NeuroReport 10, 2079–2082 (1999)

Using mismatch negativity to measure auditory temporal resolution thresholds

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IT has been hypothesized that poor auditory temporal resolution is related to language-learning problems in children as well as problems with speech perception in noise in the elderly. We show that the presence of occasional silent gaps between short tone pips elicits mismatch negativity (MMN) in young adults. We also measured gap-detection thresholds with MMN that agree well with behavioural thresholds. Near threshold, the MMN increases as the gap size increases millisecond by millisecond. The MMN methodology for measuring temporal resolution is not only robust, but can be applied identically across the life span as it does not require the attention of participants or a behavioural response. We are now in a position to examine temporal resolution in infancy. *NeuroReport* 10:2079–2082

Key words: Auditory; Event-related potential (ERP); Language; Mismatch negativity (MMN); Speech perception; Temporal resolution

Introduction

The measurement of auditory temporal resolution (the minimum time interval between events that can be detected) is of interest to speech researchers because many of the features distinguishing speech sounds, such as voice onset time, rely on timing differences of a few milliseconds. Indeed, certain kinds of language-learning problems have been linked to poor temporal resolution [1–3]. At the other end of the life span, elderly persons commonly have trouble understanding speech in noise, even when their hearing thresholds are within the normal range [4]. Again, poor temporal resolution may be responsible for this effect [5].

Gap detection is one of the most common methods of determining temporal resolution and has been employed with infants, children, younger adults and older adults [5–9], as well as the hearing impaired [10–12]. Typically, these experiments require participants to indicate behaviourally whether they detect the presence of a silent gap inserted between two auditory stimuli. It would be particularly useful to be able to measure gap detection in infants in order to diagnose potential language-learning problems early in development. Currently, language-learning problems are not usually identified until children are at least 3 years of age. With young infants, a nonverbal behaviour such as a head turn or an increase in sucking may be used to infer discrimination. However, because infants cannot be given explicit instructions and they are likely not as motivated and attentive as adults, researchers likely underestimate infants' gap detection thresholds using such behavioural measures.

In this study we examined the feasibility of using event related potentials to measure gap detection thresholds in adults. Subsequent research will extend these findings to infants and the elderly. The mismatch negativity (MMN) component [13] appears to be ideally suited to our purpose as it does not require attention or a behavioural response; at the same time, the MMN is correlated with behavioural discrimination [14]. When an infrequent auditory stimulus occurs in a series of frequent auditory stimuli (the oddball paradigm) the electrical activity recorded at the scalp is more negative for the infrequent than for the frequent stimuli at about 140–250 ms after the onset of the stimulus. MMN appears to be a rather pure measure of sensory processing, as it is affected little by attention ([13], but see [15,16]). Moreover, MMN has been elicited in infants and children [17–19]).

Although MMN has been measured for deviations in pitch, intensity, sound location, duration and rise time, as well as for deviations in some higher order features [14,20], MMN has not been used to date to measure gap detection. In this experiment, we used MMN to determine adults' thresholds for detection of a silent gap inserted between two Gaussian-enveloped sine wave tones. Schneider *et al.* [5] suggest that gaps in pure tones are easier to detect than gaps in noise and that such thresholds are not affected by the amplitude fluctuations which occur when bandlimited noise is used as a marker. Gaussian envelopes were used as they minimize the spectral splatter that occurs when a sound is turned on or off, and the degree of spectral splatter is independent of the size of the gap. Our no-gap stimuli were constructed to match the gap stimuli in duration, energy, and approximate spectral content [5].

Adults were tested in a passive listening oddball paradigm using gap sizes of 4, 5 and 7 ms in a Gaussian-enveloped 2000 Hz pure tone. MMN was measured in order to determine which gap sizes adults were able to detect. As our stimuli were identical to those of Schneider *et al.* [5] we were able to compare MMN and behavioural thresholds.

Materials and Methods

Participants: Eight right-handed adults (age range 21–24 years; four female, four male) with normal hearing who had no previous experience in a gap detection task were tested with all gap sizes. The data for one participant in gap 4 was unusable due to technical problems.

