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ERP effects of masked orthographic neighbour priming in deaf readers

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Abstract

In masked priming studies with hearing readers, neighbouring words (e.g., *wine*, *vine*) compete through lateral inhibition. Here, we asked whether lateral inhibition also characterizes visual word recognition in deaf readers and whether the neural signature of this competition is the same as for hearing readers. Only real words have lexical representations that engage in lateral inhibition. Therefore, we compared processing of target words following neighbouring prime words (e.g., *wine-VINE*) and pseudowords (e.g., *bine-VINE*). Targets following words elicited larger amplitude N400s and slower lexical decision responses than those following pseudowords, indicating more effortful processing due to lateral inhibition. Although these effects went in the same direction for hearing and deaf readers, the distribution of the N400 effect differed. We associate the more anterior effect in hearing readers with stronger co-activation of, and competition among, phonological representations. Thus, deaf readers use lexical competition to recognize visual words, but it is primarily restricted to orthographic representations.

Keywords

deaf readers; orthographic neighbours; masked priming; ERPs

The little research that has been done on the neurocognitive mechanisms of visual word recognition in deaf adult readers has focused almost exclusively on how they utilize phonology during reading (see, e.g., Perfetti & Sandak, 2000, for a review). In spite of this empirical attention, the answer remains elusive. Only about half of the studies included in the meta-analysis by Mayberry and colleagues (2011) favour involvement of phonology in reading among deaf children and adults, whereas substantial evidence exists for phonological co-activation in hearing readers (e.g., Braun, Hutzler, Ziegler, Dambacher, &

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Jacobs, 2009; Grainger, Kiyonaga, & Holcomb, 2006; Gutiérrez-Sigut, Vergara-Martínez, & Perea, 2017; Rastle & Brysbaert, 2006). It is surprising then that so little empirical work has moved beyond phonology to ask how other processes are similar or different between deaf and hearing readers. The present study investigates how deaf adults' altered access to spoken language phonology might shape their orthographic processing.

Studies on phonological co-activation in deaf readers have yet to yield conclusive results (e.g., Bélanger, Baum, & Mayberry, 2012; Bélanger, Mayberry, & Rayner, 2013; Emmorey, McCullough, & Weisberg, 2016; Fariña, Duñabeitia, & Carreiras, 2017; Gutiérrez-Sigut et al., 2017; Mayberry et al., 2011; Miller & Clark, 2011). For example, in a masked priming study, Bélanger et al. (2012) found that French words preceded by pseudohomophone primes (e.g., *baur-BORD*) elicited faster lexical decision responses than non-homophonic control primes (e.g., *boin-BORD*) in hearing readers, but not in deaf readers (see also Cripps, McBride, & Forster, 2005). This suggests that deaf readers were not sensitive to the phonological similarity between the pseudohomophonic primes and the corresponding targets (see also, e.g., Fariña et al., 2017). In contrast, Gutiérrez-Sigut et al. (2017) recently reported similar pseudohomophone ERP priming effects in deaf and hearing readers and argued that deaf readers automatically activate phonological codes; however, the amplitude of the phonological priming response was only related to reading skill for the hearing group. Thus, a subset of deaf readers might co-activate phonology, but the role of phonology is far from systematic and may be unrelated to reading ability. In order to understand how deaf individuals approach reading, it is important to investigate other aspects of the reading process, rather than focusing only on effects that involve phonological awareness or knowledge.

Preliminary results from the few studies that have investigated orthographic processing in deaf readers suggest that they are sensitive to the orthographic structure of single words (e.g., Barca, Pezzulo, Castrataro, Rinaldi, & Caselli, 2013; Beech & Harris, 1997; Cripps et al., 2005; Fariña et al., 2017; Hanson & Fowler, 1987). For example, Fariña and colleagues found a transposed letter effect in a group of highly skilled deaf readers who did not show a pseudohomophone effect. Transposed letter pseudowords (e.g., *mecidina*), which were formed by reversing the order of two non-adjacent letters in real Spanish words (e.g., *medicina*) elicited slower and less accurate lexical decision responses than pseudowords formed by replacing those same letters (e.g., *mesifina*). This result suggests that the deaf readers were sensitive to the enhanced similarity between the transposed letter pseudowords and the corresponding orthographic lexical representations. In fact, some authors have argued that deaf readers rely more than hearing readers on orthographic lexical representations and are more likely to utilize direct links from lexical orthography to semantics (as opposed to the indirect route via phonology; e.g., Barca et al., 2013; Bélanger & Rayner, 2015; Emmorey et al., 2016; Fariña et al., 2017).

