the recruitment of different cerebral networks (Tan et al., 2003). Indeed, it remains unclear to what extent the cascade effect linking orthographic transparency to grain size and reading strategy is contaminated by perceptual differences between languages.

Assessing reading performance in Welsh-English bilinguals is particularly relevant because (a) Welsh and English have visually similar alphabets, and (b) the vast majority of fluent bilinguals are formally taught to read in Welsh and in English in parallel (Baker, 1995). An advantage of studying Welsh-English bilinguals acquiring both oral and written language skills from very early on is that differences in proficiency and age of acquisition between languages are negligible. In particular, this is a promising population to study orthographic transparency effects in reading (Beaton and Davies, 2007; Tainturier et al, 2007).

In addition to influencing the nature of the strategy adopted when reading, orthographic transparency may shape a number of specific visual cognitive skills required for letter strings encoding and reading acquisition (e.g., Bosse et al., 2007; Dehaene et al., 2005; Facoetti et al., 2010; Vidyasagar and Pammer, 2010; Whitney, 2001). For instance, letter position encoding may be a critical factor in normal (Duñabeitia et al., 2007; Tydgat and Grainger, 2009; Whitney, 2001) and impaired (Pammer et al., 2005; Pammer et al., 2004) visual string processing, and may therefore be modulated by orthographic transparency. Ktori and Pitchford (2008) assessed letter search performance within non-pronounceable 5-letter strings in monolingual speakers of Greek (transparent language), Greek-English bilinguals, and English monolinguals. For native language stimuli (i.e., Greek letters for the Greek groups and English letters for English groups), the modulation of search reaction times depended on the position of targets in strings, such that the groups performed along a search strategy continuum (i.e., from a left-to-right sub-lexical to a lexical whole-string strategy) which mirrored an orthographic transparency continuum (i.e., from Greek to English via Greek-English). Indeed, search facilitation for the final 5th letter as compared with the 4th letter was found in English monolinguals only and this differential search pattern was interpreted as a greater reliance on lexical processing in readers of the opaque English orthography.

Besides letter position encoding, Bosse et al. (2007) suggested that distributing simultaneously and evenly visual attention resources over the whole letter string is required to adequately extract orthographic lexical information. The notion of visual attention span (hereafter VA Span) is defined as the number of distinct visual elements that can be processed simultaneously within a multi-element array (Lassus-Sangosse et al., 2008). The VA Span is typically measured using whole and partial letter report tasks which, require naming all of the letters of a five-consonant string (whole report) or, a single post-cued letter within the string (partial report). In these tasks, the consonant strings are displayed for a time period short enough to avoid useful ocular saccades (<200ms), so that participants have to engage enough visual attention resources to process all five elements simultaneously (Peyrin et al., 2011). Only consonants are used as stimuli to compose unpronounceable illegal letter strings. In the whole report task, the five elements need to be verbally reported without order constraint whereas in the partial report task the cued letter alone has to be reported. A deficit on such tasks is reflected by a poor accuracy report score, interpreted as a reduction of the VA Span. VA Span skills have been shown to affect reading in normally developing and dyslexic readers (Bosse et al., 2007; Bosse and Valdois, 2009; Lallier et al., 2010; Lassus-Sangosse et al., 2008; Prado et al., 2007; Valdois et al., 2003) and to recruit parietal brain regions (Peyrin et al., 2011; Peyrin et al., 2012). Importantly, VA Span skills may be influenced by grapheme-to-phoneme regularity, since they contribute more to word - lexical coarse grain strategy - than pseudo-word - sub-lexical small grain strategy - reading (Bosse and

Valdois, 2009). Thus, in accordance with the PGST, learning to read in a more transparent language might lead to processing letter strings with a smaller visual attentional window (i.e., a smaller VA Span/grain size).

The present study

We aimed at showing that orthographic transparency influences positional encoding and VA Span/grain size as indexed by the performance obtained in a 1-back task. The task entailed judging whether or not a target letter displayed at fixation was previously presented in an English word probe, or a nonword probe (5-consonant string) in position 1, 3 or 5. The present research aimed at clarifying the influence of orthographic transparency on such visual skills by (i) using both behavioral and electrophysiological measures; (ii) testing simultaneous bilingual readers whose long-term bilingual reading experience in both a transparent and an opaque orthography should favor the observation of string encoding strategies different from those used by English monolinguals.

Because both the monolingual and the bilingual groups were composed of skilled and equally proficient readers of English, behavioral performance was expected not to be affected by target letter position in English words in either group because of the automatic global processing of the string (Ans et al., 1998). We however predicted English monolinguals to use a larger grain size for encoding new orthographic stimuli than the grain size used by Welsh-English bilinguals because learning to read in an opaque orthography only enhances the processing of larger units (via larger VA Span skills) as compared to learning to read in a transparent orthography also. We therefore predicted a stronger position effect on behavioral performance in bilinguals than monolinguals on the nonword condition.

In addition to behavioural measures, we recorded event-related potentials (ERPs) to gain fine temporal information on differences regarding VA Span/grain size and orthographic stimuli integration mechanisms between Welsh-English bilinguals and

English monolinguals before any motor response. Indeed, ERPs will allow capturing effects that may not be observable on behavior only, because windows chosen to perform ERP analyses will occur before the motor responses. If the transparency of Welsh results in reduced VA Span/grain size in bilinguals and greater difficulty to detect target letters presented at the right and/or centre of fixation in orthographic stimuli, ERPs elicited by those targets should be affected accordingly. Target detection here was indexed by the P3b wave. The P3b is a positive peak of ERPs maximal circa 300 ms after the onset of a stimulus and typically elicited by attention orienting. Its amplitude has been shown to relate to task difficulty and perceptual saliency in target detection (Sawaki, and Katayama, 2007). Larger P3b amplitudes are elicited when a match is detected between information previously encoded and stored (e.g., letter string probes) and an ongoing event (e.g., a target letter). If Welsh transparency is associated with reduced VA Span/grain size in bilinguals, the 5^{th} and/or 3^{rd} letter(s) in probes should be less accurately encoded than the 1^{st}. Such position effect on P3b was therefore predicted to be smaller in monolinguals (in particular for nonwords). Lastly, we did not expect to find any modulation of earlier P1 or N1 peaks locked to probes between group (monolinguals and bilinguals) or condition (words and nonwords) since P1 and N1 components index respectively *letter physical features processing* (e.g., Thierry et al., 2009) and *orthographic expertise* (see Xue et al., 2008, for a review). Moreover, no difference in N1 lateralization was expected between groups since both groups were expected to be equally familiar with English high frequency words and equally unfamiliar to the presented nonwords (see Grossi et al., 2010).

2. Results

2.1. Behavioral results on target detection: accuracy and reaction times.

As expected, overall target detection accuracy for words was almost at ceiling for the three positions in both groups preventing us to run the ANOVA in the absence of variability between participants (Cramer and Howitt, 2005; see Table 1 and Fig. 1). Therefore, the ANOVA was performed only on nonwords, where accuracy did not differ between groups ($F(1,30) = 2.4$, $p = .12$). Accuracy was modulated by target position in nonwords ($F(2,60) = 51$, $p < .001$; post-hoc tests, all $ps < .001$). No other effect was found on target detection accuracy on nonwords (see Fig. 1 and Table 1).

Regarding RTs, a main effect of condition was found ($F(1,30) = 367.5$, $p < .001$) reflecting faster responses for target presented in word than nonword probes. A position main effect was also found ($F(2,60) = 207.7$, $p < .001$) reflecting a gradually slower target detection from position 1 to 5 (post-hoc tests, all $ps < .001$). The factors position and condition interacted significantly, reflecting slower performance to detect target presented in position 5 than in positions 1 and 3 in words (post-hoc comparisons, $ps < .001$), whereas for nonwords, a gradual slower performance was observed (for 1 *vs.* 3, 3 *vs.* 5 and 1 *vs.* 5, post-hoc comparisons, $ps < .001$). Lastly, a significant main effect of group showed that bilinguals were overall slower at detecting targets than monolinguals ($F(1,30) = 7.9$, $p < .01$), reflecting a consistent "bilingual" delay across conditions and positions of 38ms in average. No other significant effect was found (see Fig.1 and Table 1).