Stimuli: In each of three conditions, gap stimuli were constructed with two 2000 Hz Gaussian-enveloped tone pip markers (s.d. 0.5 ms) whose peak amplitudes were separated by 4, 5 or 7 ms (Fig. 1). The matching no-gap stimuli were created as in Schneider *et al.* [5] to match the gap stimuli in duration and energy, and roughly in spectral content.

Apparatus: The sounds were generated with in-house software running on a Comptech pentium computer with a ProAudio Spectrum 16 card (Mediavision Inc.). They were presented with a Denon PMA 480R amplifier and a Grason Stadler speaker at a comfortable listening level, 65 B(B) SPL over a noise floor of 27 dB(A) SPL. The EEG was recorded with NeuroScan 4.0 software, using 32-channel Synamps and electrocaps in a shielded room.

Procedure: A target–non-target oddball methodology was used. In each condition only one gap size was tested. Each condition consisted of 400 trials with onset-to-onsets of 600 ms; 80% of trials consisted of the no-gap stimulus and 20% the gap stimulus. The order of the gap size conditions was random across participants.

Adults were seated directly in front of a computer monitor on which a screen saver was playing. The stimuli were presented via a central loudspeaker

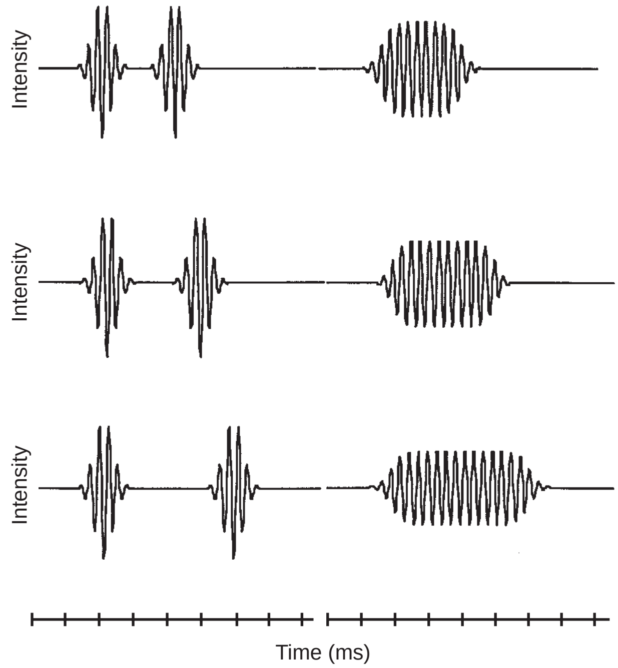

FIG. 1. Gap (left panels) and no-gap (right panels) stimuli for gap sizes 4 ms (upper panels), 5 ms (middle panels) and 7 ms (lower panels). Ticks represent 2 ms intervals. The no-gap stimuli are matched to the corresponding gap stimuli in duration and intensity.

located ~1 m in front of the participant. Adults were tested in a passive listening paradigm, whereby they were simply instructed to watch the screen saver. Although MMN in adults is typically measured while participants read a book or perform a demanding secondary task, we wanted to mimic the conditions under which infants would probably be tested in future experiments.

Recordings: Recordings were made from the following 27 sites: Fpz, Fp1, Fp2, Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, T3, T4, T5, T6, PC5, PC6, Pz, P3, P4, Oz, O1, O2. The sampling rate was 500 Hz, and the bandpass was set between 0.15 and 30 Hz. Impedance levels were maintained below 5 kΩ. Cz was used as a reference during recording, and a common average reference was calculated for the analyses.

Data analysis: The recordings were low pass filtered at 18 Hz. Baseline was defined as the mean amplitude for the 50 ms preceding the onset of the stimulus. Epochs were defined as 400 ms beginning from the onset of the stimulus. FP1, FP2, F7, and F8 were used to reject trials contaminated by eye movement artifact.

For each participant in each condition, the waveforms on the standard (no-gap) trial epochs were averaged together, as were the waveforms on the oddball (gap) trial epochs. The averaged standard waveforms were subtracted from the averaged oddball waveforms to create difference waves. *t*-tests were employed to determine the portions of the difference waves between 140 and 250 ms that were significantly less than 0 across participants.