If it is true that deaf readers bypass phonology more often than hearing readers, then this may have implications for the ways in which they represent orthographic information. For example, the imprecise phonological representations acquired by deaf individuals (e.g., Friesen & Joanisse, 2012; McQuarrie & Parrila, 2009) may be less effective in tuning orthographic representations (see Perea, Marcet, & Vergara-Martínez, 2016, for a similar argument). This hypothesis receives support from the reading development literature, in which phonology is posited to be critically involved in the fine-tuning of orthographic representations (e.g., Ehri, 1992; Perfetti, 1992; Share, 1995). It is also consistent with the proposal by Grainger and Ziegler (2011) that processing along the direct orthographic-to-semantic route involves more coarse-grained orthographic representations that only code for approximate letter position information (as compared to a more fine-grained orthographic route that involves co-activation of phonology). Alternatively, it is possible that deaf readers' altered access to phonology and their reliance on orthographic processing requires that they develop *even more* precise orthographic codes than hearing readers (see Cripps et al., 2005) or that they fine-tune orthographic codes through other mechanisms, such as morphological sensitivity (see Rastle, in press). In other words, deaf readers' altered access to phonology may have implications for the precision of individual orthographic lexical representations, but it is unclear a priori if their orthographic representations should be more or less precise.

Recent studies using the masked neighbour priming paradigm with hearing readers have suggested that it indexes the precision of orthographic representations (e.g., Andrews & Hersch, 2010; Andrews & Lo, 2012; Meade, Grainger, Midgley, Emmorey, & Holcomb, 2018). The orthographic neighbours of a word (e.g., *vine*) are other words of the same length that differ by only one letter (e.g., *wine*, *line*, *vibe*). Word targets preceded by masked neighbour word primes of a higher frequency (e.g., *wine-VINE*) elicit slower and less accurate lexical decision responses than those preceded by unrelated prime words (e.g., word-VINE; e.g., Andrews & Hersch, 2010; Andrews & Lo, 2012; Davis & Lupker, 2006; Massol, Grainger, Dufau, & Holcomb, 2010; Meade et al., 2018; Segui & Grainger, 1990). However, when word targets are preceded by related pseudowords (e.g., *bine*) or partial primes (e.g., *#ine-VINE*), they elicit faster responses (i.e., facilitation) than the corresponding unrelated conditions (e.g., Andrews & Hersch, 2010; Davis & Lupker, 2006; Grainger & Jacobs, 1993; Massol et al., 2010). In direct comparisons, word targets preceded by related words elicit slower responses than those preceded by related pseudowords (e.g., Massol et al., 2010). The interference between masked primes and neighbour targets that are real words is interpreted in terms of lateral inhibition between neighbouring lexical representations (i.e., lexical competition; e.g., Andrews & Hersch, 2010; Davis & Lupker, 2006; Meade et al., 2018; Segui & Grainger, 1990). Further evidence that the behavioural interference is lexical in origin comes from the finding that target words preceded by neighbour word primes elicit larger amplitude N400s than those preceded by either an unrelated word prime or a neighbour pseudoword prime (Massol et al., 2010; Meade et al., 2018). The N400 component is generally associated with whole word lexico-semantic processing (Grainger & Holcomb, 2009). Thus, a larger N400 in the only conditions where lexical competition is hypothesized to occur suggests that this competition makes the target word more difficult to recognize.

Among hearing young adults, both the behavioural and N400 effects are larger for better spellers who have more precise letter position coding (e.g., Andrews & Hersch, 2010; Andrews & Lo, 2012; Meade et al., 2018). Precise orthographic lexical representations for the prime and target lead to greater levels of lateral inhibition (i.e., more competition) between these two representations and therefore stronger interference. Recent evidence further suggests that the size of the behavioural interference effect also positively correlates with phonological skills (Elsherif, Wheeldon, & Frisson, 2018). Thus, phonology seems to be contributing to the competition indexed in this paradigm either indirectly (i.e., by tuning orthographic representations over the course of reading experience) or directly (i.e., due to on-line competition between co-activated phonological lexical representations). This finding raises even more questions as to whether or not deaf readers rely on competition to recognize visual words.