Insert Table 1 about here

Insert Fig. 1 about here

2.2. ERPs

2.2.1 ERPs locked to letter-string probes

There was neither an effect of group or condition on probe-P1 or probe-N1 amplitude (*Fs* < 1), nor of hemisphere (*F* < 1) or group-by-hemisphere interaction ($F(1,30) = 1.9$, $p = .2$) on probe-N1 amplitude. On probe-P1 latency, the group-by-condition interaction was significant ($F(1,30) = 4.2$, $p = .048$; for the group and condition main effects, *F*s <1) but Bonferroni tests failed to show any significant post-hoc difference between modalities (all ps > .22). On probe-N1 latency, no significant effect was found (*Fs* < 1).

2.2.1 ERPs locked to target letters

Target-P3b

On target-P3b amplitude, both main effects of condition ($F(1,30) = 25.9$, $p < .001$) and position ($F(2,60) = 3.6$, $p < .05$) were significant, reflecting larger amplitude in the word than in the nonword condition, and for targets presented in position 1 in probes than for targets in position 5 (post-hoc tests: 1 *vs.* 5, p < .01, but for 1 *vs.* 3 and 3 *vs.* 5, ps > .05). The two latter factors interacted with each other ($F(2,60) = 11.2$, $p < .001$) indicating that target-P3b amplitude was modulated by target position in nonwords (post-hoc comparisons: 1 *vs*. 5, p < .001, but 1 *vs*. 3 and 3 *vs*. 5, ps > .05) but not in words (all ps > .9). Importantly, the group-by-position significant interaction ($F(2,60) = 6.3$, $p < .01$) indicated that target-P3b amplitude was modulated by target position in probes in bilinguals (post-hoc comparisons: 1 *vs*. 5, p < .001, 1 *vs*. 3, p = .05, 3 *vs*. 5, ps > .05) but not in monolinguals (all ps > .9)[See Fig. 2, Fig. 3 and Table 2]. No other significant main effect or interaction between the different factors was observed on target-P3b amplitude (all ps > .05).

Insert Table 2 about here

Insert Fig. 2 about here

Target-P3b latency was modulated by condition ($F(1,30) = 4.7$, $p = .038$) showing that P3b locked to target letters presented in words were elicited faster than P3b locked to target letters presented in nonwords. No other factor was found to influence target-P3b latency (all $ps > .05$)[Fig. 2, Fig.3 and Table 2].

Insert Fig. 3 about here

Target-LPC amplitude

The target-LPC amplitude was significantly modulated by the position of the target letter in probes ($F(2,60) = 5.8$, $p < .01$) illustrating that target letters presented at position 5 in probes elicited a lesser positivity than target letters presented at positions 1 and 3 (post-hoc comparisons, $ps < .05$). Moreover, the interaction between condition and position was significant ($F(2,60) = 5.1$, $p > .01$), showing that the position of the target letter in probes influenced target-LPC amplitude in the nonword condition (post-hoc comparisons: 1 *vs*. 5, $p < .01$; 3 *vs*. 5, $p < .01$; 1 *vs*. 3, $p > .9$) but not in the word condition (for all comparisons, $ps > .9$). Lastly, a group-by-position interaction was observed ($F(2,60) = 5.0$, $p > .01$), indicating a position effect on target-LPC in monolinguals (post-hoc comparisons: 1 *vs*. 5, $p < .01$, 1 *vs*. 3 and 3 *vs*. 5, $ps > .05$) but not in bilinguals (all $ps > .9$) [Fig. 4 and Table 3][1].

Insert Table 3 about here

Insert Fig. 4 about here

----

3. Discussion

We investigated the effects of orthographic transparency on early visual processing underlying letter-string encoding in a group of simultaneous skilled Welsh-English bilingual readers and a group of matched English monolinguals. This study is the first reporting effects of orthographic transparency on reading development in bilingual adults who have normally acquired reading in both Welsh and English (see Beaton and Davies, 2007 and Tainturier et al, 2007 in participants with acquired dyslexia; Ellis and Hooper, 2001 and Spencer and Hanley, 2003 in children).

We measured those visual skills with a task where participants had to detect whether a target letter was present in a letter-string probe presented immediately before. Although we aimed at measuring VA Span skills in our participants, we are aware that the present task also taps into visual working memory (for remembering the letters in the probe and judging whether the target is one of those letters). We think that this paradigm is still a good candidate for measuring VA Span skills (described as visual attentional resources) for two main reasons: first, both visual attention and visual working memory share the same processing resources (Feng et al., 2012) and second, these two cognitive components are subtended by similar brain areas (Fusser et al., 2011), including superior parietal lobules found to correspond to the neural substrate of VA Span skills (Peyrin et al., 2012).

Our task included two conditions: a word condition (high frequency English 5-letter words) aimed at providing a control for reading skills in the two groups of participants and the nonword condition (5-consonant strings). Target detection in the nonword condition allowed us to capture orthographic processing strategies prompted when orthographic and phonological lexical activation cannot (fully) support letter-string encoding (i.e., when no lexical trace is stored in long-term orthographic memory). The nonword condition was therefore a way of investigating the strategies automatically triggered by the encoding of new letter-strings, simulating reading acquisition processes.

Two behavioural measures were collected and analysed in the present study: (i) the accuracy of target detection, namely the percentage of correct responses in deciding that the target was present in probes, and (ii) a reaction time (RT) measure, corresponding to the time taken to correctly detect the target. Each of these two measures gives us different information about how the letter-string probe has been encoded whilst being presented for a very short time (i.e., 180 ms). On the one hand, accuracy can be viewed as an index of the *quantity of the letter-string information* attended (i.e., via VA Span skills) and encoded in short-term memory; therefore this measure should be relevant for answering our question regarding the differential grain size for letter string encoding between the two groups. On the other hand, RTs for correct target detection trials reflect the *time taken to correctly decide* whether the target letter was part of the previously presented letter string, likely to be driven by both an evaluation process of the probe's short term memory trace, and processing differences between bilinguals and monolinguals when it comes to lexical stimuli (discussed later). Therefore different patterns of performance should be expected between accuracy and RT measures within and between groups.

Similarly, different ERP components were analysed which could follow different patterns within groups. In the context of the present task, P3b amplitude was thought to index the quality of probe encoding (i.e., quality of the orthographic information transferred via VA Span skills into visual short-term memory), and letters precisely encoded and easily retrieved were expected to elicit larger P3b as compared to not precisely encoded letters and retrieved with difficulty or not retrieved at all. Because our task required participants to retrieve whether a target letter was present or not in a letter-string presented immediately before, the ERPs generated may resemble the ERPs sensitive to old/new effects (e.g., Rugg et al., 1998; Wilding and Rugg 1996). Old/new effects are observed in tasks where participants are required to remember whether they had been presented with a specific word earlier, i.e., whether it is an "old" or a "new" item. Generally, two ERP waves with distinct topographies and timing are sensitive to the old/new effect: a parietal positive wave (starting within 400-500ms post-stimulus onset) and a late frontal positive wave (starting about 600ms post-stimulus onset). In one hand, parietal old/new effects have been suggested to reflect the quality and amount of the information retrieved (e.g., Wilding, 2000; Wilding and Rugg, 1996), indicating greater positivity for old than new items. Such parietal effects may be related to the P3b effects observed in the present study. On the other hand, late frontal effects have been related to post-retrieval evaluation processes occurring after participants' responses (e.g., Allan et al., 1998; Curran and Clearly, 2003). Therefore, in the present study, target-LPC amplitude may reflect a post-retrieval evaluation made by participants on their own responses.

