Cortical influences on brainstem FFR during productions whilst speakers hear their own voice

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The current study focused on investigating the relation between the cortical and brainstem levels in falling and rising tones during self production. The goal was to see whether the techniques used to investigate shadowing could be employed to situations where the speaker heard their own voice (auditory feedback). This involved solving the tricky problem of generating a synchpulse that was sufficiently precisely coordinated with the produced speech sound to allow sensible averaging (for the FFR and concurrent cortical activity). We report results demonstrating the success of our procedures for FFR responses and concurrent cortical measures. Results are reported on cortical components (early N1 component and later P2 component) and parameters reflecting the fidelity of the brainstem FFR.

INTRODUCTION

- The amplitude of early **cortical ERP responses** such as N1 and P2 is reduced by a concurrent speech task (Agnew et al. 2013; Chen et al. 2012; Numminen & Curio 1999; Paus et al. 1996).
- Production of Mandarin falling versus rising tones are actions where the brain mechanisms that control the laryngeal muscles may differentially weight on N1 and P2 components. One hypothesis is that a falling tone needs early control of laryngeal muscle tension that can then be passively released whereas a rising tone needs laryngeal tension to be controlled over the whole length of the syllable carrying the tone (Howell et al., 2012).
- **Brainstem frequency following response** (FFR) has been shown to reflect considerable fidelity of different acoustic features of speech, especially the fundamental frequency (F0) (Kraus & Nicol, 2005).
- **What has only rarely been investigated is how cortical and brainstem networks interact during speech perception and production**. Walczak et al (2014) recorded ABRs and ERPs while participants listened to, shadowed (repeated simultaneously) or tapped synchronously to the auditorily presented [da] syllable. Cortical ERPs showed that **N1 was involved with falls and P2 with rises**. Second, the **cortical-brainstem correlations indicated some evidence for Enhanced Production (EnhPro) control when falls were produced, and firmer evidence for Enhanced Perception (EnhPer) when rises were perceived**. Furthermore, **when rises were produced, the EnhPer effect was supressed** (cortical activity worked indirectly on production by suppressing the EnhPer effect on rises). What Walczak et al. could not rule out was that the reduction in the FFR and cortical responses by simultaneous production might have been affected by the participants hearing their own voice which could have suppressed activity of the auditory pathway without any reference to auditory-motor interaction.

The main research questions

1. Does cortical activity differ across perception, silent mouthing (speech motor activity control), production (speech shadowing) and self-production (production of [da] without hearing the auditory stimulus) tasks?
2. Is it possible to reliably measure FFRs during self-production and how do the FFRs differ from shadowing?
3. Are cortical measures in tone production (shadowing and self-production) and perception (passive perception and silent mouthing) associated with changes in the fidelity of FFR measures that reflect how accurately pitch is represented at the brainstem level?

