Better readers show larger N400 effects during naturalistic listening

Daniel Kleinman[1], Luca Campanelli[1,2], Vishakha Agrawal[1], Julie Van Dyke[1], & Nicole Landi[1,3]

[1] Haskins Laboratories [2] The Graduate Center, CUNY [3] University of Connecticut

Research partners: AIM Academy; The Windward School

What processing deficits are associated with decoding-based reading disability?

Individuals with decoding-based reading disability (dyslexia) often exhibit deficits in lower-level speech sound processing:

- Phonological processing (Shaywitz, 1996)
- Tasks requiring production of speech sounds (Schulte-Körne & Bruder, 2010; Vellutino et al., 2004)
- Low-level auditory processing more generally (Giraud & Ramus, 2013; Lehongre et al., 2011)

Although reading disability can leave higher-level oral language processes relatively spared, it is sometimes associated with higher-level language difficulties (Adlof & Hogan, 2018)

- Children with dyslexia exhibit deficits in vocabulary, syntactic comprehension, & other domains relative to typically developing children (Adlof et al., 2017; Bishop et al., 2009; Ramus et al., 2013)
- …but not always (Eisenmajer et al., 2005; Fraser et al., 2010)

The current study

Goal: Investigate higher-level language processing in a reading-disabled population using a naturalistic task

- Population: Students with language-based learning difficulties
- Task: Listening to audiobooks while measuring EEG
- Effect of interest: Semantic integration (N400 effect of word frequency; e.g., Kutas & Hillyard, 1984)
  - Adult listeners show larger N400s to lower-frequency words in continuous speech (Brennan & Hale, 2019)
  - Children with reading difficulties show smaller N400s with printed sentence processing (e.g., Shulz et al., 2008), but it is not known whether such effects extend to auditory language tasks

Methods

Participants

- 58 students at schools that treat language-based learning difficulties (AIM Academy, n=37; The Windward School, n=21)
- Student diagnoses include dyslexia, ADHD, anxiety, Asperger's
- Assessment battery was administered to measure phonological processing, word reading, and nonword reading:

Measure	Assessed skill	Range	M	SD	μ	σ
Age		[7.5, 15.5]	10.8	1.8		
Grade		[2, 9]	5.0	1.7		
TOWRE Sight Word Efficiency	Timed word reading	[66, 117]	86.2	10.5	100	15
TOWRE Phonemic Decoding Efficiency	Timed nonword reading	[60, 118]	84.5	11.5	100	15
WJ-4 Letter-Word ID	**Untimed word reading**	**[63, 120]**	**89.2**	**11.2**	**100**	**15**
WJ-4 Word Attack	Untimed nonword reading	[71, 111]	92.6	9.3	100	15

Standard scores (age-adjusted) used here to index reading ability

Materials/Task

- Audiobook stimuli: 3 excerpts from Alice in Wonderland and 3 excerpts from Stuart Little
  - Each participant heard 1 excerpt per story (~11 min total)
  - Normal speaking rate (M=2.9 words/sec)
- Attention checked via 4 comprehension questions (2AFC)

Pre-processing:

- Band-pass filtered (0.1-30 Hz); re-referenced to average
- EEG epoched from [-300 1000] ms; baseline-corrected; time-locked to auditory onset of content words
  - # artifact-free epochs: Range=[520,1062], M=890, SD=130