Looking first at behavioral accuracy data, no position effect was observed in the word condition (performance at ceiling) whereas it was found in the nonword condition. These two results can be interpreted in the framework of the multi-trace memory model for polysyllabic word reading proposed by Ans et al. (1998; hereafter abbreviated MTM). A key component of the MTM model is the visual attention window, which corresponds to the VA Span behavioral measure (Bosse et al., 2007). According to the MTM model, reading relies on two procedures, one global and one serial, differing in the size of the attention window through which information from visual input is first processed and extracted. In global reading mode, the window extends over the whole letter string whereas in serial reading mode (i.e., decoding mode), the window narrows down to focus attention on the successive parts of the input. Although the two procedures are not *a priori* dedicated to reading a particular type of letter strings, most familiar words are processed in global mode, whereas non-familiar letter strings, such as consonant strings, are processed serially. The position effect observed on accuracy for the nonword condition is consistent with the predictions of the MTM model since the global mode is expected to fail for unfamiliar items, leading to a reduction of the VA Span size. In line with the behavioral accuracy results, and as expected, P3b amplitude and analyses showed a significant target position effect only in the nonword condition only, reinforcing the hypothesis of a sequential parsing of the unfamiliar consonant strings. Similarly, the condition effect on P3b latency (P3b peaked elicited earlier in the word than the nonword condition) may also be reflecting these different processing modes (i.e., global versus serial) between words and nonwords.

Against our prediction, the absence of any differential position effect on target detection accuracy between groups in any of the two conditions suggests the use of similar VA Span in the two groups when encoding new letter strings. However, ERP results showed a significant decrease between the amplitudes of P3b elicited by target letter presented at position 1 and 5 in bilingual participants only, regardless of the condition. At that point, it must be noted that in the present study divergence between behavioral data and ERP results were found (no modulation by position or condition of the group performance on accuracy or RTs). However, ERPs provide a more sensitive index of processing, and such divergence is especially informative when the goal of a study is to determine the unconscious components at work in a particular cognitive task. P3b peaks were elicited before the participants pressed the response key, and therefore offer a measure of letter strings encoding, not yet polluted by motor activity and response strategies bias. Moreover, ERPs have been shown to be highly sensitive to priming even in conditions when no measurable behavioral effects are observed (e.g., Thierry and Wu, 2007; Wu and Thierry, 2010, 2012). These ERP results provide evidence that Welsh-English bilinguals better encode the leftmost letters of an orthographic string, compared to rightmost letters, consistent with the hypothesis of a reduced VA Span/grain size. Thus, we hypothesize a differential tuning of visual attention skills underlying orthographic processing (including word reading and nonword decoding) when reading is acquired simultaneously in both an opaque and a transparent language compared to when it is acquired in an opaque language only.

Although this could be hypothesized, it is rather unlikely that the group-by-position interaction on P3b amplitude resulted from poorer reading skills in the bilingual group. Indeed, in the word condition, the presence of a ceiling accuracy effect independent of target position suggests that English words were fully encoded as a whole in both groups. Furthermore, P1 and N1 visual ERP components elicited by probes were not different in amplitude or latency across groups and conditions. On the one hand, P1 can reflect differences in visual physical properties of the stimulus (e.g., Thierry et al., 2009), and the absence of group effect in the P1 range suggests that word and nonword probes were perceived as visually complex in bilingual and monolingual participants, in line with the fact that the two languages have a very similar alphabet. On the other hand, the N1 may be a good index of reading expertise as shown by studies comparing children and adults (Maurer et al., 2006) or dyslexic and skilled readers (Maurer et al., 2007). Studies in unbalanced bilinguals have shown N1 amplitude differences between L1 and L2 processing (Liu and Perfetti 2003; Wong et al., 2005). Here, the highly proficient Welsh-English bilinguals tested exhibited no difference in N1 amplitude as compared to English monolinguals for both words and nonwords probes. This suggests that the bilinguals tested had equivalent levels of reading expertise in the two languages. In the same vein, the absence of group differences on N1 lateralization suggests that the two groups exhibited similar familiarity/expertise with letter-strings (Grossi et al., 2010)[2].

Regarding RTs, position effects were found in both the word and the nonword conditions, suggesting a cost of left-right screening of the memory trace, similar for the two groups. Short-term memory traces of probes may have been available only partially or/and degraded for rightward letter positions in probes, resulting is longer RTs. Such an effect was however not predicted in the word condition by the MTM model, which assumes that letters of familiar orthographic entries are processed simultaneously since they are retrieved automatically from the lexical orthographic knowledge. Yet, ceiling performance for target detection suggests that English words were decoded as a whole, yielding a stable and clear memory trace by the time of target presentation (supported by long-term orthographic lexical knowledge). Hence, the position effect observed on RTs for words (and nonwords) might have been the consequence of a left-to-right evaluation process of the short term memory trace[3].

Interestingly, we found a significant group main effect on RTs, showing that bilinguals took longer to correctly detect targets regardless of their position in words or nonwords. Because no group difference was found on early indices of word or nonwords analysis (cf. P1 and N1 results), the bilingual delay observed on RTs resulted from an additional processing step occurring right after the full perceptual encoding of probes in bilinguals. We propose that this step involved figuring out whether the letter string belongs to L1, to L2 or neither. Bilinguals typically access visual letter strings differently to monolinguals because of spontaneous co-activation of L1 and L2 lexical forms even when the task is contextually monolingual (Grainger and Dijkstra, 1992; Thierry and Wu, 2007; Wu and Thierry, 2010). Indeed, given their much greater lexicon, Welsh-English bilinguals may have required in our task more resources to evaluate what has been encoded in their short term memory and realize that a consonant string is not a lexical item. Moreover, nonwords naturally contained consonant-consonant digrams which may have cued Welsh activation in bilinguals (Mathey and Zagar, 2000; Vaid and Frenck-Mestre, 2002), although stereotypical Welsh digrams such as dd, ll, ff were carefully avoided[4].

In addition to being a potential cause for the main group effect observed on RTs, this specific trait of bilingualism (i.e., the constant competition between two lexica) may have contributed to the failure of observing in bilinguals any target position modulation of the frontal target-LPC, indexing post-retrieval evaluation processes (e.g., Allan et al., 1998). Post-retrieval evaluation mechanisms depending on the position of the target letter in probes may have been hindered in bilinguals compared to monolinguals, because of lexical access competition processes that did not affect monolingual participants' responses. An alternative explanation for this positional effect differing between groups on late frontal ERPs is that it could reflect in monolinguals a greater specificity regarding the representation of the letters in probes (i.e., identity and/or position), which in turn affected the evaluation of their response. This might have resulted from a better quality of orthographic encoding in monolinguals, in line with the interpretation of the P3b results regarding orthographic transparency differences between Welsh and English. Along those lines, it has been suggested that post-retrieval evaluation processes, as indexed by late frontal effects, were more affected by stimulus characteristics in good than poor performers in a task where participants had to remember whether a stimulus was presented or not earlier (Curran et al., 2001) – in our task, whether a letter was present in the previous string or not.

To conclude, the present results suggest that orthographic transparency of the language(s) used during the period of reading acquisition shapes the specific cerebral strategies commanding orthographic encoding. In addition, our results suggest that learning to read in a transparent language affects the processing of the more opaque language (inasmuch as consonant strings can be viewed as English linguistic stimuli). Although no differences were noticeable at the behavioral level between our two groups of fluent readers of English, their orthographic encoding strategies were subtended by different electrophysiological responses. Future work should determine whether the degree of orthographic transparency of the language(s) learned affects reading strategies at the early stages of reading development, at the behavioral level. Our study furthermore sheds new light on previous differences observed in both the time-course of reading acquisition and manifestations of reading disorders across language groups. Thus, future work investigating typical or atypical orthographic processing should take into account variations in the linguistic characteristics of the language(s) learned by the individuals assessed.

4. Material and Methods

4.1 Participants

4.1.1 General characteristics

Sixteen Welsh-English bilingual adults (6 males, 23.4 years, age range 19-36 years) matched for age ($p > .05$) with 16 English monolinguals (8 males, 19.8 years, age range 18-27 years) participated in the study. They were psychology students at Bangor University and received course credits for their participation. The study was approved by Bangor University ethics committee and was therefore performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants had normal or corrected-to-normal vision, no self-reported neurological disorders, developmental dyslexia, or mild reading difficulties.