In the present study, we used the masked neighbour priming paradigm to investigate visual word recognition and lexical competition in deaf readers. Deaf and hearing participants made lexical decision responses to targets preceded by masked primes that were orthographically related (i.e., neighbours) or unrelated. In order to index competition between lexical orthographic representations, we compared processing of word targets preceded by related word (e.g., *wine*-*VINE*) and pseudoword (e.g., *bine*-*VINE*) primes. In the case of word primes, both the prime and target have lexical representations; therefore, the prime should inhibit the target and interfere with its recognition. However, in the case of pseudoword primes, the prime does not correspond to a lexical representation that could inhibit the target. This comparison is arguably better than the comparison between related and unrelated word primes that is often made, as it controls for sublexical orthographic overlap and isolates the influence of the lexical representation. We expected to find evidence of interference in the hearing group, as reflected in slower RTs and larger amplitude N400s for the targets preceded by related word primes compared to those preceded by related pseudoword primes (see Massol et al., 2010). If phonology is necessary for tuning orthographic representations, then deaf readers may not have precise enough representations to elicit competition. In this case, we would expect no effect of prime lexicality for the deaf participants. Similarly, if the effect is driven by co-activated phonological representations instead of competition among orthographic representations, then we may not expect the deaf participants to show an effect of prime lexicality. However, if the effect is orthographic in nature and deaf readers achieve precise orthographic representations through mechanisms other than phonology (e.g., morphology), then we should find evidence of competition similar to the hearing group. Comparing ERP effects of masked neighbour priming in deaf and hearing readers will therefore lend insight into whether or not reduced access to spoken phonology impacts the tuning of orthographic representations or the nature of lexical competition in visual word recognition.

Methods

Participants

A total of 48 participants took part in this study. Half of the participants (N=24) were severely-to-profoundly deaf (12 female; mean age 29.4 years, *SD* 6.6). All of the deaf participants had normal or corrected-to-normal vision and were congenitally or prelingually deaf, and all but one were right-handed. Seventeen of them were native signers (born into deaf signing families), six had acquired American Sign Language (ASL) before the age of seven, and one began acquiring ASL at 12 years of age. Two of the deaf participants reported using only spoken English in elementary school and the remaining 22 participants used ASL or some other form of manual-visual communication. An additional seven deaf people who met these criteria participated in the experiment but were excluded from analyses due to high ERP artefact rejection rates (> 25% of all trials). The hearing group was composed of 24 individuals (19 female; mean 22.1 years, *SD* 3.0 years) who had normal or corrected-to-normal vision and were right-handed. Data from these participants were recently reported by Meade and colleagues (2018). An additional two hearing participants completed the experiment but were excluded from all analyses – one due to low spelling scores outside the range of the hearing participants in the study by Andrews and Hersch (2010) and the other due to experimenter error. Informed consent was obtained from all deaf and hearing participants in accordance with the Institutional Review Board at San Diego State University.

Because spelling and reading ability are known to influence the size of the lexical competition effects of interest (Andrews & Hersch, 2010; Andrews & Lo, 2012; Meade et al., 2018), the two groups were matched on these measures. Deaf participants had a mean score of 85.4% (*SD* 7.5%) and hearing participants had a mean score of 84.6% (*SD* 8.0%) on the spelling recognition measure developed by Andrews and Hersch, $t(46) = .32$, $p = .752$. Scores on the reading comprehension subtest of the Peabody Individual Achievement Test – Revised (PIAT-R, Markwardt, 1989) were also comparable between groups. Deaf participants had a mean raw score of 85.8 (*SD* 10.1) and hearing participants had a mean raw score of 89.0 (*SD* 8.5), $t(46) = 1.19$, $p = .239$.

In contrast to reading and spelling skill, there were significant differences in performance between groups on the phonological awareness test developed by Hirshorn, Dye, Hauser, Supalla, and Bavelier (2015) for profoundly deaf adults. In the first task of this test, participants see sets of three pictures and are asked to select one (the "odd man out"). In the first block, they choose which of the three picture names has a different first sound than the other two. In the second block of the "odd man out" task, they choose the picture name with a different vowel sound. In the second task, they see two pictures and are asked to type the word that emerges when the first sound of the first picture name is combined with the rime of the second picture name. Mean accuracy was significantly higher across tasks for hearing readers (mean 94.4%, *SD* 5.1%) than for deaf readers (mean 64.0%, *SD* 14.6%), $t(46) = 9.68$ $p < .001$.

Stimuli

The stimuli are described in detail elsewhere (Meade et al., 2018). Briefly, each participant saw 356 prime-target pairs that were four to five letters long and had a similar orthographic neighbourhood density. For the current study, the critical stimuli were 60 word targets preceded by a related word prime (e.g., *wine-VINE*) and by a related pseudoword prime (e.g., *bine-VINE*). Pseudorandomized lists were counterbalanced such that each target appeared in a different condition in each list. Each prime and target pair differed by only one letter. Based on stimulus characteristics extracted from N-Watch (Davis, 2005), related word (mean 6.46, *SD* 4.76) and pseudoword (mean 5.78, *SD* 4.39) primes had a similar number of orthographic neighbours, $t(358) = 1.42$, $p = .158$. Related word primes (mean 261.55, *SD* 652.96) also had higher frequencies than their targets (mean 19.09, *SD* 43.97), $t(358) = 4.97$,

$p < .001$, which is a prerequisite for eliciting interference between them when the prime is masked (e.g., Segui & Grainger, 1990).

