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ADVANCING OBJECTIVE ASSESSMENT OF SPECTRAL DISCRIMINATION USING EEG: AMPLITUDE ROVING MINIMIZES LOUDNESS CONFOUNDS

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ABSTRACT

The measurement of cortical responses to frequency cues relevant for speech understanding can potentially lead to earlier and more effective clinical diagnosis and intervention in hard-to-test populations. To assess cortical responses to changes in frequency, it is important to minimize the presence of other simultaneous cues, such as loudness, which might also evoke cortical responses, potentially biasing the interpretation of the response data. To minimize this effect, we propose a new method that uses amplitude roving—commonly used in behavioral testing to ensure the cue of interest is focused on—to reduce loudness-related cortical responses. Neurophysiologically, the effect of intensity roving might translate to a form of neural adaptation to signal variance, which results in a reduced sensitivity to intensity changes.

In this study, we investigate the effects of amplitude roving on EEG responses to spectral changes in pure tones. We investigate the extent to which intensity roving can reduce cortical responses driven by intensity changes. The results show that intensity roving can significantly reduce the cortical response to amplitude changes, while responses to spectral changes remain salient.

Keywords: *acoustic change complex, amplitude roving, loudness, speech discrimination*

1. INTRODUCTION

The use of cortical auditory evoked potentials (CAEPs) as objective biomarkers of hearing in clinical practice has promising potential for guiding diagnostics in hard-to-test populations [1–3]. Cortical measures of suprathreshold discrimination can potentially supplement existing methods, particularly within the context of spectral discrimination as a proxy of perceptual vowel discrimination abilities. One such measure is the acoustic change complex (ACC), a cortical response driven by suprathreshold acoustic cue transitions. ACC responses have, for example, been demonstrated with frequency and amplitude transitions [4–8]. While the ACC is sensitive to changes in frequency, inherent simultaneous changes in loudness may also evoke neural responses [9, 10]. Cortical responses to loudness must therefore be disentangled from the compound response, and potential methods for minimizing this confound must be investigated.

In psychophysical studies, amplitude roving across trials is commonly used to reduce the perceptual weight

of loudness cues [11]. Roving involves the randomization of task-irrelevant acoustic features—here, the stimulus intensity—to render them unreliable for the listener. In the neurophysiological domain, amplitude roving can be applied via random fluctuations in stimulus level across stimulus presentations and, as such, increases the stimulus level variance, which might reduce neural sensitivity to intensity changes. Animal studies indicate that neuronal adaptation to level variance occurs in the auditory cortex [12–14]. An increase in intensity variance through amplitude roving might therefore lead to reduced EEG-measured cortical sensitivity to intensity fluctuations as populations of neurons adapt their firing rate.

In this study, the concept of cortical neural adaptation is exploited through amplitude roving in a suprathreshold frequency discrimination paradigm employing pure tones. Specifically, we investigated ACC responses to periodic changes in intensity (as a proxy measure of loudness changes) as well as changes in frequency. ACCs were obtained either with or without amplitude roving in the form of random low-frequency amplitude modulations applied across the signal intervals.

2. METHODS

This paper presents a subset of the data that was obtained from a study of 26 young (≤ 33 years) normal hearing participants, in which their electroencephography (EEG) responses were recorded. Recordings were carried out at the Technical University of Denmark (Kongens Lyngby, Denmark). All the experiments were approved by the Science-Ethics Committee for the Capital Region of Denmark (H-1-2013-138). All participants provided their written consent prior to taking the test.

Stimuli consisted of amplitude modulated (AM'ed; $41\,\mathrm{Hz}$) loudness-balanced tones. ACC responses to the following stimulus changes were examined: (1) *intensity change*, where two $848\,\mathrm{Hz}$ AM'ed tones are presented with a level increment of +5 dB and (2) *frequency change*, where a $848\,\mathrm{Hz}$ AM'ed tone is followed by a loudness-balanced AM'ed tone of $970\,\mathrm{Hz}$—i.e., with loudness cues minimized. These conditions were then presented again, but with the intensity levels roved by applying a low-frequency randomized envelope to the stimulus (envelope frequency components from $0.5\,\mathrm{Hz}$ to $4\,\mathrm{Hz}$, fully modulated). In all conditions, the baseline intensity was set to a sound pressure level (SPL) of $65\,\mathrm{dB}$. An overview of these conditions is presented in Table 1.

Cortical responses were recorded using a BIOSEMI$^{\mathrm{TM}}$ ActiveTwo system using a 64 + 2 external channel layout, following the 10-20 system, and responses were referenced to the Cz-electrode. Recordings lasted around 5 minutes, divided into epochs of 2 seconds (150 epochs), corresponding to the time intervals of the acoustic change in the stimuli.