4.1.2. Language history

Participants were instructed to fill out a language questionnaire before starting the testing procedure. Two different questionnaires were administered to the bilingual and monolingual groups. Six bilingual participants learned Welsh and English "from birth"; four and six participants learned respectively English and Welsh later (from age 3 to 6). On average, the group was characterized by a simultaneous learning of Welsh and English reflected by a mean age of acquisition of 1.9 years (± 1.7) for English and 2.1 years (± 1.4) for Welsh ($p > .1$). During childhood, eight participants spoke more Welsh than English (> 50% of the time on average). Participants were well balanced bilingual children since Welsh was used 59% (±31) of the time on average (not significantly different from English use). Regarding the education received by the bilingual participants, the main language of instruction of the group was Welsh, both in primary (Welsh 88% ± 17; $p < .001$) and secondary (Welsh 74 ± 21; $p < .01$) schooling. Importantly, nine participants reported having been formally taught to read and write in

English and Welsh at the same time (age 4 or 5). Four participants learned to read and write in Welsh first, two participants in English first (1 or 2 years gap). At the time of testing, all bilinguals included in the study reported speaking Welsh as well as English fluently: on a scale going from 1 (i.e., native speaker, can carry out extended conversation) to 3 (i.e., non native speaker, only know some words and expressions), all selected 1 for both Welsh and English). They reported speaking mostly English (67%; ±24; $p < .05$), and three participants reported speaking essentially Welsh (> 60% of the time). As adults, the bilingual group reported reading in Welsh occasionally, and two participants reported using Welsh to write most of the time (> 80%), whereas the group average was 14% (± 26).

All monolingual participants considered themselves as English monolinguals and reported English as the only language spoken at home during childhood. All of them learned a second language at school but reading, writing, speech comprehension and conversational fluency, were all rated below 5 out 10 on average (1 = not proficient, 10 = very proficient). Individual ratings confirmed that none of the monolingual participants were proficient in L2. For eight monolinguals, L2 was characterized by a transparent orthography (Spanish, German or Welsh), and by an opaque orthography for the remaining eight participants (French or Irish).

4.2 Task

4.2.1 Stimuli

A list of 216 English 5-letter familiar (range 401-644, M = 515 ± 55, z = .33) and concrete (range 400-638, M = 537 ± 65, z = .82) singular nouns were selected from the MRC psycholinguistic database (Coltheart, 1981). A list of 216 5-consonant strings (nonwords hereafter) was created using 14 consonants (i.e., B, C, D, F, G, H, K, L, M, N P, R, S, T, and V) appearing 14 or 15 times in the five possible positions. Nonwords did not include grapheme clusters corresponding to English or Welsh phonemes (e.g., CH) and were not Welsh or English word skeletons (e.g., C M P T R for “computer”). Stimuli did not include the same letter twice and were designed following report tasks previously used to quantify VA Span skills (e.g., Bosse et al., 2007). They were presented on a white screen with *E-prime 2.0* software *(Psychology software Tools, Inc)* on a PC computer, in black upper-case Arial font. Letter strings length varied between 5.3° and 5.55° of visual angle at a distance of 60 cm. The centre-to-centre distance between each adjacent letter was 1.2° so that lateral masking effects were minimized. To reduce visual similarity with letters presented in letter strings, target letters were presented in red bold italic.

4.2.2 Procedure

Participants were tested in a sound-attenuating dim lit room. At the start of each trial, a central fixation point was displayed for 1000 ms followed by the 5-letters string stimuli centered on fixation (probe). After 180 ms, probes were followed by five snowflakes (mask) for 100 ms, and then, by a single letter at fixation (target). Participants were instructed to press the space bar as fast as possible when the target letter was present in the probe stimulus (go trial) and withhold their response otherwise (no-go trial). Participants were told that probes would be either English words or consonant strings. For the go trials, the target could be the 1st, 3rd or 5th letter of the probe. The target disappeared after any space-bar responses and after 2000 ms in case of no response. Fifty-four no-go trials and 54 go trials were presented randomly per condition. Stimuli were presented in blocs of 9 min each with a break in between, and preceded by 10 practice trials. The experimental session lasted a maximum of two hours including ERP set up (section 2.2.3).

4.2.3 ERP recording

Electrophysiological data were recorded in reference to electrode Cz at a rate of 1kHz from 64 Ag/AgCl electrodes placed according to the 10-20 convention. Impedances were kept below 7 kOhm. EEG activity was filtered on-line band pass between 0.1 Hz and 200 Hz and re-filtered off-line with a 30 Hz low pass zero phase shift digital filter. Eye blink artifacts were mathematically corrected based on a model artifact computed from a minimum of 50 individual artifacts in each participant using the procedure implemented in Scan 4.3 (Neuroscan, Inc., El Paso, TX, USA) and remaining artifacts were manually dismissed. Epochs ranged from -100 to 1000 ms after the onset of probe presentation. Baseline correction was performed in reference to pre-stimulus activity and individual averages were digitally re-referenced to a global field power reference which summarizes the contribution of all electrodes in the form of a single vector norm (Picton, Bentin et al. 2000). Behavioural data were collected simultaneously to ERP data.

4.2.4. Data analysis

Mean reaction times (RTs) were computed from correct responses only and RTs exceeding the mean RT by more than 2.5 standard deviations within each condition and group were replaced by the corresponding mean RT (10% and 13% RTs replaced for the bilingual and the monolingual groups respectively). Behavioral data (RTs and accuracy) was analyzed for go trials using analyses of variance (ANOVAs) with group (bilingual, monolingual) as a between-subject factor, and condition (words, nonwords) and position (1, 3, 5) as a within subject-factors.

For ERPs, individual averages were computed from correct and incorrect trials in experimental conditions and averaged to produce grand-mean averages. Regarding the ERPs locked to the probes (words and nonwords), visual inspection of the data across participants, allowed to identify P1 as the first visible positive peak within the 70-130 ms time window after the probe onset, which was followed by a N1, identified as the first negative peak within the 150-230 ms time window after the probe onset: these two peaks will be referred to as probe-P1, probe-N1 respectively, hereafter. Regarding the ERPs locked to the target letter, we identified P3b peaks in the time window of 340-570 ms after the letter onset: this peak will be referred as target-P3b hereafter. Also, a late wave was identified within the 600-1000 ms time window after the presentation of the target letter, showing the maximal amplitude over frontal sites, i.e., the target-LPC (Late Positive Component).

Time intervals for mean amplitude analyses were determined based on *a priori* expectations and mean global field power analysis. Peak detection was time-locked to the electrode of maximal amplitude for each observed peak: PO8 for the probe-P1; PO7 for the probe-N1; Pz for the target-P3b. Mean amplitudes were measured at electrodes checked for maximal sensitivity based on visual inspection: P7, PO7, PO9, P8, PO8, and PO10 for the probe-P1 and the probe-N1; CP1, CP2, CPz, P1, P2, Pz, PO3, PO4 and POz for target-P3b; F3, F4 and Fz for the target-LPC.

Regarding ERPs locked to letter-string probes, probe-P1 and probe-N1 amplitude and latency were analyzed by means of ANOVAs with group as a between-subject factor. Hemisphere was entered as an additional within-subject factor for the analysis conducted on probe-N1 amplitude. Regarding ERPs locked to the target letters, target-P3b amplitude was analyzed for go trials using ANOVAs with group as a between-subject factor and condition (words, nonwords) and position (1,3,5) as within subject-factors.

Greenhouse-Geisser corrections were applied if necessary (sphericity not assumed) and Bonferroni post-hoc tests were run for analyses following up significant main/interaction effects. Regarding ERP scalp distribution analyses, electrode was entered as a within-subject factor. Only interactions between electrode and any other factor surviving Greenhouse-Geisser correction or vector normalization will be presented (McCarthy and Wood, 1985).

