Objective Measurements of Music Discrimination in Individual Experienced and Recently Implanted Cochlear Implant Users

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Introduction. In clinical context as well as in research, CI-users' auditory perception skills are typically measured by behavioral methods. Recently, EEG has been successfully applied as a non-invasive and objective supplementary measure. EEG offers the recording of event-related brain potentials (ERPs). One ERP, the Mismatch Negativity (MMN) response, has proven to be a reliable and objective marker for CI users' discrimination of auditory stimuli [1]. Whereas the MMN provides strong evidence at the group level [2] the reliability of the MMN in individuals still has to be improved [3].

With this study we aimed to test the validity of MMN responses to musical stimuli in individual experienced and recently implanted CI users as well as in normal hearing controls. Furthermore, we aimed to study the plastic changes involved in the CI adaptation process of recently implanted CI users at both the individual and the group level.

Methods. EEG recordings were carried out using a new musical multifeature MMN-paradigm (CI MuMuFe) [4]. Deviants in intensity, pitch, timbre and rhythm are embedded in an Alberti bass pattern and presented randomly at four levels of magnitude.

Participants. Eleven experienced CI-users (CI^{ex}, ^{M}age: 60.7 y), 7 recently implanted CI users (CI^{re}, ^{M}age: 59.9 y) and 14 normal hearing controls (NH, ^{M}age: 63.4 y) underwent EEG-recording while listening to the CI MuMuFe paradigm. CI users received sound through direct audio input while NH controls listened through in-ear headphones. CI^{re} participants were measured twice: shortly after switch-on (T1) and after three months (T2).

Data analysis. A new spike-density component analysis (SCA) method for high-accuracy isolation of specific neural sources was used to isolate MMN from other brain activity [5] (Figure 1).

Results. We found significant MMN responses to all deviants at all deviant levels in all of the individual CI^{ex} and NH participants. Figure 2 exemplifies MMN individual responses in two CI^{ex} and in one NH participant. The results of the NH and CI^{ex}1 participants are consistent with the respective group findings with regard to amplitudes and levels. CI^{ex}2 shows abnormally low MMN amplitudes.

CI^{re}. Quite remarkably, the CI^{re} group showed MMN-like negative ERPs for all deviants, even after a short duration of experience. For pitch and timbre, there was a marked increase in MMN amplitude at T2, not found in the responses to the intensity and rhythm deviants. This indicates that the progress following daily exposure to the CI sound is manifested stronger in the discrimination of the spectrally complex rather than in the more basic features of music (Figure 3).

MMN responses of the CI^{re} group showed a large variance. Figure 4 shows MMN responses to the pitch deviant at T1 and T2 in two recently implanted CI users. The patient in the top panel demonstrates "normal" amplitude levels while the patient in the bottom panel shows abnormally low and decreasing responses. This patient was subsequently reimplanted due to an emerged structural displacement in the inner ear. The accordance between MMN responses and diagnosis is an indication of the potential clinical usefulness of the paradigm and the SCA method.
Figure 6 shows the progress in discrimination skills as illustrated by increasing MMN amplitudes and lower latencies in a single CI^{re} participant.

Correlation. Using the SCA method, we estimated MMN amplitudes for each feature and level in each single CI^{re} participant. We categorized the data according to strength and correlated with behavioral measurements of music discrimination. As shown in figure 5, there is a strong relationship between MMN amplitude and behavioral hit rates. This implies that the CI MuMuFe paradigm may offer the possibility to predict CI outcome.

Figures

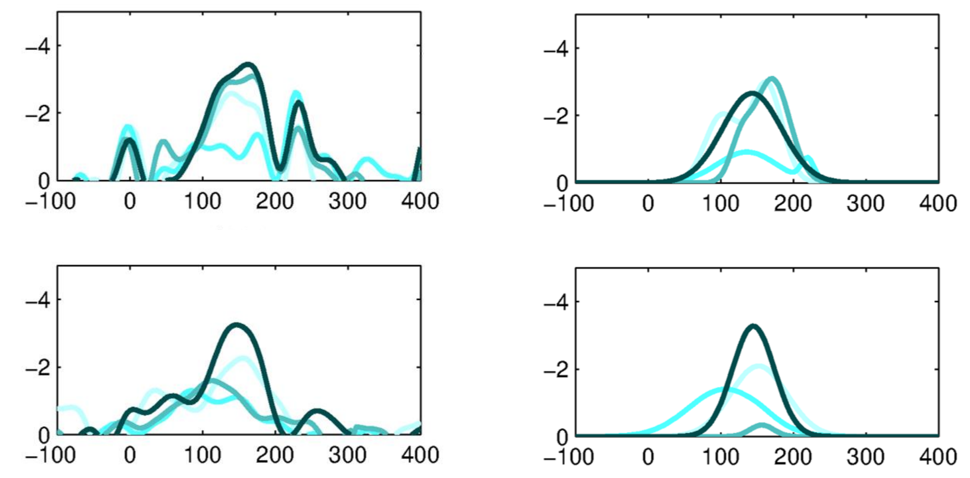

Figure 1. Left: Difference waves for the 4 levels of the timbre deviant from 2 exp. CI users, original. Right: The same difference waves after SCA analysis.*

***SCA analysis.** The accuracy of EEG in identifying neural evoked responses is challenged by overlapping neural sources. This lack of accuracy is a severe limitation to the application of evoked responses to single-patient clinical diagnostics. Therefore we introduce a theory of stochastic neuronal spike timing probability densities for describing the large-scale spiking activity in neural assemblies, and a spike density component analysis (SCA) method for isolating specific neural sources. The method is tested in three studies with 564 cases of evoked responses to auditory stimuli from 94 humans, each measured with 60 EEG electrodes and 306 MEG sensors.