EEG from the mastoid electrodes were analyzed using a statistical detection method termed the Fmpi [15]. The Fmpi measures the probability that a given F-value—the ratio between the variance of the averaged recording within a time window where the cortical response is expected (50 to 550 ms after change onset) and the variance of the post-average residual noise—is obtained by chance.

EEG processing included band-pass filtering (2-30 Hz) and weighted averaging according to [16]. To investigate how the response strength increases as more epochs are averaged together, we performed the analyses in incrementing number of epochs (step = 20 epochs).

The response detection threshold was set at an alpha level of 0.05. The total number of significant detections was then converted to a percentage of the total number of recordings per condition, denoted as detection rate.

Statistical analyses were performed via analyses of variance using a Generalized Linear Mixed Model (GLMM) with a Gamma distribution.

#	Δf [Hz]	ΔSPL [dB]	Roving
1	0	+5	No
2	122	0	No
3	0	+5	Yes
4	122	0	Yes

Table 1. Overview of experimental conditions (labeled by number). Δ**f** and Δ**SPL** refer to frequency- and intensity changes respectively. The last column indicates whether roving was applied (yes/no).

3. RESULTS

Figures 1A&B show an overview of the ACC waveforms averaged across all participants and epochs. Responses to intensity changes only (Fig. 1A) are visibly smaller than ACCs to changes in frequency (Fig. 1B). Similarly, responses when the amplitude level of the stimuli was not roved (fig. 1A&B, top panels) are larger than for the roved conditions (fig. 1A&B, bottom panels). This is especially apparent in the intensity change conditions (Fig.
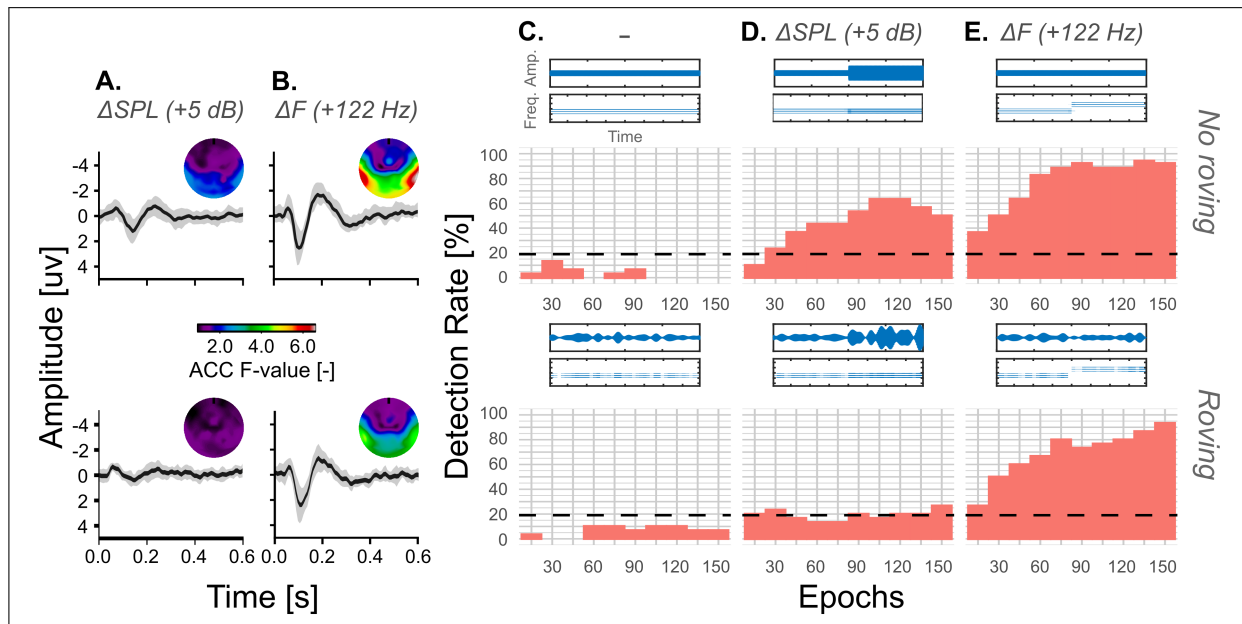
Figure 1. **A-B**: Waveforms and topographic maps of average ACCs across all participants and two mastoid channels for intensity (**A**) and frequency (**B**) conditions. Non-roved conditions are at the top, roved conditions on the bottom. Waveforms are plotted in time window 0 to 0.6 s and expressed as voltage in µV. Mean (solid) waveforms with standard deviation (shaded) are given. Additionally, topographic maps show ACC F-values from the Fmpi-detector (full recording length, number of epochs = 150) across all 64 (excluding mastoid) recorded channels along the scalp. All results are referenced to Cz. **C-E**: Results from an Fmpi-detector across varying number of epochs (time window: $50\,\text{ms}$ to $550\,\text{ms}$) across all participants. Results are categorized by condition; Panel **D** shows the intensity change condition, panel **E** shows the frequency change condition. Non-roved conditions are at the top and roved conditions are on the bottom. Panel **C** shows results for the no change reference. The x-axis shows the varying number of epochs used in the detector, with the detection rate (percentage of significant responses that were obtained) on the y-axis. Dashed lines show the Bernoulli confidence interval (95%) for chance detection. The explanatory diagrams above the detection plots show the stimulus of the respective condition both in the time- and frequency domain.

