# Electrophysiological Measurements of Letter-Sound Congruency Effects

Emily Coderre[1], Zachary Fisher[1], Barry Gordon[1,2], & Kerry Ledoux[1]

[1]Department of Neurology, The Johns Hopkins University School of Medicine, Baltimore, MD

[2]Department of Cognitive Science, The Johns Hopkins University, Baltimore, MD

## Introduction

Learning to read is difficult because of the arbitrary mappings between letters and sounds. With extensive experience, typically-developing children and normal adults acquire the ability to read; over time this becomes a relatively automatic process. However, in populations learning letter-sound mappings for the first time, implicit measures of the knowledge of these correspondences would be extremely valuable in assessing teaching or interventions, especially for individuals unable to make overt responses.

Individuals with autism show various forms of language impairment. Our lab has been working with a low-functioning autistic individual, AI (not his real initials), on assessing and improving his capacity for speech and language. AI has been receiving explicit letter-sound association training for the past 2 years. Although he has shown overall improvement, AI's behavioral performance between testing sessions is inconsistent, making assessment of the success of this intervention difficult. Here we use implicit EEG measures to assess his knowledge of letter-sound associations.

The N400 component of ERP waveforms is associated with semantic processing: words or pictures that are semantically incongruent with their proceeding context elicit a larger N400 amplitude than congruent words/pictures. This difference is known as the N400 congruency effect (Kutas & Federmeier, 2011). Semantic processing paradigms also sometimes report a later positive component (LPC), such that incongruent conditions are more positive than congruent, occurring after the N400; this may reflect semantic reanalysis when integration fails (e.g. van de Meerendonk et al., 2008).

Previous work has shown that the N400 can be used as an implicit measure of vocabulary knowledge in normal adults (Ledoux et al., in preparation): an N400 congruency effect is elicited for known words but not for unknown words. Here, we extend this N400 congruency paradigm to single letters and their corresponding sounds. We test this paradigm in a group of normal adults, in whom all letters are 'known' or 'trained', as well as in AI, in whom we can compare 'trained' and 'untrained' letters. For normal adults, a larger N400 and LPC component was expected for incongruent letter-sound pairs compared to congruent pairs. For AI, this pattern should emerge for trained, but not untrained, letters.

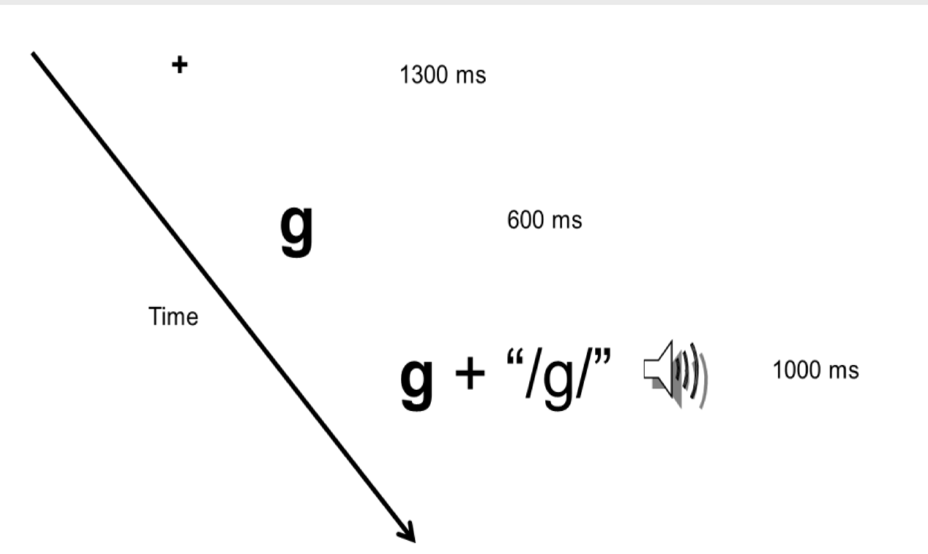
## Methods

***Stimuli*:**

- 26 letters of the English alphabet
- 26 auditory phonemes: a, /æ/; b, /b/; c, /k/; d, /d/; e, /ɛ/; f, /f/; g, /g/; h,/h/; I, /I/; j, /dʒ/; k, /k/; l, /l/; m, /m/; n, /n/; o, /o/; p, /p/; q, /k/; r, /r/; s, /s/; t, /t/; u, /u/; v, /v/; w, /w/; x, /ks/; y, /j/; z, /z/.

