One Versus Two Lexicons: Modeling the Age-Old Question

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Abstract

The question of whether a bilingual speaker stores their words in one lexicon or two has been considered for many years. Recent research in psychology has explored this topic. With the question far from answered, we turned to developmental data to try to find an answer. Cantonese-English bilingual children and their vocabulary-size-matched English monolingual children were modeled in noun networks. Graph-theoretic statistics were then calculated. We found that bilingual networks are less coherently connected than monolingual children's networks, which lends support to the idea that bilinguals store their languages in two separate lexicons. Random networks created to reflect the number of words in the bilingual and monolingual children found that there was less overlap in words between bilingual children in these random networks than was found in actual networks. There is some evidence that these random networks were less coherently connected than the monolingual random networks, lending further support to the two lexicons answer. The third set of networks explored were those grown by preferential attachment. In this situation, the monolingual grown networks were less coherently connected than the bilingual counterparts. Further study is needed on this type of network to account for differences between the learning processes of the actual children and the networks.

Introduction

People have long been curious about the question of whether bilingual speakers store their vocabularies as one lexicon or two. Psychologists became interested in the topic during the 20th Century, with the amount of research being conducted to try to resolve it exploding in the second half of that century. The question fundamentally comes down the question of how the words of the two (or more) languages are stored in relation to each other. One possibility is that the words of both languages are stored together in the same lexicon, with the words in some way being marked as to what language they belong to, although how they are marked has yet to be decided. The other possibility is that the words of the two languages are stored in separate lexicons and therefore are not connected as strongly.

The first research to be conducted on the topic was experimental data collected using translation and naming tasks (see eg. Chen and Ng, 1989, Kirsner et al., 1984). This and other research led to the development of four main models of how lexicons and concepts were connected together and connected to the concept the words represented (see Potter et al., 1984; deGroot, 1992; and Kroll & Stewart, 1994 for more details). The experimental data was collected that supported the one lexicon answer to the bilingual representation question, as well as data collected that supported the two lexicon answer.

Later research created computational models of bilingual typical individuals using a variety of assumptions and methods. Each model was compared to experimental data and each model had several similarities to the data. (see Kroll & Tokowicz, 2009 for a review) These models matched experimental data quite well, but the field as a whole could not resolve the question of one or two lexicons. Models were created that supported one answer or the other, but no definitive answer has yet been found. (see Miikkulainen & Kiran, 2009; French & Jacquet, 2004; Thomas & Plunkett, 1995; and Thomas, 1997 for examples of successful models)

One approach to try to resolve the question of one or two lexicons is to look at the problem from a developmental perspective. This allows researchers to look at the problem through learning, a technique that the computational models use. Most computational models do not compare to developmental data as the model is learning, which is another way to see how the lexicon or lexicons form.

For bilingual children, several projects have been done that look at the question of one versus two lexicons, mainly through the use of case studies. Redlinger and Park (1980) studied the conversations of a German/Spanish bilingual boy with his German-speaking father and Spanish-speaking mother. They found that boy used German predominantly in all conversations and that he appeared to have one lexical system with words from both languages. Murrell (1966) looked at conversations of a Swedish/Finnish/English trilingual girl with her parents. Only Finnish was spoken at nursery school, Swedish by her mother and her father spoke a mixture of Swedish and English. It was found that the girl spoke mostly Swedish to her mother, with occasional English and a mixture of Swedish and English with her father. The author concluded that she had one lexicon of all three languages. (see Volterra & Taeschner, 1978; and Meisel, 1990 for similar studies)

Genesee (1989) reinterpreted the data, arguing that there was indeed differential treatment of the spoken languages in both of the above studies. He argued that this could indicate two distinct lexicons. In addition, it was found that children as young as 6 weeks could differentiate phonetic contrasts in language they had never been exposed to (Trehub, 1973), which Genesee (1989) suggested would allow young language learners to differentiate their languages in order to allow for two lexicons. This ability to differentiate languages, as well as use the languages they are learning in contextually sensitive ways shows that it is possible that children have two lexicons (Genesee, 1989). This possibility means that the question of one versus two lexicons is far from answered.