Procedure

Each trial consisted of a forward mask (########) presented for 300 ms, followed by a lowercase prime for 50 ms, a backward mask (########) for 20 ms, and an uppercase target for 300 ms. Thus, the total stimulus onset asynchrony (SOA) between the prime and target was 70 ms. Masking the prime in this way minimizes the extent to which it can be consciously recognized. Stimuli were presented in white Courier font at the centre of a black screen and subtended a horizontal visual angle of 1.85 degrees or less. Between trials, a white fixation cross was displayed for 1100 ms followed by a purple fixation cross for 900 ms. Participants were asked to try to blink during the purple fixation cross and during longer blink breaks that occurred approximately every 10 trials. They were told that they would be seeing words and made-up words on the screen but were not informed about the presence of the primes. Participants made a lexical decision as quickly and accurately as possible by pressing the left button on a videogame response box for real word targets and the right button for made-up word targets. Instructions were provided in written English and American Sign Language for the deaf participants and in written and oral English for the hearing participants. The session began with a practice that had 10 trials, five of which had word targets.

EEG Recording

EEG was amplified with SynAmpsRT amplifiers (Neuroscan-Compumedics) with a bandpass of DC to 100 Hz and was sampled continuously at 500 Hz. Impedances for the 29 active electrodes (see Figure 1) in the Electro-Cap were maintained at or below 5 kΩ. We also used four additional electrodes placed on the mastoids, under the left eye and on the outer canthus of the right eye with impedances at or below 2.5 kΩ. The electrode on the left mastoid was used as a reference during recording and for subsequent analyses. The electrode located below the left eye was used together with electrodes on the forehead to identify blinks and the electrode next to the right eye was used to identify horizontal eye movements.

Data Analysis

Of the 120 critical trials, an average of 6.8 (*SD* 6.9) trials in the deaf group and 2.5 (*SD* 4.8) trials in the hearing group were excluded for eye movement or drift artefacts within our 800 ms epoch that included a 100 ms pre-stimulus-onset baseline. ERPs were created by averaging artefact-free trials that had correct responses between 200 and 2000 ms after target onset. Separate averages were created for each condition and each group at each electrode site and low-pass filtered at 15 Hz. Analyses focused on the 15 representative sites in Figure 1 (see also, e.g., Massol et al., 2010; Meade et al., 2018). As in our previous masked neighbour priming study, we measured N400 amplitude between 350 and 550 ms (Meade et al., 2018). We used omnibus ANOVAs with factors Group (Deaf, Hearing), Prime Lexicality (Word, Pseudoword), Laterality (Left, Midline, Right), and Anterior/Posterior (Prefrontal, Frontal, Central, Parietal, Occipital) to compare mean N400 amplitude.[1] Greenhouse-Geisser correction was applied for all within-subject measures with more than one numerator degrees of freedom. Partial eta squared (η_p^2) is reported as a measure of effect size.

Results

Behaviour

Mean RTs and accuracy rates for both groups are presented in Table 1. RT analyses included trials with correct responses between 200 and 2000 ms after target onset. A significant main effect of Prime Lexicality indicated that word targets preceded by word primes elicited slower responses than those preceded by pseudoword primes, $F(1,46) = 24.12$, $p < .001$, $\eta_p^2 = .34$. A significant main effect of Group further indicated that the deaf readers were slightly slower overall than the hearing readers, $F(1,46) = 4.11$, $p = .049$, $\eta_p^2 = .08$. However, the effect of Prime Lexicality was similar between groups, Group × Prime Lexicality, $F(1,46) = .47$, $p = .499$. In planned follow-ups, we confirmed that the effect of Prime Lexicality was significant for the deaf group alone, $F(1,23) = 15.57$, $p = .001$, $\eta_p^2 = .40$, and the hearing group alone, $F(1,23) = 8.99$, $p = .006$, $\eta_p^2 = .28$. Accuracy was quite high overall but was not affected by Prime Lexicality and did not differ between groups, all *p*s > .27.

ERPs

N400.—A significant main effect of Prime Lexicality indicated that target words preceded by word primes elicited larger amplitude negativities than those preceded by pseudoword primes, $F(1,46) = 4.73$, $p = .035$, $\eta_p^2 = .09$. N400 amplitude did not significantly differ overall between the two groups, all *p*s > .12. However, the distribution of the N400 lexicality effect differed between the two groups, Group × Prime Lexicality × Anterior/Posterior, $F(4,184) = 3.73$, $p = .037$, $\eta_p^2 = .08$. Grand average waveforms are plotted in Figures 2 and 3 for the deaf and hearing groups, respectively and voltage maps showing the scalp distribution of the effect for both groups are presented in Figure 4. In the deaf group, the effect was stronger across posterior sites and slightly reversed over the front of the head, Prime Lexicality × Anterior/Posterior, $F(4,92) = 5.34$, $p = .010$, $\eta_p^2 = .19$. In the hearing group, the effect appeared to be stronger over anterior sites, but only the main effect approached significance, Prime Lexicality, $F(1,23) = 3.66$, $p = .068$, $\eta_p^2 = .14$.