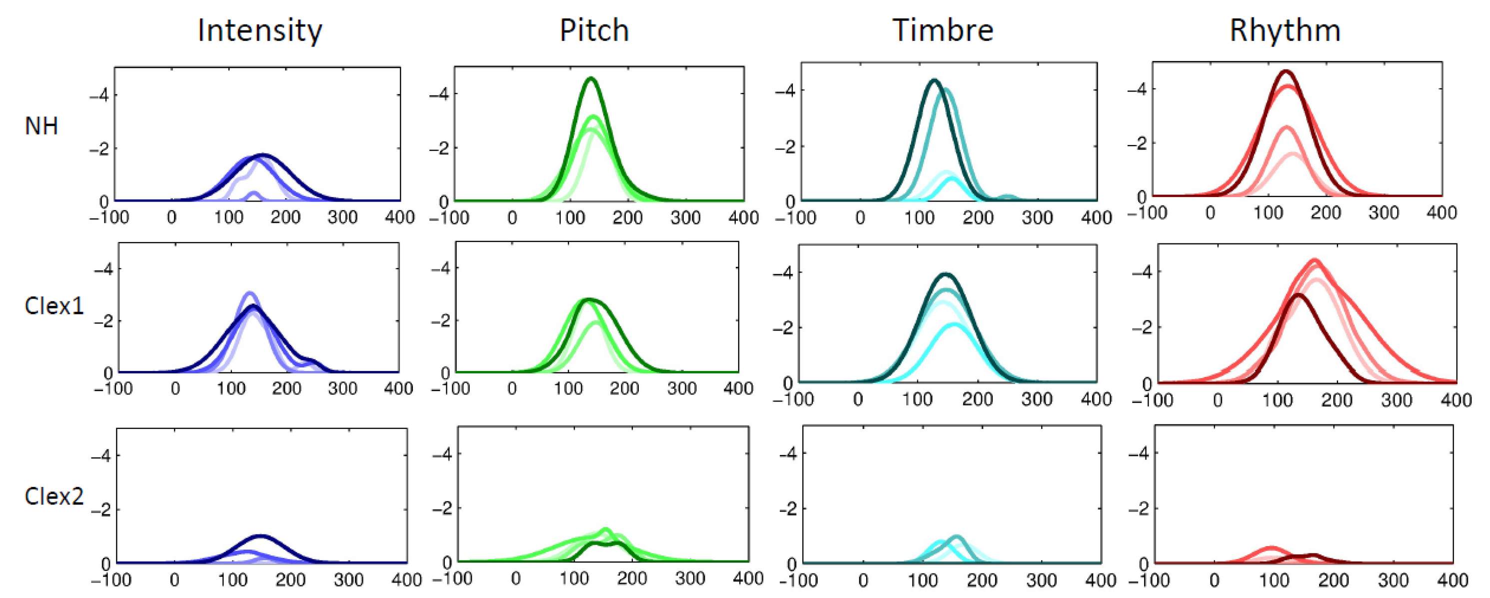

Figure 2. Examples of MMN responses to the presented deviants and levels in a single NH listener and two single experienced CI users. (CI^{ex}1: CI exp: 7y; age @ HL: 30y; CI^{ex}2: CI exp: 8y; age @ HL: 4y)(Darker shades = larger deviation magnitude).

