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Published in:
Neuroscience Letters

Document Version:
Publisher's PDF, also known as Version of record

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P300 investigation of phoneme change detection in dyslexic adults

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Received 3 August 2003; accepted 11 December 2003

Abstract

A specific impairment in phoneme awareness has been hypothesized as one of the current explanations for dyslexia. We examined attentional shifts towards phonological information as indexed by event-related potentials (ERPs) in normal readers and dyslexic adults. Participants performed a lexical decision task on spoken stimuli of which 80% started with a standard phoneme and 20% with a deviant phoneme. A P300 modulation was expected for deviants in control adults, indicating that the phonological change had been detected. A mild and right-lateralized P300 was observed for deviant stimuli in controls, but was absent in dyslexic adults. This result suggests that dyslexic adults fail to make shifts of attention to phonological cues in the same way that normal adult readers do.

Keywords: Dyslexia; Phonological processing; Phoneme awareness; Event-related Potential; P300; Attentional deficit

Developmental dyslexia is a disorder characterized by reading difficulties affecting between 2 and 10% of native speakers of English [19]. Although the impairment is primarily observed in reading (visual input), one of the main hypotheses as to the core deficit in dyslexia relates to phonological processing [17,18,20]. The results of many cross-sectional and longitudinal studies have suggested that deficient phoneme awareness is a common symptom and may even be a cause of dyslexia [2,13,20]. Amongst the various tasks used to assess dyslexia, phoneme awareness tasks have emerged as being some of the most effective predictors of reading skill [2,6,9].

The P300 event-related potential (ERP) component is a reliable index of conscious attentional shifts observed when infrequent stimuli (deviants) are detected within a series of identical frequent stimuli (standards) [3,15]. It is therefore possible to use the P300 to index phoneme awareness by manipulating the local probability of a phoneme within a series of words. P300 investigations in dyslexic individuals have shown quantitative differences (e.g. a delayed and/or reduced P300 [5,7]) but no qualitative differences have yet been reported, possibly because language-specific stimuli are rarely used.

We engaged dyslexic adults and matched controls in a lexical decision task while the phonological probability on the words’ initial phoneme was varied: Eighty percent of the stimuli were alliterated (standards) and twenty percent were phonological deviants (i.e. started with another phoneme). We hypothesized that deviant stimuli would elicit a P300 in normal readers as compared to standard stimuli. However, if phoneme awareness is deficient in individuals with developmental dyslexia, we would expect the P300 to be significantly reduced or cancelled.

Twenty-four students (12 dyslexic and 12 controls) from the University of Wales Bangor research panel participated. The 12 dyslexic adults (six males, six females, age range 18–29, mean 21.4 ± 3.7 years, one left-handed) were selected on the basis of an educational psychologist’s assessment focusing predominantly on discrepancies between verbal and non-verbal performance. There was no record of reading difficulties in the control group (six males, six females, age range 19–30, mean 21.3 ± 3.2 years, all right-handed), which was matched to the dyslexic group for mean age and level of education. Individuals were further assessed on three sub-tests of the dyslexia adult screening test (DAST [10]). Control participants performed significantly better than dyslexic adults on both the 1-min reading (control adults: 100 ± 11 and dyslexic adults: 72 ± 22, $F(1,20) = 14.56, P < 0.01$) and the 2-min spelling tests (control: 32 ± 3, dyslexic: 24 ± 4.
Stimuli were 352 nouns spoken by a female speaker with natural prosody and selected from the CELEX database [1]. The words were controlled for lexical frequency (CobLog greater than 0.8) and length (4–7 phonemes). Eight sets of words were prepared: four sets of 70 nouns starting with the phonemes /b/, /k/, /p/ or /r/ (standards) and four sets of 18 nouns starting with the phonemes /l/, /m/, /n/, and /g/, respectively (deviants). An equal number of pseudo-words was derived from the words by changing their medial consonant (third or fourth phoneme).

Participants were presented with four blocks each comprising 140 alliterated words and pseudo-words, and 35 deviant words and pseudo-words starting with a highly contrasting phoneme (e.g. /b/ for standards and /l/ for deviants). Trial order was quasi-randomized so that there was no more than one deviant and no less than two standards presented in succession. Participants were asked to press keyboard keys set under their left and right index fingers according to whether they heard a word or a pseudo-word. Response side and block order were fully counterbalanced across participants.

Continuous recordings sampled at 1 kHz and bandpass filtered on-line between 0.1 and 40 Hz were measured from 64 Ag/AgCl electrodes referenced to Cz, before being digitally re-filtered (low pass, 35 Hz, 48 dB/Oct). Impedances were kept below 9 kΩ. Eye blink artefacts were mathematically corrected and recordings were visually inspected for the rejection of any remaining artefacts before being cut into 1100 ms epochs. Baseline correction was applied relative to the 100 ms pre-stimulus activity.