***Procedure*:**

- 10 blocks of 52 randomly-presented trials (26 congruent letter-phoneme pairs, 26 incongruent)

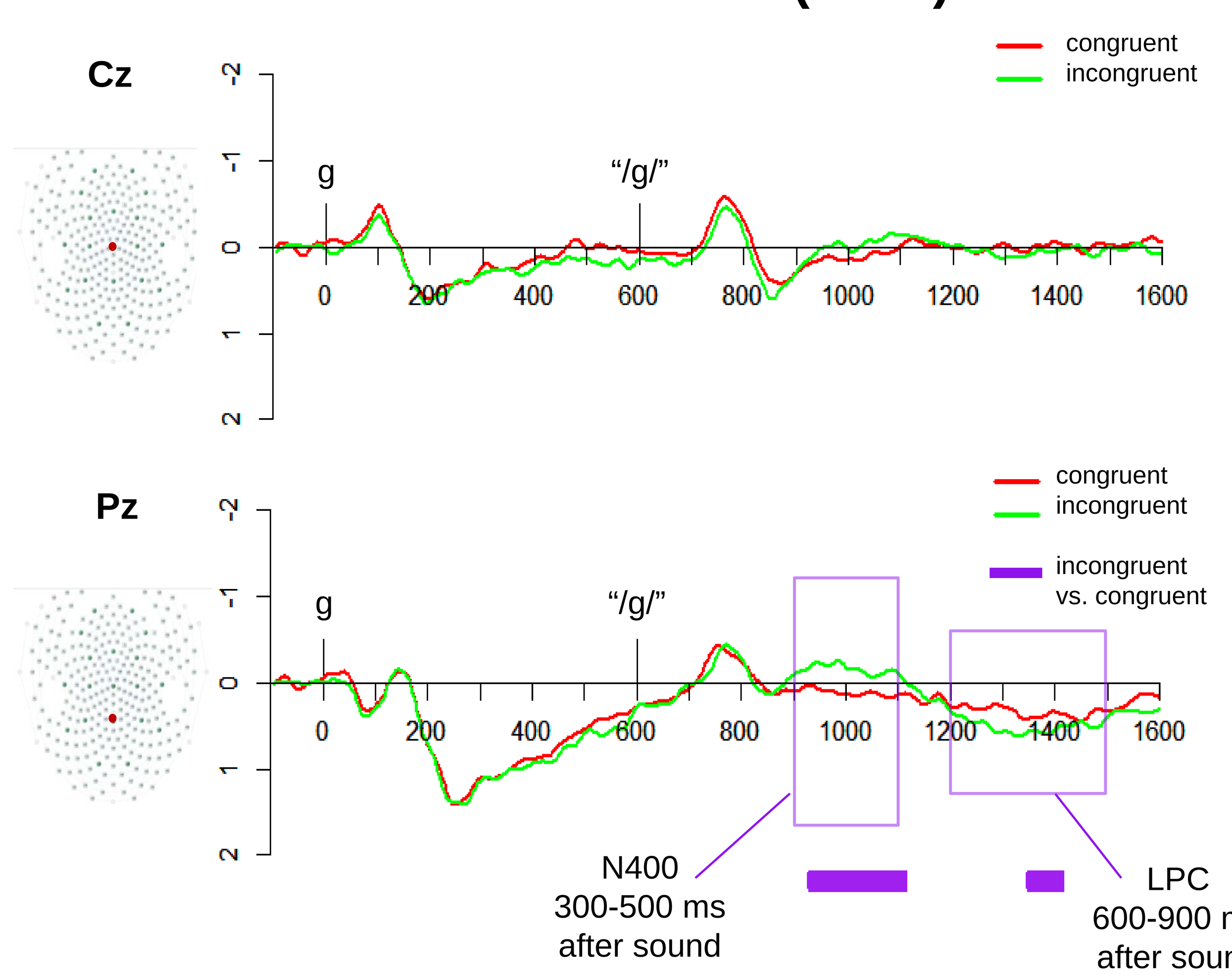



## Results

### Normal adults (n=16)

***Participants and Methods***

- Right-handed native English speakers
- Mean age 31 years (range 23-51)
- Tested at JHU in Baltimore
- EEG recorded at 250 Hz using an Electrical Geodesics Inc. GES 300 EEG System with 256-channel Hydrocel Geodesic Sensor Nets and NetStation version 4.3.
- Motion and eye movement artifacts removed using ICA decomposition.
- Analysis at Cz and Pz using running *t*-tests and at 6 electrode clusters across the scalp using repeated-measures ANOVAs.