Discussion

In the present study, we used a masked neighbour priming paradigm to investigate orthographic processing in deaf readers. More specifically, we asked whether lexical competition is engaged during visual word recognition for deaf readers in the same way as hearing readers. Across groups, we found that target words preceded by related word primes elicit larger amplitude N400s and slower lexical decision responses than those preceded by related pseudoword primes. This comparison controls for sublexical orthographic overlap and isolates the influence of prime lexicality. The behavioural effect is unlikely to be caused by the congruency in lexical status between the word prime and word target given that 1) congruency effects should have followed the opposite pattern than the one we observed (i.e.,

[1]Orthographic neighbourhood density was also included as a factor in the analyses reported by Meade et al. (2018). In the present study, there were no significant interactions between Neighbourhood and Prime Lexicality, so we only focus on the latter.

faster responses when the lexicality of the prime and target was congruent) and 2) recent evidence suggests that prime lexicality has little effect on lexical decision responses so long as the prime is orthographically legal (Fernández-Lopéz, Marcet, & Perea, in press). Rather, we interpret the slower RTs following word primes as evidence that lexical competition between the prime and target hindered recognition in that condition (more so than in the condition with pseudoword primes).

The RT effect held for the deaf and hearing groups individually and did not differ between them. Given previous work indicating that the precision of orthographic representations modulates interference due to lexical competition (e.g., Andrews & Hersch, 2010; Andrews & Lo, 2012; Meade et al., 2018), this result would seem to suggest that deaf readers' altered access to phonology does not have a major influence on the tuning of their orthographic representations. This conclusion would appear to conflict with the conclusions drawn by Perea and colleagues (2016), who argued that the absence of strong phonological lexical representations in deaf readers does influence their early orthographic processing. In hearing readers, masked identity primes preceding pseudowords are more effective when they are in the same case (e.g., *GEDA-GEDA*) compared to different cases (e.g., *geda-GEDA*), but this result does not hold true for word targets (i.e., RTs are similar for the targets in *REAL-REAL* and *real-REAL*; e.g., Jacobs, Grainger, & Ferrand, 1995; Perea, Jiménez, & Gómez, 2014; Vergara-Martínez, Gómez, Jiménez, & Perea, 2015). The absence of an advantage for words is attributed to top-down feedback from phonological representations that are similarly activated by the lowercase and uppercase primes and overwhelm the small differences in visual/orthographic similarity. In deaf readers, Perea et al. (2016) found an advantage when the case of the prime and target were the same for both pseudowords (as in hearing readers) and words (in contrast to hearing readers). They argued that the top-down lexical phonological representations did not have as strong a top-down influence on early orthographic processing in deaf readers and thus, deaf readers were sensitive to the small differences in visual/orthographic similarity between *real-REAL* and *REAL-REAL*. Another possibility is that deaf readers are more sensitive to visual/orthographic differences than hearing readers in that paradigm, possibly due to changes in visual attention and processing that occur with congenital deafness (see Pavani & Bottari, 2012, for a review). Yet, as Perea and colleagues argue, this account would predict that visual similarity between corresponding uppercase and lowercase letters (e.g., c and C are similar, but a and A are not) should modulate the size of the effect in deaf readers, which they found not to be the case. Additional research is needed to better characterize how altered access to spoken phonology and/or differences in visual processing might affect the orthographic representations developed by deaf readers.

The only significant difference that we found between groups in the behavioural measures was that deaf readers were slower than hearing readers overall, despite being matched for spelling and reading comprehension abilities. In contrast, in a recent study with skilled deaf and hearing readers who were also matched on reading measures, Fariña and colleagues (2017) reported faster lexical decision RTs for deaf readers compared to hearing readers (see also, e.g., Morford, Occhibo-Kehoe, Piñar, Wilkinson, & Kroll, 2017). They proposed that the deaf readers might have been faster because they were using a more direct route from orthography to semantics, whereas hearing readers were slowed by co-activation of phonology. Given that accuracy did not significantly differ between groups here or in the study reported by Fariña et al., it seems unlikely that the difference in RTs is due to a speed-accuracy trade-off. The lexical competition between orthographic representations elicited in the present paradigm might have disproportionately disrupted the direct orthographic route and contributed to the slower RTs for the deaf readers. However, if this were true, the effect of prime lexicality on RTs also should have been larger in the deaf group, which was not the case. Alternatively, the studies where deaf readers are faster generally involved presentation of single words, whereas we used a masked priming paradigm here. The successive presentation of visual stimuli in this paradigm may hinder processing in deaf readers more than in hearing readers, possibly related to enhanced visual reactivity in deaf compared to hearing individuals (Bottari, Caclin, Giard, & Pavani, 2011). Unfortunately, analyses in previous masked priming studies with comparable SOAs were conducted separately for hearing and deaf readers, making it difficult to statistically evaluate this possibility in a broader context. However, the numbers are promising; across eleven of the twelve conditions reported in the masked priming studies by Bélanger et al. (2012) and Cripps et al. (2005), the deaf readers were between 20 and 50 ms slower on average than their hearing counterparts. The present results are within a similar range, suggesting that the slower RTs in the deaf group could be specifically due to the masked priming paradigm that we used.