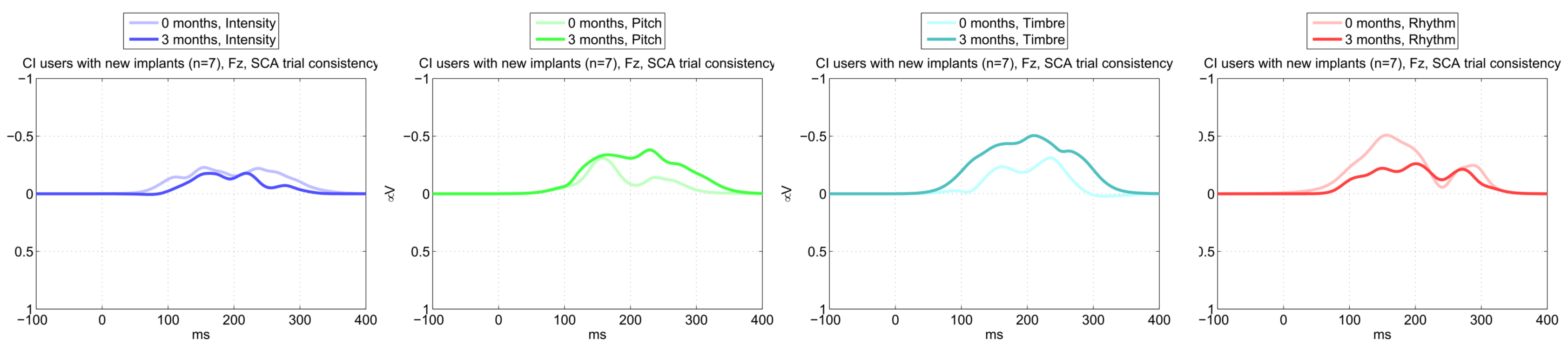

Figure 3. Mean MMN difference waves of 7 recently implanted CI-users @ T1 (light shades) and T2 (dark shades).

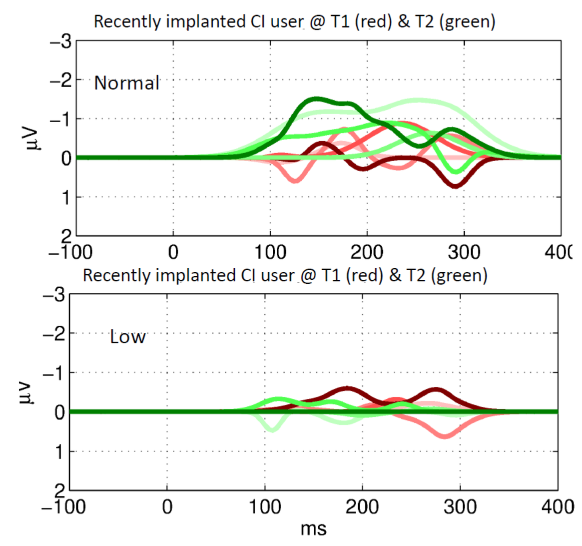

Figure 4. MMN responses to the pitch deviant in two recently implanted CI users at T1 (red shades) and T2 (green shades). Top: normal amplitudes; bottom: abnormally low amplitudes.

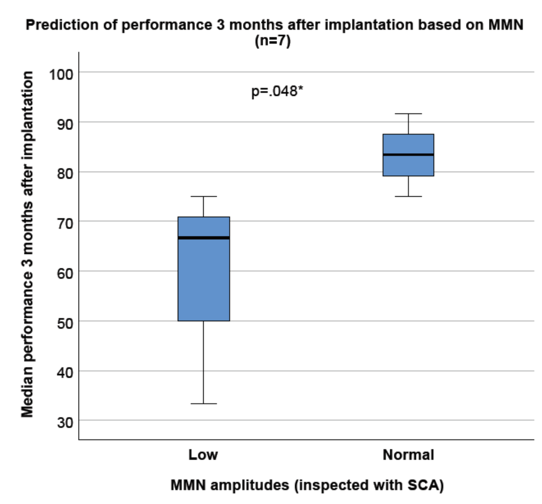

Figure 5. Box plot showing the relationship between low and normal MMN amplitudes category and hit rates in the behavioral discrimination test.

Conclusion. Applying the novel SCA approach and the new musical MMN-paradigm, we found reliable MMN-responses in individual NH and CI participants. Furthermore, in naïve CI users, we were able to trace signs of improvement in detection of pitch and timbre features as an effect of experience with the CI, reflecting functional changes in the auditory system. The results are an encouraging indication of the potential application of the new methodologies as prognostic and diagnostic tools in clinical settings. This may be relevant for infants and small children with CIs, as means for assessing the adequacy of the CI functioning, its improvement as a function of time of CI use, and the efficiency of different rehabilitation procedures. With presumed inclusion of future new CI users, we anticipate further support of our findings, with the perspective of bringing important new knowledge about music and CI.

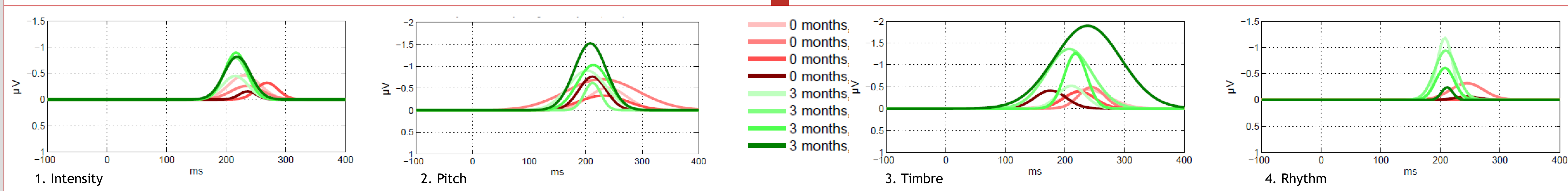

Figure 6. MMN responses to four deviants at four levels of magnitude in a single recently implanted CI user at 0 months and 3 months after implantation. 1. Intensity, 2. Pitch, 3. Timbre, 4. Rhythm. Analyses are based on SCA analysis

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