Neural Basis of Sensorimotor Adaptation in the Speech Production System

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Introduction

Background

Speech production is mediated by a series of motor movements developed for communicative intent. Vocal production is an important subcomponent of speech that enables individuals to control the pitch and loudness of their voice through controlling the movement of respiratory and laryngeal muscles. Recent models of the vocal system have emphasized the role of auditory and somatosensory feedback mechanisms in motor control of vocalization [e.g., 1, 2, 3]. Evidence from previous studies has supported the notion that motor behaviors can be shaped temporarily with corrective intent (adaptive behaviors) and new behaviors can be developed with lasting effects (learned behaviors) following changes in sensory feedback stimuli [4, 5].

Objective

The present study investigated the underlying neural mechanisms of behavioral responses involved in sensorimotor adaptation to pitch-shifted auditory feedback.

Method

Experimental task

12 healthy subjects with no reported history of voice or musical training (2 males, age range: 22–27 years, mean age: 24.8 years) repeatedly produced steady vocalizations of the vowel sound /a/ while receiving voice auditory feedback across four vocalization phases:

1) Baseline: Voice auditory feedback not altered
2) Adaptation (onset): Auditory feedback pitch shifted by -100 cents
3) Adaptation (offset): Continuation of the previous adaptation phase
4) Washout: Auditory feedback returned to baseline (no alteration)
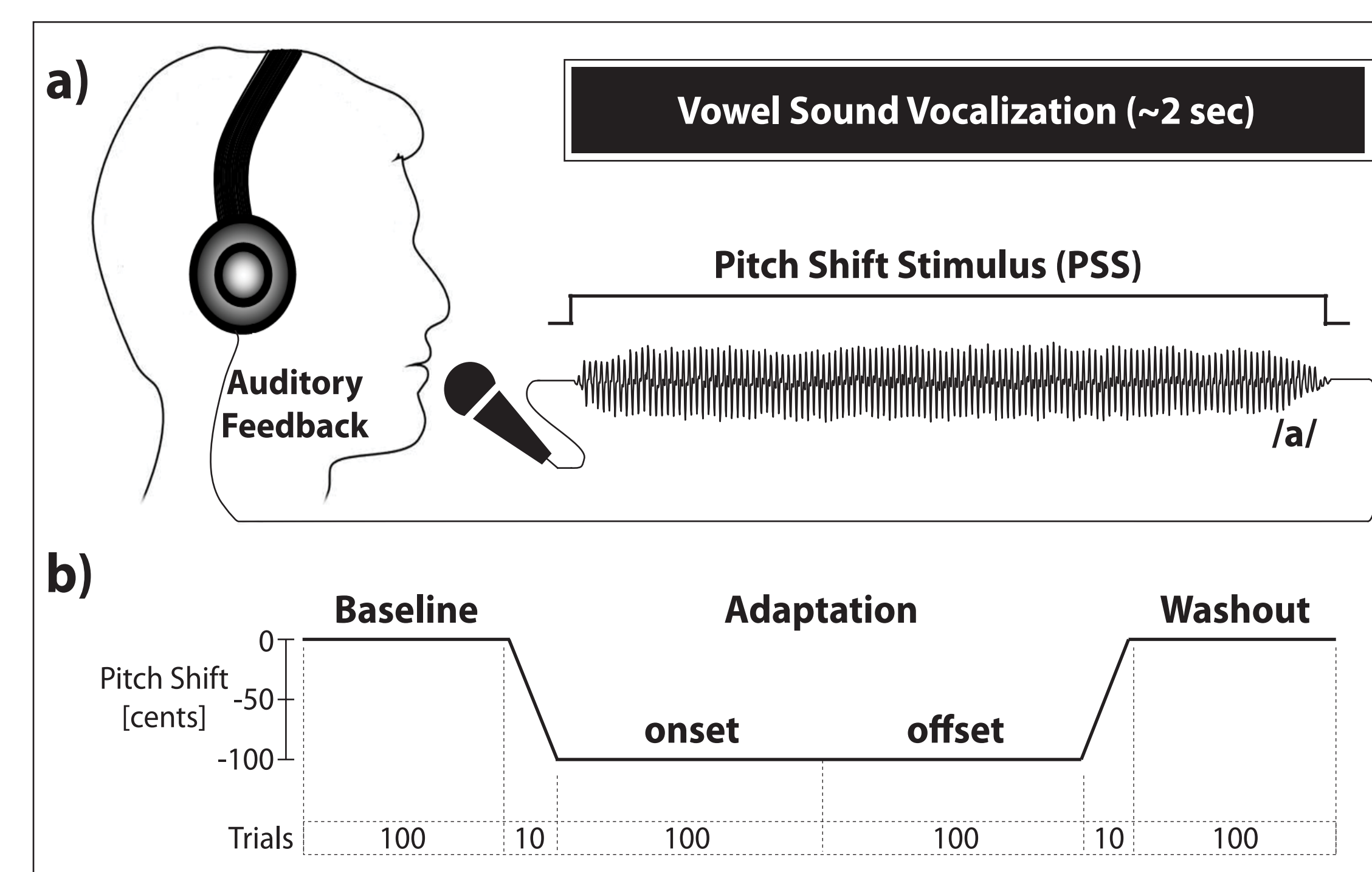
EEG recording