One might be tempted to conclude on the basis of these behavioural data that lexical competition manifests itself similarly in deaf and hearing readers. However, the strikingly different scalp distributions of the N400 effect between groups suggest otherwise. Target words preceded by a related word elicited larger amplitude N400s compared to those preceded by a related pseudoword across groups, but the effect had a more restricted posterior distribution in the deaf group (and was only marginally significant in the hearing group). This difference in distribution is difficult to attribute to language dominance given that there were no overall differences in N400 amplitude between groups; the bilingual literature consistently suggests that words in the dominant language elicit larger amplitude N400s than words in the less dominant language (e.g., Midgley, Holcomb, & Grainger, 2009). It also seems unlikely that the different distributions were driven by reading ability given that the two groups had comparable spelling and reading comprehension scores. However, the hearing participants did score significantly higher on our measure of phonological awareness, and the current literature suggests that hearing readers activate phonology more systematically while reading (see, e.g., Bélanger et al., 2012; Bélanger et al., 2013; Bélanger & Rayner, 2015; Fariña et al., 2017; Perfetti & Sandak, 2000). Critically, not only do hearing readers activate the phonological lexical representation of a visually-presented word, they also activate the word’s phonological neighbours (e.g., Carrasco-Ortiz, Midgley, Grainger, & Holcomb, 2017; Grainger, Muneaux, Farioli, & Ziegler, 2005; Yates, 2005; Yates, Locker, & Simpson, 2004). We therefore suggest that the anterior portion of the effect that was specific to the hearing group might be related to competition between co-activated phonological representations of the prime and target, whereas the posterior portion that is shared between groups (albeit stronger in the deaf group) is due to competition between prime and target at an orthographic level. Consistent with this claim, previous masked priming studies have shown that phonological effects have a more anterior scalp distribution compared to orthographic effects, at least within the window preceding the

N400 (e.g., Grainger et al., 2006). Nevertheless, the assignment between scalp distribution and functional significance remains tentative and awaits future ERP studies designed to directly compare phonological competition in deaf and hearing readers.

The proposal that competition at the phonological level contributed to the effect that we observed in hearing readers in this paradigm is consistent with extant research implicating phonology in this paradigm. Most notably, Frisson, Bélanger, and Rayner (2014) tried to tease apart the role of phonology in masked neighbour priming by using pairs that were both orthographically and phonologically related (e.g., *crush-brush*) and pairs that were only phonologically related (e.g., *booth-truth*). Relative to an unrelated pseudoword baseline condition, they found significant interference for word pairs related on both dimensions and a trend in the same direction for phonologically-related pairs. The latter result indicates that competition between co-activated phonological neighbours (irrespective of orthography) may have contributed to the effect that we measured here. Although we did not systematically control for phonology, a high proportion of word-word pairs were also phonological neighbours. Post-hoc analyses using a single phoneme substitution definition of phonological neighbourhood (e.g., wine and vine are phonological neighbors, but rack and race are not; see also, e.g., Yates et al., 2004) revealed that 118 of our 180 word-word pairs were also phonological neighbours and could have contributed to the more anterior distribution of the effect reflecting neighbour interference in hearing readers.

Finally, investigations of individual differences in masked neighbour priming have suggested that stronger spellers and better readers tend to show larger competition effects in this paradigm (Andrews & Hersch, 2010; Andrews & Lo, 2012; Meade et al., 2018), which could be due in part to stronger (or faster) phonological co-activation in these hearing individuals (see, e.g., Andrews, 2008; Mason, 1978; Unsworth & Pexman, 2003; Welcome & Trammel, in press). More directly, as reviewed in the Introduction, recent evidence suggests that phonological abilities also account for variance in the size of masked neighbour interference effects, with hearing readers who have better phonological skills showing stronger competition for words from dense neighbourhoods (Elsherif et al., 2018). Thus, in the present study it is possible that the hearing participants' better phonological skills led to stronger competition among phonological neighbours, which could have shifted the scalp distribution of the prime lexicality effect in comparison to the deaf participants. Under this view, one might expect the behavioural interference effect to be larger for hearing participants due to additional phonological competition, but this was not the case. We suggest that the interference effect may converge between groups in the interval between the N400 and the behavioural response, as lexical orthographic competition builds over time (bearing in mind that, on average, the response came about 150 ms after the end of the N400 window).

