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Pre-attentive processing of auditory patterns in dyslexic human subjects

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Abstract

It has been hypothesized that auditory temporal processing plays a major role in the aetiology of dyslexia. Event-related brain potentials (mismatch negativity, MMN) of auditory temporal processing were assessed in 15 dyslectic adults and 20 controls. A complex tonal pattern was used where the difference between standard and deviant stimuli was the temporal, not the frequency structure. Dyslexics had a significantly smaller MMN in the time window of 225–600 ms. This result shows that dyslexics have a significant pre-attentive deficit in processing of rapid temporal patterns suggesting that it may be the temporal information embedded in speech sounds, rather than phonetic information per se, that resulted in the attenuated MMN found in dyslexics in previous studies. MMN scalp topographies were similar for both groups, showing a maximum over fronto-central leads.

Keywords: Mismatch negativity; Auditory temporal processing; Pattern processing; Dyslexia; Speech perception

Dyslexia is a disorder resulting from a developmental impairment in the ability to read and spell despite adequate educational resources, an IQ in the normal range (85–115), no obvious sensory deficits and adequate sociocultural opportunity [3]. It has been described in all languages. The prevalence rate is between 4 and 9% [11]. Whereas reading disability may become compensated, spelling problems often persist into adulthood [3].

Many of the features distinguishing speech sounds, like voice onset time and formant transitions, require the detection of timing differences of complex auditory patterns in just a few milliseconds. In recent years the hypothesis of an underlying auditory temporal processing deficit in dyslexia has become very popular [4]. Tallal [12] described a deficit in dyslexics regarding processing of brief, rapidly changing auditory stimuli. The finding that dyslexics are mainly impaired in processing stop consonants [2,7] which are characterized by brief and rapid spectral changes supports the role of temporal processing for speech perception in dyslexics. In the following years evidence has been published that repeated short sequences of auditory stimuli are recognized and analyzed as auditory patterns at a very early pre-attentive stage of signal processing [1,14].

A neurophysiological paradigm which is best suited to examine pre-attentive and automatic central auditory processing is the mismatch negativity (MMN). The MMN is a negative component of the event related potential (ERP), elicited when any discriminable change occurs in a sequence of repetitive homogeneous auditory stimuli [9]. The MMN is elicited by changes in frequency, intensity and duration of tone stimuli, or changes in complex stimuli such as tone patterns or phonetic ones. MMN is assumed to be the result of a mechanism that compares each current auditory input with a trace of recent auditory input stored in the auditory memory. The MMN usually reaches its amplitude maximum over fronto-central scalp [9].

Winkler and Schröger [14] used a complex tonal pattern comprising four tones and assessed MMN. While the pitch pattern of their sequences was invariant, the only difference between the sequences was the duration of the single tones: two segments of the same pitch were exchanged. The infrequent (deviant) pattern elicited a more negative wave when compared with the frequent (standard) sequence. Due to the frequencies of the exchanged segments were identical, the change could not have been detected without a representation of the temporal structure of the patterns. Thus it can be concluded that temporal information is indeed included in

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the memory traces indexed by the MMN, supporting the hypothesis that patterns are represented as unified auditory events.

In an earlier work [10] we have shown that dyslexics do not have an attenuated MMN on frequency differences of sinusoidal tones. However, it has not been investigated yet whether dyslexics are impaired with regard to complex auditory pattern information as embedded in complex tonal patterns. In the current study, we used the temporal processing paradigm of Winkler and Schröger [14] to assess MMN in dyslexics and normals. Our hypothesis was that dyslexics have difficulties in processing temporal patterns, resulting in an attenuated MMN.

Thirty-five adults (15 dyslexics, all male, mean age 22.3 ± 6.6) and 20 controls (male:female = 13:7, mean age 25.9 ± 14.0) participated in the study. The two groups did not differ with regard to their IQs (mean IQ of dyslexics was 117.5 ± 14.2; mean IQ of controls was 123.5 ± 8.7). The dyslexics had either completed or were from the final class of a boarding school for dyslexics and were selected as a result of their continuing reading and spelling disability. Spelling disability was defined by the presence of a discrepancy of at least one standard deviation between actual spelling and expected spelling based on IQ (regression model). The spelling disabled group had a significantly lower word decoding ability in comparison to the controls, with significant differences between the groups on both reading test scores: reading accuracy (one-sided *t*-test, $P < 0.0001$) and reading speed ($P < 0.0001$). The control group were undergraduate psychology students. The spelling ability of the control group was in the normal range. Inclusion criteria were to be a native, monolingual German speaker with no neurological, emotional or behavioural deficits or unusual educational circumstances that could account for poor reading and spelling ability and to have normal corrected visual acuity and no hearing problems. All subjects had normal hearing and reported themselves to be strongly right-handed.

