A neural network model of naming impairment and treatment response in bilingual speakers with aphasia

Claudia Peñaloza[1]; Uli Grasemann[2]; Maria Dekhtyar[1]; Risto Miikkulainen[2]; Swathi Kiran[1]
[1]Boston University, [2]University of Texas at Austin

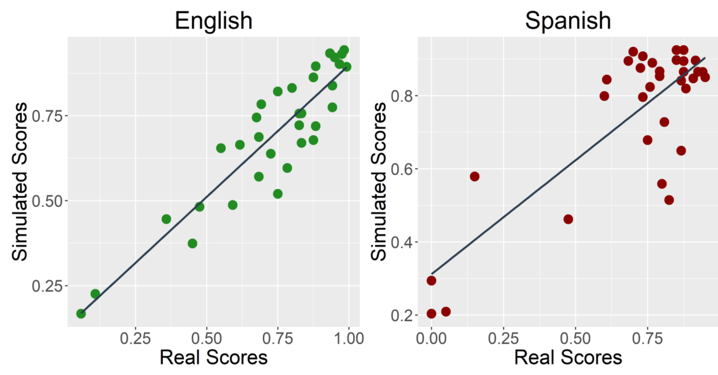
Background

Bilinguals with aphasia (BWA) show varying degrees of impairment and recovery in their first (L1) and second (L2) language. Impairment and recovery are modulated by prestroke factors (i.e., L2 age of acquisition (AOA), use and exposure to each language) and poststroke factors (i.e., lesion effects and severity) [1]. Individual variation in such factors makes it difficult to predict treatment response and determine the language that when treated will lead to optimal gains in both languages [2].

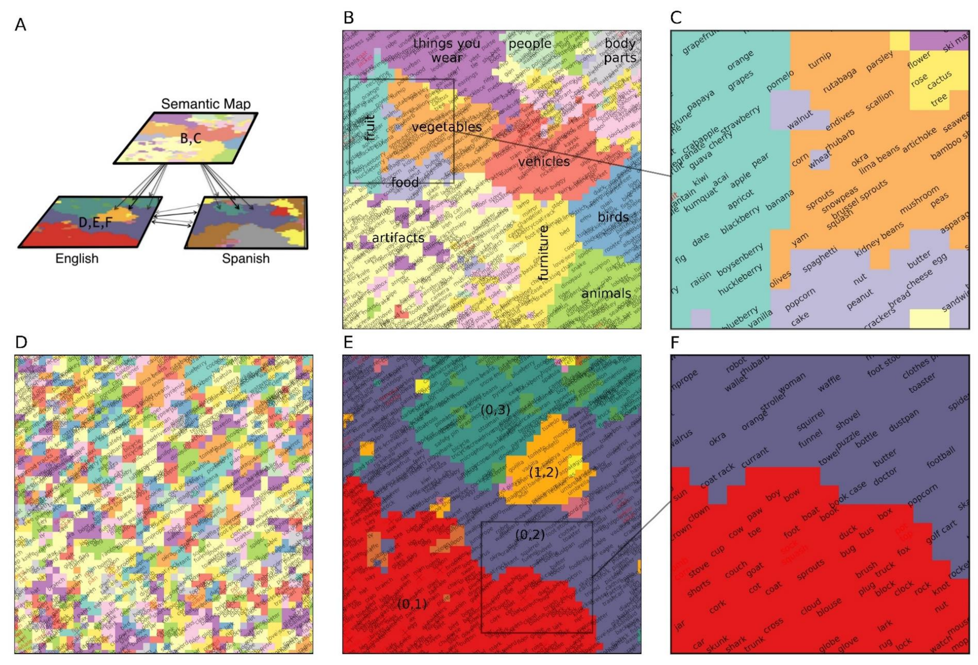
Aims. To simulate naming impairment and treatment response in BWA in both the treated and the untreated language using BiLex, a neural network model of lexical access in bilinguals with varying degrees of language proficiency [3]. The ultimate goal of the model is to predict rehabilitation outcomes in BWA.

