EEG reflects efficency but not disengagement in artificial speech segmentation

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Introduction

Statistical Learning (SL)

Language learning through exposure to syllable transitional probabilities in speech, commonly tested with artificial languages.

- SL is a skill in children & adults (Saffran et al., 1996)
- SL useful in natural language acquisition as well (Pelucchi, Haye, & Saffran, 2009)

SL in Bilingualism

SL of two languages is difficult when statistics are not compatible, and learners must infer different structures. (Qian, Jaeger, & Aslin, 2012; Weiss, Poepsel, & Gerfen, 2015)

One theory for failing to learn L2 in artificial languages is the primacy effect or "entrenchment" (Gebhart et al., 2009)

- participants learn first language (L1)
- L1 hinders learning second language (L2)

Entrenchment connects to the native language neural commitment (NLNC) theory (Kuhl, 2004).

- NLNC claims neural networks code for patterns of L1 speech, later constraining foreign patterns
- NLNC consistent with the primacy effect: stable L1 learning is an impediment to L2 learning

Second theory for failing to learn L2 is the "neural efficiency" hypothesis (Karuza et al., 2016)

- Neural efficiency states that once a language is learned, participants disengage from the exposure to the speech stream.
- Participants who do not disengage learned L2 more successfully.

Research Question 1: Is entrenchment with artificial languages a model for the NLNC theory?

- Would an unstable presentation of two artificial languages improve L2 performance?
- How does the presentation differ among participants of varying levels of natural L2 proficiency?

Research Question 2: Do participants disengage from the speech stream, per the neural efficiency hypothesis?

- Do participants' EEG data cohere with the speech envelope of the acoustic stimulus?
- How does cortical tracking differ as acquisition occurs over time?

Method

Experiment 1

L1 and L2 in the Speech Stream: 2 languages, 12 syllables and 4 words each. Within-triplet order is fixed, between triplet order is random. L1 and L2 were presented differently based on the day and condition of the experiment.

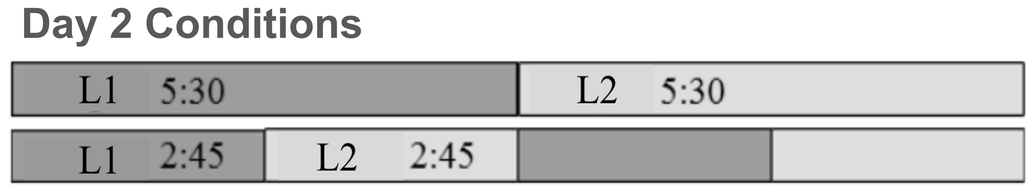
2-AFC Task: Participants chose between either the correct word from the speech stream or an incorrect word made from the same syllables of the stream. There were 16 questions per language.

2 Day Behavioral Experiment:

Day 1 → Listen to 2:45 (m:s) of L1 + 2-AFC (16 questions).

Day 2 → 11:00 of L1 and L2, then randomly sorted 2-AFC of L1 and L2 (32). Day 2 conditions differed by the number of transitions (stable condition had 1 transition, unstable had 3).

Day 2 Conditions



Stable: L1 for 5:30, then L2 for 5:30

Unstable: Order of L1, L2, L1, L2 for 2:45 each

Statistical Analysis: T-tests and Pearson's correlations for both conditions. A linear regression was performed to assess L1 performance, the switching condition, and bilingualism on L2 performance.

Experiment 2

L1 Speech Stream: One language from Exp. 1

2-AFC Task: Same AFC task from Exp. 1

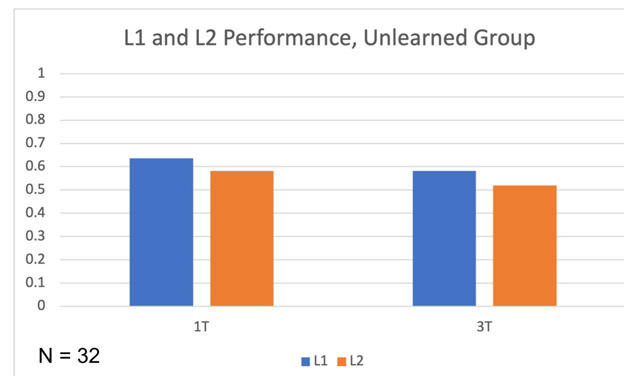
EEG Data Collection: Participants listened to 11:00 of L1 under the EEG, then completed the 2-AFC.

