Influence of Attention on Speech Error Correction Performance and EEG Mu Rhythm Brain Response

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INTRODUCTION

Understanding the role of higher-level cognitive processes in speech sensorimotor integration is a topic that has received limited research attention. While progress has been made in uncovering the neuro-computational mechanisms involved in speech production [1-5], the specific contribution of higher-level cognitive processes to such mechanisms remains largely unclear.

Controversy exists among previous models in the field of speech sensorimotor integration. Levelt's model [1] proposed a higher-level conceptualizer system, serving as an interface between speech comprehension and production, facilitating error detection and correction. However, more recent models, such as Wernicke-Lichtheim's model, the state feedback control model, and the DIVA model, suggest an alternative pathway directly linking auditory and motor systems for speech error detection and correction [2-5]. These latter models propose a two-pathway system: a direct auditory-motor loop utilizing internal models without higher-level cognitive mechanisms, and an indirect auditory-conceptualizer-motor loop involving higher-level cognitive processes. These debates highlight the need for further research to gain a deeper understanding of the specific mechanisms and contributions of higher-level cognitive processes in speech sensorimotor integration.

The current study aimed to compare speech compensation magnitudes and the EEG time frequency (theta, alpha, low beta, high beta, and gamma bands) between attention-focus instruction and no-attention-focus-instruction conditions, and to examine the association between these variables. Additionally, our study aimed to examine the linear association between the EEG time-frequency data and the performance of the attentional task.

MATERIALS AND METHODS

Participants: Two independent and randomized groups of 21 (14 females; age range: 52-74 yrs; mean age: 62 yrs) and 23 subjects (17 females; age range: 55-87 yrs; mean age: 64 yrs) were recruited for this study to participate in the focal-attention and no-attention experimental conditions, respectively. Subjects in both groups had no history of speech, language, hearing, or neurological disorders and passed a binaural hearing screening at 40 dB threshold for frequencies at 250, 500, 1000, and 2000 Hz.

Experimental Task: The altered auditory feedback (AAF) paradigm was used to investigate speech control mechanisms (**Fig. 1**). Subjects produced steady vocalizations of the speech vowel sound /a/ for approximately 2–3 sec while receiving a 200 ms pitch-shift stimulus at ±100 cents at 750–1250 ms delays following the vocalization onset. Subjects in the focal-attention group were explicitly instructed to pay attention to their speech auditory feedback and press a green button (Yes) to indicate the detection of pitch-shift stimuli and press a red button (No) for the absence of pitch shifts in control trials. No such instruction was given to subjects in the no-attention group.

