Mismatch Negativity (MMN) as an Index of Spectral Contrast Discrimination

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Abstract

The ability to detect spectral envelopes has shown a strong correlation with speech perception in quiet and noisy listening conditions in normal hearing, hearing-impaired and cochlear implant listeners. Spectral envelope perception can be characterized by measuring spectral modulation detection threshold (SMT), or the spectral contrast (in dB) needed to discriminate a sinusoidal spectral modulation (measured in cycles/octave) from an unmodulated spectrum. Modulation detection thresholds as a function of modulation frequency is known as the spectral modulation transfer function. Historically, most studies have focused on psychophysical methods requiring a subjective response. In this preliminary study, the mismatch negativity (MMN) was collected from 10 normal-hearing adult listeners and used to determine if SMTs derived electro-physiologically were correlated with previously reported psychophysical data. The MMN is a useful pre-attentive objective measure of small differences in acoustic stimuli. MMNs were collected using 400 ms narrowband noisebursts modulated at 0.5 cycles/ octave with spectral contrasts at 0, 5, 10, or 20 dB. MMNs were demonstrated for most listeners with spectral contrasts at 20 dB tapering off to MMNs in fewer listeners for smaller spectral contrasts. Thus, the MMN may be a promising neurophysiologic measure of spectral envelope perception when non-behavioral measures are desired.

Introduction

The ability to identify and differentiate various spectral patterns is a fundamental aspect of auditory perception. Several investigators have correlated spectral envelope perception and auditory tasks such as vowel and consonant identification (Henry & Turner, 2003; Laback et al, 2004) and speech perception in noise (Fu et al, 1998). One method of evaluating spectral envelope perception is by psychophysically measuring spectral modulation detection thresholds (SMTs) using simple sinusoidally-modulated spectra (Saoji & Eddins, 2001; Saoji et al, 2005; Litvak et al, 2007).

As with many psychophysical tasks requiring an overt response, the measurement of SMTs demands a great deal of sustained attention over long periods of time. Such demand, along with physical and physiological noise, observer criterion, and fatigue, can influence thresholds. This is not to say that the results of the psychophysical tasks are not worthwhile. Depending on the methodology, some psychophysical tasks may result in unreliable results for certain patient populations. Therefore, objective measurements of the same phenomena are often welcomed. Since psychophysically-obtained SMTs represent a form of differential sensitivity, the mismatch negativity (MMN) could provide an electrophysiological analog to psychophysical results.

The MMN response is an event-related brain potential that is non-invasively recorded from the scalp surface that reflects the auditory system's ability to detect small differences between otherwise similar sounds. Extensive reviews of the literature by Näätänen (1995) and Kujala et al (2006) attest to the numerous and broad investigation of the MMN.

The MMN is a desirable neuroscience tool as it is not affected by the attention or state (asleep or awake) of the participant and ultimately provides information regarding the auditory neural integrity associated with sound discrimination. In other words, the MMN is considered preconscious or pre-perceptual. Moreover, the MMN does not require that the participant respond behaviorally. Because the participants do not have to attend to the sounds, they could sleep, read quietly, or even watch a muted, subtitled movie of their choice. It is for this reason that the MMN has a potential advantage over behavioral procedures that require participants to sit for long periods while completing a task that demands constant attention, physical energy, and cooperation. To lend credence to the use of the MMN, it has been used to confirm the detection of a difference of 20 Hz between frequencies (Tiitinen et al,1994) which is in close agreement with a psychophysical study conducted by Wier et al (1977).

Methods

Participants

- Ten normal-hearing participants between the ages of 18 and 35
- No known neurological disorder or head injury
- Air-conduction thresholds ≤ 25 dB HL from 250 to 8000 Hz
- Tympanograms with static admittances between 0.3 and 1.8 mmhos and tympanometric peak pressure between -100 and +50 daPa
- Participants read a book or magazine of their choice during the evoked potential recordings

Sinusoidal Spectral Modulation Detection Stimulus

- Stimulus duration: 400 msec
- Carrier band: 350 to 5600 Hz
- Modulation frequency: 0.5 cyc/ oct
- Spectral contrast: 0, 5, 10, and 20 dB (difference between spectral peaks and valleys)
- Spectral phase: 0 degrees
- Presentation level: 60 dB SPL

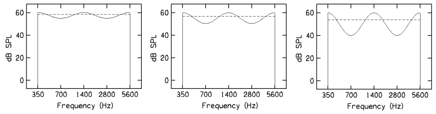

Figure 2. Sinusoidal spectral modulation detection stimuli in the frequency domain.

Evoked Potential Stimulus Presentation

- Presentation ear: Right ear only
- Transducer: ER-3A insert earphone
- Stimulation Rate: 1.25/ sec

Evoked Potential Equipment and Procedures

Equipment
- 2-Channel Bio-Logic NavPro Auditory Evoked Potential System
- Electrode montage: Fz referred to linked mastoids and ground between and above eyebrows

Recording Parameters
- #Points: 512
- Amplification: 50,000x
- Rejection rate: 100 µV
- Epoch: 533 msec (-21 msec pre-stimulus)
- Bandpass filter: 0.1 to 30 Hz

Experimental Conditions
- **Oddball Recordings**
  - 280 standards (0 dB contrast) and 50 deviants (5, 10, or 20 dB contrast) per block = 330 stimuli (17.9% probability of deviants)
  - Averaged recordings of four blocks per deviant (for a total of 200 deviants)
- **Deviant-Alone Recordings**
  - 140 deviants (5, 10, or 10 dB) per block
  - Averaged recording of 2 blocks per deviant (for a total of 280 deviants)
- **Presentation Order**
  - Oddball and deviant-alone recordings were randomized

MMN Derivation
- MMN waveforms for each spectral contrast were derived as a difference between the responses to a stimulus presented as deviant (or infrequent) and deviant stimuli presented alone in a repetitive sequence

Results

MMN Latencies and Amplitudes

	Latency (msec)	Amplitude (µV)	*n*
5 dB	267.00	-1.09	1
10 dB	225.16 (16.52)	-0.85 (0.29)	8
20 dB	213.92 (15.52)	-0.91 (0.40)	9

Standard deviations in parentheses.