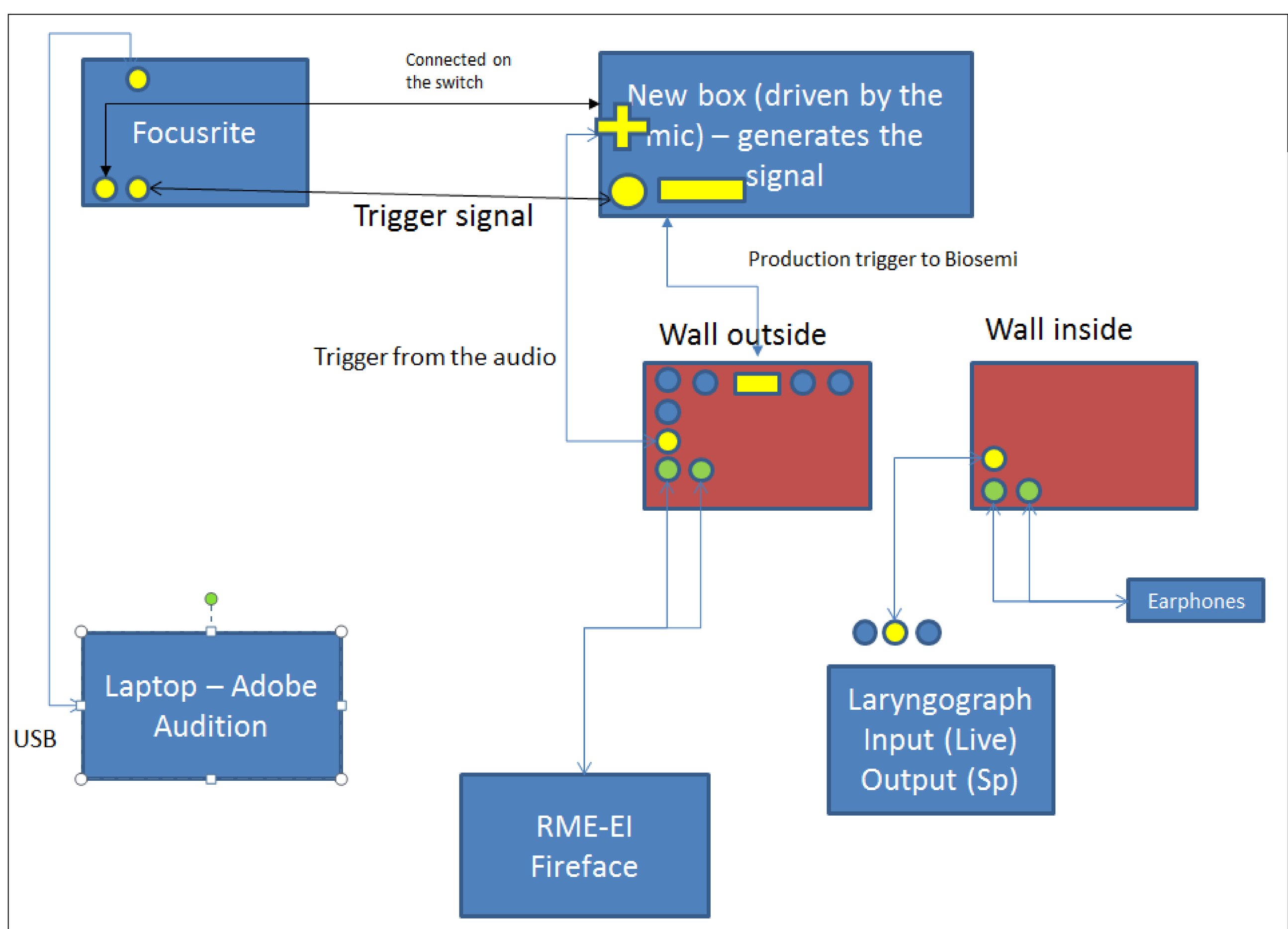

Fig. 1. Schema of the set-up used in the Self-production condition.

PARTICIPANTS

Eight native Mandarin speakers (age range 19-23 years) took part. All participants had normal hearing, and were right-handed females.

MATERIALS

The stimuli were synthetic [da] syllables used as a standard stimulus in many ABR studies (e.g. Russo et al., 2004). The original [da] syllable was given a fall or rise pitch movement and female gender using Praat (Boersma & Weenink, 2013). The pitch of the stimulus with the rise tone started at 189 Hz and rose linearly to 269 Hz over 170 ms. The pitch of the stimulus with the fall tone started at 255 Hz and fell to 166 Hz again over 170 ms.

BRAINSTEM FFR & CORTICAL EVENT-RELATED POTENTIAL ANALYSES

- EEG recorded using 35 active electrodes according to the 10-10 system (SR 16KHz).
- FFR (Cz referenced to the seventh cervical vertebra) and analysed using the Brainstem Toolbox (Skoe & Kraus, 2010).
- The cortical ERPs were analysed using nine electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4) covering the anterior-posterior and left-right hemispheres to quantify N1 and P2 responses. The Fp1 electrode was used to record eye movements. Before artefact rejection, Independent Component Analysis (EEGLAB, Delorme et al 2004) was employed to remove eye movement artefacts. N1 and P2 responses were analysed separately, first for cortical influences and then for cortical-brainstem correlations, respectively. Repeated measures ANOVA with factors components, electrodes, tone and task was used to analyse the cortical data.

RESULTS

Frequency following response: The *fidelity of pitch representation* was quantified using **pitch error** statistic (the absolute distance in Hz that the response pitch deviates from the stimulus pitch on average across the duration of the stimulus). The second measure was *Fundamental frequency (F0) correlation* (Pearson's *r* between the stimulus-track and the response-track). The averaged FFR response for rising and falling tones in the perception and production tasks are shown for one participant in **Figure 2.**

The main statistically significant differences between conditions were found in the pitch error suggesting that the fidelity of the F0 was compromised when production task was involved.

