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The Emergence of Competing Modules in Bilingualism

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How does the brain manage to store and process multiple languages without encountering massive interference and transfer? Unless we believe that bilinguals live in two totally unconnected cognitive worlds, we would expect far more transfer than actually occurs. However, imaging and lesion studies have not provided consistent evidence for the strict neuronal separation predicted by the theory of modularity. We suggest that emergentist theory offers a promising alternative. It emphasizes the competitive interplay between multiple languages during childhood and by focusing on the dual action of competition and entrenchment, avoids the need to invoke a critical period to account for age of acquisition effects in second-language learning. This view instantiates the motto formulated by Elizabeth Bates that'modules are made, not born.'

Introduction

Across the 30 years of her career in psycholinguistics, Elizabeth Bates constructed an emergentist account of first- (L1) and second- (L2) language acquisition that emphasized neuronal plasticity, competition and transfer [1]. She rejected the idea that there was a genetically programmed instinct for language learning that would expire at some particular critical period of development [2,3]. However, she never fully succeeded in explaining why it should be that adult second-language learners typically fail to achieve anything close to native competence in a second language [4]. The idea of a biologically determined critical period plays a pivotal role not just in linguistic theory, but in cognitive science as a whole. If emergentists cannot provide an alternative account for age-of-acquisition effects, then their position is significantly weakened. In this opinion article, we sketch out an account of second-language learning based on processes of competition and entrenchment. We suggest that this account explains age-of-acquisition effects in second-language learning in a way that is fully compatible with Bates' emergentist vision.

Early simultaneous bilinguals

Let us first consider the case of children who grow up bilingual from infancy. Jusczyk [5] has shown that, by 6 months, children are able to distinguish between speech in their native language and speech in another language. depends on prosodic differences. If the languages are as close in prosodic and segmental structure as, for example, Castilian and Catalan [6] then it will take children a few more months to pick up the specific segmental differences that separate the two languages. By the time they begin producing their first words, bilingual children have spent at least 16 months learning to segment the speech stream [7] and differentiate between the two languages. During this long preverbal period, we see the emergence of weakly separated modules to process the two incoming speech streams.

The child's first words demonstrate a great deal of phonological interaction between these still rather labile modules [8–10]. These interactions are predicted by emergentist accounts, such as the Competition Model [11], that emphasize the roles of competition, interaction and transfer. Months later, however, when the child begins to produce the first sentences, we often see a surprisingly low level of interaction between the two languages [12], even when the two languages share many syntactic constructions.

Resonance within emerging modules

The Competition Model [11,13] interprets this relative lack of interaction in terms of the dynamics of balanced competition between two emergent modules. As detailed in Box 1, the model relies on the notions of competition, resonance, parasitism and entrenchment to account for age-related differences in L2learning. For example, when the Spanish–English bilingual child is speaking Spanish, both mesa and table are activated as ways of talking about a table. However, because mesa is richly interconnected with other Spanish words, constructions, postures and meanings, it receives far more activation than table during Spanish speech. On the other hand, when the child's two languages are less perfectly balanced in strength, we find a far greater level of intrusion of the stronger language (SL) into sentences of the weaker language (WL) [9,14]. In such cases, continual practice with the WL eventually allows it to 'fight off' intrusions from the SL.

Each language achieves this insulation against intrusion by relying on patterns of mutual activation inherent

Box 1. Competition, resonance, parasitism and entrenchment

The Competition Model account of age-related changes in bilingual acquisition can be expressed in terms of the constructs of competition, resonance, parasitism and entrenchment. Competition arises when two words compete for the same referent. For a Spanish–English bilingual, the Spanish word tasa (meaning cup) competes directly with the English word cup. Without further support, Spanish–English bilingual children would have no clear way of deciding when to use 'tasa' and when to use cup. However, from their first exposures to the two languages, bilingual children encounter reliable cues that separate the two languages. Learning from these cues, children will use tasa when they are speaking to their Spanish-speaking father, and cup when they are speaking to their English-speaking mother. When these two parallel forms compete, the one that receives additional input from the activation of relevant supporting context will win.

The problem with relying simply on the context to resolve the competition between words in the two languages is that contexts are not fully reliable. For example, sometimes the mother might speak Spanish, or the father might speak English. There will also be visitors who will shift back and forth between languages. To further control the competition, the child must also rely on language-internal resonance. Consider the case in which the child has activated English forms such as myand wantto produce an utterance such as 'I want mycup of juice'. These forms co-activate each other through resonant interactive activation. As active forms within English activate other forms within English, the entire English lexicon becomes resonantly activated while the Spanish lexicon remains available but deactivated.