Naming in healthy bilinguals

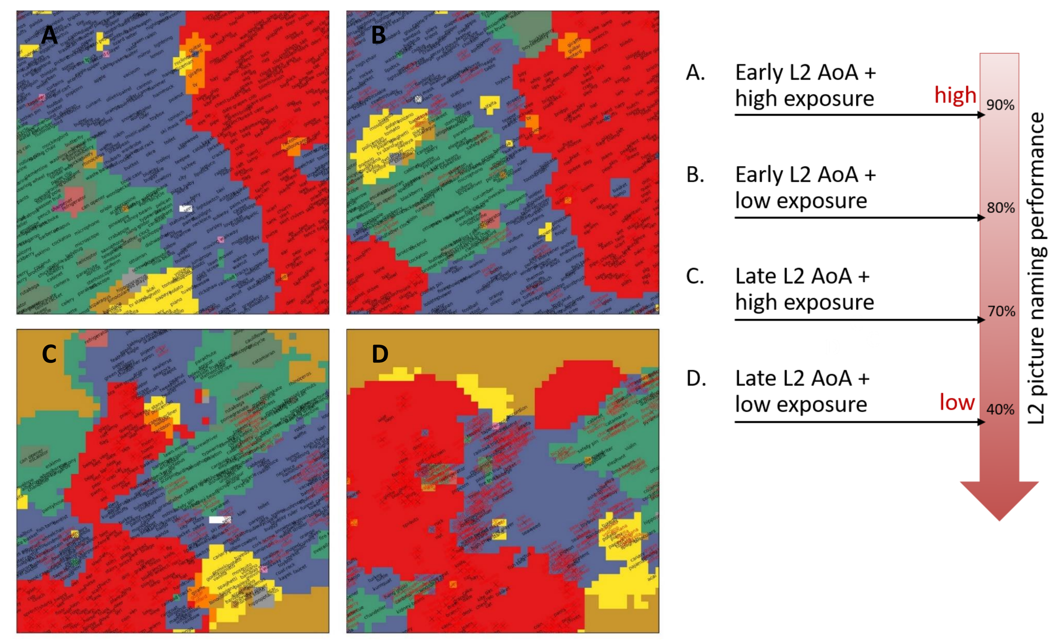
Five-fold cross-validation. Participants were divided into 5 training sets (n = 26 or 27) for parameter optimization and 5 test sets (n = 6 or 7) to evaluate generalization (goodness-of-fit). Results showed BiLex can accurately simulate naming in bilinguals.



Simulated scores predict actual naming scores in healthy bilinguals



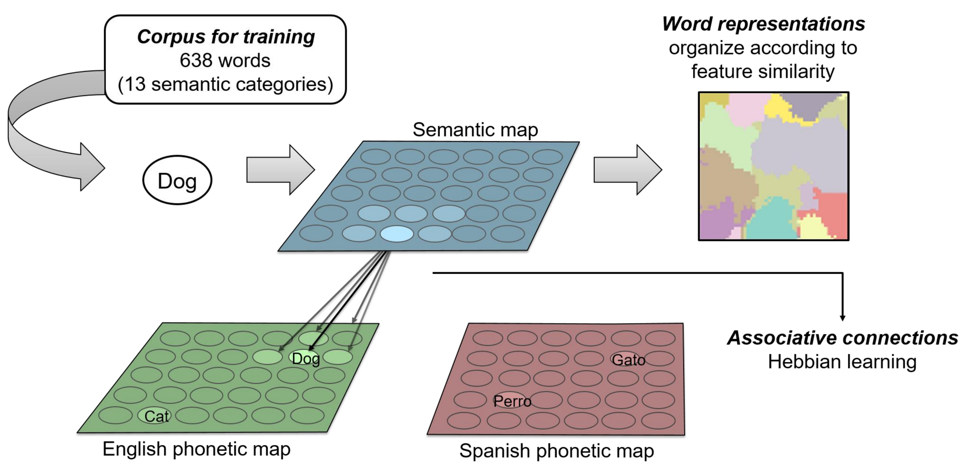
SOM organization in a model simulating a proficient bilingual (A). Semantic map (B-C) and L2 English phonetic map (D-F).



Differences in L2 English phonetic map organization in four BiLex models across a range of L2 AOA (early-late) and lifetime exposure (high-low)

The BiLex Model

Model architecture. As in theoretical models of the bilingual mental lexicon [4], BiLex includes 3 interconnected Self-Organizing Maps (SOM) [5], one for word meanings shared across languages, and two for their phonetic representations in L1 and L2.



BiLex model architecture and training procedure

Model training. A standard SOM algorithm trains maps in parallel. Hebbian learning is used to train associative connections between active neurons. Each best-fit training schedule included:

- ***Individual training parameters*** (i.e., age, L2 AOA and use and exposure to each language) reflect the bilingual background of each participant [6].
- ***Global training parameters*** (i.e., learning rate, neighborhood size, and random noise to reflect aging and language attrition effects) are common to all simulated participants and were determined using an Evolutionary Algorithm [7].