EEG signals were sampled at 1 kHz and recorded by 64 electrodes.

Behavioral vocal response

Vocal responses to pitch shift stimuli were calculated by extracting and averaging the pitch frequency contours (in cents) across all trials.

Results

Behavioral vocal responses

Vocal pitch output during baseline condition was relatively stable. Downward pitch shifts in auditory feedback were compensated for with a progressive change in voice pitch in the upward direction during adaptation that was maintained during washout.

On average, subjects compensated for 60.9% of pitch shifts in the auditory feedback during adaptation onset and 73.5% during adaptation offset. Vocal pitch output remained at 57.2% above baseline level during washout.
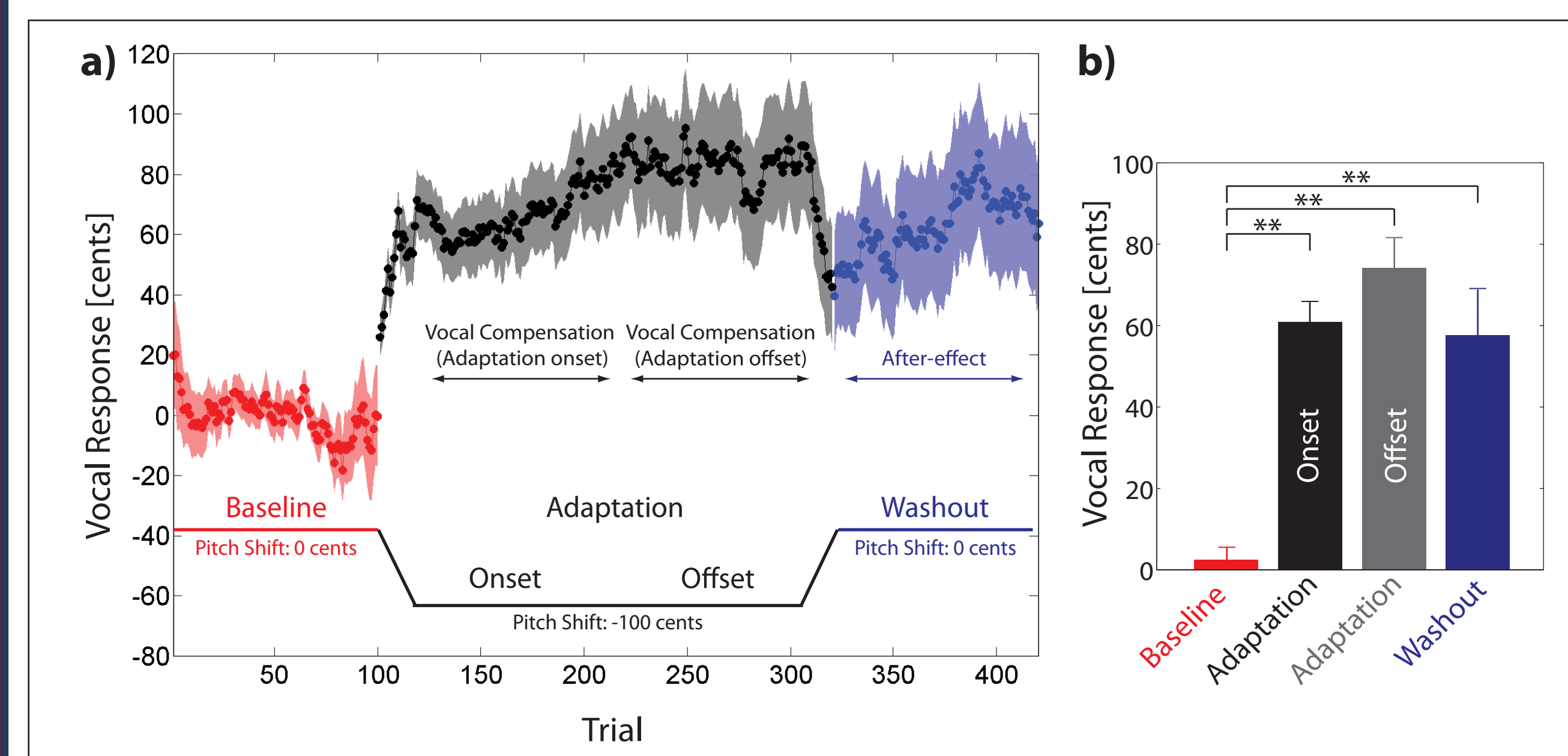