***N400:*** 300-500 ms after sound

- Average amplitudes over the N400 window were subjected to a 2 (congruency) x 3 (site: frontal, central, parietal) x 2 (hemisphere) ANOVA, which showed an interaction of congruency x site ($F(2,30) = 6.52$, $p < 0.01$).
  - Frontal sites: main effect of congruency ($F(1,15) = 9.46$, $p < 0.01$), such that incongruent was less negative than congruent.
  - Central sites: no effect of congruency, $p = 0.88$.
  - Parietal sites: main effect of congruency ($F(1,15) = 7.12$, $p < 0.05$) such that incongruent was more negative than congruent.

***LPC:*** 600-900 ms after sound

- The 2 (congruency) x 3 (site: frontal, central, parietal) x 2 (hemisphere) ANOVA showed an interaction of congruency x site ($F(2,30) = 7.83$, $p < 0.01$).
  - Frontal sites: main effect of congruency ($F(1,15) = 8.62$, $p < 0.05$) such that incongruent was less positive than congruent.
  - Central sites: no effect of congruency, $p = 0.66$.
  - Parietal sites: main effect of congruency ($F(1,15) = 12.18$, $p < 0.01$) such that incongruent was more positive than congruent.

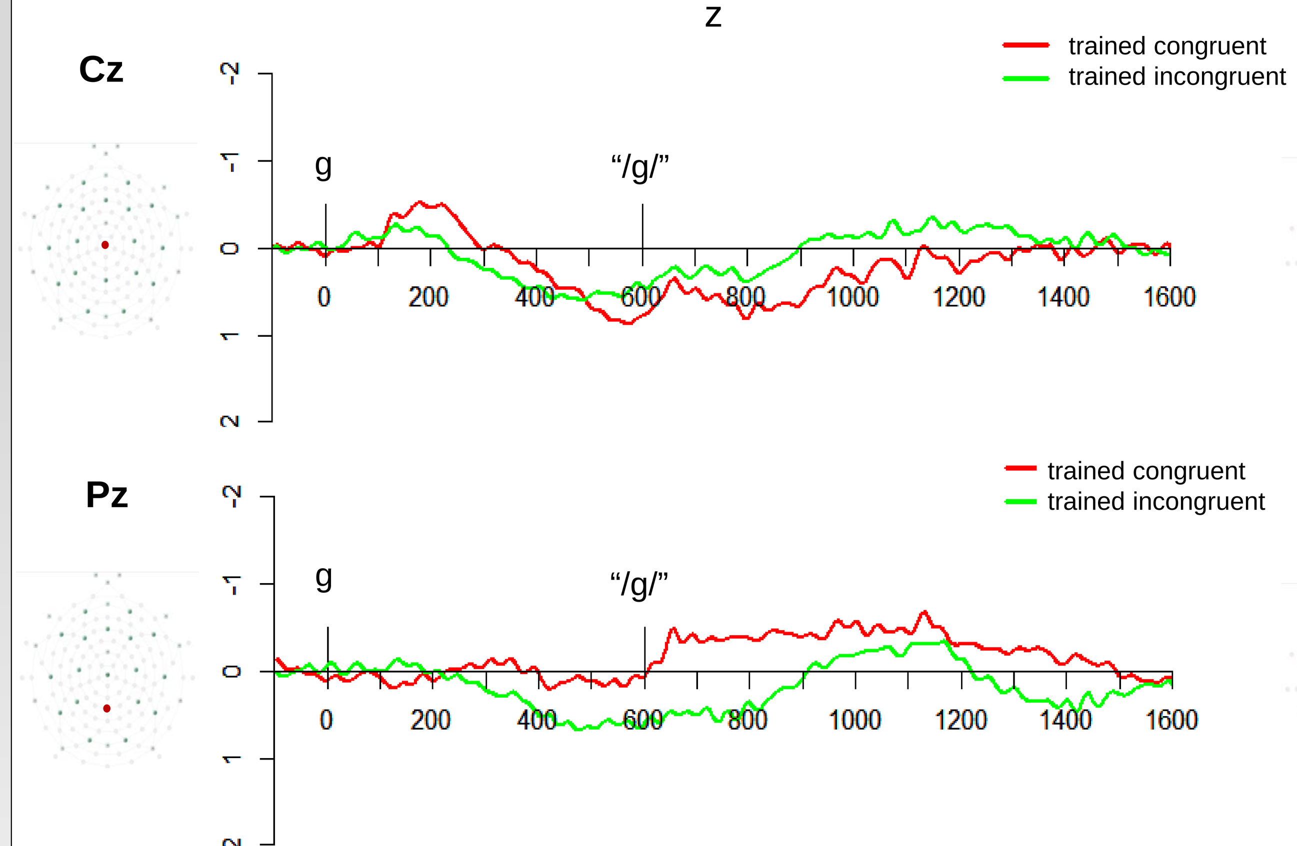
### Low-functioning individual with autism, AI