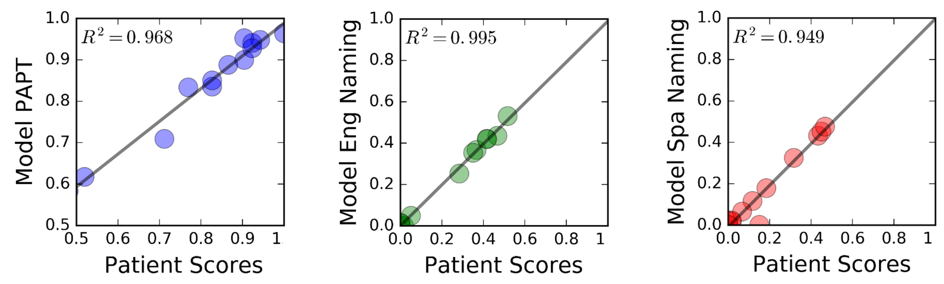
Naming Simulations. For each word in the corpus, its semantic representation was presented to the semantic map, activation propagated to the phonetic map and the winning output unit was compared to the input unit (i.e., simulated score).

Participants and assessments. Participants were 28 Spanish-English bilinguals (age = 42.9 ± 15.9 years) and 5 monolinguals (age = 56 ± 5.1 years). Their scores on the Boston Naming Test (BNT) [8] and a 60-item naming screener in each language were averaged (i.e., naming score) and simulated.

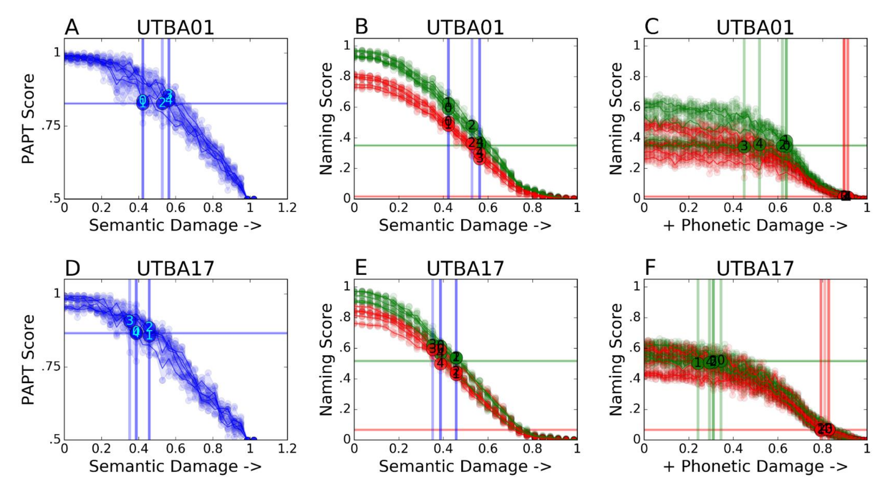
Naming impairment in BWA

Participants and assessments. 13 BWA (age = 58.4 ± 19.5 years) filled out the LUQ, and completed the Pyramid and Palm Trees (PAPT) [9] a test of semantic knowledge and the BNT evaluating naming performance in each language.

Simulations. Prestroke BiLex models were trained combining the individual training parameters of the BWA with the global training parameters validated with healthy bilinguals. Specific neuronal damage (i.e., round lesion) was applied at varying degrees of intensity to the semantic and phonetic SOMs to match the semantic (PAPT scores) and naming impairment (BNT scores) of BWA. Results showed accurate simulations of language impairment in BWA with different bilingual backgrounds and profiles of semantic and naming deficits.



