A Neural network model of Bilingualism and Cognitive Reserve

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Background: Does bilingualism protect against cognitive decline?

- Moderating factors exist between aging and cognitive decline (Katzman et al.,1993; Stern, 2002; Stern, 2009)
- The ability to speak more than one language has been hailed as one of the more recent additions to the list of proxies of this 'cognitive reserve' (Bialystok et al., 2008).
- Cognitive reserve in bilinguals may arise from application of greater inhibitory mechanisms when retrieving both lexical and conceptual representations
- More grey matter has been observed in the bilingual brain in regions involved in language control and semantic storage (Abutalebi et al., 2014)
- Phenomenon of retrieval-induced inhibition (Anderson, Bjork, & Bjork, 1994) – where retrieval of one memory can inhibit the recollection of other similar memories – suggests inhibitory control is required during retrieval in order to discriminate between the target representation and similar representations
- Theoretical models of inhibitory control in bilingualism have been developed: e.g., Green's (1998) inhibitory control (IC) model of bilingual language use

Aim: To present a computational model investigating idea that inhibition of lexical and categorical representations is greater in bilinguals due to greater overlap in the representational space; to show the impact of ageing on this system, under different levels of Brain Reserve Capacity (BRC; Stern, 2002)

An artificial neural network model of bilingual picture naming

The models used in this simulation were simple three-layer, feedforward back propagating artificial neural networks. Two versions were used, a monolingual version and a bilingual version. For each of the two networks, 50 simulants were trained for hidden layer sizes of 5, 10, 15, and 20 nodes, to implement differences in brain reserve capacity. Age was represented by incremental 'gain' decline of the sigmoidal transfer function in processing units, creating a progressive loss of sensitivity to differences in the input to each neuron.

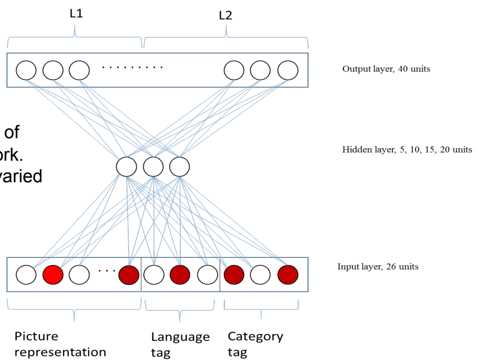


Figure 1. Schematic of picture naming network. Hidden layer size is varied over four levels.

Training set

The inputs used in both models were patterns of 26 binary digits. In addition to language, input further divided by semantic category tags. For the bilingual model, inputs were mapped onto English (L1) and Modern Greek words (L2). For the monolingual, inputs were mapped onto English words only. Networks were trained for 800 epochs, with ageing commencing after 220 epochs.

Results

Multidimensional scaling was applied to the activation profile of the hidden layer for both monolingual and bilingual networks at asymptote. This was only applied to both semantic categories A and B in L1 for each of the network types.

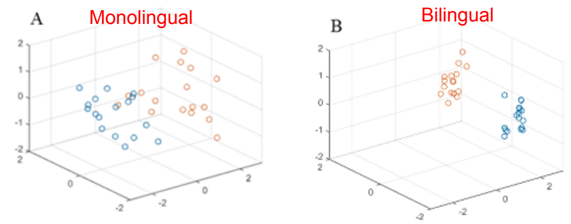
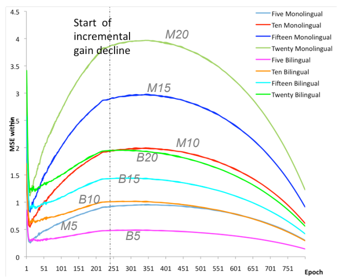


Figure 2. Scatterplots representing the distributions of representations of semantic categories A and B within L1 of the monolingual (A) and bilingual (B) network at 220 epochs.

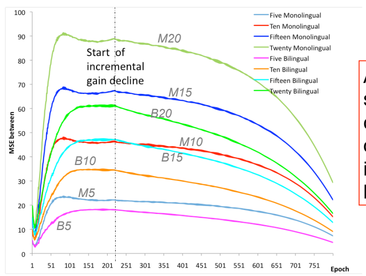
Figure 3. Plots of the mean spacing within semantic categories, and between the categories, during development and then with the onset of ageing (shown by dotted vertical line)

Loss of within-category representational spacing



Representations were more spaced in monolingual networks than bilingual networks, and more spaced in networks with more capacity than less capacity.

Loss of between-category representational spacing



Ageing caused loss of spacing (increased confusability), and occurred at a faster rate in networks with initially higher spacing.

To investigate if language tags created more inhibition in a bilingual network than a monolingual network, the weight values from language tags to the hidden layer of the 20-node versions of both the monolingual and bilingual networks are plotted. Inhibitory control emerges in the bilingual network.

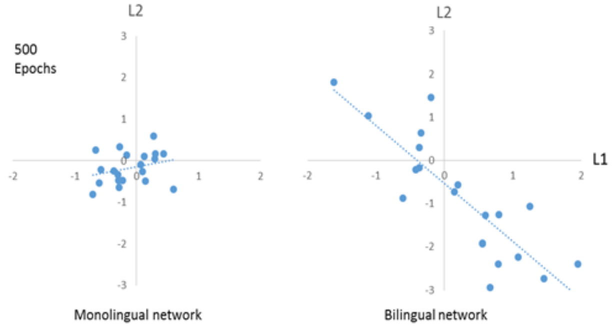


Figure 4. Scatterplots of weights from language tags to the 20-node hidden layer of monolingual and bilingual networks. Bilingual network shows significant negative correlation between L1 and L2 weights ($p<.001$).

Discussion

- Two factors influenced the overlap between representations in the naming networks: capacity (less overlap in bigger networks) and bilingualism (less overlap in monolingual networks). Bilingual networks have to fit more information into the same capacity.
- Inhibitory control circuits emerged in the bilingual networks to facilitate accurate naming in the presence of more overlapping representations
- Ageing caused overlap / greater confusability of representations, as processing units lost the ability to distinguish small differences in their inputs
- Ageing-related declines were faster in monolingual networks than bilingual networks
- Bilingual resilience to ageing may arise from greater inhibitory control, allowing accurate performance in the face of more overlapping representations

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