Loudness Dependency of Mismatch Negativity (MMN): Evidence from CSD-PCA

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Abstract / Introduction

In a loudness dependency (LDAEP) paradigm, auditory N1/P2 covaries with stimulus intensity (e.g., Gallinat et al 2000, Hegerl & Juckel, 1993). In a MMN paradigm, intensity deviants produce a MMN (e.g., Näätänen et al., 1987) but it is unclear to what extent this effect is affected by loudness. These relations were explored in a modified MMN task in which binaural tones (1000 Hz; 40-ms; 500 ms ISI) were presented at four intensities (70-100 dB SPL), using one intensity in a block as standard (70%) and the remaining three as deviants (10% each). Standards (across blocks) and block order (across subjects) were counterbalanced. An additional block used equiprobable (25%) intensities to validate LDAEP effects. Healthy adults (N = 13) watched a silent film and reported its content (underwater scenes) after each block. Using 72-channel ERPs, temporal principal components derived from reference-free CSD waveforms characterized neuronal generator patterns underlying loudness dependency and MMN, which included: 1) N1 sink (113 ms peak; tangential sink/source topography); 2) temporal N1 sink (159 ms; radial temporal lobe sink); 3) P2 source (218; midline and bilateral temporal sources). These three factors revealed robust, monotonic relationships with intensity for standards and equiprobable stimuli. In marked contrast, tangential N1 was augmented with increases but not decreases in deviance. Whereas temporal N1 sink and temporal P2 sources for deviants showed a similar relationship with intensity, these factors had secondary midline topographies (N1: frontocentral; P2: midcentral) that were predominantly responsive to large increases (≥ 20 dB) but not decreases in deviance. These effects were also observed for factor score differences (deviant minus standard) revealing characteristic MMN (temporal N1 sink) and P3a (P2 source) topographies. These findings suggest that MMN of tone intensity is elicited primarily by louder rather than softer deviants, and that LDAEP effects may be affected by a selective MMN for loud tones.

Stimuli and Procedure

Basic Design

Block	70% Probability ("Standard")	10% Probability ("Deviant")	10% Probability ("Deviant")	10% Probability ("Deviant")
A	70 dB	80 dB	90 dB	100 dB
B	80 dB	70 dB	90 dB	100 dB
C	90 dB	70 dB	80 dB	100 dB
D	100 dB	70 dB	80 dB	90 dB

Block	20% Probability ("Equiprobable")	20% Probability ("Equiprobable")	20% Probability ("Equiprobable")	20% Probability ("Equiprobable")
E	70 dB	80 dB	90 dB	100 dB

Magnitude of Deviance: +/- 10 dB, +/- 20 dB, +/- 30 dB

1000 Hz Sine Tones
40 ms (10 ms rise/fall) Duration
500 ms SOA

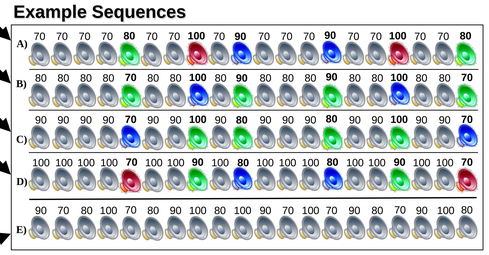

Figure 1. Study Design

Tones were presented at four levels of intensity (70, 80, 90, 100 dB) and occurred at two levels of probability in four experimental blocks. For each experimental block, one intensity was presented as a standard (70%) and the three remaining intensities as deviants (each at 10% probability; see A – D). An additional block (block E) of equiprobable intensities served as a standard intensity-modulation paradigm to validate intensity effects on N1-P2.

Example segments of each experimental block. The magnitude in intensity discrepancy between each deviant and standard tone are shown as:

+/-10 dB
+/-20 dB
+/-30 dB

400 stimuli consisting of 280 standards and 120 deviants (40 per deviant intensity) were counterbalanced and pseudorandomized across blocks A – D. Block order was counterbalanced across subjects.

