A Temporal Predictive Code for Voice Motor Control: Evidence from Neurophysiology and Vocal Behavior

Roozbeh Behroozmand[1], Stacey Sangtian[1], Oleg Korzyukov[2], Charles R. Larson[2]

[1]Speech Neuroscience Lab, Department of Communication Sciences and Disorders, University of South Carolina
[2]Speech Physiology Lab, Department of Communication Sciences and Disorders, Northwestern University

Introduction

Background

Speech is a complex, goal-directed motor behavior developed to facilitate human communication. Execution and control of speech is believed to be driven by the effective integration of feedforward (i.e., internally-predicted) and sensory (e.g., auditory) feedback mechanisms to achieve optimal outcome [1]. Errors in prediction resulting from a mismatch between the internal prediction and actual sensory feedback are used to monitor and correct subsequent vocal motor behavior [2,3].

Recent studies have suggested that predictions about different aspects of auditory feedback stimuli (e.g., magnitude and direction of a pitch-shift stimulus) subsequently affects behavioral and neural responses during vocal production and motor control.

Objective

The present study investigated how predictions about timing of pitch perturbations in voice auditory feedback modulate ERP and behavioral responses during vocal production.

Questions

1 – How does temporal predictability of perturbations in auditory feedback modulate vocal responses?

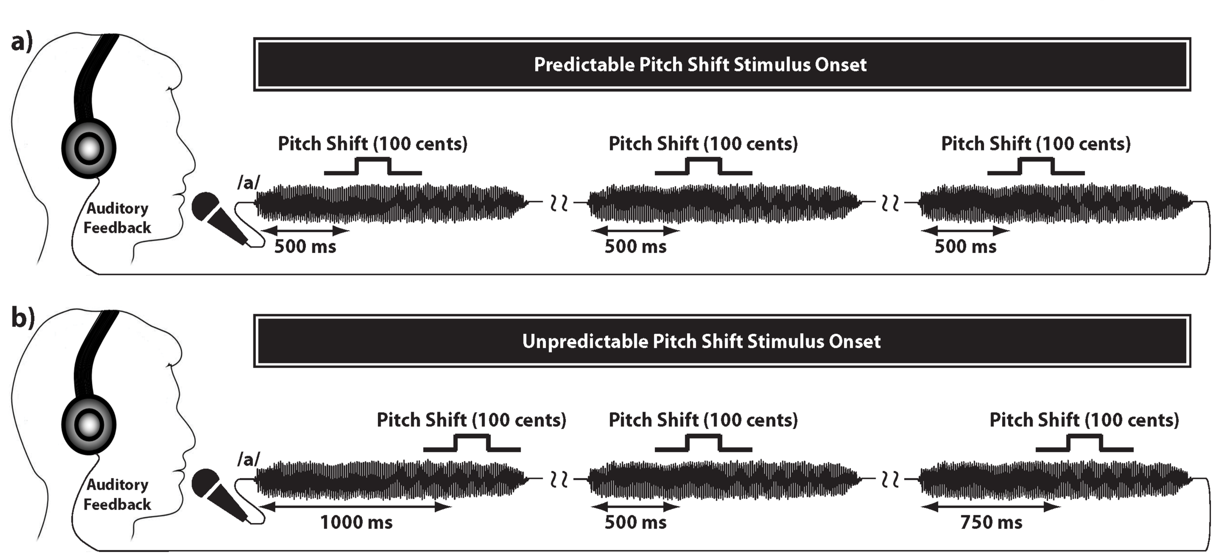
2 – What are the neurophysiological correlates that reflect expectancy of changes in auditory feedback?

Method

Experimental task

15 healthy subjects (6 male, 9 female) repeatedly produced steady vocalizations of the vowel sound /a/ and received brief (200 ms) upward pitch shifts (+100 cents) in their voice auditory feedback throughout six counterbalanced vocalization blocks.

In three blocks, there was a fixed delay of 500, 750 or 1000 ms between voice and pitch shift stimulus onset (predictable timing). In the remaining three blocks, the time delay between voice and stimulus onset was randomized between 500, 750 or 1000 ms (unpredictable timing).



EEG recording

EEG signals were sampled at 2 KHz and recorded by 32 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 to pitch shift stimuli

Predictability of temporal changes in auditory feedback modulated voice motor control.