***Participant and Methods***

- 25 years of age
- 20 blocks tested over 3 sessions at JHU site in NYC
- EEG recorded at 1000 Hz using an Electrical Geodesics Inc. GES 300 EEG System with a 32-channel Hydrocel Geodesic Sensor Nets and NetStation version 4.5.
- Motion and eye movement artifacts removed using ICA decomposition. Additional bad trials manually removed by two individual raters.

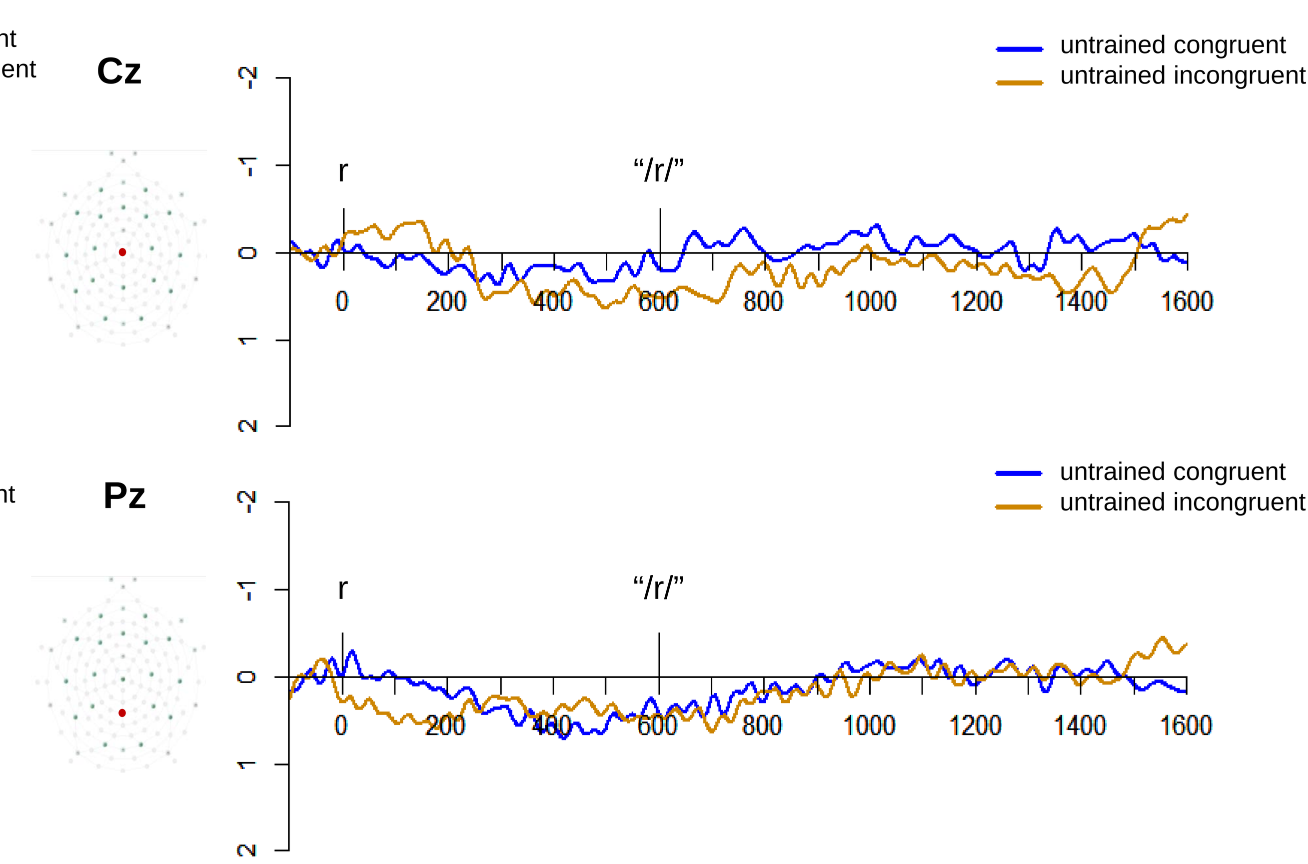
**Trained Letters**

b, d, f, g, h, j, k, i, m, n, o, p, s, t, u, v, w, x, z




**Untrained Letters**

a, c, e, l, q, r




***N400:*** 300-500 ms after sound (Trained Letters)

- Average amplitudes over the N400 window were subjected to a 2 (congruency) x 3 (site: frontal, central, parietal) x 2 (hemisphere) ANOVA, which showed a trend of interaction of congruency x hemisphere ($F(1,2) = 9.43$, $p = 0.09$).
  - Slightly larger congruency effect in right hemisphere ($F(1,2) = 2.38$, $p = 0.26$), in which incongruent was more negative than congruent, than in left hemisphere ($F(1,2) = 0.61$, $p = 0.52$), in which congruent was more negative than incongruent.

***LPC:*** 600-900 ms after sound (Trained Letters)

- 2 (congruency) x 3 (site: frontal, central, parietal) x 2 (hemisphere) ANOVA showed no significant main effects or interactions.

***N400:*** 300-500 ms after sound (Untrained Letters)

- Average amplitudes over window subjected to a 2 (congruency) x 3 (site: frontal, central, parietal) x 2 (hemisphere) ANOVA, which showed a trend of a main effect of congruency ($F(1,2) = 18.29$, $p = 0.05$) such that congruent was more negative than incongruent.

***LPC:*** 600-900 ms after sound (Untrained Letters)

- 2 (congruency) x 3 (site: frontal, central, parietal) x 2 (hemisphere) ANOVA showed a trend of a main effect of congruency ($F(1,2) = 9.07$, $p = 0.09$) such that congruent was more negative than incongruent.

## Discussion

**Normal Adults:**

The letter-sound incongruency paradigm elicited an N400 effect (incongruent more negative than congruent) from approximately 300-500 ms and an LPC effect (incongruent more positive than congruent) from approximately 600-900 ms after sound presentation. These effects were largest over parietal scalp.