Figure 1. Results of the behavioral vocal response analysis: a) trial-by-trial profile of the grand-average (n=13) vocal responses during baseline, adaptation onset, adaptation offset and washout conditions. b) Bar plot representation of the statistical analysis for the differences between the mean of the grand-average vocal responses during baseline, adaptation onset, adaptation offset and washout conditions (** p<0.01).

ERP responses

During baseline trials, a left-lateralized ERP component over the temporal area was elicited in a time window from -100 ms to 200 ms after vocalization onset. This activity was diminished during adaptation and washout.

Pre-vocalization ERP activity was elicited from -100 to 0 ms prior to the onset of vocal production with centro-parietal distribution.

Post-vocalization ERP activity was elicited within 0-100 ms with parietal distribution and within 100-200 ms with central distribution after voice onset. ERP activities were of larger amplitude during adaptation onset.

Post-vocalization ERP activity was also elicited with fronto-central distribution from 200-500 ms with no significant difference in amplitude among all conditions.
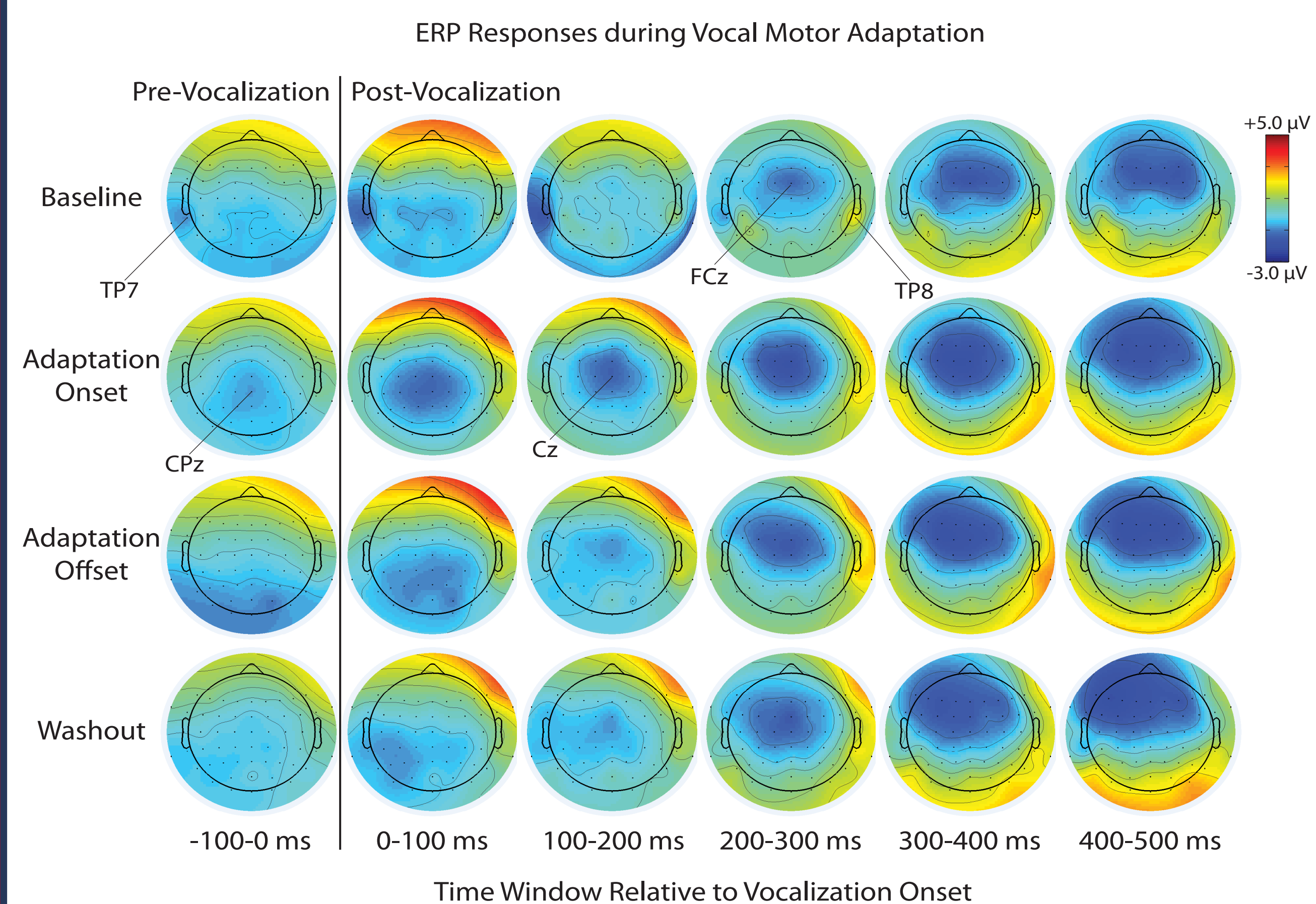