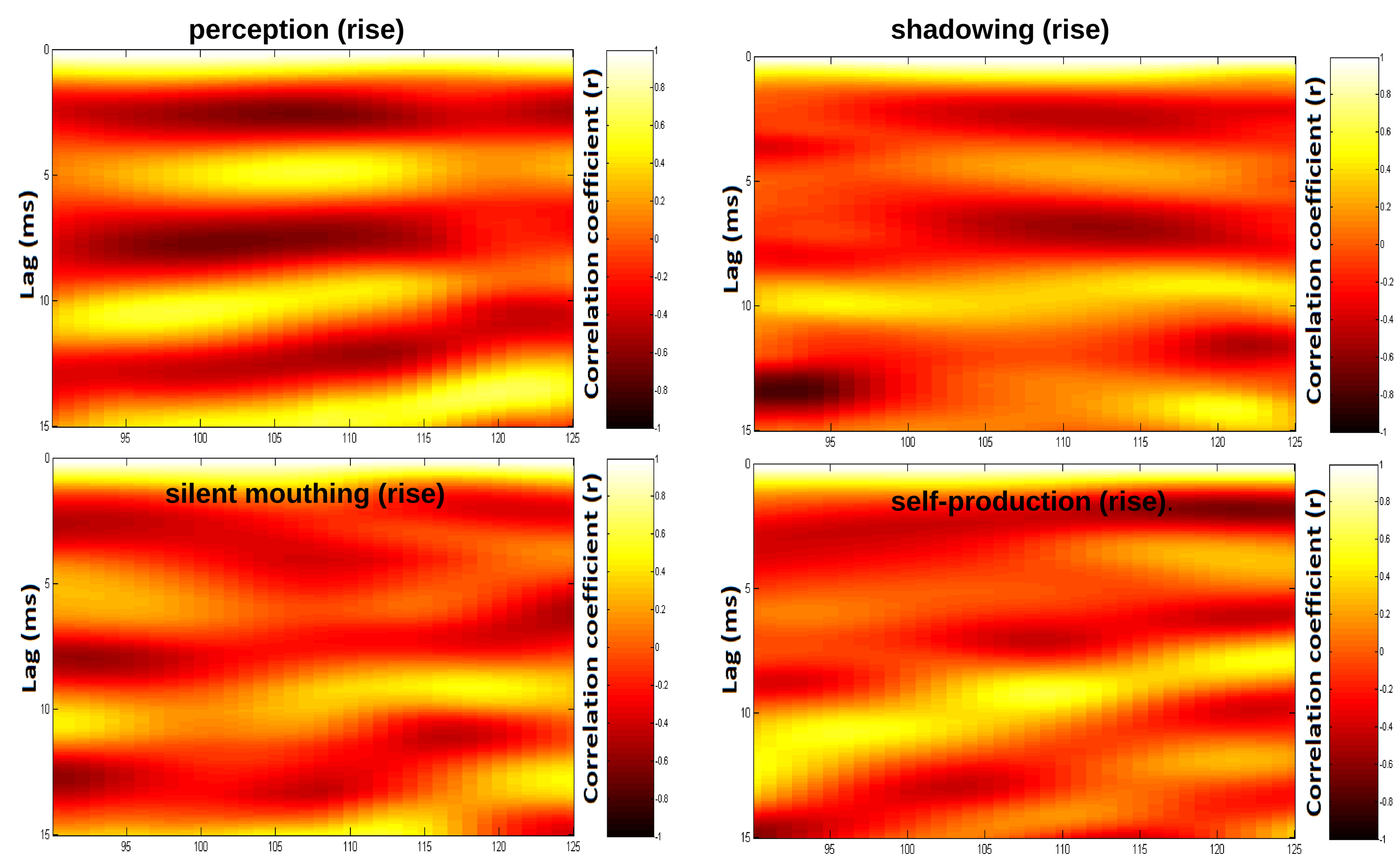

Fig. 2. Autocorrelogram showing FFR responses for one participant. Time (in ms) is on the x axis and the y axis is transformed to provide a plot that tracks fundamental frequency. The brightest colours indicate highest positive correlations. **No clear differences between shadowing and self-production were found**.