These N400 and LPC effects are similar to those elicited by pictures and words (Kutas & Federmeier, 2011; van de Meerendonk et al., 2008), suggesting similar processes of semantic integration for single letters.

We are continuing to collect data from normal adults on this paradigm. This preliminary data demonstrates that the N400 congruency paradigm can be used to assess implicit knowledge of letter-sound pairings in normal adults.

**AI:**

For AI, trained letters showed an N400-like effect at Cz; however, the polarity of this effect was flipped at Pz. Additionally, at Pz the differences between congruent and incongruent conditions emerged before the onset of the second stimulus, making interpretation difficult.

At Pz, there was a trend of an LPC within the appropriate time frame and with the right polarity, but this effect was not statistically significant. If this effect remains after further testing, this may be similar to results reported by Pijnacker et al. (2010), who found an absent N400 but intact LPC in high-functioning individuals with ASD compared to individuals with Asperger's Syndrome and normal controls. This may indicate that initial semantic integration failed (no N400 effect), therefore a later, more extensive analysis was needed (LPC effect).

For untrained letters, there was an overall effect of congruency in both the N400 and LPC windows. This contradicts our predictions, as AI should have no experience with these letters and should therefore not show a congruency effect.

Efforts are ongoing to try to collect cleaner data with AI, especially by:

- Minimizing movement by creating dynamically interesting stimuli
- Using video and eye-tracking recordings to code 'good' trials
- Utilizing new techniques for additional cleaning during pre-processing.

## Conclusions

Overall, our results suggest that this paradigm can be used to assess implicit knowledge of letter-sound mappings and to evaluate teaching interventions in low-functioning individuals.

**References**

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ecoderr1@jhmi.edu