Results

Significant MMN occurred for gaps 5 and 7 ms (Fig. 2). Specifically, the difference wave was significantly below 0 ($p < 0.05$) for an extended number of successive time steps at FC2 (186–210 ms) for gap 5 and at Fz (154–218 ms), F3 (170–206 ms), F4 (154–200 ms), FC1 (164–218 ms) and FC2 (144–226 ms) for gap 7 ms. As expected, the MMN component reversed polarity at T5, as can be seen in Fig. 2. At gap 4 ms, however, there was significant MMN only for a very brief portion of the waveform at F4 (178–182 ms). From this we can conclude that the gap threshold for these stimuli as measured by MMN is in the neighbourhood of 4 ms. It can also be seen from Fig. 2 that the MMN is very sensitive to the size of the gap; increases of only 1 or 2 ms result in a larger MMN component.

Topologies are shown in Fig. 3. Again, the topologies show how sensitive the MMN is to very small increases in gap size. The size of the right

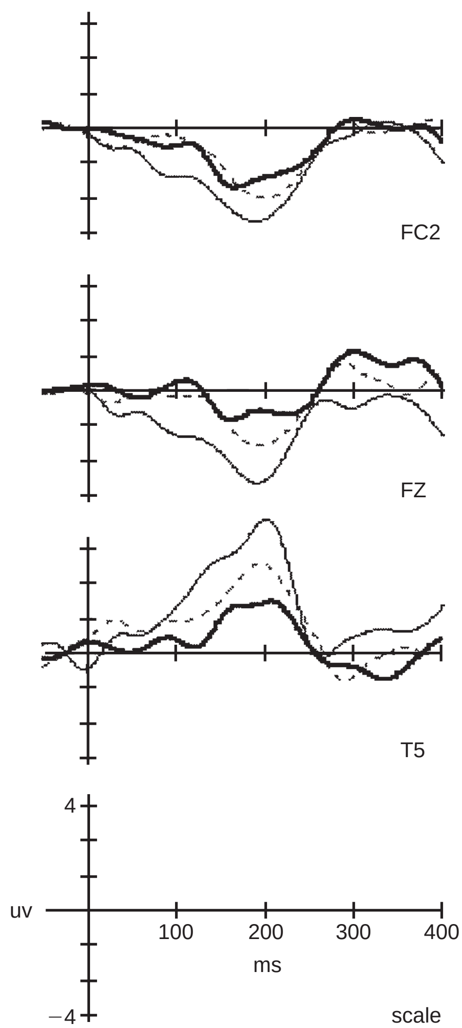

FIG. 2. Grand-average difference waves (oddballs minus standards) for gap sizes 4 (dark lines), 5 (dotted lines), and 7 (light lines) ms at FC2, Fz, and T5 showing the MMN. Note that the MMN component increases with gap size and that it reverses polarity at T5.