Simulated scores predict actual semantic and naming scores in the BWA

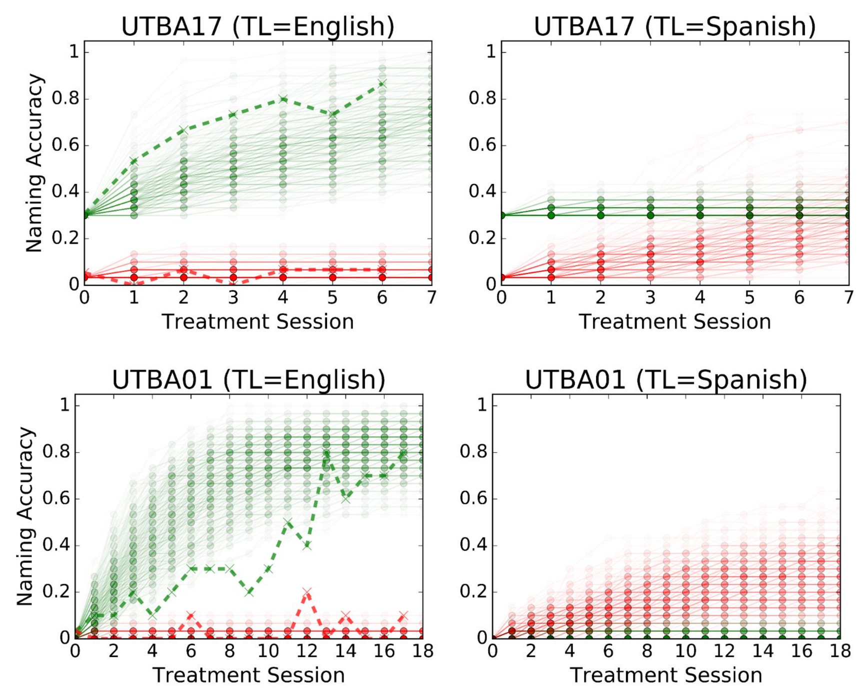


Real (horizontal line) vs simulated (dotted lines) performance of patients UTBA01 and UTBA17. BiLex matches (vertical intersection) semantic (A,D) and naming deficits (B-F) in English (green) and Spanish (red).

Treatment outcomes in BWA

Participants and treatment. The same 13 BWA underwent semantic treatment in English (n = 6) or Spanish (n = 7) [10]. 10 BWA showed significant treatment effects in the treated language and 3 of them showed cross-language transfer effects.

Simulations. Each lesioned model was retrained to simulate treatment effects in both languages. Re-training parameters (i.e., learning rates) were defined using the EA and real treatment responses during treatment were optimization targets. After each retraining cycle, naming performance was simulated and compared to actual naming performance during treatment in each BWA. Cross-correlations between behavioral treatment and computational model times-series data ranged between 0.48 and 0.96 (treated language) and -0.15 and 0.63 (untreated language) and show that BiLex captures treatment effects in BWA.



Left: simulations (dotted lines) of treatment response (solid lines) for patients UTBA01 and UTBA 17 in the treated (English) vs the untreated (Spanish) language. Right: simulations of treatment response if treatment had been provided in the opposite language.

Conclusions

BiLex can simulate naming impairment and treatment effects in both the treated and the untreated language in BWA. In the future, BiLex could guide clinical decisions on the language to targeted in treatment with BWA.

Contact

Claudia Peñaloza, PhD
Email: penaloza@bu.edu

Funding

NIH-NIDCD grant 1U01DC014922

References

1. Peñaloza, C., & Kiran, S. (2019). Recovery patterns in multilingual aphasia. In: J. W. Schwieter, (Ed.), *The Handbook of the Neuroscience of Multilingualism* (553-571). New Jersey: Wiley-Blackwell Publishing.
2. Kiran, S., Grasemann, U., Sandberg, C., & Miikkulainen, R. (2013). A computational account of bilingual aphasia rehabilitation. *Bilingualism, Language and Cognition, 16,* 325-342.
3. Peñaloza, C., Grasemann, U., Dekthyar, M., Miikkulainen, R. & Kiran, S., (2019). A computational approach to the effects of age of acquisition and language exposure on bilingual lexical access. *Brain and Language, 195*, 104643.
4. Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language*, *33*(2), 149–174.
5. Kastenbaum et al., (2018). The influence of language combination and proficiency on bilingual lexical access. *Bilingualism, Language and Cognition, 22,* 300-330.
6. Kohonen, T. (2001). *Self-organized maps.* Berlin: Springer.
7. Bäck, T. (1996). *Evolutionary algorithms in theory and practice.* Oxford: Oxford University Press.
8. Kohnert, K., J., Hernandez, A. E., Bates, E. (1998). Bilingual performance on the Boston Naming Test: Preliminary norms in Spanish and English. Brain and Language, 65, 422-440.
9. Howard, D., & Patterson, K. (1992). *The Pyramids and Palm Trees Test: A test of semantic access from words and pictures*. Thames Valley Test Co.
10. Kiran et al (2013). Rehabilitation in bilingual aphasia: Evidence for within and between-language generalization. American Journal of Speech-Language Pathology, 22, 298-309.