In response to unpredictable stimuli, subjects produced compensatory (opposing) vocal responses that started at 80 ms after pitch shift onset. The magnitude of opposing responses was significantly larger at 500 ms compared with 750 and 1000 ms stimulus onset latencies.

In response to predictable stimuli, vocal responses followed the direction of the stimulus and were initiated 20 ms before pitch shift onset.The magnitude of following responses was not modulated across different stimulus onset latencies.

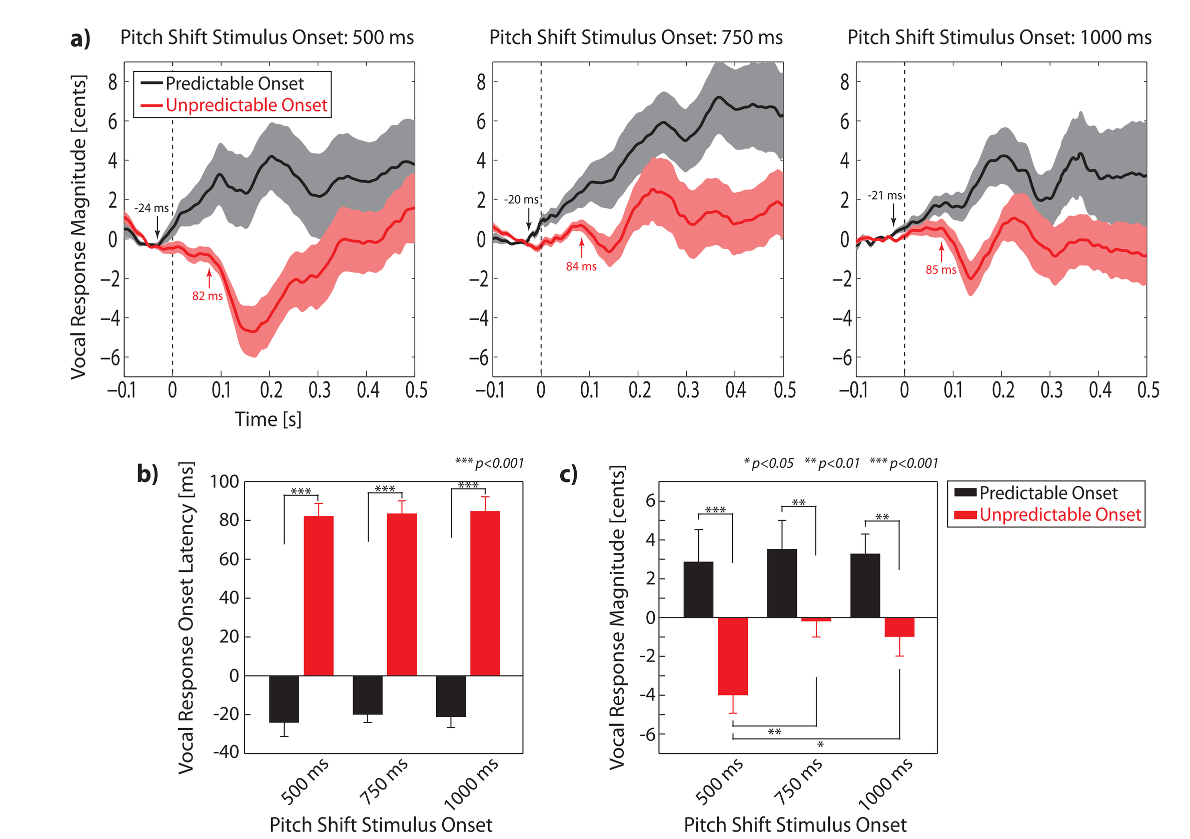


Figure 1. a) Behavioral vocal responses to pitch shift stimuli overlaid across predictable and unpredictable stimulus onset for three different stimulus onsets at 500 ms, 750 ms and 1000 ms. **b)** Bar plot representation of the results of analysis on the magnitude and onset latency of vocal responses to predictable and unpredictable pitch shift stimuli onset at 500, 750 and 1000 ms latencies.

ERP responses to pitch shift stimuli

Amplitudes of the N1 and P2 ERP components were significantly reduced in response to predictable compared with unpredictable stimuli.