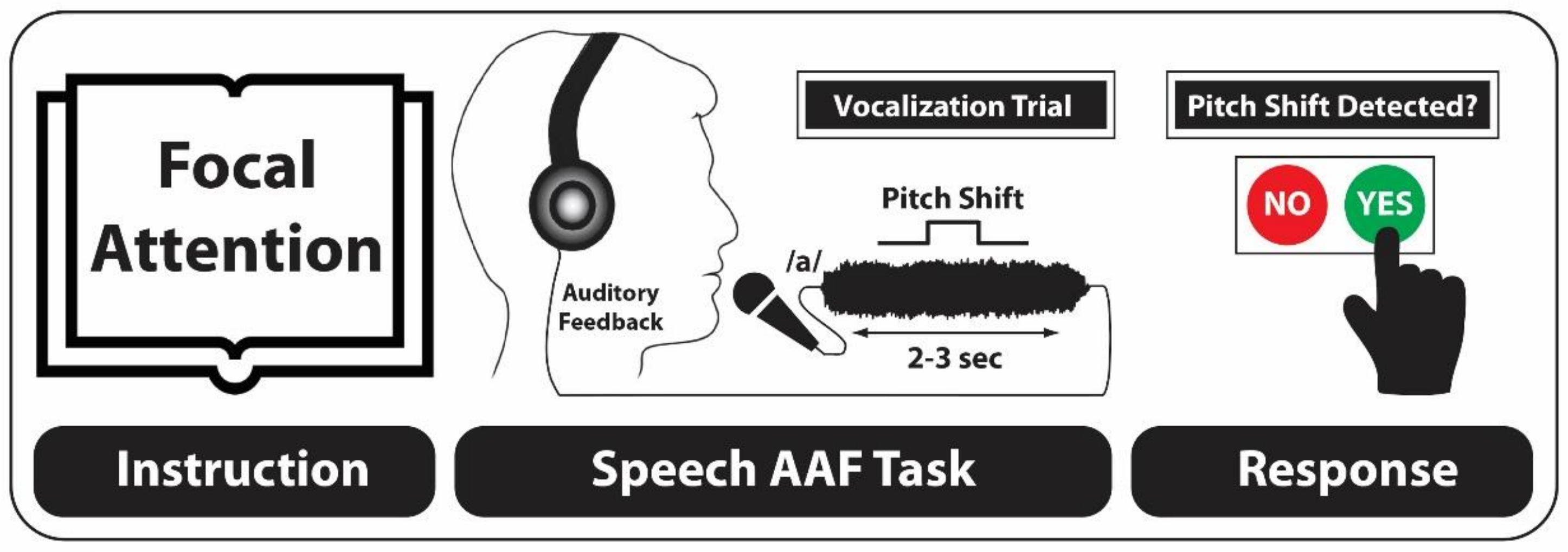

Fig. 1. The altered auditory feedback (AAF) experimental paradigm.

Data Analysis: Pitch frequencies were extracted to calculate speech compensation response magnitude. Pitch contours were averaged for each individual across all trials for pitch shifts, and individual pitch contours were averaged across all subjects. EEG data were preprocessed and extracted into different frequency bands (theta, alpha, low beta, high beta, and gamma). The time-frequency data was averaged over all 64 channels to obtain the global field power (GFP).