Tone-burst patterns (Fig. 1; 3000 events, $P = 0.15$ for the deviant pattern, $P = 0.85$ for the standard pattern) were presented at an intensity of 70 dB SPL (sound pressure level). Segments 2 and 4 had identical frequencies but different durations. The duration of each tonal pattern was 215 ms.

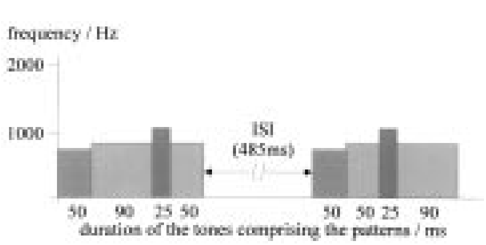

Fig. 1. Tonal patterns (standard and deviant) presented in the experimental condition. The vertical axis shows the frequencies of the tones (720, 815 and 1040 Hz), the horizontal axis shows the duration of the single tones (ms). Between the patterns there is an ISI of 485 ms. The difference between the two patterns is that two segments of identical frequency (815 Hz) but different duration (segments 2 and 4) have been exchanged, thus the patterns differ only regarding the duration but not the frequencies of the tones.

The auditory stimuli were presented binaurally by headphones in a pseudorandom order (at least five standards between two deviants) with a constant interstimulus interval (ISI) of 485 ms (from offset to onset). To control for level of arousal and to minimize subjects attention to the stimuli, they were told to watch videotaped silent movies and to ignore the test stimuli. Subjects were instructed to follow the screen play and to answer several questions on topics of the movies after the EEG recording.

Electrodes were placed at 19 scalp sites based on the International 10–20 System: Fp1, Fp2, 1;7, F8, F3, F4, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, O2 (referred to linked ears; ground electrode at Fpz, between Fp1 and Fp2). Eye movements and blinks were monitored by two electrodes placed below the subjects right and left eyes and the Fp1 and Fp2 electrodes. The EEG was amplified with Schwarzer amplifiers, time constant 0.6 s; upper frequency cut-off 85 Hz. The EEG was recorded continuously, A/D converted at a sampling rate of 172 Hz and transferred for further analysis to a DEC Alpha computer. The signals were averaged into epochs of 750 ms, including a prestimulus baseline of 50 ms. Epochs with artefacts were excluded from averaging. Peak amplitudes of the components were measured with an event related potential parameter programme developed at our Institute. In order to define the time window for the

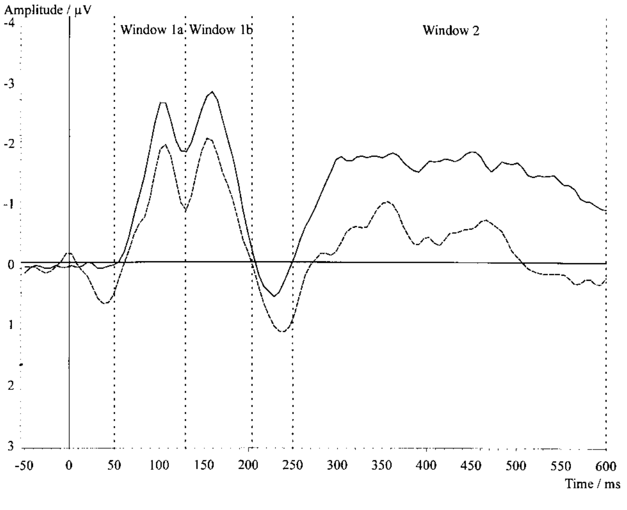

Fig. 2. Grand average of the MMN for dyslexics (dotted line) and controls (solid line) at Fz (fronto-central lead). The MMN was calculated by subtracting the ERP of the standard condition from that of the deviant condition. According to the shape of the wave, the MMN wave was subdivided into three analysis windows, window 1a (50–130 ms), window 1b (130–205 ms) and window 2 (250–600 ms). The time axis is aligned at the reference latency (the point at which the two patterns presented as standard and deviant stimuli start to differ from each other). This point equals the value zero on the time axis.

MMN potential, the difference curves (deviant-standard) at Fz were plotted.

Fig. 2 shows the grand average of the MMN for dyslexics and controls. We found three distinguishable components (50–130 ms, window 1a; 130–205 ms, window 1b; 250–600 ms, window 2). Peak amplitudes and latencies were assessed for window 1a and 1b. Since no clear peak is visible in window 2, we used the area below the curve (µV × ms) as measure for further data analyses.

Table 1 shows means and standard deviations of MMN peaks and areas, respectively, measured over Fz. In order to test for group differences *t*-tests were performed.

While there were no significant group differences for windows 1a and 1b, the MMN area in window 2 is significantly attenuated in dyslexics when compared with controls.

Fig. 3 shows the scalp topographies for both groups. Maximum activation is over fronto-central leads, respectively. There is no evidence for distribution differences between the groups.