Footnotes

[1] At the parieto-occipital sites (PO3, POz and PO4) a negative late component was observed, mirroring the LPC effects with a reverse polarity at the parieto-occipital sites (see Fig. 2 and 3). Each “condition-by-position” modality showed significant negative correlations between individual amplitudes recorded over the frontal and parieto-occipital electrodes (all *r*s < -.50, ps < .007, two-tailed). Because potential fields recorded at the surface of the scalp are dipolar with equal positive and negative fields (Nunez, 1981), polarity inversion is frequently observed when ERPs are computed based on the average reference as in the present study. We therefore considered the position effect observed within the late window as a greater “frontal (F3, Fz and F4) *versus* posterior (PO3, POz and PO4)” amplitude difference elicited by letters at position 1 than at position 5 in probes: an additional ANOVA comparing frontal *and* posterior difference waves (see Curran, 2000 for a similar procedure) mirrored those of the ANOVA conducted on the frontal electrodes only (i.e., position main effect: $F_{(2,60)} = 7.04$, $p < .005$; condition-by-position interaction: $F_{(2,60)} = 6.6$, $p < .005$; position-by-group effect: $F_{(2,60)} = 4.05$, $p < .05$ which illustrated greater wave differences for target letters presented at position 1 in probes than at position 5 in monolinguals only, post-hoc test, $p < .001$).

[2] Note that the absence of N1 lateralization may be due to the fast presentation time of the probes (i.e., 180ms, see also Martin et al., 2006) as compared to other studies, which have shown larger N1 over the left than the right hemisphere (e.g., Grossi et al., 2010).

[3] The position effect found on RTs for words might also have been induced by the presence of nonword trials intermixed with word trials (cf. Lima and Castro, 2010 for similar conclusion but on length effects).

[4] Potential interferences between Welsh and English letter names in bilinguals are unlikely to be responsible for the group by position interaction observed on accuracy

and P3b amplitude because such interferences would also have been expected in the control condition.

References

Abutalebi, J. 2008. Neural aspects of second language representation and language control. Acta Psychol. 128(3), 466–478.

Allan, E.L. Wilding, M.D. Rugg, 1998. Electrophysiological evidence for dissociable processes contributing to recollection, Acta Psychol. 98, 231–252

Ans, B., Carbonnel, S., Valdois, S. 1998. A connectionist multiple-trace memory model for polysyllabic word reading. Psychol. Rev. 105(4), 678-723.

Baker, C. 1995. Bilingual education in Wales. In O. Garcia and C. Baker (eds) Policy and Practice in Bilingual Education. Clevedon: Multilingual Matters.

Beaton, A. A., Davies N. W. 2007. Semantic errors in deep dyslexia: does orthographic depth matter? Cognitive Neuropsych. 24(3), 312-23.

Bosse, M. L., Tainturier, M. J., Valdois, S. 2007. Developmental dyslexia: the visual attention span deficit hypothesis. Cognition. 104(2), 198-230.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., Ziegler, J. 2001. DRC: a dual route cascaded model of visual word recognition and reading aloud. Psychol. Rev. 108(1), 204-256.

Coltheart, M. 1981. MRC Psycholinguistic Database User Manual: Version 1.

Cramer, D. Howitt, D. 2005. The SAGE Dictionary of Statistics: A Practical Resource for Students in the Social Sciences (Third ed.), London. p. 21 (entry "ceiling effect").

Curran, D.L., Clearly, A.M. 2003. Using ERPs to dissociate recollection from familiarity in picture recognition, Cogn. Brain. Res. 15, 191-205.

Curran, T., Schacter, D.L., Johnson, M.K., Spinks, R. 2001. Brain potentials reflect behavioral differences in true and false recognition, J. Cogn. Neurosci. 13, 201–216

Dehaene, S., Cohen, L., Sigman, M., Vinckier, F. 2005. The neural code for written words: A proposal. Trends Cogn. Sci. 9, 335–341.

Duñabeitia, J.A., Perea, M., Carreiras, M. 2007. Do transposed-letter similarity effects occur at a morpheme level? Evidence for morpho-orthographic decomposition. Cognition. 105, 691-703.

Duncan, C., Barry, R., Connolly, J., et al. 2009. Event related potentials in clinical research: Guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400, Clin. Neurophysiol. 120(11), 1883-1908.

Ellis, N. C., Hooper, A. M. 2001. It is easier to learn to read in Welsh than in English: Effects of orthographic transparency demonstrated using frequency-matched cross-linguistic reading tests. Appl. Psycholinguist. 22, 571–599.

Ellis, N.C., Natsume, M., Stavropoulou, K., Hoxhallari, L., van Daal, V.H.P., Polyzoe, N., Tsipa, M-L., Petalas, M. 2004. The effects of orthographic depth on learning to read alphabetic, syllabic and logographic scripts, Read. Res. Quart. 39(4), 438-68.

Facoetti, A., Trussardi, A. N., Ruffino, M., Lorusso, M. L., Cattaneo, C., Galli, R., Molteni, M., Zorzi M. 2010. Multisensory Spatial Attention Deficits Are Predictive of Phonological Decoding Skills in Developmental Dyslexia. J. Cognitive Neurosci. 22(5), 1011-1125.

Feng, J., Pratt, J., Spence, I. 2012. Attention and visuospatial working memory share the same processing resources. Front. Psychol. 3(103), 1-11.

Fiez, J.A. 2000. Sound and meaning: how native language affects reading strategies. Nat. Neurosci. 3, 3–5.

Frost, R. 1994. Prelexical and postlexical strategies in reading: Evidence from a deep and a shallow orthography. J. Exp. Psychol. Learn, 20(1), 116-129.

Frost, R., Katz, L., Bentin, S. 1987. Strategies for visual word recognition and orthographical depth: A multilingual comparison. J. Exp. Psychol. Human. 13(1), 104-115.

Fusser, F., Linden, D.J., Rahm, B. ,Hampel, H., Haenschel, C., Mayer, J.S. 2011. Common capacity-limited neural mechanisms of selective attention and spatialworking memory encoding. Eur. J. Neurosci. 34, 827–838.

Goswami, U., Gombert, J. E., de Barrera, L. F. 1998. Children's orthographic representations and linguistic transparency: Nonsense word reading in English, French and Spanish. Appl Psycholinguist. 19(1), 19-52.

Grainger, J., Dijkstra, T. 1992. On the representation and use of language information in bilinguals. In R. J. Harris (Ed.), Cognitive processes in bilinguals (pp. 207-220). Amsterdam: Elsevier.

Grossi, G., Savill, N., Thomas, E., Thierry, G. 2010. Posterior N1 asymmetry to English and Welsh words in Early and Late English-Welsh bilinguals. Biol. Psychol., 85, 124-133.

Ktori, M. Pitchford, N.J. 2008. Effect of orthographic transparency on letter position encoding: A comparison of Greek and English monoscriptal and biscriptal readers. Lang. Cognitive Proc. 23, 258–281.

Kroll, J. F., De Groot, A. M. B. 2005. Handbook of Bilingualism: Psycholinguistic Approaches, Oxford University Press, New York.

Lallier, M., Donnadieu, S., Berger, C., Valdois, S. 2010. A case study of developmental phonological dyslexia: Is the attentional deficit in the perception of rapid stimuli sequences amodal? Cortex. 46(2), 231-241.

Lassus-Sangosse, D., N'Guyen-Morel, M. A., Valdois, S. 2008. Sequential or simultaneous visual processing deficit in developmental dyslexia? Vis. Res. 48(8), 979-988.

Lima, C. F., Castro, S. L. 2010. Reading strategies in orthographies of intermediate depth are flexible: Modulation of length effects in Portuguese. Eur. J. Cogn. Psychol. 22(2), 190-215.

Liu, Y., Perfetti, C. A. 2003. The time course of brain activity in reading English and Chinese: an ERP study of Chinese bilinguals. Hum. Brain Mapp. 18, 167–175.

Martin, C. D., Nazir, T., Thierry, G., Paulignan, Y., Demonet, J. F. 2006. Perceptual and lexical effects in letter identification: an event-related potential study of the word superiority effect. Brain Res. 1098, 153–160.

Mathey, S., Zagar, D. 2000. The neighborhood distribution effect in visual word recognition: Words with single and twin neighbors. J. Exp. Psychol. Human. 26, 184-205.

Maurer, U., Brem, S., Bucher, K., Kranz, F., Benz, R., Steinhausen, H.-C., et al. 2007. Impaired tuning of a fast occipito-temporal response for print in dyslexic children learning to read. Brain. 130, 3200–3210.

Maurer, U., Brem, S., Kranz, F., Bucher, K., Benz, R., Halder, P., et al., 2006. Coarse neural tuning for print peaks when children learn to read. NeuroImage. 33, 749–758.