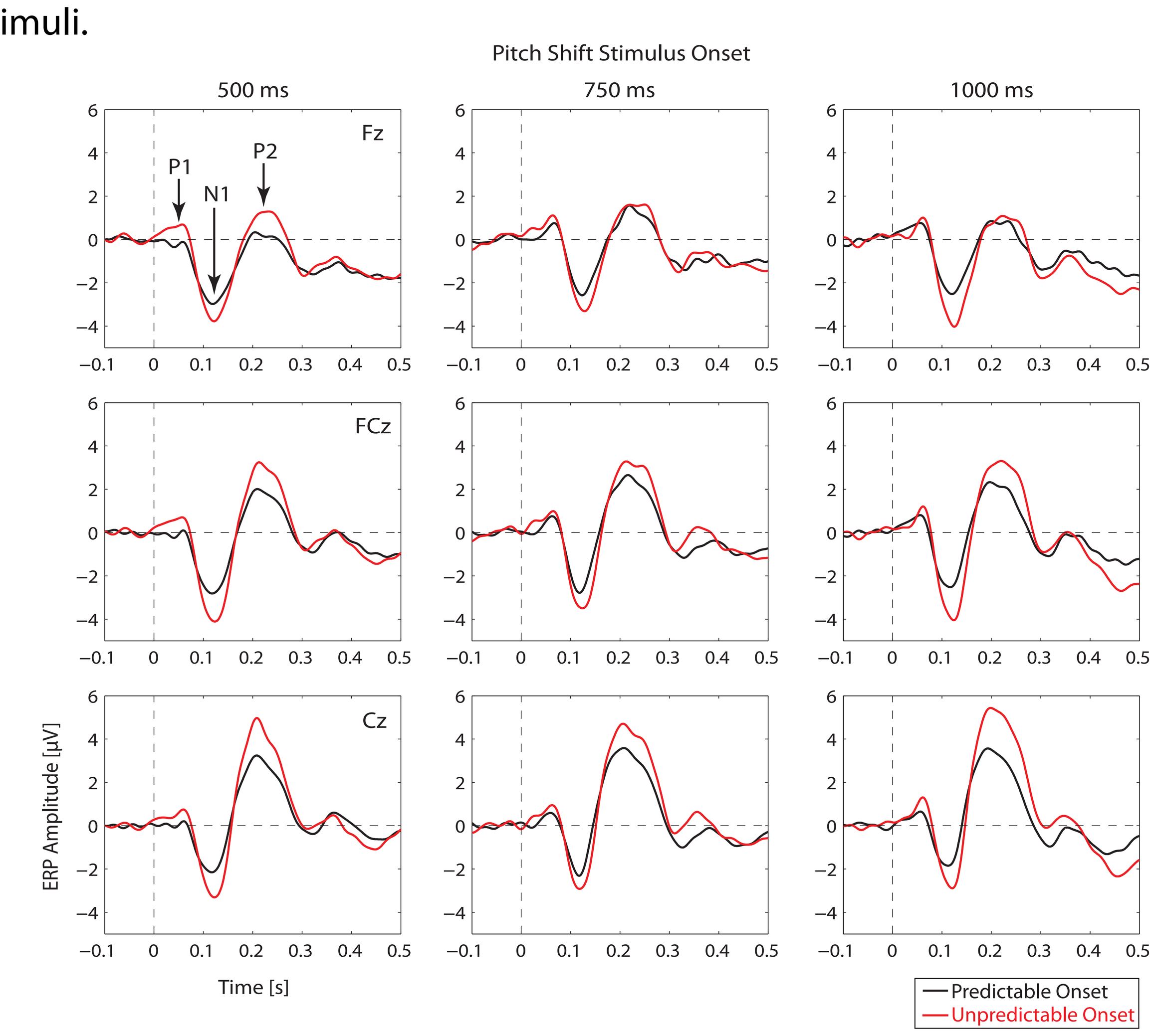


Figure 2. The overlaid ERP responses for predictable and unpredictable pitch shift stimulus onset at Fz, FCz and Cz electrodes plotted for each stimulus onset time, separately.

N1 responses were stronger over the fronto-central electrodes with an inverted polarity over the bilateral temporal areas.

The P2 component was distributed more posteriorly with stronger activity over the central electrodes and an inversion over the bilateral temporo-parietal areas.