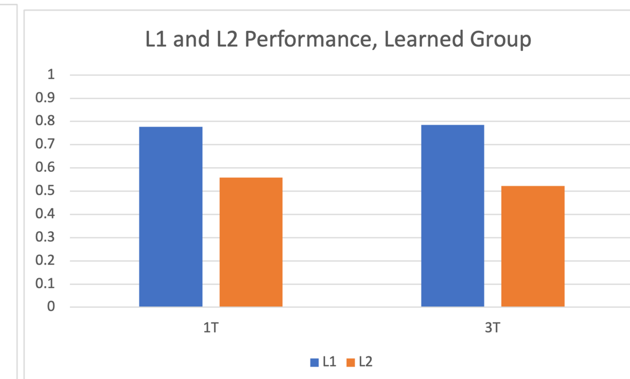
EEG Data Analysis: Data was preprocessed and analyzed for power and coherence at frequencies of 4.3 and 1.4 Hz (based on the frequencies of syllables and words in the stream). Data was also analyzed for coherence to the envelope of the speech stream using multivariate temporal response function (mTRF).

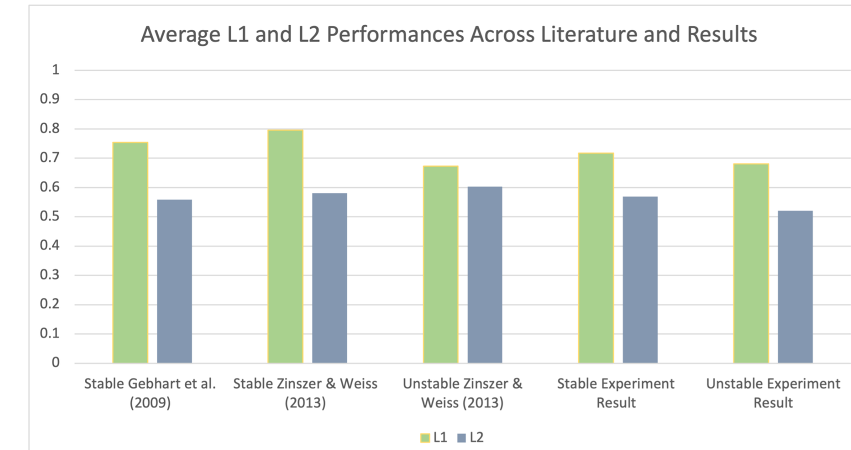
Statistical Analysis: Syllable power and coherence, and the mTRF scores, were analyzed using a linear regression assessing track (time) and mean performance on the 2-AFC. The frequency domain analyses also assessed word power and coherence.

Experiment 1 Results

62 students aged 18 to 23 participated in both days of the research, with 3 students who participated on only the first day. Each participant was compensated for their work.







	L1: Day 1 vs. Day 2	Stable vs. Unstable	
		Day 2, L1	Day 2, L2
T-Value	1.3146	0.79952	0.98289
P-Value	0.1911	0.4271	0.33