Taken together, these results suggest that deaf readers engage in lexical competition during visual word recognition. Assuming that precise orthographic representations are a prerequisite for lexical competition, a further implication of this study is that deaf readers are able to tune these representations through mechanisms other than phonology. However, the restricted posterior distribution of the N400 effect (relative to hearing readers) suggests that their altered access to phonology does alter the nature of the competition, and may restrict it to the level of orthographic representations. Overall, the study of deaf readers provides insight into both the stability and the plasticity of the reading circuit.

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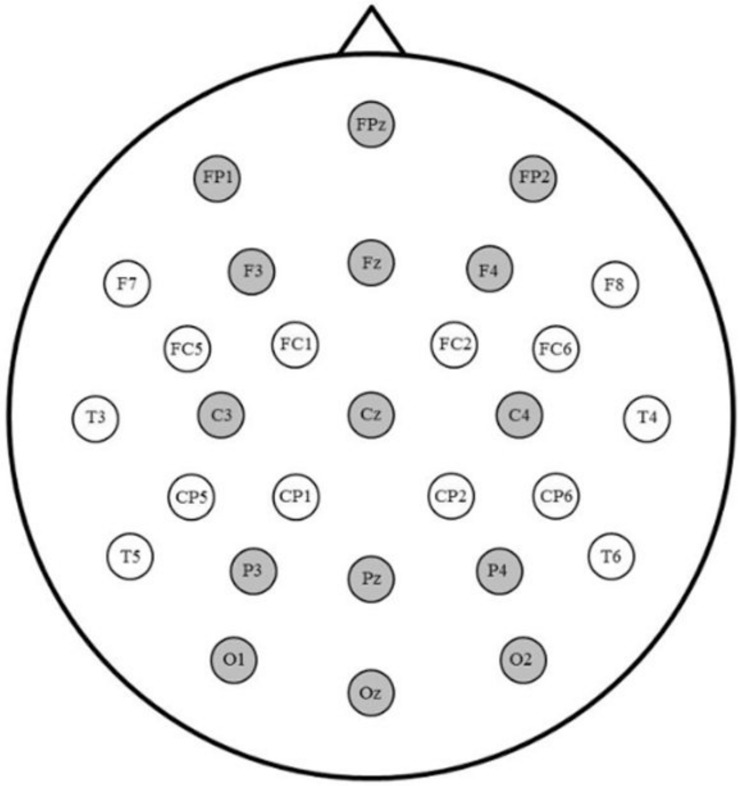

Figure 1. Electrode montage

Sites highlighted in grey were included in analyses.

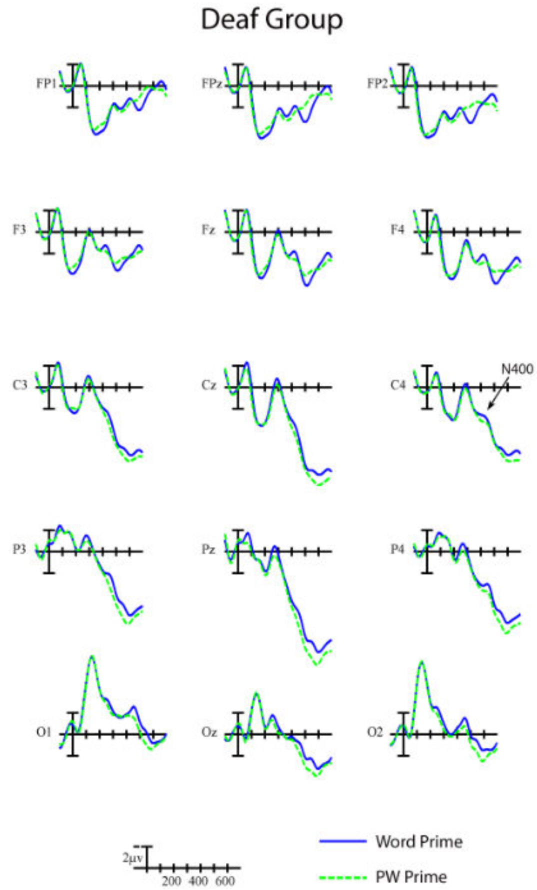

Figure 2. Deaf Group ERPs

Grand average ERP waveforms elicited by word targets preceded by a related word (blue) or pseudoword (green) prime in deaf readers. Each tick marks 100 ms and the calibration bar marks 2 μV. The N400 is indicated at representative site C4.