McCarthy, G., Wood, C. C. 1985. Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section. 62(3), 203-208

Meschyan, G., Hernandez, A. E. 2006. Impact of language proficiency and orthographic transparency on bilingual word reading: An fMRI investigation. NeuroImage. 29(4), 1135-1140

Nunez, P. L. 1981. Electrical fields of the brain. New York: Oxford. NA Fox, SD Calkins, and MA Bell.

Pammer, K., Lavis, R., Cooper, C., Hansen, P. C., Cornelissen, P. L. 2005. Symbol-string sensitivity and adult performance in lexical decision. Brain Lang. 94(3), 278-296.

Pammer, K., Lavis, R., Hansen, P., Cornelissen, P. L. 2004. Symbol-string sensitivity and children's reading. Brain Lang. 89(3), 601-610.

Paulesu, E., McCrory, E., Fazio, F., Menoncello, L., Brunswick, N., Cappa, S.F., Cotelli, et al. 2000. A cultural effect on brain function. Nat. Neurosci. 3, 91–96.

Perani, D., Abutalebi, J. 2005. The neural basis of first and second language processing. Curr. Opin. Neurobiol. 15(2), 202-206.

Perea, M., Duñabeitia, J. A., Carreiras, M. 2008. Masked associative/ semantic priming effects across languages with highly proficient bilinguals. J. Mem. Lang. 58, 916-930.

Perfetti, C. A., Dunlap, S. 2008. Learning to read: General principles and writing system variations. In K. Koda and A. Zehler (Eds.). Learning to read across languages (pp. 13-38). Mahwah, NJ: Erlbaum.

Peyrin, C., Démonet, J.F., N'guyen-Morel, M.A., Le Bas, J. F., Valdois, S. 2011. Superior parietal lobe dysfunction in a homogeneous group of dyslexic children with a visual attention span disorder. Brain Lang. 118, 128-138.

Peyrin, C., Lallier, M., Baciu, M., Démonet, Le Bas, J.F., Valdois S. 2012. Dissociation of phonological and visuo-attentional processing in dyslexia: FMRI evidence from two case reports. Brain Lang. 120(3), 381-394.

Prado, C., Dubois, M., Valdois, S. 2007. The eye movements of dyslexic children during reading and visual search: impact of the visual attention span. Vis. Res. 47(19), 2521-2530.

Rugg, M.D., Schloerscheidt, A.M., Mark, R.E. 1998. An electrophysiological comparison of two indices of recollection, J. Mem. Lang. 39, 47–69.

Sawaki, S., Katayama, J. 2007. Difficulty of discrimination modulates attentional capture for deviant information. Psychophysiology. 44(3), 374-382.

Seymour, P. H. K., Aro, M., Erksine, J. M. 2003. Foundation literacy acquisition in European orthographies. Brit. J. Psychol. 94, 143-174.

Share, D. L. 2008. On the anglocentricities of current reading research and practice: the peril of overreliance on an "outlier" orthography. Psychol. Bull. 134 (4), 584-615.

Simon, G., Bernard, C., Lalonde, B., Rebai, M. 2006. Orthographic transparency and grapheme-phoneme conversion: An ERP study in Arabic and French readers. Brain Res. 1104, 141-152.

Spencer, L l., Hanley, R. 2003. Effects of orthographic transparency on reading and phoneme awareness in children learning to read in Wales. Brit. J. Psychol. 94, 1–28.

Spinelli, D., De Luca, M., Di Filippo, G., Mancini, M., Martelli, M., Zoccolotti, P. 2005. Length effect in word naming in reading: Role of reading experience and reading deficit in Italian readers. Dev. Neuropsychol. 27(2), 217-235.

Tainturier, M.J., Roberts, J., Schiemenz, S., Leek, E.C. 2007. Do reading processes differ in transparent vs. opaque orthographies? A study of acquired dyslexia in Welsh/English bilinguals. Brain Lang.103(1-2), 97-98.

Tan, L. H., Spinks, J. A., Feng, C. M., Siok, W. T., Perfetti, C. A., Xiong, J., Fox, P.T., Gao, J. H. 2003. Neural systems of second language reading are shaped by native language. Hum. Brain Mapp. 18, 158–166.

Thierry, G., Athanasopoulos, P., Wiggett, A., Dering, B., Kuipers, J. R. 2009. Unconscious effects of language-specific terminology on pre-attentive color perception. P. Natl. Acad. Sci. USA. 106, 4567–4570

Thierry, G., Wu, Y. J. 2007. Brain potentials reveal unconscious translation during foreign-language comprehension. P. Natl. Acad. Sci. USA. 104, 12530–12535.

Tydgat, I., Grainger, J. 2009. Serial position effects in the identification of letters, digits, and symbols. J. Exp. Psychol. Human. 35(2),480-98.

Vaid, J., Frenck-Mestre, C. 2002. Do orthographic cues aid language recognition? A laterality study with French-English bilinguals, Brain Lang. 82, 47–53.

Valdois, S., Bosse, M. L., Ans, B., Carbonnel, S., Zorman, M., David, D., et al. 2003. Phonological and visual processing deficits can dissociate in developmental dyslexia: Evidence from two case studies. Read. Writ. 16, 541-572.

Vidyasagar, T. R., Pammer, K. 2010. Dyslexia: a deficit in visuo-spatial attention, not in phonological processing, Trends Cogn. Sci. 14, 57–63

Wang, M., Koda, K., Perfetti, C. A. 2003. Alphabetic and nonalphabetic L1 effects in English word identification: A comparison of Korean and Chinese English L2 learners. Cognition. 87(2), 129-149.

Whitney, C. 2001. How the brain codes the order of letters in a printed word: The SERIOL model and selective literature review. Psychon. B. Rev. 8, 221–243.

Wilding, E.L. 2000. In what way does the parietal ERP old /new effect index recollection?, Int. J. Psychophysiol. 35, 81–87.

Wilding, E.L., Rugg, M.D. 1996. An event-related potential study of recognition memory with and without retrieval of source. Brain 119, 889-905.

Wimmer, H., Goswami, U. 1994. The influence of orthographic consistency on reading development—Word recognition in English and German children. Cognition. 51, 91–103

Wong, A. C., Gauthier, I., Woroch, B., DeBuse, C., Curran, T. 2005. An early electrophysiological response associated with expertise in letter perception. Cogn. Affect. Behav.l Neurosci. 5, 306–318.

Wu, Y.J., Thierry, G. 2010. Chinese-English bilinguals reading English hear Chinese. J. Neurosci. 30, 7646 –7651.

Wu, Y.J., Thierry, G. 2012. Unconscious translation during incidental foreign language processing. Neuroimage. 59, 3468 –3473.

Wydell, T. N., Butterworth, B. 1999. A case study of an English-Japanese bilingual with monolingual dyslexia. Cognition. 70(3), 273-305.

Wydell, T. N., Vuorinen, T., Helenius, P. Salmelin, R 2003. Neural Correlates of Letter-String Length and Lexicality during Reading in a Regular orthography: an MEG study. J. Cogn. Neurosci. 15, 7, 1052-1062.

Xue, G., Jiang, T., Chen, C., Dong, Q. 2008. Language experience shapes early electrophysiological responses to visual stimuli: The effects of writing system, stimulus length, and presentation duration. Neuroimage. 39, 2025–20.

Ziegler, J.C., Goswami, U. 2005. Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory. Psychol. Bull. 131 (1), 3–29.

Ziegler, J. C., Perry, C., Jacobs, A. M., Braun, M. 2001. Identical words are read differently indifferent languages. Psycholo. Sci. 12, 379–384.

Figures legend

Figure 1. Accuracy and RTs for target detection for monolingual (black squares) and bilingual (white squares) participants for the word and nonword conditions. Standard error bars are depicted.

Figure 2. Target-P3b peaks at the nine selected electrode sites according to the target position in the word condition in the monolingual and bilingual groups. The window of analysis is highlighted.

Figure 3. Target-P3b peaks at the nine selected electrode sites according to the target position in the nonword condition in the monolingual and bilingual groups. The window of analysis is highlighted.