RESULTS

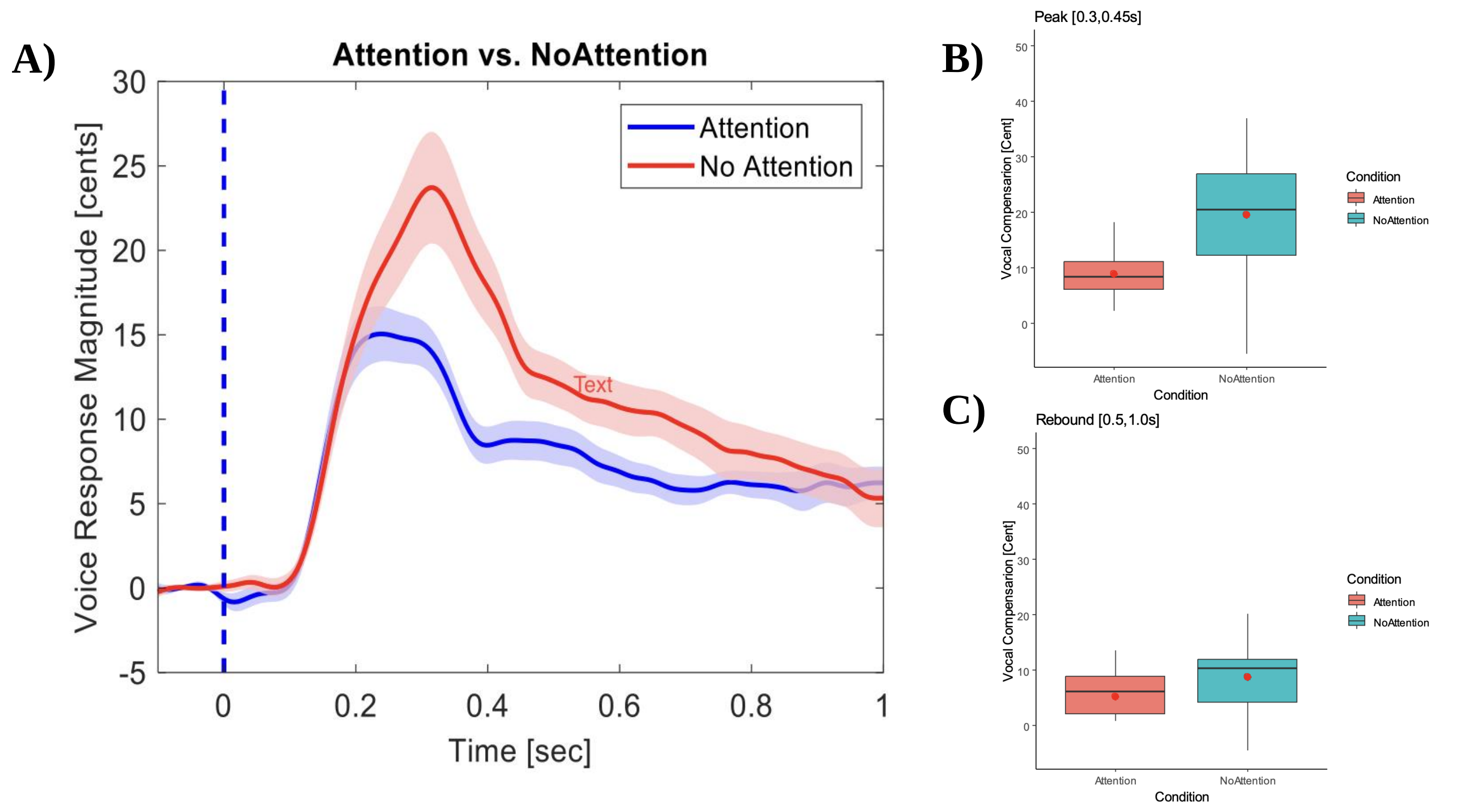

Fig. 2. A) the combined grand-average speech compensation responses of the two groups as they performed the AAF task in both focal-attention and no-attention experimental conditions. The ANOVA model revealed a significant effect of interaction between the condition (attention *vs.* no attention) and phase (peak *vs.* rebound) on speech compensation (t_{82} = -2.171, $p < 0.0328$, power = 0.42). **B)** The t-test results revealed smaller peak magnitudes of speech compensation for the attention compared with the no-attention group ($t_{29.9} = -3.925$, $p = 0.0005$, $\eta_p^2 = 1.1791$). **C)** No significant difference was found in the speech compensation rebound period between the two groups ($t_{39.4} = -1.975$, $p = 0.0554$, $\eta_p^2 = 0.5989$).