Figure 2. Topographical distribution maps of the ERP activity during baseline, adaptation onset, adaptation offset and washout conditions in 100 ms time bins within a window from 100 ms before to 500 ms after the onset of vocalization.
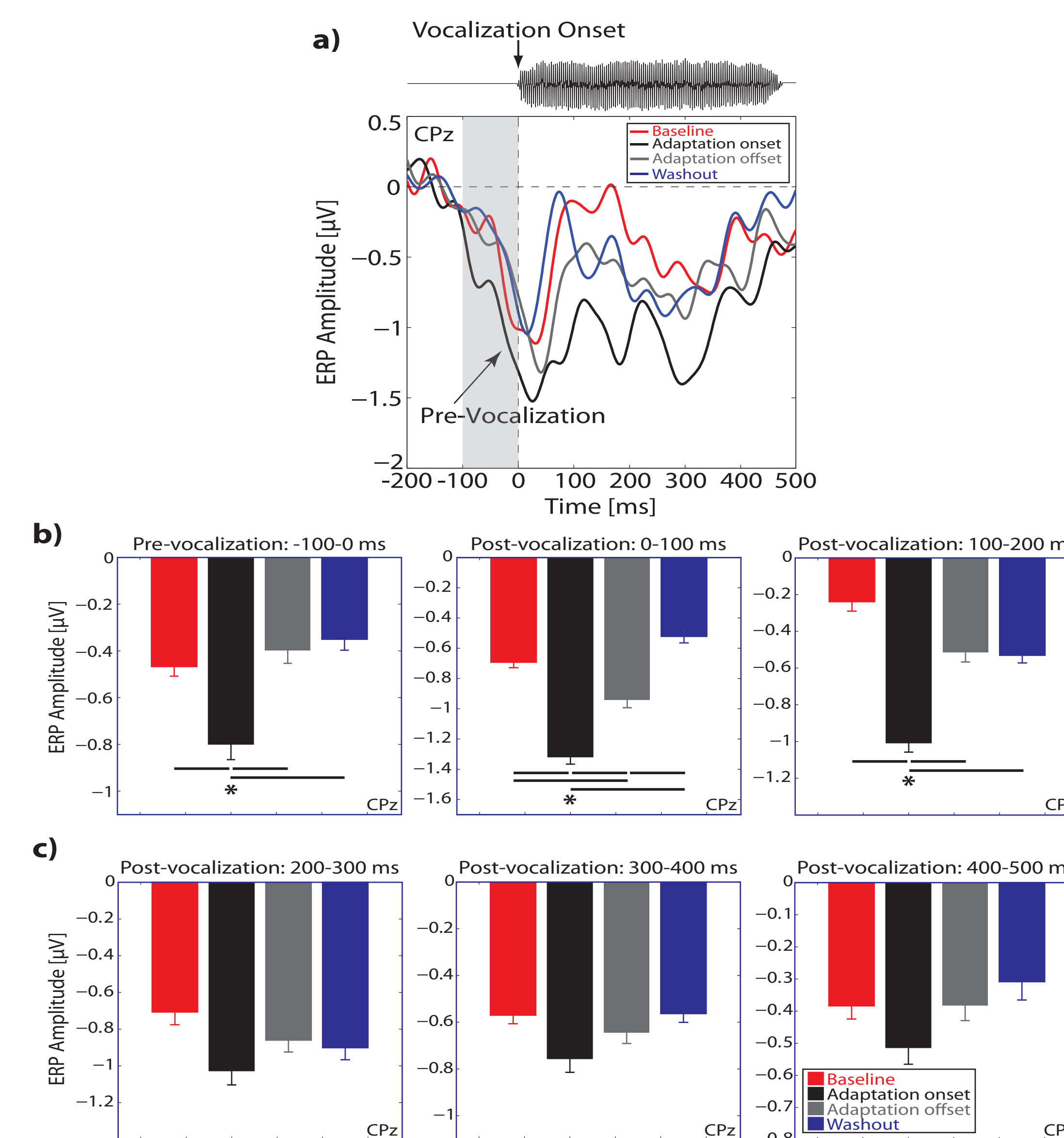