Analyses

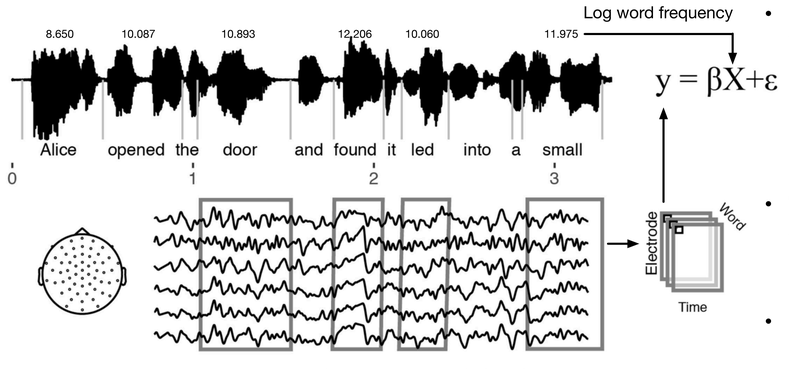
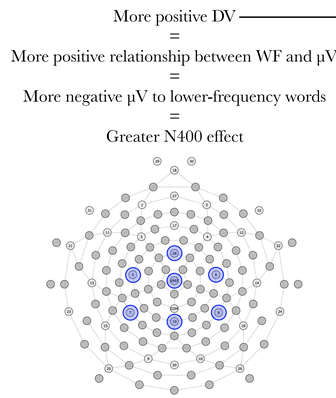
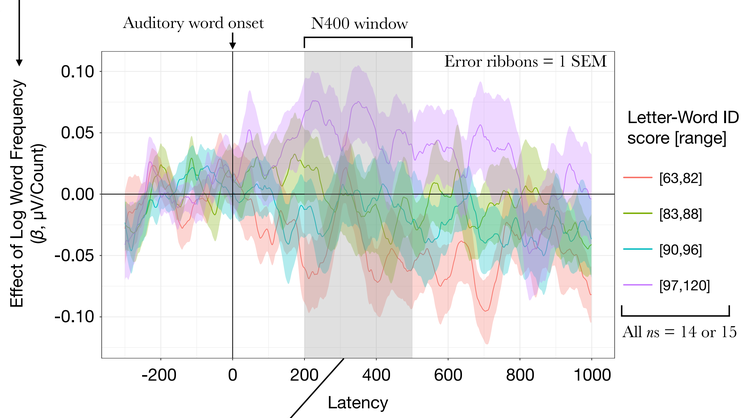


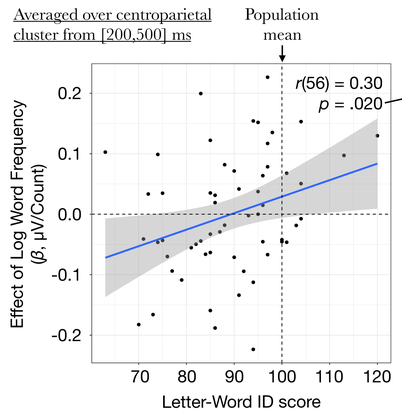
Figure adapted from Brennan & Hale (2019), Fig. 2.

- Effect of log word frequency (WF) on μV computed via regression-based ERPs (Smith & Kutas, 2015; Brennan & Hale, 2019)
  - For each participant, μV regressed on WF across epochs at every latency/channel
  - Covariates: WF of words n-1 and n+1
  - ➡ Yields β coefficients representing WF effect across time/space
- Time window and electrode montage based on prior N400 findings using naturalistic speech (e.g., Brennan & Hale, 2019)
  - When: 200–500 ms
  - Where: 7 centroparietal channels
- Significance test: Correlation
  - DV: Mean β across latencies/channels
  - IVs: Letter-Word ID score

Results



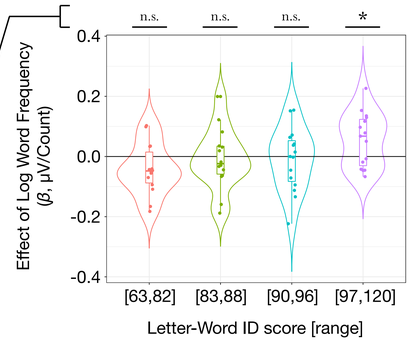




Key result:

The effect of word frequency on N400 amplitude was greater for participants with higher age-adjusted reading scores…

…and significantly different from 0 only for participants with the highest reading scores.



Relationship between word reading ability and WF effect robust to trial-level covariates

- Model with 4 additional covariates (auditory power, sentence number in passage, word number in sentence, un-lexicalized CFG-derived syntactic surprisal; modeled after Brennan & Hale, 2019): $r(56) = 0.35$, $p = .007$
- Model with WF as sole predictor: $r(56) = 0.32$, $p = .015$

Conclusions

1) Better readers show larger effects of word frequency on N400 amplitude during naturalistic listening.
   - ➡ Reliably significant only for the most skilled readers in our sample – those with average or above-average reading scores
   - ➡ Similar to word frequency effects observed in adults

2) Our results provide further evidence that reading disability may be associated with higher-level language difficulties, even in non-visual modalities.

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Contact email: daniel.kleinman@yale.edu
http://sites.google.com/site/kleinman/