MMN Individual Waveforms and Grand Averages

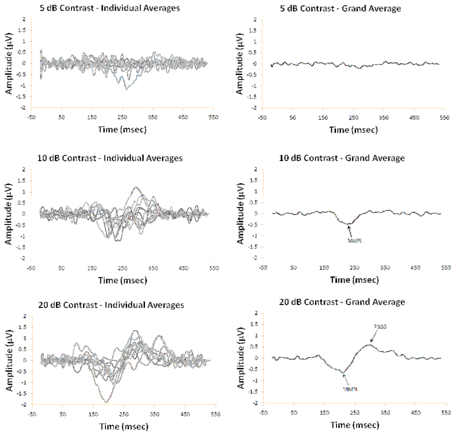

Figure 2. Individual and grand average MMN waveforms for spectral contrasts of 5, 10, or 20 dB. MMN waveforms for each spectral contrast were derived as a difference between the responses to a stimulus presented as deviant (or infrequent) and deviant stimuli presented alone in a repetitive sequence.

Discussion

- Both individual and grand average results suggest that MMNs can be elicited in most normally-hearing participants to spectral contrasts as low as 10 dB. In a psychophysical task using the same frequency modulated noise, normally-hearing listeners had SMTs between 3 and 10 dB (Saoji et al, 2005). Therefore, the MMN may be a useful, objective index of spectral contrast discrimination.

- In addition to the MMN, a positive-going component between 275 and 375 msec was evident in some recordings with spectral contrasts of 10 and 20 dB. This component is probably the P300 that often appears when the difference to be discriminated is quite large.

Discussion (cont.)

Strengths of the Current Study

- The MMN appears to be a useful neurophysiological index of spectral contrast discrimination, which may be useful in the study of spectral envelope perception in hearing aid and cochlear implant users.

- Recording MMNs does not require any overt behavioral response, which may counter some of the concerns that arise in psychophysical tasks.

Limitations of the Current Study

- Any promise of using MMNs in place of a psychophysical task for other populations must be tempered by the fact that MMNs are not always identified consistently within individuals and concerns remain about stability and reliability of the MMN over time (Dalebout & Fox, 2001; Escera & Grau, 1996; McGee et al, 2001; McGee et al, 1997).

- MMN waveform quality and morphology are both directly and indirectly related to signal-to-noise ratio (SNR) issues. Indeed, using a statistical method for quantifying SNR based on Pearson's product-moment correlation coefficients (Pearson's *r*), Cacace & McFarland (2003) have reported that MMNs have low SNRs compared to other evoked potentials.

- The results were collected using a two-channel evoked potential system with linked-mastoids. Therefore, we were not able to monitor and reject artifacts to eye blinks. Secondly, the system was not designed to collect electroencephalograms (EEGs) and as a result, we were unable to implement more sophisticated methods of waveform analysis.

Conclusions

The use of the MMN for objectively measuring SMTs appears to be a promising methodology; however, more work is needed in the following areas:

- Replication of this study using more sophisticated evoked potential system (e.g., multi-channel Neuroscan system)
- Evaluation of alternative signal processing and recording strategies to improve the SNRs (or stability and reliability) of MMN
- Comparison of psychophysically- and electrophysiologically-derived SMTs in the same cohort of participants

References

- Henry, B.A. & Turner, C.W. (2003). J Acoust Soc Am, 113(5), 2861-73).
- Laback, B. et al (2004). J Acoust Soc Am, 116(2), 1208-23.
- Fu, Q.J. & Shannon, R.V. (1998). J Acoust Soc Am, 105(3), 1889-00.
- Saoji, A.A. & Eddins, D.A. (2001). J Acoust Soc Am, 109(5), 2465-66.
- Saoji, A. et al (2005). Conference on Implantable Auditory Prostheses, Asilomar, CA.
- Litvak, L.M. et al (2007). J Acoust Soc Am, 122(2), 982-91.
- Näätänen, R. (1995) Ear Hear, 16(1), 6-18.
- Kujala, T. et al (2006). Biol Psychol, 74(1), 1-19.
- Tiitinen et al (1994). Nature, 372(6501), 90-2.
- Wier, C.C. et al (1977). J Acoust Soc Am, 61(1), 178-84.
- Dalebout, S.D. & Fox, L.G. (2001). J Am Acad Audiol, 12, 245-53.
- Escera, C. & Grau, C. (1996). Electroenceph Clin Neurophysiol, 100, 549-54.
- McGee, T. et al (2001). Psychophysiol, 38, 653-58.
- McGee, T. et al (1997). Electroenceph Clin Neurophysiol, 104, 359-68.
- Cacace, A.T. & McFarland, D.J. (2003). Neurosci Lett, 251-55.