Although not related to the bilingual representation question, research has been conducted where children's vocabularies are modeled. Some of these studies model learning, such as Hills et al. (2009b). In this study the researchers modeled 130 nouns that children typically learn by 30 months using preferential attachment, preferential acquisition and the lure of the associates to determine which method best predicts age of acquisition. In another study, Hills et al. (2009a) looked at the graph-theoretic properties of noun-feature networks of words typically learned by children by the time they are 2.5 years. Beckage, Smith, and Hills (2011) modeled actual children's vocabularies rather than typically children. They looked at graph-theoretic and small world properties of typically developing children and children with language delays.

Extending the research done above, we looked at the noun-feature networks of 88 Cantonese - English bilingual children and vocabulary-size-matched English monolingual children. Only nouns were used for similar reasons as in the two Hills et al. studies. In addition, the majority of the words we were considering were nouns (57 nouns in the 70-word vocabulary). These networks were analyzed on a variety of graph-theoretic measures to determine the differences between the noun lexicons of the two language groups (bilingual and monolingual).

Experiment 1

Methods

participants. Data from 88 Cantonese - English bilingual children (age range: 3;2 to 5;0, mean age: 4;1) and vocabulary-size-matched (±1 words) 88 English monolingual children (age range: 1;4-2;5 months, mean age: 1;11 months). The bilingual children learned Cantonese at home and then started English at a Head Start Program. The vocabularies were from 70 words that overlapped between the set of common English and Cantonese words the bilingual children were asked to name pictures of and the MacArthur-Bates Communicative Development Inventory (MCDI) (Fenson et al., 1993).

procedure. For each child, all words that were not on the list of 70 words were removed from their vocabulary, and only the remaining words were considered. Each bilingual child had their composite vocabulary (words were known in Cantonese, English or both) size-matched with a monolingual English child, considering only the 70 words.

A program was written in Java that created networks for each child based on their vocabulary, considering only the nouns they knew from the overall vocabulary (57 nouns in total). Two nouns were connected if their Howell distance (Howell, Jankowicz, & Beckers, 2005) was greater than 0.85. In addition to building the network, the program calculated basic graph theory statistics for the network (i.e. number of words, number of nouns, number of edges, average degree, average distance, maximum distance and clustering coefficient). These statistics were then compared both between the two language groups (monolingual and bilingual) as a whole, and between individual pairs of children (a bilingual with its monolingual match).

measures. Number of Words: a count of the words in the vocabulary, out of the possible 70 words

Number of Nouns: a count of the nouns in the vocabulary, out of the possible 57 nouns

Number of Edges: a count of the edges in the network of the vocabulary

Average Degree: the average number of edges that are adjacent to (going into or out of) a node in the network

Maximum Distance: the longest shortest path between two nodes, calculated over all node pairs; the maximum of these shortest paths is maximum distance

Average Distance: the average length of the shortest path between two nodes, calculated over all node pairs

Clustering Coefficient: a measure of the extent to which a node's neighbors are connected to each other as well, averaged over all nodes in the network

Results and Discussion

Paired samples t-tests were conducted in each of the seven variables we were considering (number of words, number of nouns, number of edges, average degree, average distance, maximum distance and clustering coefficient). All analyses were done with the bilingual children compared to their vocabulary-size-matched monolingual child. Unsurprisingly, there was no significant difference in the number of words, since the children were all vocabulary-size-matched. On the other hand, a significant difference was found in the number of nouns between the two language groups, with the monolingual group having significantly more nouns (bilingual 44.71, monolingual 45.38, $p = 0.002$). In addition, the monolingual group had significantly more edges (bilingual 128.10, monolingual 136.54, $p < 0.001$) and higher average degree (bilingual 5.59, monolingual 5.92, $p < 0.001$). The other measures did not have any significant differences.

In addition to considering the pairs, we considered the two language groups as a whole. With language group as the only independent variable, there was a significant difference between the average degrees of the two groups, with the monolinguals having higher values (bilingual 5.58, monolingual 5.92, $p = 0.011$). We then considered the same data with the number of words as a covariant. The number of nouns was significantly higher for the monolinguals (bilingual 44.71, monolingual 45.38, $p = 0.001$). In addition, the monolingual group had higher number of edges (bilingual 128.10, bilingual 136.54, $p < 0.001$) and higher average degree (bilingual 5.59, monolingual 5.92, $p < 0.001$). We then considered the between-subjects tests with the number of nouns as a co-variant, since all measures were calculated for the noun networks. In this case, the number of edges and average degree were still significantly higher for the monolingual group (number of edges, average degree: $p < 0.001$).