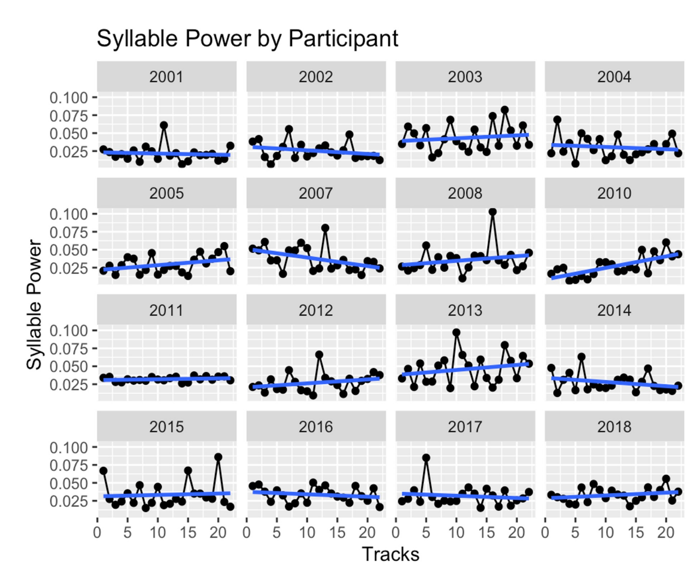
Regression Analysis

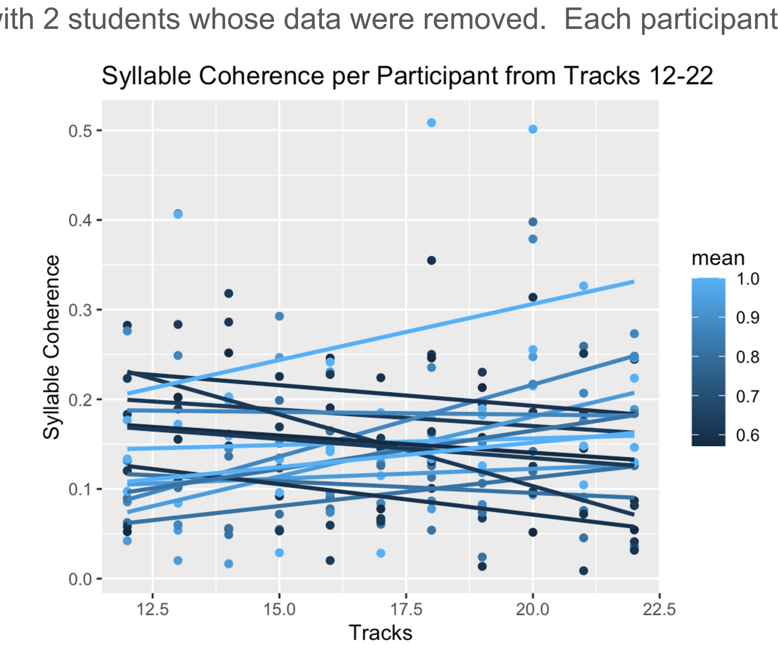
	Estimate	Std. Error	T-Value	P-Value
Intercept	0.56444	0.13311	4.240	<0.001
Day 1, L1	-0.22138	0.14857	-1.490	0.1419
Day 2, L1	0.42676	0.18510	2.306	0.0249
Counterbalance (Language B)	-0.02856	0.05797	-0.493	0.6243
Second language proficiency	-0.20045	0.12629	-1.587	0.1182
3T Switch	-0.16505	0.10840	-1.523	0.1336
2nd lang prof * 3T Switch	0.22118	0.16259	1.360	0.1793

