Neural Underpinnings of Phonotactic Rule Learning

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In a nutshell

Study Aim: To observe the neurophysiological measures of phonotactic rule violation.

Question: What is the brain response to the violation of non-adjacent phonotactic patterns?

Results: After an implicit learning task, the brain quickly formed predictions reflected in the P300 wave.

Conclusion: Violations of non-adjacent phonotactic rule elicits a P300 response.

Why is this IMPORTANT? This preliminary result will pave the way for computationally more difficult rules.

Theoretical Background

MMN is reported in response to regularity extraction from non-adjacent sounds (Bendixen et al., 2012).

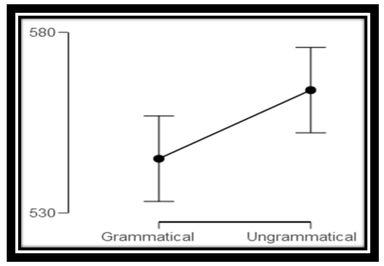
Bekinschtein et al. (2009) and Wacongne et al. (2011) found a double dissociation between the early MMN and P3b in response to non-linguistic auditory rule violations.

Domahs et al. (2009) and Moore-Cantwell et al. (forthcoming) reported a higher amplitude LPC to novel words that violated a learned phonotactic constraint than novel words that satisfied it.

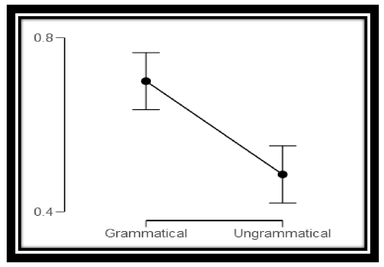
Behavioral Results

Ungrammatical words were detected with a mean sensitivity of 0.557 (d'), a score significantly different from zero, t(23)=3.34, p=0.003, d=0.684, 1-β=0.894.

Mean ACC of grammatical words was .70 (SD=.14) and .48 (SD=0.19) for ungrammatical. The difference was significant t(23)=4.78, p<0.01, d=.976, 1-β=.999.

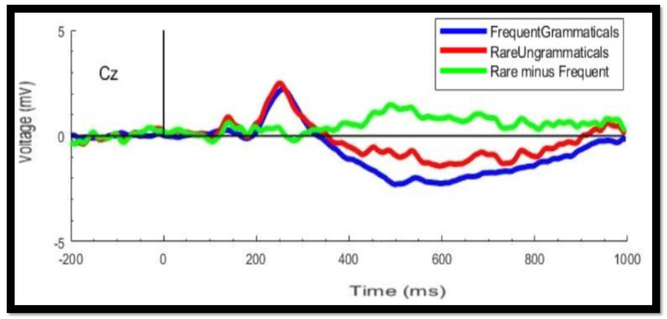


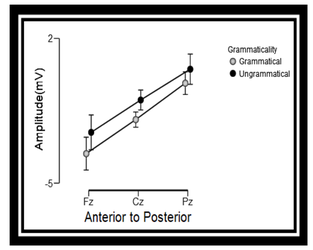
Mean RT was 545 ms (SD=106) for grammatical words and 564 ms (SD=119) for ungrammatical. The difference was significant, t(23)=2.349, p=0.028, d=.479, 1-β=.736).