We examined the hypothesis that dyslexics have an attenuated MMN for changes in auditory temporal patterns. This hypothesis was confirmed. The standard and deviant patterns used in our study do not differ regarding the frequencies of the tones; the difference between the deviant and standard stimuli is that two segments of identical frequency, but of different duration, have been exchanged. Thus it can be concluded that the temporal difference between the patterns triggered the MMN in both groups, but the dyslexics had a significantly attenuated MMN because they could not process the temporal information adequately. The result that the two groups differ only in the later time window (window 2) but not in the earlier windows (windows 1a and 1b) concurs with the finding of a significantly attenuated speech MMN in dyslexic and learning disabled children [6,10] where the differences also occurred in comparably late windows (approximately 300–600 ms).

Table 1
Mean values of the mismatch negativity (MMN) measures[a]

	Controls	Dyslexics	*P*-values
Window 1a (peak)	−3.4 ± 1.1	−2.7 ± 1.2	0.14
Window 1b (peak)	−3.7 ± 1.2	−3.0 ± 2.0	0.33
Window 2 (area)	−1.4 ± 1.2	−0.2 ± 1.6	0.030

[a] Mean and standard deviations of the MMN measures for dyslexics ($n = 15$) and controls ($n = 20$). The MMN was calculated by subtracting the ERP's to standards (2550 events) from those to deviants (450 events). The resulting MMN wave was subdivided into three analysis windows, window 1a (50–130 ms), window 1b (130–205 ms), window 2 (250–600 ms). Peaks (in µV, indicating the maximum of activation) were chosen as measures for windows 1a and 1b; since there is no clear maximum in window 2, we chose the area below the curve (µV × ms) as measure. Means are tested using *t*-tests, the *P*-values are one sided and alpha adjusted.

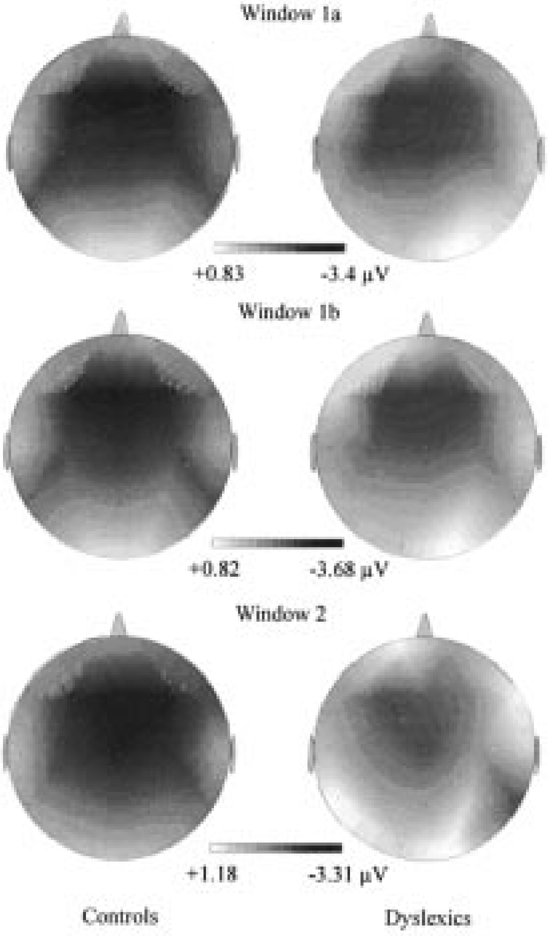

Fig. 3. Scalp distribution of the MMNs. The grey scales indicate the amount of activation. The corresponding range (in µV) was set individually for each pair of scalp distributions.

An auditory temporal processing deficit in dyslexia has previously been described for active paradigms requiring the discrimination between two or more successively presented auditory events [12,15]. However, the results in discrimination tasks might be influenced by cognitive strategies and attention. As our paradigm is pre-attentive, these factors can be disregarded in this study. Furthermore, this is the first study that demonstrated the relevance of temporal pattern processing for dyslexia, as opposed to rapid identification of and discrimination between very brief events [8]. In earlier studies we found that dyslexics have an attenuated MMN for speech stimuli, but not for tone stimuli [10], leading us to conclude that their deficit was specific to speech perception. However, as distinguishing of speech sounds requires the processing of temporal information [5], we hypothesized that it may be the temporal information embedded in speech sounds, rather than phonetic information per se, that resulted in the attenuated MMN found in dyslexics in previous studies. To test this hypothesis, we presented non-verbal tone patterns that differed only in their internal temporal structure. Results using these non-verbal, temporarily varying patterns showed that dyslexics had a similar, significantly attenuated MMN to that found previously for speech stimuli. This would also concur with the finding of Tallal et al. [13] that training with temporally modified speech results in significant improvements in speech discrimination and language comprehension in language learning impaired children. Regarding the high association between speech impairment and dyslexia this result might suggest that such a training program might also help dyslexics.

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