Constructing Individualized Computational Models for Dementia Patients

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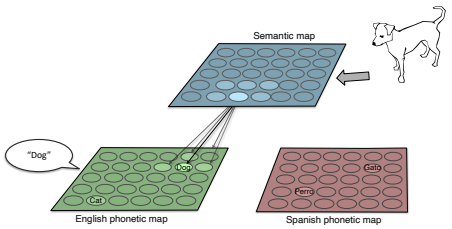
Abstract

Dementia is a common and debilitating condition that typically gives rise to increasing language impairment. There is a need to understand the nature of this impairment further so that therapies may be developed, particularly in the case of bilinguals. This paper extends BiLex, an existing computational model of bilingual lexical access, to simulate language decline in dementia. Six lesion types are evaluated for their ability to reproduce the pattern of decline in the semantic variant primary progressive aphasia (svPPA) subtype of dementia. Semantic memory lesions reproduce this pattern of decline best in monolinguals, and further suggest patterns that are likely to be found in longitudinal data from bilingual dementia patients in the future.

The BiLex Model

BiLex is a neural-network-based model of the mental lexicon in bilinguals:



- Three Self-Organizing Maps (SOMs): one for semantic representations, and one per language for phonetic representations
- Associative connections between each pair of maps
- Trained on a corpus of 638 concrete nouns
- Semantic representations are vectors where each position represents a semantic feature (e.g. "can fly")
- Phonetic representations are vectors that encode the phonetic features of the word in the given language
- Scores semantic comprehension via simulating the Pyramids and Palm Trees (PAPT) test [1]
- Scores naming ability in each language via simulation the Boston Naming Test (BNT) [2]
- Model training in English vs. Spanish can be adapted to match the bilingual language background of individual patients (e.g. native language, age, and relative exposure to English vs. Spanish over time)
- By damaging semantic and/or phonetic maps, impaired semantic comprehension and/or naming ability can be simulated

Previously used to:

- Predict naming performance in healthy Spanish-English bilinguals based on an individual's language exposure history [3]
- Make individualized predictions about post-stroke rehabilitation outcomes that will result from therapy in English vs. Spanish, by lesioning to match performance post-stroke and then simulating treatment in each language [4]

Extending BiLex to Model Dementia

Lesioning methods that are effective for modeling stroke are not applicable as-is to modeling dementia, since stroke is a one-time event and dementia is progressive.

We developed six candidate lesioning methods, all of which are progressive in nature and reflect current scientific knowledge of the neurological damage / language deficits associated with dementia:

1. Random deletion of neurons in the semantic map
   - Neurons in semantic map are randomly chosen to be lesioned (will no longer activate in response to input nor propagate any activation to phonetic maps)
2. Focused deletion of neurons in the semantic map
   - Similar to lesion 1, except next neuron(s) to be lesioned are chosen so that they are adjacent to the already-lesioned neurons
3. Blurring of semantic features in the semantic map
   - At each time step during the lesioning phase, the weight of each feature of each neuron in the semantic map is changed to be slightly closer to the average of neighboring neurons' weights for that feature
4. Deletion of associative connections
   - Connections from the semantic map to the two phonetic maps are removed at random
5. Deletion of features from the semantic input vector
   - Positions in the incoming semantic vector (each of which represents a semantic feature) are chosen at random to be added to the set of lesioned features; these positions will be ignored subsequently when choosing the semantic map neuron which most closely matches the input vector
6. Abnormal spread of activation in the semantic map
   - Neighborhood size in the semantic map is increased progressively during the lesioning phase, allowing more adjacent neurons to propagate their activation to the phonetic maps

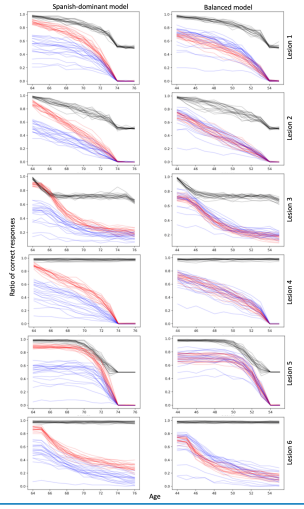
Experiment 1

Language exposure history data from two healthy bilingual controls whose data were collected as part of the initial tuning of BiLex [3] were used to generate predictions of the shape of decline that each candidate lesion can produce.

These two subjects were chosen because they represent different degrees of bilingualism: one is significantly more proficient in Spanish than English at the age when lesioning begins, and the other has approximately equal abilities in both languages.

For each lesion type and each subject, 20 BiLex models were trained using the subject's language exposure history data, and lesioning was started beginning 11 simulated years before the last available data point for the subject. Rate of progression for each lesion was chosen so that full decline happens in 10 simulated years.

The six lesion types produced a range of patterns of decline, as pictured below. Black lines represent PAPT scores (semantic comprehension), blue lines represent English BNT scores (naming ability), and red lines represent Spanish BNT scores.



Experiment 2

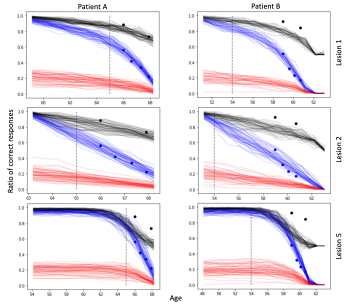
Models with different lesions were fit to the data of two English-speaking monolingual svPPA patients included in the study of Flurie et al. [5].

For each patient, 4 timepoints of naming accuracy scores were reported, spanning a period of 20-23 months, with 6-8 months between timepoints. PAPT scores also exist for each patient at the first and last timepoints.

Lesion types investigated in Experiment 1 which produce patterns of decline capable of fitting the shape of the data from these patients were fit to the data of each patient. Specifically, the free variables [time of lesioning onset] and [rate of progression] need to be fit in each case. Lesioning onset was constrained in the sense that it could be no later than the patient's reported age of onset.

An exhaustive search was run over all possible values of [time of lesioning onset] and [rate of progression] for each lesion and each patient, training 40 BiLex models for each combination of parameters. The best fit was chosen according to the least squared distance of model scores from actual patient scores.

The figure below shows the best fits found according to this process for each of the three candidate lesion types. Lesions 1 and 2, both of which involve progressive removal of semantic map neurons, are best able to replicate the patten of decline seen in these two patients' data.



Discussion / Future Work

- Two of the six candidate lesions can fit the data of monolingual svPPA patients well
- This, in combination with the patterns observed with Lesions 1 and 2 in Experiment 1, suggest patterns of decline we expect to observe in bilingual svPPA patients
- To fully validate this model, we will need data from bilingual dementia patients, which does not seem to be available yet; we are in the process of recruiting and testing patients to gather this data
- Subtypes of dementia other than svPPA will likely be better modeled with different lesion types (maybe some of the other lesions developed here, or maybe new lesion types will need to be developed)
- Combining multiple lesion types may allow a closer fit to the data
- Variable progression rate for lesioning may also allow a closer fit to the data

References

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4. Grasemann, Peñaloza, Dekhtyar, Miikkulainen, & Kiran (2021). Predicting language treatment response in bilingual aphasia using neural network-based patient models. *Scientific Reports, 11*, 10497.
5. Flurie, Ungrady, & Reilly (2020). Evaluating a maintenance-based treatment approach to preventing lexical dropout in progressive anomia. *Journal of Speech, Language, and Hearing Research, 63:12*, 4082-4095.

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