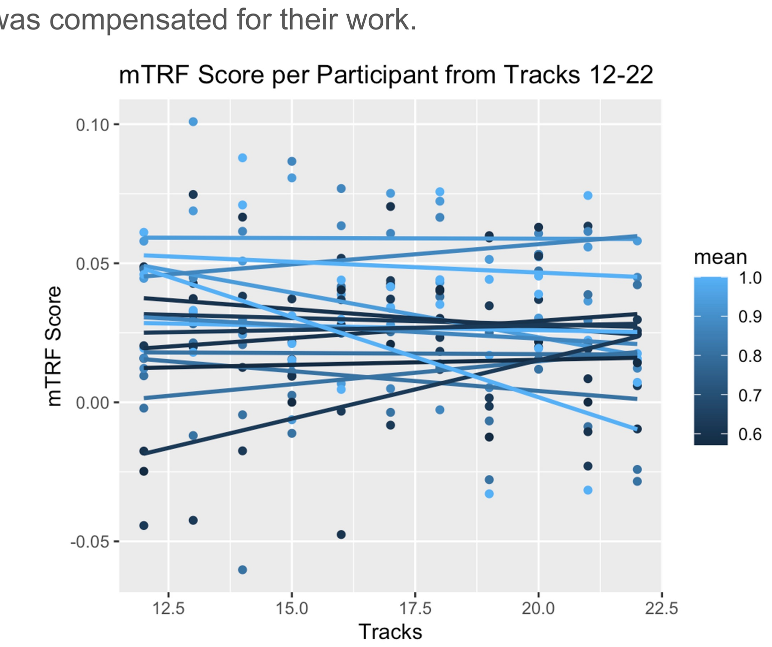
Multiple R^2	Adjusted R^2	F-Statistic	P-Value
0.1454	0.05214	1.559	0.1766

Experiment 2 Results

18 students aged 18 to 22 participated in the research, with 2 students whose data were removed. Each participant was compensated for their work.







Syllable Coherence Regression

Tracks 12-22	Estimate	P-Value
Word Coherence	0.003	0.970
Track	-0.032	0.005
Mean Accuracy	-0.688	0.004
Track*MeanAcc	0.043	0.003

Simple Slopes: Syllable Coherence and Accuracy

Mean Behav. Accuracy	Estimate of Track Slope	P-Value
0.633 (-1 SD)	-0.005	0.120
0.781 (mean)	0.001	0.500
0.928 (+1 SD)	0.008	0.012

mTRF Regression on frontocentral channels

Tracks 12-22	Estimate	P-Value
Track	0.010	0.046
Mean Accuracy	0.292	0.005
Track*MeanAcc	-0.014	0.023

Simple Slopes: FC mTRF and Accuracy

Mean Behav. Accuracy	Estimate of Track Slope	P-Value
0.633 (-1 SD)	0.0009	0.492
0.781 (mean)	-0.001	0.222
0.928 (+1 SD)	-0.325	0.017

Discussion

Experiment 1

- ➔ L1 performance is not significantly greater than L2 performance for both conditions.
- ➔ L1 was not different between conditions. L2 was also not different between conditions.

Learned vs Unlearned Groups

- ➔ Participants who learned L1 on Day 1 had greater primacy for L1 over L2 on Day 2. Unlearned groups had more similar performances for both languages.

Whole Sample Regression Analysis

- ➔ For each percent in performance on Day 2, L1, there is a correlated +0.43% increase on Day 2, L2.
- ➔ For each percent in self reported second language proficiency, there is a correlated -0.20% on Day 2, L2.
- ➔ In the 3T condition, for each percent in second language proficiency, there is a +0.04% on Day 2, L2.

Experiment 2

- ➔ Regression analyses of power were insignificant.
- ➔ On the assumption that the latter tracks would show more effects of neural efficiency, tracks 12-22 were modeled and shown here. (All-track analysis was not conclusive.)
- ➔ For coherence, the greater performance was associated with significant increase of syllable coherence over time.
- ➔ For the mTRF, the greater performance was associated with weaker cortical tracking of the envelope over time.

Conclusions & Future Directions

- ➢ Experiment 1 suggests that entrenchment does not explain the L1-L2 discrepancy in acquisition, as L1 and L2 acquisition were positively related.
- ➢ Experiment 2 suggests that neural efficiency might explain the primacy of L1 over L2, as participants who learned the L1 encoded low-level stimulus properties (envelope) less closely.
- ➢ Important to note coherence to syllable-frequency signal continued to improve in this same group.
- ➢ Better EEG measure of L1 learning (Tracks 1-11) may allow researchers to pinpoint when exactly it's learned.

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