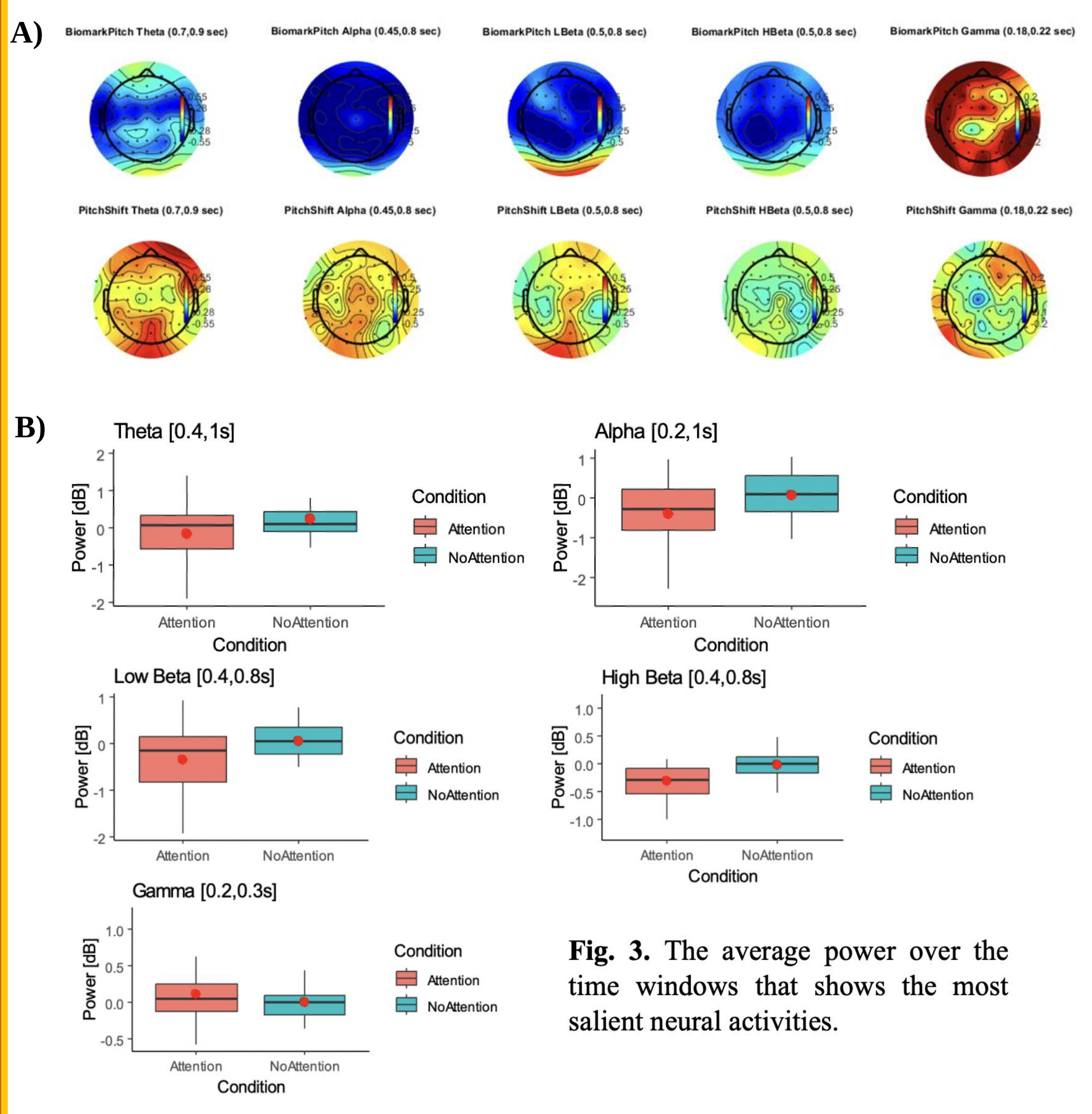

Fig. 3. The average power over the time windows that shows the most salient neural activities.

Fig. 3. The high beta band for the attention group was significantly higher than the no-attention group after multiple comparison corrections ($t_{33.2} = -2.839$, $p = 0.0077$, $\eta_p^2 = 0.8752$). Moreover, after multiple comparisons, there was no significant difference between the attention and no attention group in theta ($t_{37.4} = -2.198$, $p = 0.0343$, $\eta_p^2 = 0.6747$) and alpha ($t_{32.4} = -2.284$, $p = 0.0291$, $\eta_p^2 = 0.7048$) bands, although the p-values were significant before multiple comparison correction. Further, we did not find any significant effect of attention in the low beta ($t_{34.8} = -1.6806$, $p = 0.1018$, $\eta_p^2 = 0.5173$) and gamma bands ($t_{32.3} = 1.103$, $p = 0.0982$, $\eta_p^2 = 0.5254$`).