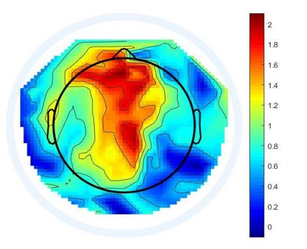


EEG Results

Stimulus-Locked

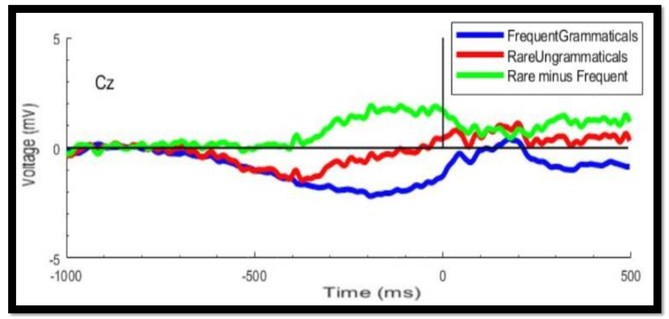


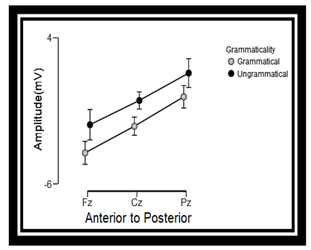


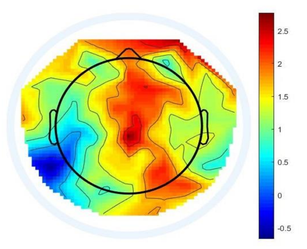


Stim-locked P3 mean amplitude (μV) shows a significant region effect: F(1,23)=31.415, p<.001, η^2=.577, 1-β=0.999; and a grammaticality effect: F(1,23)=11.436, p=.003, η^2=.332, 1-β=0.875. P3 amplitude difference was significant between grammatical and ungrammatical words (t(23)=3.38, p=0.003, d=0.690, 1-β=0.948.), especially at Cz.

Response-Locked







Response-locked P3 mean amplitude (μV) shows a significant region effect: F(1,23)=44.650, p<.001, η^2=.660, 1-β=0.999; and a grammaticality effect: F(1,23)=12.499, p=.002, η^2=.352, 1-β=0.910. P3 amplitude difference was significant between grammatical and ungrammatical words (t(23)=3.535, p=0.002, d=0.722, 1-β=0.962.), especially at Cz.

The main P3 measurements were taken from rare-minus frequent difference waves. It was measured at frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) electrode sites. Amplitudes were measured as the mean voltage in a given measurement window (Stim-locked P3 400 to 700 ms and Resp-locked P3 -200 to -100 ms, following Luck (2009)). Analysis of variance (ANOVA) was used with the Greenhouse-Geisser epsilon correction for non-sphericity. The P3 analyses included factors of region (frontal, central, parietal), and grammaticality (grammatical, ungrammatical words).

Artificial Grammar Learning: Methods

Subjects: 24 native English speakers

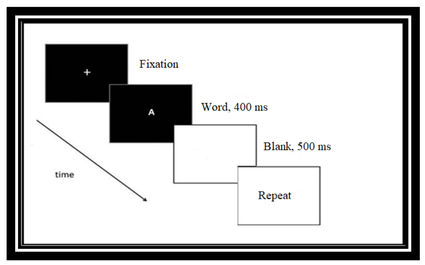
Stimuli: CV.CV
- C: [s, ʃ]
- V: [a, ɛ, ɔ, i, u]
  - Ex: saso, ʃuʃi, seʃa, ʃisu
- Each word 400 ms long
  - Violation at 200ms

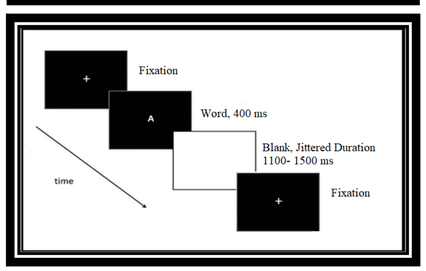
Procedure: Two phases – Training and Testing.

Training:
- Listen and Repeat.
- 20 words presented 10 times each in random order (200 trials).
- Duration: 15 mins

Testing:
- Press a button in response to each stimulus to categorize the stimulus as grammatical (harmonic) (left hand) or ungrammatical (disharmonic) (right hand).
- Oddball Design: Grammatical words appear in 80% of trials and ungrammatical words appear in 20% of trials.
- 300 trials (250 grammatical, 50 ungrammatical)
- Duration: 15 mins*

*This poster has only ¼ of the entire experiment that has other 3 blocks that are not presented here.





Pre-processing:
- Artifact corrected and averaged in Dien's ERP PCA toolbox.
- Segment: -200ms to 1000ms stim-locked and -1000 to 500 ms resp-locked
- Reference: linked mastoids
- Filter: 0.1 - 40Hz band-pass

Discussion & Conclusion

Our results demonstrated that participants learned the simple non-adjacent phonotactic pattern (d' was above zero, and accuracy was greater than chance). We aimed to correlate the learning with a neurophysiological measure and were able to show the brain detected the violation exactly at 200 ms which was marked in P300 peak that happens at 500 ms (300 ms after the violation).

As a next step we will investigate words of different lengths to see if the timing is relative to the point of violation (here in the onset of the second syllable, 200 ms) or to the end of the word (400 ms).

Ultimate aim of this project is to test the neurophysiological correlates of learnability predictions put forward by Heinz (2010).

References

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