Figure 4. Target-LPC peaks at the three selected electrode sites according to the target position in the word condition in the monolingual and bilingual groups. The window of analysis is highlighted.

List of Figures

Figure 1

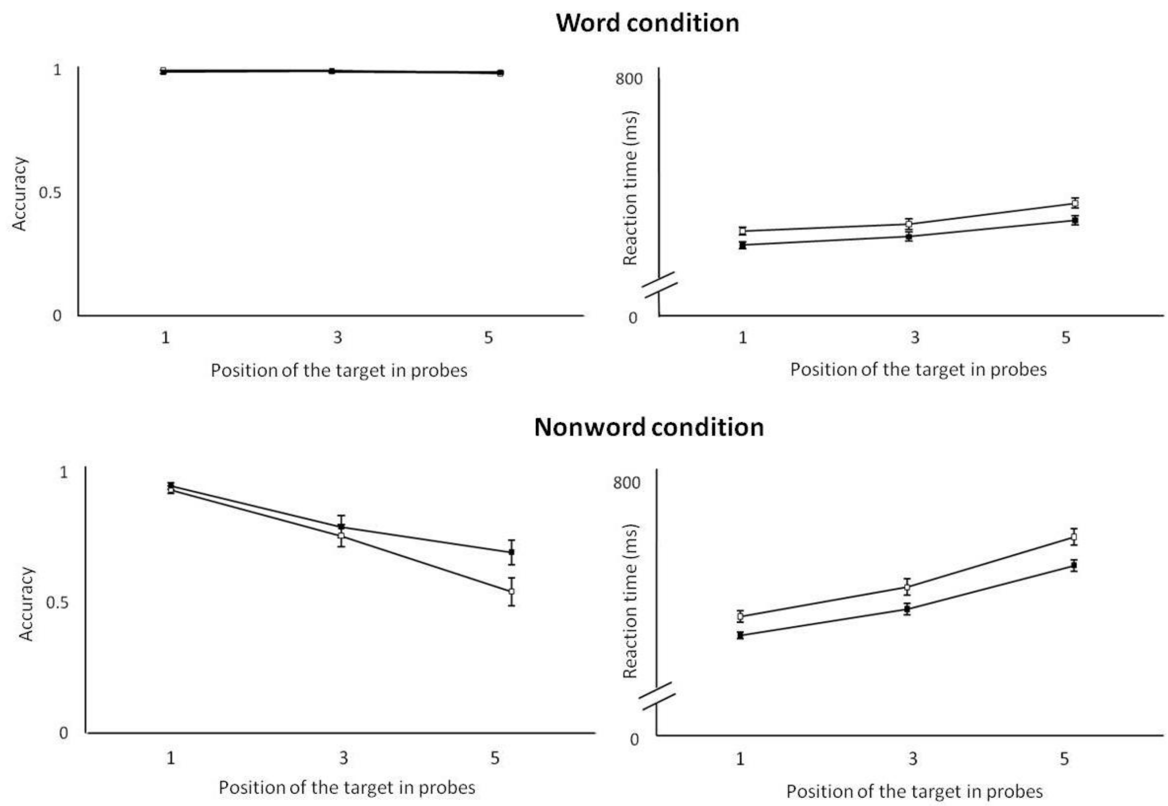
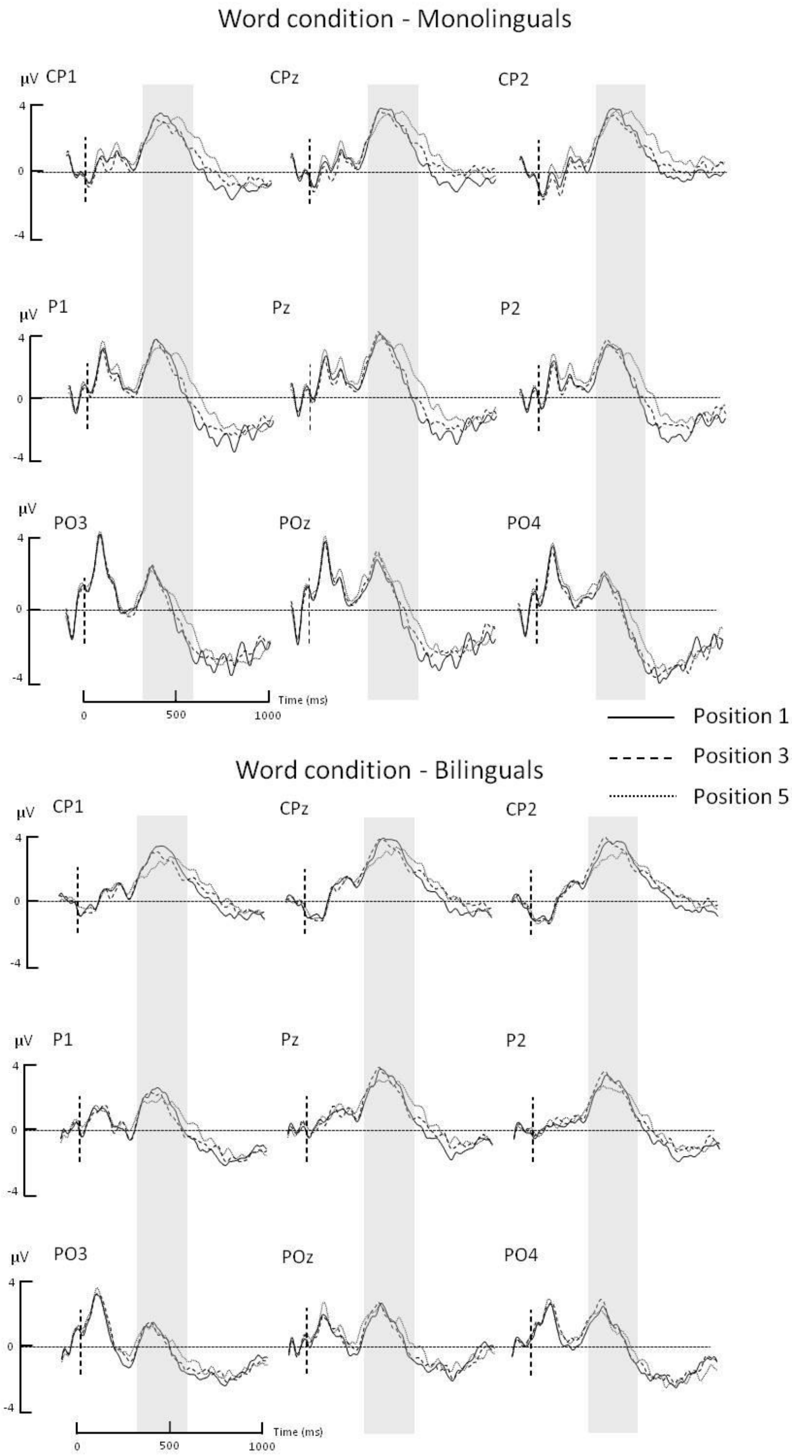
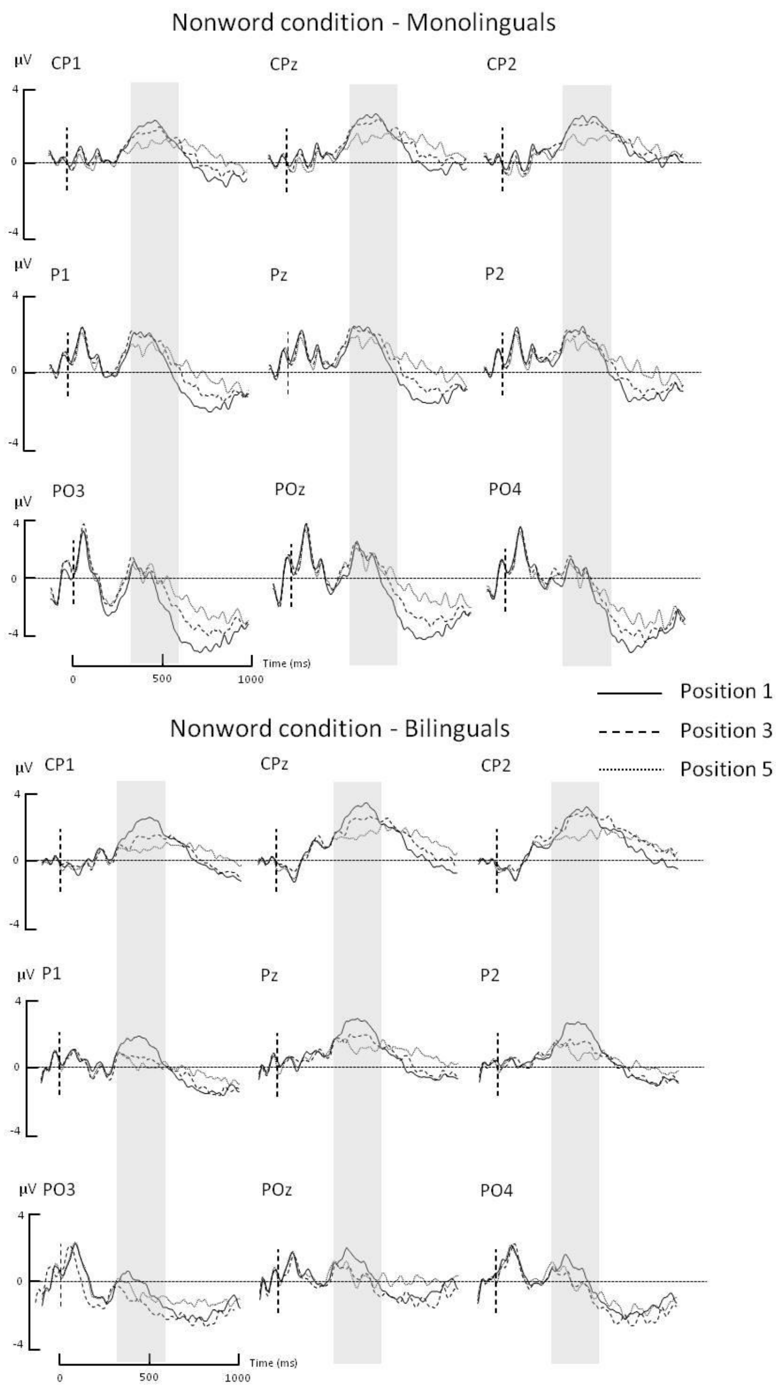