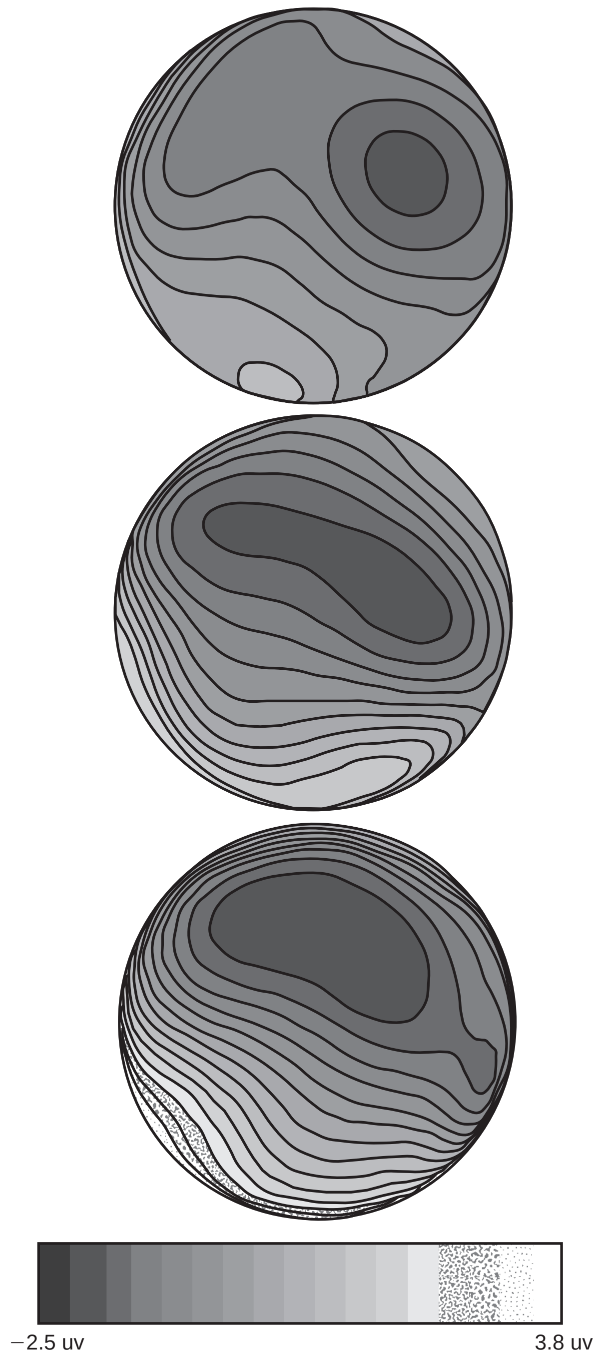

FIG. 3. Spherical spline isocontour voltage maps at 200 ms for gap 4 (upper panel), gap 5 (middle panel) and gap 7 (lower panel), looking down on the head with the front of the head at the top. Note the increase in the MMN component with gap size increase, the right anterior negative focus, and the left posterior reversal in polarity.

frontal negativity increases substantially with millisecond increases in gap size. At all gap sizes, the distribution has a right anterior negative focus and a left posterior positive focus. This distribution is consistent with MMN measured across a variety of auditory tasks [14,20]. Thus, even though adults watched a screen saver (to mimic the conditions under which infants will be tested) rather than perform a demanding secondary task, we were able to successfully measure MMN. This methodology can now be used with infants without modification.

Discussion

We have shown that not only does a gap detection task elicit MMN, but that the MMN is very robust even near threshold, with increases in gap size of 1 or 2 ms resulting in larger MMN components. Our measured threshold of 4 ms is in good agreement with the behavioural literature. Schneider *et al.* [5] found that practiced young adults had thresholds in the neighbourhood of 2–3 ms with stimuli identical to ours, when presented in a two-alternative forced-choice procedure with feedback on every trial. Our listeners were naive and not instructed to attend to the stimuli. Philips *et al.* [7] found that gap thresholds with broadband markers with similar leading marker durations to those of the present study were between 4 and 6 ms for inexperienced listeners.

These results indicate that MMN provides a good measure of temporal resolution thresholds. Unlike with behavioural methodologies, MMN can be measured identically throughout the lifespan. We are currently using the MMN methodology to measure gap detection thresholds in normal infants. These results will inform us as to the development of normal auditory temporal processing and its relation to language learning. We are hopeful that the procedure can eventually be used with populations such as very low birth weight infants in order to identify those infants who are at highest risk for language-learning problems years before they are currently identified.

Conclusion

Gap detection thresholds that agree well with behavioural thresholds can be measured in young adults using MMN. The MMN is sensitive to increases in gap size of 1 or 2 ms near threshold. The identical methodology can now be used to test temporal resolution in infants and the elderly, in order to better understand the relation between temporal processing and speech processing.

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ACKNOWLEDGEMENTS: This research was supported by an MRC grant to L.J.T. and an OMHF fellowship to R.M.D. We thank Claude Alain and Terry Picton for helpful discussions about MMN, and Mark Hahn for technical support.

Received 28 April 1999; accepted 12 May 1999