Figure 3. a) Profile of the grand-average (n=12) ERP responses in CPz (centro-parietal) electrode from -200 ms before to 500 ms after the onset vocalization overlaid across baseline, adaptation onset, adaptation offset and washout conditions. b and c) Bar plot representation of the post-hoc statistical analysis for the differences between grand-average ERP activities across all conditions in 100 ms time bins within a window from 100 ms before to 500 ms after the onset of vocalization. (* p<0.05)
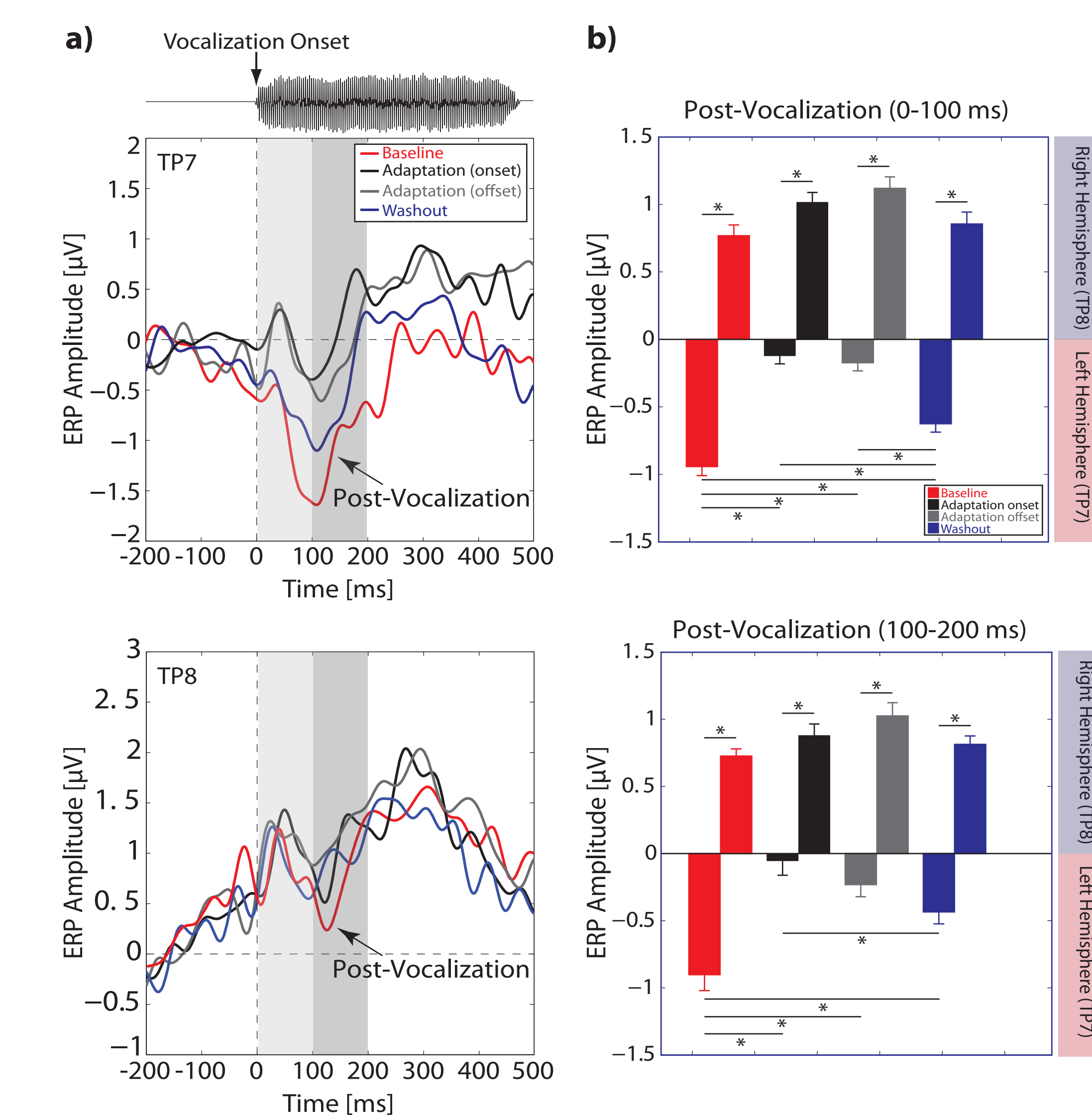

Figure 4. a) Profile of the grand-average (n=12) ERP responses in TP7 (left temporo-parietal) and TP8 (right temporo-parietal) electrodes from -200 ms before to 500 ms after the onset vocalization overlaid across baseline, adaptation onset, adaptation offset and washout conditions. b) Bar plot representation of the post-hoc statistical analysis for the differences between grand-average ERP activities in the left and right hemispheres and across all conditions in time windows from 0-100 ms and 100-200 ms after the onset of vocalization. (* p<0.05)

Results (cont.)