Cortical responses:

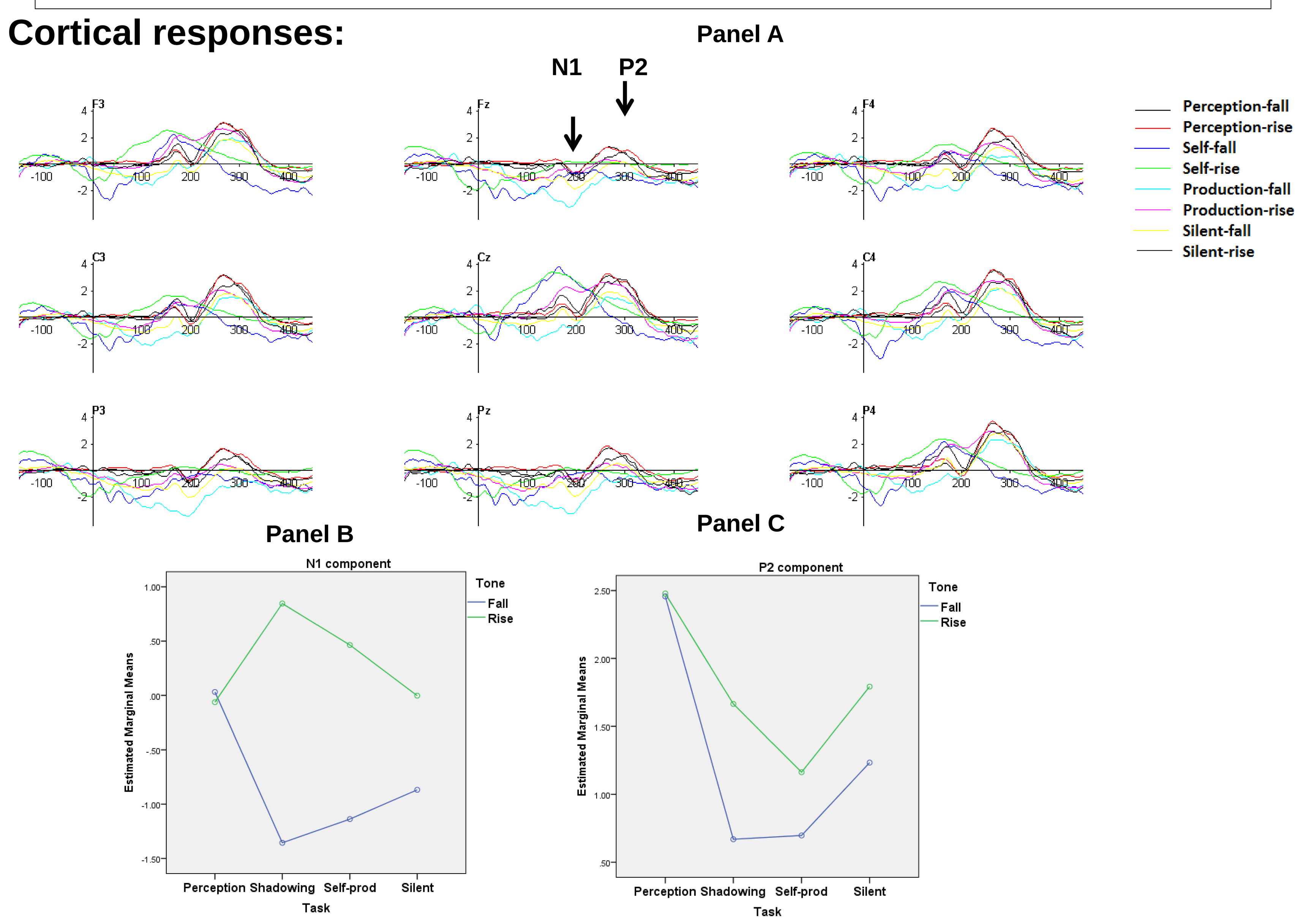

Fig. 3. Cortical ERPs in the eight different experimental conditions. Panel A shows the waveforms for all electrodes and conditions. Panel B (N1 response) and C (P2 response) show the mean amplitudes in microvolts for a significant Task by Component or Component by Tone interaction.
The results indicate a reduced N1 response in speech production in the fall tone condition (blue line) but not in rise tone (green line), and a larger P2 response in the fall condition (green line) compared to the rise condition (blue line).
No significant correlations between the FFR parameters and N1/P2 responses were found.

SUMMARY

- N1 is more involved with falls and P2 with rises (replication of Walczak et al. 2014), see above the EnhPro and EnhPer accounts.
- We successfully showed that cortical and brainstem responses can be recorded during self-production.
- The results suggest that production and perception of rise and fall tones have different effects on the cortical-brainstem interactions.

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