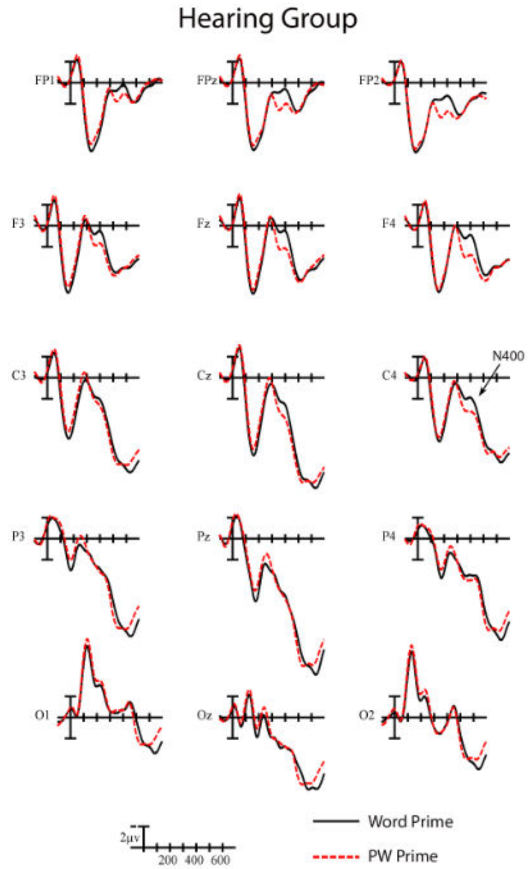

Figure 3. Hearing Group ERPs

Grand average ERP waveforms elicited by word targets preceded by a related word (black) or pseudoword (red) prime in hearing readers. Each tick marks 100 ms and the calibration bar marks 2 μV. The N400 is indicated at representative site C4.

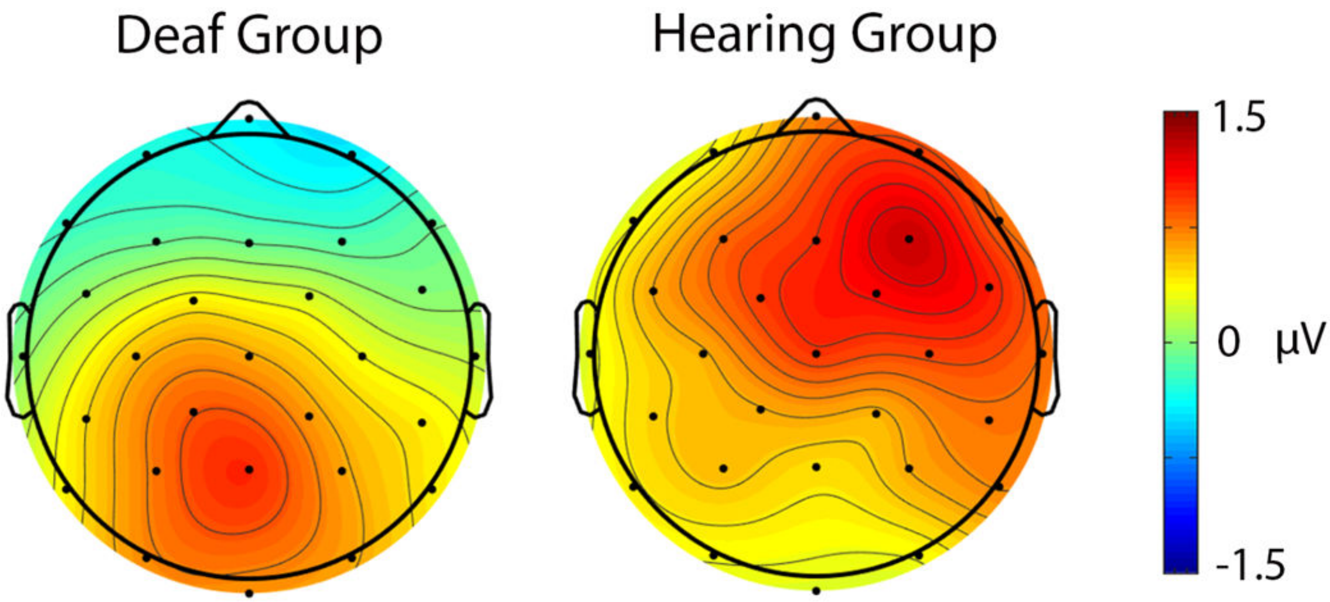

Figure 4. Voltage maps

The distributions of the effect of prime lexicality (pseudoword - word) on target words within the N400 epoch (350-550 ms) for each group.

Table 1.

Behavioral results [Mean (SD)]

		Deaf	Hearing
Word	RT (ms)	734 (83)	684 (81)
Prime	% Correct	85.6 (7.9)	84.6 (6.7)
Pseudoword	RT (ms)	709 (86)	665 (76)
Prime	% Correct	86.1 (6.6)	86.6 (7.5)