Correlation analysis

Distinct ERP response patterns that significantl correlated with the magntiude of vocal motor adaptation pre- and post-vocalization.
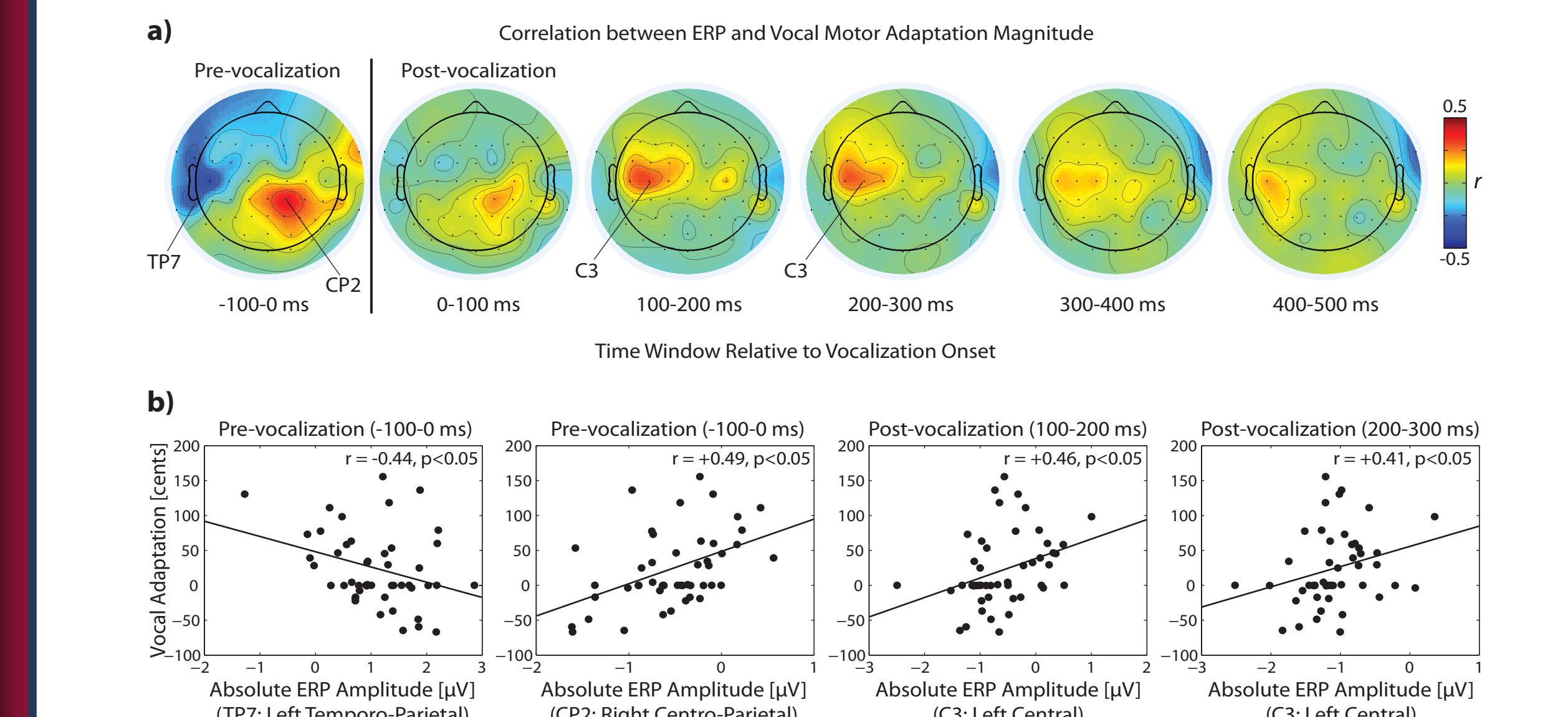

Figure 5. a) Topographical distribution maps of correlation between absolute ERP amplitudes and the magnitudes of vocal motor adaptation responses to pitch-shifted auditory feedback in 100 ms time bins within a window from 100 ms before to 500 ms after the onset of vocalization. b) The trend line plots of the significant correlation results in representative contacts before and after the onset of vocalization.

Discussion

We propose that our findings support the following:

Behavioral vocal motor adaptation is indicative of sensorimotor remapping of feedforward motor commands in response to pitch-shifted auditory feedback.

This is consistent with previous studies on altered auditory feedback [e.g., 4 - 10]. Moreover, modulation of ERP activity supports that:

Distinct neural substrates in the auditory (temporal), motor (central), and sensorimotor (parietal) cortical areas are involved in motor adaptation during vocal production under pitch-shifted auditory feedback.

Early stages of sensorimotor adaptation to pitch-shifted feedback involves increased contribution of the parietal cortex to incorporate auditory feedback for error detection and remapping of feedforward motor commands for error correction. However, as learning proceeds the error correction is internalized within the feedforward motor mechanisms of the frontal cortex and the contribution of the auditory feedback, and subsequently the interfacing parietal cortical mechanisms, are declined during vocal motor adaptation. Furthermore, we suggest that the process of error internalization is mediated by establishing an updated map of feedforward motor commands in the cortical motor areas of the left hemisphere.

References

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