Figure I illustrates the very different situation facing the late L2 learner. Here, new L2 forms begin as word associations dependent on L1 forms (Figure Ia). As L2 forms gain in strength, they form new direct links to meaning [51] and the translation route from L1 to L2 becomes stronger (Figure Ib). Then as L2 resonance grows, the asymmetry between the two languages decreases. However, as L1 becomes more deeply entrenched, the strength of L2 links to concepts will never 'catch up' with the strength of L1 links. As a result, L2 will remain partially parasitic.

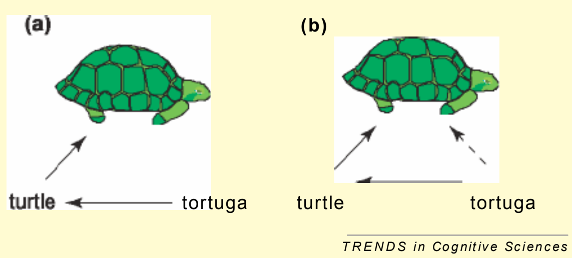

Figure I. (a) Parasitism: the Spanish 'tortuga' is a word associate of turtle without a direct link to meaning. (b) Later in learning, direct connections form between the L2 form 'tortuga' and the meaning in L1. As L2 forms gain strength, they can compete with L1, and L1 can access L2 more readily.

in the input. When a WL word becomes active, it spreads activation interactively to other WL words [15]. Through Hebbian learning [16], this interactive co-activation solidifies the bonds between WL forms and allows them to resist SL intrusions. The result of this interactive activation is the establishment of a long-term resonance between all the forms of a given language. As the resonance increases, each language is able to maintain full activation with minimal intrusion from the other. To manage on-line code-switching, as well as translation from one language to the other, the bilingual must learn to partially inhibit or dampen this resonance and activate a coordinated resonance in the other language [17].

The DevLex model

Bates highlighted three important features associated with the emergence ofthese experience-dependent modules: early plasticity, competition, and experience-dependent synaptic changes [18]. Implementing these features in a computationally concrete form, Li, Farkas and MacWhinney designed the DevLex model, a self-organizing neural-network model of the development of the lexicon [19]. At the core of the model is a self-organizing, topography-preserving feature map [20] that processes semantic and co-occurrence information in the input. The model acquired the early English vocabulary incorporated in the CDI (The MacArthur–Bates Communicative Development Inventory; [21]) by receiving input from maternal sentences in the CHILDES database [22]. Figure 1 illustrates the model's evolution in the lexical representation of nouns, verbs, adjectives and closed-class words, with snapshots taken across stages of development. The figure shows that lexical organization is shaped by the increases in lexical size and representational richness.

DevLex can also be used to illustrate the core predictions of the Competition Model for simultaneous bilingual acquisition. Li and Farkas [23] used a variant of the DevLex model for bilingualism to model simultaneous acquisition of English and Cantonese, using input from the Hong Kong Bilingual Child Language Corpus [14]. The network was trained to learn the 400 most frequent word types in parental speech (184 Chinese words and 216 English words, covering about 56% of the total word tokens). Figure 2 presents a snapshot of the model's representation of lexical categories in Chinese and English at the end of training, illustrating the distinct lexical representations for the two languages. Within each lexicon, the network further distinguished various grammatical categories in its representation (e.g. nouns vs. verbs, state verbs vs. activity verbs, etc.). The ability of the network to develop modular representations for different languages and different linguistic categories provides a concrete illustration of Bates's dictum that 'modules are made, not born.'

The Competition Model also predicts that bilingual children will acquire phonological and lexical maps that pull their two languages apart in a similar way. We do not predict that this type of code-based separation occurs for underlying distributed conceptual representations, but only for mappings at the levels of lexicon, phonology and parts of speech [24–26]. Because conceptual systems are grounded on distributed perceptual–motor cycles [27,28], they are relatively less affected by bilingual modularization [29] .