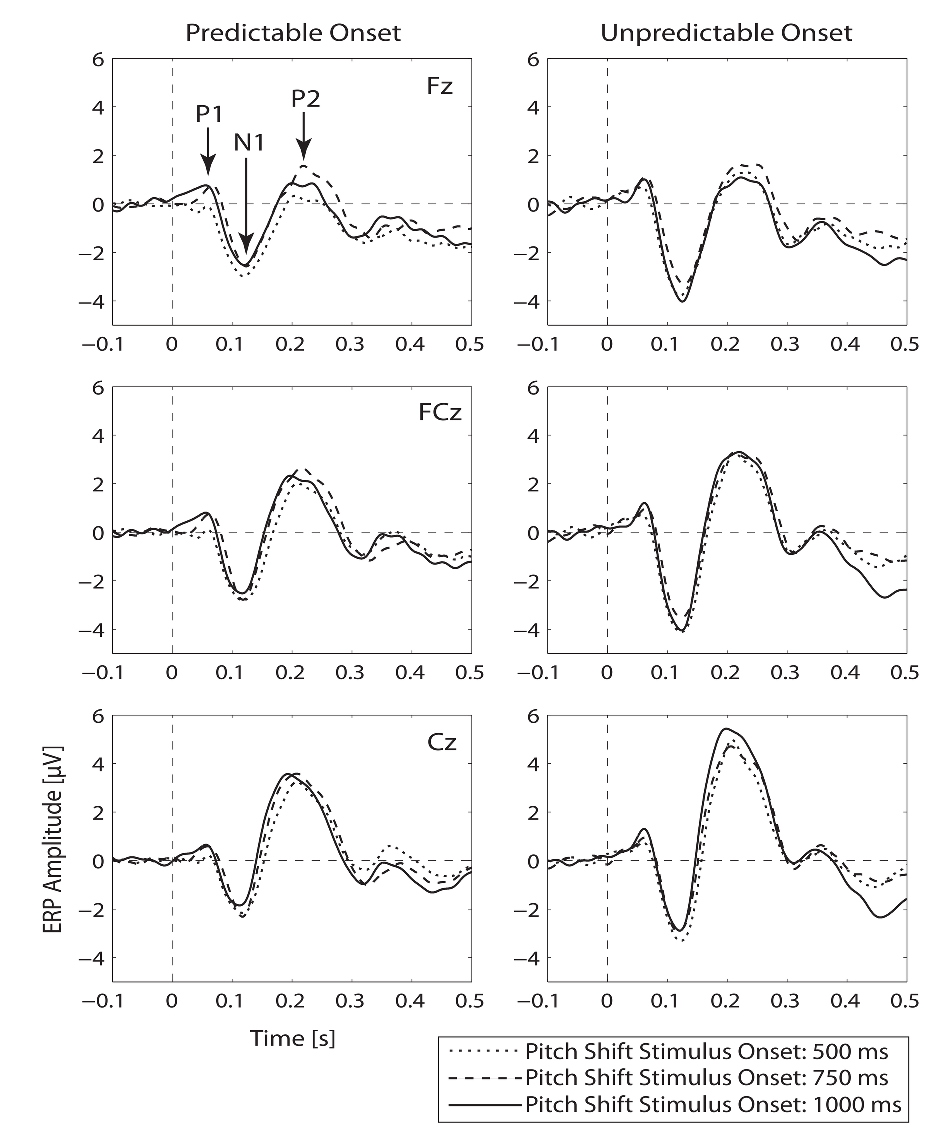


Figure 3. The ERP responses overlaid across all three stimulus onset times (500, 750 and 1000 ms) plotted separately for predictable and unpredictable pitch shift stimulus onsets at Fz, FCz and Cz electrodes.