Individual ERPs were re-referenced to the global average reference and grand-averages for each condition were computed. Electrodes T7 and T8 were not included in the statistical analysis due to excessive artefacts. Search intervals for ERP peaks were identified on the basis of major modulations of the mean global field power (MGFP [14]): 70–140 ms for the N1, 140–240 ms for the P2, 240–300 ms for the N2, 300–340 ms for the P3. Mean signal amplitudes were analyzed in nine scalp regions defined by laterality (left, central, right) and anteriority (frontal, central, parietal) using a 2 × 2 × 9 within- × 2 between-subject MANOVA [14]. Within-subject factors were: Lexicality (word, pseudo-word), Oddity (standard, deviant), and Region (9 levels). Interactions involving the Region factor were validated using vector normalization [8].
Error rates were significantly lower ($F(1, 22) = 9.08, P < 0.01$) in controls (mean 4.3 ± 2.5%) than dyslexic adults (mean 11.9 ± 10.3%, see Fig. 1). The performance of both groups was significantly better ($F(1, 22) = 18.80, P < 0.001$) for deviants (3.1 ± 2% errors) than standards (5.5 ± 2.4% errors). However, a significant lexicality by group interaction ($F(1, 22) = 5.05, P < 0.05$), indicated that whereas control participants did not differ at identifying words (9.2 ± 6% errors), dyslexic participants were significantly better at identifying words (9.2 ± 6% errors for words and 14.7 ± 12.9% errors for pseudo-words).

Control reaction times (RTs, 981 ± 108 ms) were significantly shorter ($F(1, 22) = 8.55, P < 0.01$) overall than dyslexic adult RTs (1132 ± 156 ms). Both groups responded faster ($F(1, 22) = 7.47, P < 0.05$) to deviants (1052 ± 153 ms) than standards (1062 ± 155 ms), and faster ($F(1, 22) = 38.58, P < 0.001$) to words (1016 ± 133 ms) than pseudo-words (1098 ± 162 ms). No interactions were found.

Words and pseudo-words elicited an N1–P2–N2 peak sequence in all participants. The N1 peaked around 100 ms, the P2 around 190 ms and the N2 around 290 ms on average. None of these peaks were significantly influenced by experimental factors.

In the P300 range, only an interaction between Oddity, Group and Region was significant after normalization ($F(8, 15) = 2.90, P < 0.05$). Post hoc paired $t$-tests showed that the ERP amplitudes were significantly more positive for deviants than standards over the right central region in controls ($t(11) = +3.14, P < 0.05$, one-tailed, corrected for multiple comparisons) but not in dyslexic adults (Fig. 2). This effect was maximal at electrode C6 310 ms after stimulus onset. Importantly, individual amplitudes of the P300 effect correlated significantly ($r = 0.40, P < 0.05$, one-tailed) with individual reading scores on the DAST subtest (Fig. 3).

As shown by the behavioural results, dyslexic adults are slower than matched controls in language tasks in general, and in lexical decision tasks in particular [11]. In addition, dyslexic participants made more errors than controls, possibly due to the minimal difference between words and pseudo-words.

As expected, phonological probability induced a deflection in the P300 range in control participants which can be compared to the classical P300 component [3]. Although participants were not explicitly instructed about the phonological manipulation, a change in the first phoneme of words and pseudo-words induced a phonological ‘surprise’. The P300 effect has been proposed to index conscious attentional shifts [3, 15]. The absence of the P300 modulation in dyslexic adults suggests that their attention was not diverted from the lexical decision task. Unlike the classical P300 [3], the modulation observed in this study was right-lateralized and small in amplitude. Other authors have described a right-lateralized P300 topography in passive oddball tasks [12]. Furthermore, the amplitude of the P300 has been shown to decrease depending on task relevance and interference from another concurrent task [16].

Importantly, despite the absence of a P300 modulation in the dyslexic group, dyslexic participants responded significantly faster to deviants than to standards. This suggests that although they did not shift their attention toward phonological cues during the experiment, they implicitly processed the difference in the first phoneme to some extent. If this is the case, it tends to support a deficit in phoneme awareness rather than implicit phoneme discrimination abilities in dyslexic individuals. The significant correlation between the P300 effect and individual reading scores further supports a relationship between phoneme awareness and reading skill.

The absence of a shift in attention in dyslexic participants needs to be explained. It may be the case that dyslexic adults have a normal implicit phoneme processing ability while having a limited capacity to attend to phonological cues that are not directly relevant for the current task. Alternatively, it is possible that attentional resources of dyslexic adults are insufficient to allow good performance in the lexical decision task while, at the same time, noticing phonological variations. It is therefore possible that the absence of a P300 effect relating to phoneme change detection is due to a more general attentional deficit rather than one specific to phonological processing [4].

Further investigation will be required to dissociate the presence of an attention deficit specific to phonological cues (phoneme awareness) from one that is non-specific.

Acknowledgements

The authors wish to thank Mark Roberts and Heather Roberts for technical assistance, and Marilyn Vihman for useful comments. T.F. is supported by the ESRC Grant R42200134186.
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