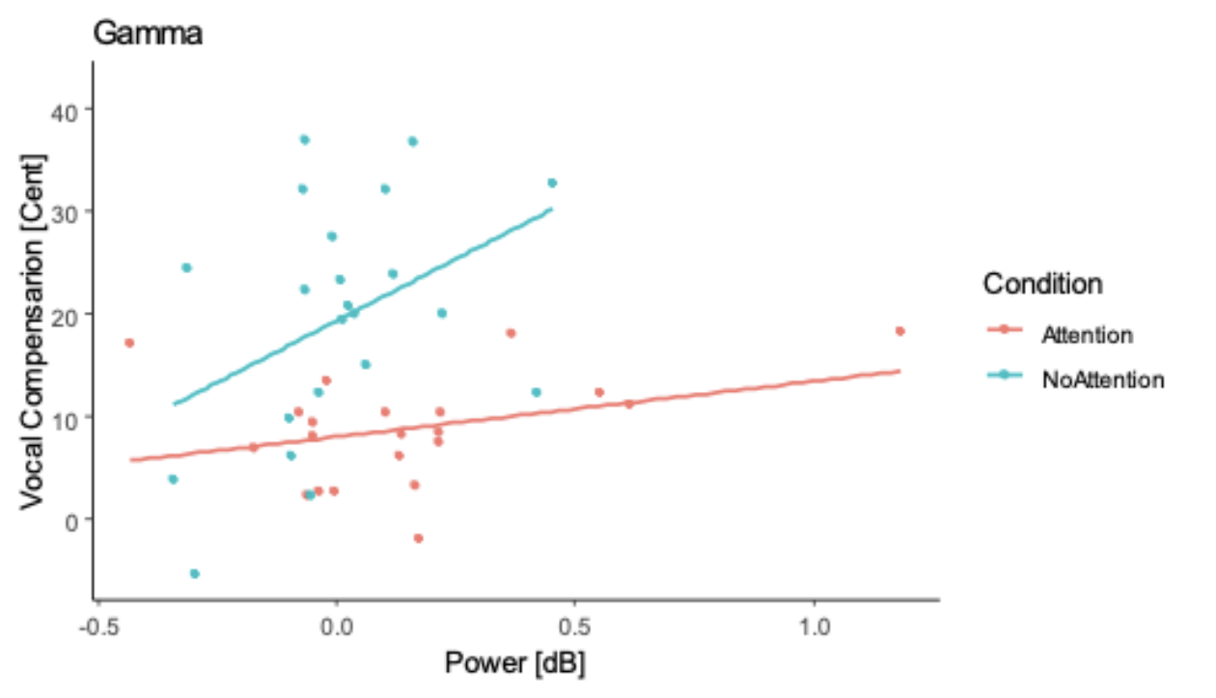

Fig. 4. The linear regression model revealed a positive association between gamma band neural oscillation and speech compensation peak magnitudes while controlled for condition ($t_{40} = 4.43$, $p = 0.0421$, power = 0.995).