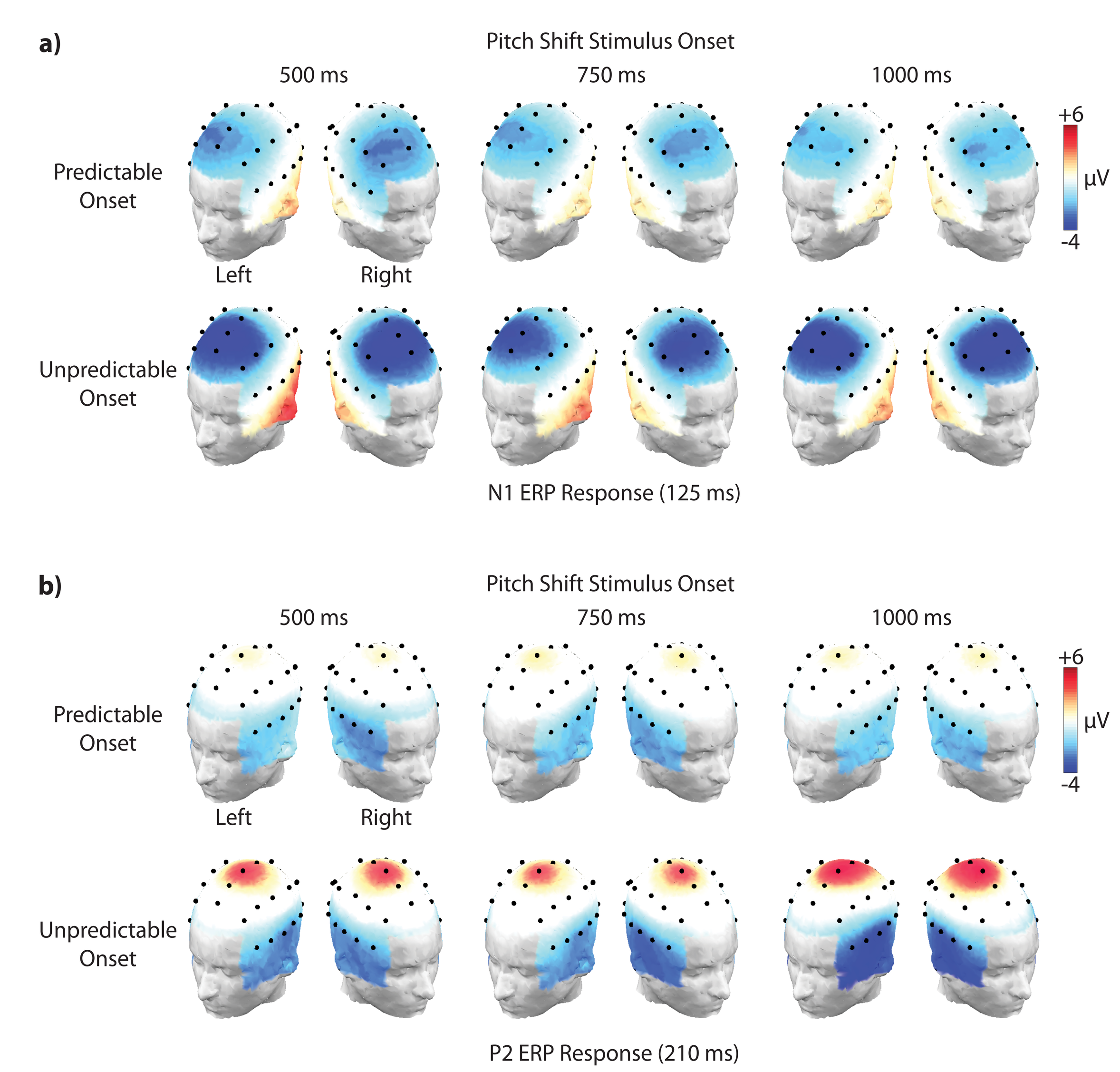


Figure 4. The topographical distribution maps of the scalp-recorded potentials in response to predictable and unpredictable pitch-shift stimulus onsets for **a)** the N1 and **b)** the P2 ERP components.

Discussion

We propose that our findings support the following notions:

Exposure to repeated presentations of predictable stimuli results in the *increased contribution of feedforward mechanisms* during vocal motor control

This is in line with previous studies which suggest that expectancy of the predictable stimulus eventually develops into recognition of the perturbation as being an external stimulus thereby leading to reduced vocal compensation (i.e., opposing responses) and a change in allocation of neural resources as reflected by modulation of the N1/P2 components [4,5]. This reasoning supports the framework for predictions by the internal forward model:

Learned predictions result in *more accurate efference copies.*

Consequently, a decreased mismatch in sensory feedback thereby leads to a reduced need for neural processing resources [4,5,6,7,8].

Therefore, results from our study indicate that:

Neural mechanisms of auditory feedback processing is *sensitive to timing* between the vocal motor commands and the incoming auditory feedback.

As such, the observed suppression effect in ERP responses is not merely a movement-related non-specific effect.

Acknowledgement

This research was supported by NIH Grant No. 1R01DC006243.

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