1A), while this difference is less distinguishable in the frequency change condition (Fig. 1B). Topographic maps of the ACC F-value across the scalp (Fig. 1A) suggest that responses are reduced when roved in both conditions.

Detection rates across all participants (see Section 2) are shown in Figures 1C-E. By assessing detection rates in baseline recordings (i.e., a non-change reference) (Fig. 1C), the detection rates fall within the Bernoulli confidence interval (95%) for chance detection (dashed lines). For the intensity change (Fig. 1D) and frequency change (Fig. 1E), the patterns differed depending on whether roving was employed or not. In the intensity change con-

dition without roving (Fig. 1D, top panel) the number of detections increased steadily throughout the recording. However, in the intensity change condition with roving (Fig. 1D, bottom panel), responses fluctuated roughly around chance level. In the frequency change conditions, both with and without roving, the number of detections increased steadily throughout the recording.

To provide statistical evidence on the effects of frequency, intensity and roving on the ACC we performed an analysis of variance (ANOVA) using a GLMM to predict the F-value using the following independent factors: the *acoustic cue* (frequency or intensity), *amplitude rov-*

ing (applied or not applied), and their interactions. The participant was included as a random factor. The results revealed that *acoustic cue*, ($\chi^2(1)$ = 40.60, p < 0.001), *amplitude roving* ($\chi^2(1)$ = 17.91, p < 0.001) and their interaction ($\chi^2(1)$ = 9.78, p = 0.0018) were significant factors.

Post-hoc analyses (Bonferroni corrected) on the model's estimated marginal means revealed a significant difference between intensity (roving vs. no roving; ΔF-value = 0.72, p < 0.001), and no significant difference for the frequency condition (roving. vs. no roving; ΔF-value = 0.74, p = 0.13). Further inspections revealed that responses to the frequency change with roving were still significantly larger than responses to the loudness change without roving (ΔF-value = 1.00, p = 0.006).

4. DISCUSSION

Our results indicate that ACC responses to intensity changes decreased significantly when employing amplitude roving, whereas ACCs to frequency changes did not significantly differ when roving was applied. Moreover, the responses to frequency changes were larger compared to those in response to intensity changes. Overall, this suggests that amplitude roving effectively reduces the contributions of intensity cues in the cortical response, without compromising the response to frequency changes.

Through roving, the stimulus statistics were manipulated to increase the variance. Previously, animal studies have shown that, when subjected to a high amplitude variance context, intensity-rate decoding functions of individual cortical neurons are more adapted to the increased intensity range over which they operate, in comparison to a low amplitude variance context [12, 13]. In the present study, increasing the variance reduced the compound response to intensity changes, suggesting that like in animals, human cortical responses to changes in intensity becomes less distinct when these changes are contextualized by an increased level of variance. Since intensity changes were introduced as a proxy measure for perceptual changes in loudness, our results suggest—based on the strong reduction in responses—that cortical responses arising from changes in loudness are similarly reduced by applying amplitude roving.

5. CONCLUSIONS

Amplitude roving reduced cortical responses to loudness changes, but minimally affected responses to fre-

quency changes. This finding can be particularly useful in the development of clinical objective methodologies of suprathreshold auditory processing. In cases where loudness cues cannot be strictly controlled for, e.g. when evaluating cortical responses to spectral changes between vowels, roving can be applied to minimize the potentially confounding loudness cue. Additionally, this method could be useful in populations where loudness perception is changed, e.g. due to hearing impairment. However, additional research is needed to confirm a reduction in loudness-driven responses via amplitude roving in these populations.

6. ACKNOWLEDGMENTS

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