- Presentation® stimulus delivery and experimental control software (Neurobehavioral Systems Inc., 2008) was used to calibrate and deliver the experimental tones through the computer sound card. A 20-s 1000 Hz continuous sinus tone was calibrated with a sound level meter at 100, 90, 80, and 70 dB sound pressure level (SPL) for a matched pair of TDH-49 headphones. The calibrated tones will be cut into segments of 40 ms duration (10 ms rise/fall time) to be used in the intensity oddball tasks.
- Subjects were instructed to ignore tones and attend to a silent video (underwater scenes taken from the Discovery Channel—Planet Earth DVD) presented on a computer monitor (constrained to 6 X 4 inches). Subjects were tested on the film content following each experimental block.
- No responses were required from subjects during the EEG recordings.
- The intensity MMN task was performed in a single session after the completion of three EEG/ERP tasks required for a larger study. These tasks include (a) a resting EEG task, (b) a novelty oddball task, and (c) an intensity modulation task. Breaks were provided to subjects within and between tasks.

Participants

Healthy adults (*N* = 13; 8 female; age = 32.2±9.6 yrs) with no history of any psychopathology or neurological disorder

All subjects right-handed (Edinburgh Handedness Inventory LQ=81.9 ± 18.0).

ERP Recording and Data Analysis

ERP Recording ERPs were recorded from 72 scalp sites (ActiView; BioSemi), using an active recording reference composed of sites PO1 (common mode sense) and PO2 (driven right leg), and rereferenced to nose offline. Continuous data were exported to NeuroScan format using PolyRex (Kayser, 2003). Amplifier drift was eliminated by padding the beginning of the file and applying a rectangular high-pass filter (10 s time constant). Continuous EEG blink corrected using a spatial, singular value decomposition (NeuroScan). Stimulus-locked epochs (700 ms, 200 ms prestimulus) were extracted and screened for electrolyte bridges (Tenke & Kayser, 2001). Channels containing amplifier drift, residual eye activity, muscle or movement-related artifacts or noise for any given trial were identified using a reference-free approach (Kayser & Tenke, 2006a), and replaced by spherical spline interpolations (Perrin et al., 1989) when possible. ERP averages were then low-pass filtered at 12.5 Hz (-24 dB/octave) and finally baseline-corrected using the 200 ms preceding stimulus onset.

Current Source Density (CSD) ERPs were averaged for each stimulus intensity and probability (standard, deviant, and equiprobable) condition . Reference-free CSD waveforms (spherical spline Laplacian Perrin et al., 1989) were computed from ERP averages to sharpen topographies, eliminate volume-conducted contributions from distant regions, and quantify underlying current generators (Kayser & Tenke, 2006b; Tenke & Kayser, 2005).

CSD-PCA CSDs were submitted to unrestricted PCA derived from the covariance matrix followed by unscaled Varimax rotation (Kayser & Tenke, 2003).

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Acknowledgments

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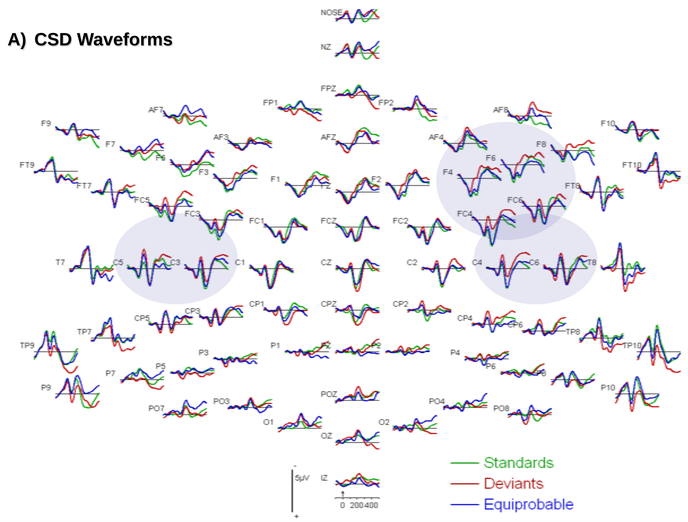