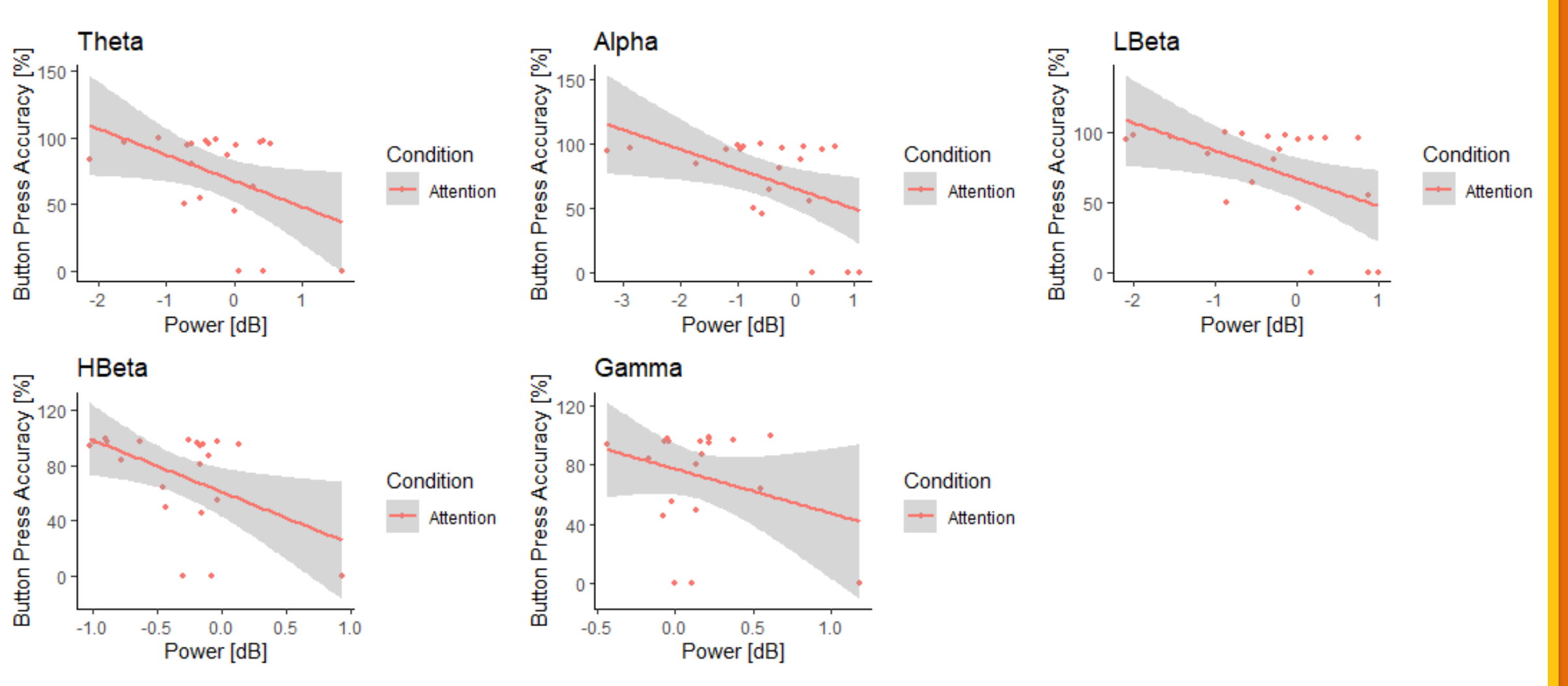

Fig. 5. The correlation model showed that there were positive relationships between the button press accuracy and alpha ($t_{19} = -2.458$, p = 0.0238, power = 0.92), low beta ($t_{19} = -2.545$, p = 0.0198, power = 0.92), and high beta ($t_{19} = -2.472$, p = 0.0231, power = 0.92) bands after FDR multiple correction. The data also indicated a significant positive association between button press accuracy and the theta band ($t_{19} = -2.198$, p = 0.0405, power = 0.92) before multiple comparisons, but this association was not found to be significant after FDR correction. In addition, there was no association between the gamma band and button press accuracy ($t_{19} = -1.305$, p = 0.208, power = 0.92).

DISCUSSION

Our study provides support for the idea that directing attention to auditory feedback improves speech error detection and sensorimotor processing. This is evidenced by the increased desynchronization of high-beta band power observed during the attentional compared to non-attentional task. Furthermore, the significant linear association between neural and behavioral responses to auditory feedback alterations suggests that gamma band activity may encode the correction of auditory prediction errors using efference copies of speech-motor commands. This implies that gamma band responses could reflect the neural state of the sensorimotor system, potentially serving as an internal model that translates auditory error signals into corrective motor commands for speech compensation.

Additionally, the positive relationships observed between button press accuracy and alpha, low beta, and high beta bands indicate that these frequency bands may be involved in higher-level cognitive processes in the brain. Lastly, our finding of reduced speech compensation in the attention-focus-instruction group suggests that attentional instructions may enhance the processes underlying speech feedback error correction.

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