Figure 2



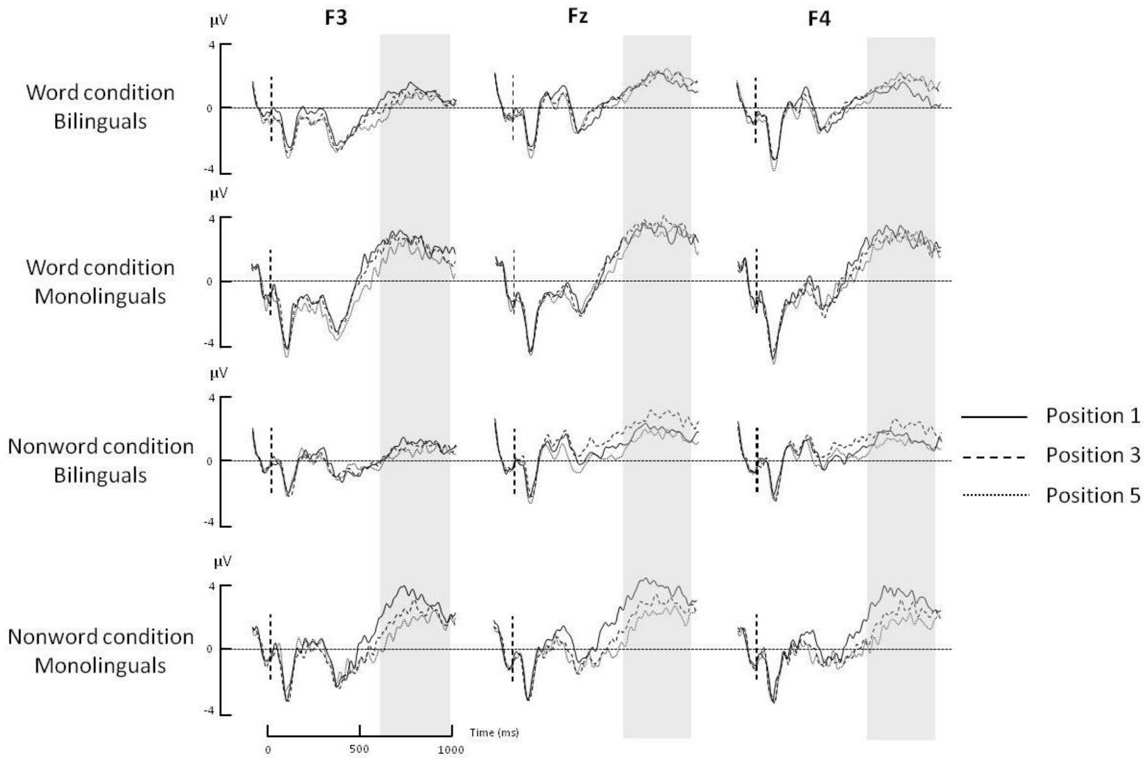
Word condition - Monolinguals
μV
CP1
CPz
CP2
P1
Pz
P2
PO3
POz
PO4
4
0
-4
Time (ms)
0
500
1000
Position 1
Position 3
Position 5
Word condition - Bilinguals

Figure 3



Nonword condition - Monolinguals
μV
CP1
CPz
CP2
4
0
-4
μV
P1
Pz
P2
4
0
-4
μV
PO3
POz
PO4
4
0
-4
0
500
1000
Time (ms)
Position 1
Position 3
Position 5
Nonword condition - Bilinguals
μV CP1
CPz
CP2
4
0
-4
μV P1
Pz
P2
4
0
-4
μV PO3
POz
PO4
4
0
-4
0
500
1000
Time (ms)

Figure 4



F3
Fz
F4
µV
4
0
-4
Word condition
Bilinguals
Word condition
Monolinguals
Nonword condition
Bilinguals
Nonword condition
Monolinguals
Position 1
Position 3
Position 5
0
500
1000
Time (ms)

List of Tables

Table 1. Means and SDs of performance for target detection in the two groups of participants

	Monolingual group			Bilingual group		
Target position	**1**	**3**	**5**	**1**	**3**	**5**
Word condition						
Accuracy (%)	99(2)	99(2)	99(2)	99(1)	99(1)	99(2)
RT (ms)	450(30)	466(39)	501(37)	478(33)	493(46)	537(42)
Nonword condition						
Accuracy (%)	95(1)	80(4)	69(5)	93(5)	76(16)	54(18)
RT (ms)	498(26)	551(47)	637(46)	536(43)	594(65)	694(63)

Table 2. Means and SDs of target-P3b mean amplitude measured over the nine selected sites (CP1, CP2, CPz, P1, P2, Pz and PO3, PO4, Poz) and target-P3b latency (at Pz) obtained in the two groups

	Monolingual group			Bilingual group		
Target position	**1**	**3**	**5**	**1**	**3**	**5**
Word condition						
Mean amplitude (μV)	1.72(1.6)	1.73(1.6)	2.29(1.8)	1.97(1.5)	1.84(1.6)	1.86(1.5)
Latency (ms)	413(61)	398(50)	438(72)	459(54)	434(56)	463(54)
Nonword condition						
Mean amplitude (μV)	1.37(1.8)	1.41(1.6)	0.98(1.5)	1.72(1.8)	0.92(1.6)	0.55(1.5)
Latency (ms)	438(65)	437(69)	462(78)	466(61)	464 (73)	446(85)

Table 3. Means and SDs of target-LPC amplitude (μV) at frontal (F3, F4 and Fz) sites obtained in the two groups

	Monolingual group			**Bilingual group**		
Target position	**1**	**3**	**5**	**1**	**3**	**5**
Word condition	2.74(2.6)	2.71(2.4)	2.37(2.2)	1.17(2.5)	1.32(2.4)	1.39(2.2)
Nonword condition	3.11(2.3)	2.17(2.5)	1.58(2.4)	1.30(2.3)	1.78(2.4)	0.99(2.4)