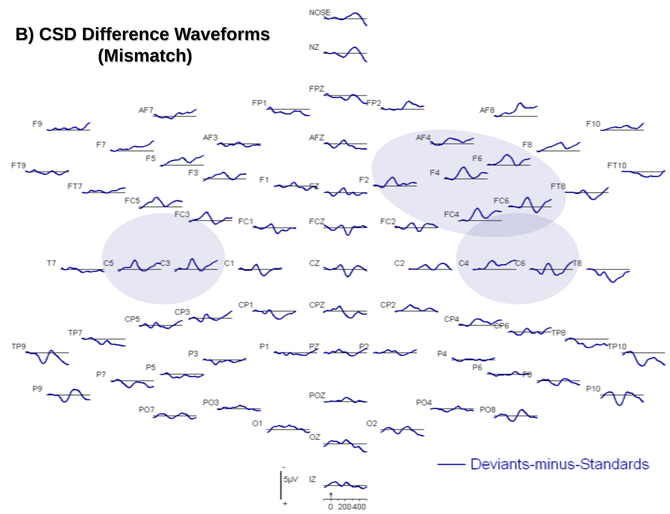

Figure2. A) Grand mean CSD waveforms for Intensity-Dependence (Equiprobable) and Intensity MMN (Standards/Deviants) tasks. Reference-free CSD waveforms show robust bilateral central sinks (e.g., C3/4; 113 ms), bilateral temporoparietal sinks (TP7/8; 153 ms) and bilateral central sources (e.g., C3/4; 218 ms) across all conditions. A marked enhancement of sink activity over bilateral central and right frontocentral (e.g., FC4) sites was observed for deviant trials compared to standards. A slight enhancement for equiprobable trials over standards was observed for all components.

B) CSD mismatch difference waveforms. Differential activity was seen at bilateral central sites (e.g., C3/4; 124 ms) stemming from enhanced sinks for deviants, which inverted at lateral temporoparietal sites (e.g., TP9/10). In addition, the enhanced sinks were more prominent over right than left frontal sites (e.g., F3/4; 202 ms).

CSD-PCA Factor Loadings and Scores

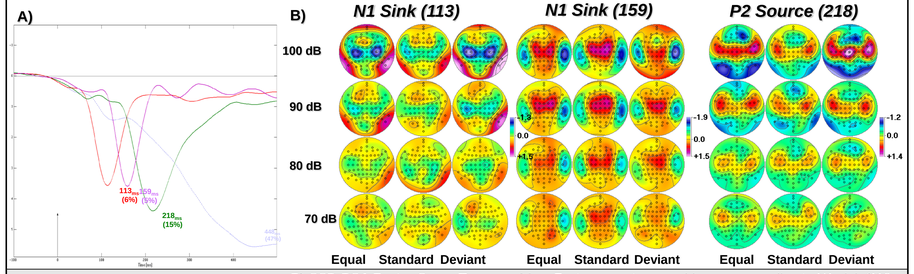

Figure 3. A) Unrestricted CSD-PCA Factor Loadings. The first four factors explained 75% of the variance.

B) CSD-PCA Factor Score Topographies. Factor score topographies corresponding to N1 sink (113 ms), temporal N1 sink (159 ms), and P2 source (218 ms) for all intensities (70 – 100 dB) were highly similar for equal, standard, and deviant conditions. Loudness dependency of all components was observed across all conditions. An attenuated N1 sink for standards is characteristic of fast (500 ms SOA) repetitive stimuli.

CSD-PCA of Mismatch Waveforms

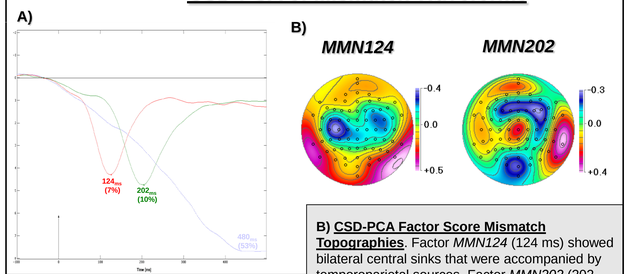

Figure 5. A) Unrestricted CSD-PCA Factor Loadings for Mismatch Waveforms. The first three factors explained 70% of the variance.

B) CSD-PCA Factor Score Mismatch Topographies. Factor *MMN124* (124 ms) showed bilateral central sinks that were accompanied by temporoparietal sources. Factor *MMN202* (202 ms) had a right-greater-than-left frontocentral sink that was accompanied by a lateral temporal and a secondary vertex source.