The differences found in the number of nouns shows that the vocabularies of the two language groups have different compositions. The additional nouns (although admittedly only a small number added) frequently lead to more connections, which would be reflected in the average degree and the number of edges. Since these differences are likely not due to the additional nouns, as shown in the tests with the number of nouns as a co-variant, there is another reason for the differences found in the networks of the two language groups. These differences do show that there is a difference in the densities of the networks of the two groups, with the monolingual group having more dense networks than the bilingual group. This shows that the bilingual networks are not as coherently connected. The difference in coherence of connectivity indicates that how the networks are being made are fundamentally different. This lends support to the idea that there are two lexicons for the bilinguals, each of which is coherently connected.

Experiment 2

Methods

participants. Same as Experiment 1.

procedure. In order to determine if the differences between the bilingual and monolingual children's networks were a fact of their language status or an artifact of the vocabulary set, random vocabularies were created for each child. For each monolingual child, a randomly chosen vocabulary was made with the same number of known words. A program was written in Java to do this. For each bilingual child, a randomly chosen vocabulary was made of the same size as their Cantonese vocabulary, as well as a random vocabulary of the same size as their English vocabulary. These were then combined to make their randomly chosen combined vocabulary. These may be different in size from their actual combined vocabulary due to differences in how many words are overlapping, but this is an important feature that should be considered. These vocabularies were run using the same program as used in Experiment for the actual vocabularies of the children and analyzed in the same way.

Results and Discussion

Considering the same measures as in Experiment 1, we started by pairing the subjects using the same pairings as the actual children. We found the bilingual group had significantly higher number of words (bilingual 57.82, monolingual 55.45, $p < 0.001$), higher number of nouns (bilingual 46.95, monolingual 45.31, $p < 0.001$), higher number of edges (bilingual 140.43, monolingual 132.05, $p < 0.001$), higher maximum distance (bilingual 6.53, monolingual 6.01, $p = 0.017$) and higher average distance (bilingual 4.84, monolingual 4.51, $p = 0.018$). There was also a moderately significant difference in the average degree, with the bilingual group having a higher value (bilingual 5.82, monolingual 5.68, $p = 0.053$).

We next looked at the two language groups as a whole to compare them in between-subjects tests. This shows that the maximum distance of the bilingual networks is significantly higher than for the monolingual group (bilingual 6.53, monolingual 6.01, $p = 0.021$). In addition, there is a similar pattern in the average distance (bilingual 4.84, monolingual 4.52, $p = 0.025$). Once we include the number of words as a co-variant, there are no significant differences between the two language groups. The average degree was marginally higher for the bilingual group (bilingual 5.82, monolingual 5.68, $p = 0.068$). In addition, maximum distance and average distance were marginally higher for the bilinguals.

The higher average and maximum distances found in the bilingual group could indicate less coherently constructed networks. This is because the networks are shown to be more spread out by these higher values. Since the effect disappears when we control for the number of words, despite that variable not being significantly different between the two groups, it may be due simply to the difference in the amount of overlap between the languages of the bilinguals compared to that seen in the real children.

Experiment 3

Methods

participants. Same as Experiment 1.

procedure. To give a better picture of vocabularies, we need to consider that a vocabulary is not created entirely randomly, but instead grown to full size. To do this, we grew networks using preferential attachment. This method of growth is well documented in the literature as a driving force in learning new words (eg. Hills et al., 2009b). A program was written in Java to start with an input number of randomly chosen words from the average 16 month-old vocabulary (since all children were at least 16 months) and to then build the network to the input size based on preferential attachment, considering only nouns. We then grew 20 networks for each child starting with five words. For each monolingual child, the 20 networks were grown to the full size of their noun vocabulary. For each bilingual child, 20 networks were grown with their noun vocabulary size in Cantonese, and 20 more for their English noun vocabulary. These were then combined in the same manner as the random networks to make a full combined vocabulary. Again, these may not be the same size as the actual children's full combined vocabularies, but this is an important feature to be considered. These vocabularies were run using the same program from Experiment 1 for the actual vocabularies of the children and analyzed in the same way. The averages over the 20 networks for each child were then taken to make the overall data to be analyzed.