Difference Topographies as a Function of Intensity Deviance

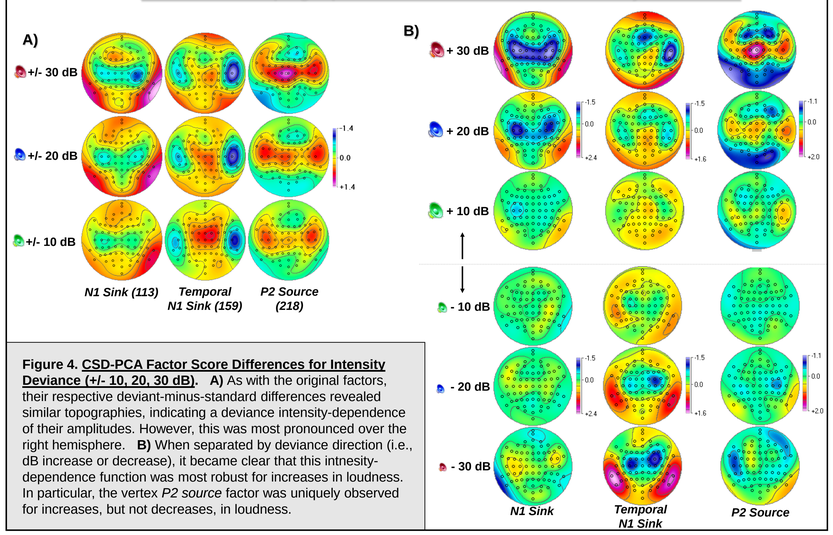

Figure 4. CSD-PCA Factor Score Differences for Intensity Deviance (+/- 10, 20, 30 dB). **A)** As with the original factors, their respective deviant-minus-standard differences revealed similar topographies, indicating a deviance intensity-dependence of their amplitudes. However, this was most pronounced over the right hemisphere. **B)** When separated by deviance direction (i.e., dB increase or decrease), it became clear that this intnesity-dependence function was most robust for increases in loudness. In particular, the vertex *P2 source* factor was uniquely observed for increases, but not decreases, in loudness.

Mismatch Topographies as a Function of Intensity Deviance

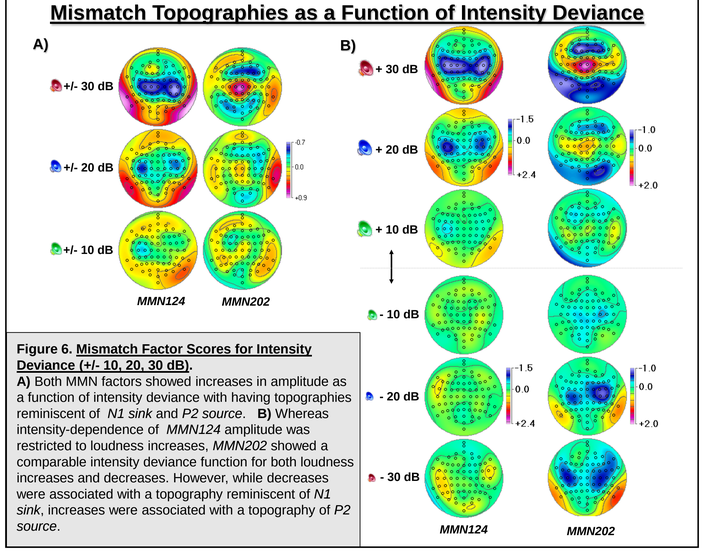

Figure 6. Mismatch Factor Scores for Intensity Deviance (+/- 10, 20, 30 dB).
A) Both MMN factors showed increases in amplitude as a function of intensity deviance with having topographies reminiscent of *N1 sink* and *P2 source*. **B)** Whereas intensity-dependence of *MMN124* amplitude was restricted to loudness increases, *MMN202* showed a comparable intensity deviance function for both loudness increases and decreases. However, while decreases were associated with a topography reminiscent of *N1 sink*, increases were associated with a topography of *P2 source*.

Conclusions

- Using a CSD-PCA approach on a modified MMN task, a loudness-dependency of MMN was shown.
- Consistent loudness-dependency effects were observed for PCA factors derived from both CSD waveforms and CSD mismatch waveforms (an analysis of effect sizes should evaluate their effectiveness in measuring MMN effects).
- MMN activity approximately spanned from 100 to 200 ms, overlapping factors unambiguously corresponding to N1 sink and P2 source.
- As previously found, MMN varied with the amount of deviance.
- A right-greater-than-left MMN asymmetry at frontal sites is consistent with effects previously reported (for a review, see Näätänen et al, 2007).
- However, amplitude and topography of MMN were differentially affected by increases or decreases in intensity when compared to standards.
- These findings suggest that MMN effects may be composed of distinct attentional subprocesses with different time-courses and topographies indicative of different regional generators underlying automatic deviance detection.