Results and Discussion

We again followed the same pattern as the analyses in Experiment 1 and started by looking at the vocabulary-size-matched pairs developed from the actual children using paired t-tests. We found that the count measures (number of words, number of nouns and number of edges) were all significantly different between the two language groups, with the monolingual group having higher values (number of words: bilingual 44.06, monolingual 45.38, $p < 0.001$; number of nouns: bilingual 44.06, monolingual 45.38, $p < 0.001$; number of edges: bilingual 161.47, 165.29, $p = 0.003$). In addition, maximum distance and average distance were found to be significantly different, with the monolingual group again being higher in these measures (maximum distance: bilingual 4.86, monolingual 5.17, $p < 0.001$; average distance: bilingual 3.68, monolingual 3.85, $p < 0.001$). The clustering coefficient measure was moderately significant, with the bilingual group having higher values (bilingual 0.649, monolingual 0.646, $p = 0.053$).

Again, as in Experiment 1, we looked at the two language groups as a whole. There was a significant difference in the maximum distance of the networks in the two groups, with the monolinguals having higher values (bilingual 4.86, monolingual 5.17, $p = 0.024$). We next controlled for the number of words, since these were a bit different, by including the number of words as a co-variant. In this case, the number of edges was significantly higher for the monolingual group (bilingual 161.47, monolingual 165.29, $p = 0.002$). In addition, the maximum distance was still found to be significantly greater for the monolingual group (bilingual 4.86, monolingual 5.17, $p = 0.003$). We do not need to consider the case with the number of nouns as a co-variant, since the number of words and the number of nouns are the same for these networks.

The differences found in the maximum distance and the number of edges indicates that there is a difference in the networks of the bilingual grown and combined networks and the monolingual networks. These differences show that the additional edges in the monolingual networks are not adding additional connectivity, and therefore do not decrease the maximum distance. The greater maximum distance means that the monolingual networks are less coherently connected and have lower density than the bilingual networks.

General Discussion

There are distinct differences in the significant differences found between the actual children and the random networks. This was expected since the random networks do not accurately reflect the learning mechanisms that govern how children's networks are grown. The possible difference in maximum distance found in the random networks does indicate that there is a possibility that the combining of two noun networks is sufficient to lead to the reduced coherence found in the bilingual networks. Since this difference disappeared when accounting for the slight difference in the number of words in the random networks of the two groups, it seems that there is something else working to create the difference found between the actual monolingual and bilingual networks.

We then looked at the preferential attachment grown networks, and found that these have differences even when accounting for the number of words in the networks. These differences are not the same as those found in the actual networks though. The grown networks indicate that the monolingual networks are actually less dense than the bilingual networks, the opposite of what was found in the actual children's networks. There are a few possibilities of why this is what we found.

It is possible that preferential attachment is not a good way to describe actual word learning. There are been numerous studies looking at this and other methods, and frequently the finding is that there are multiple mechanisms effecting how words are added to the vocabularies of children. Although preferential attachment has been shown to be a good measure, it may not be as good a measure to describe the learning of bilingual children as they learn both languages.

In addition, there is the possibility that there are idiosyncrasies within the word set that we are looking at. For example, the word 'chopstick' exists in the Cantonese MCDI and is likely to be a word that the bilingual children know, but it is not included in the English MCDI so we could not consider it in our study. We lack the measures of similarity necessary to include nouns not found in the MCDI, so we could only consider those words that have translations found in both the Cantonese and English MCDIs. Since this is the case, we cannot completely accurately represent the vocabularies of the bilingual children, so there may be differences that we cannot look at. This means that the differences we are looking at are minimized between the two language groups, since it is likely that the monolingual children do not know the English words for the more Cantonese-specific nouns, like 'chopsticks'. In order to see the true effect of this, we must consider a more comprehensive list of words. If a more comprehensive vocabulary was included, the actual children's networks may look more like those of the preferential attachment grown networks, since this learning mechanism has been shown to be effective at predicting vocabulary growth.

On the other hand, we still found differences between the two language groups when considering the actual children. This makes these differences all the more striking since they are minimized from what they likely actually are. It is possible that some measures that were only marginally different in our present study may actually be significantly different once a more complete vocabulary is considered.

There is a third possibility for the differences we found between the preferential attachment grown networks and the actual networks. This is in how the children learn language. The actual bilingual children are learning both of their languages at the same time, and there may be interplay between these languages. In addition, the bilingual children we looked at here started English after already knowing some Cantonese. It is possible that their Cantonese networks influenced the development of their English networks. In order to accurately account for these differences, the preferential attachment networks need to be grown with these things in mind. The networks should be grown simultaneously and account for the age that the children started to learn English. When these are taken into account, it may be that the preferential attachment grown networks are much more similar to the actual networks than they appear now.

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