Late bilinguals

When older children or adults begin to learn a second language, they face a very different situation. It has often been noted that people who pick up a second language after the age of 5 retain some form of L1 accent [30], even if it is only very slight. The standard nativist account of age-of-acquisition effects is that some critical period for language learning has expired [2]. In fact, the concept of

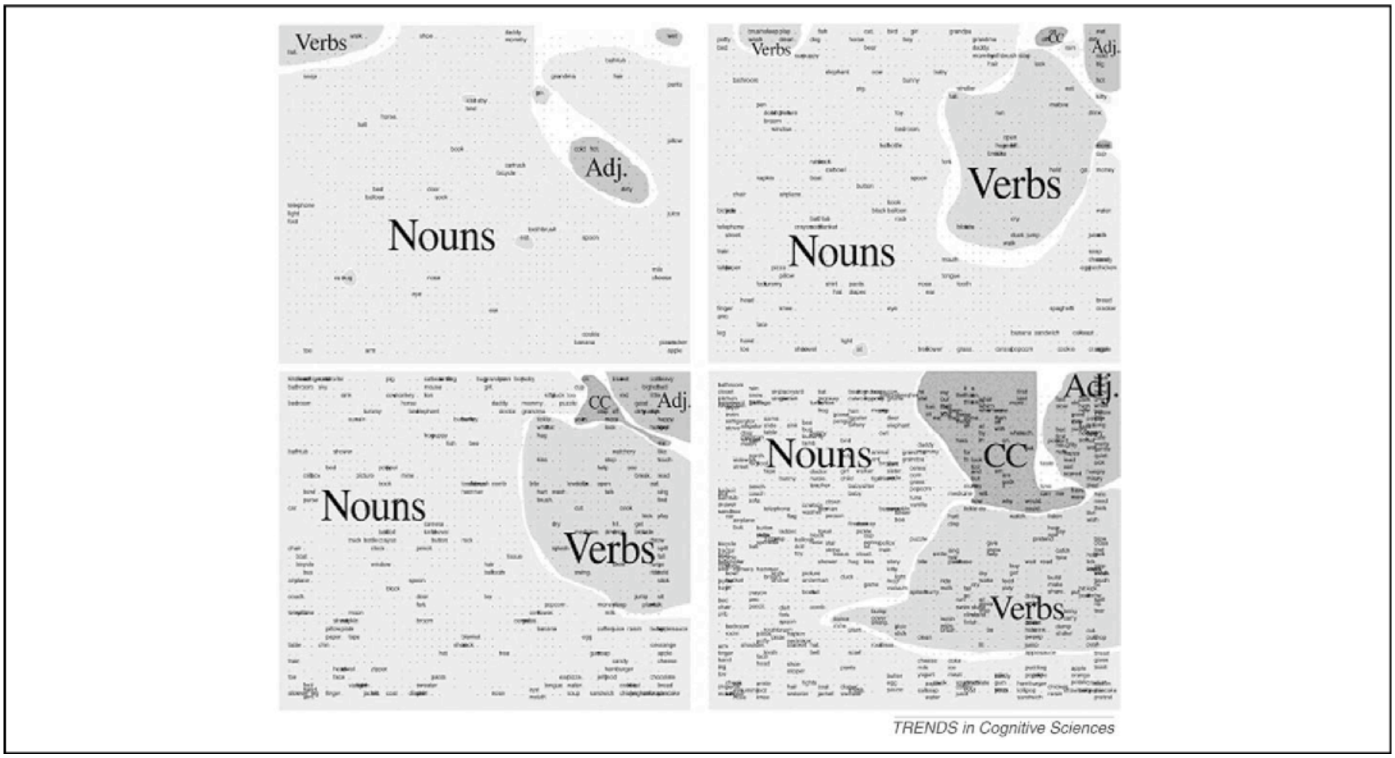

Figure 1. Snapshots of the DevLex model across stages of lexical development: Stage 1(upper left) 50 words; Stage 3(upper right) 150 words; Stage 5(lower left) 250 words; and Stage 10 (lower right) all 500 words. The self-organizing map separates the four major categories – Nouns, Verbs, Adjectives, and closed class words (CC) – clearly towards the final stage. (The labels for individual words are not legible because of the large number of words represented.)

critical period as formulated in ethology and developmental biology does not apply in any obvious way outside embryogenesis or infant development. Researchers have addressed the terminology problem by referring to a sensitive period, rather than a critical period [31], but this still requires us to believe in some undiscovered biological mechanism with an unspecified expiration date.

Our emergentist account provides a very different explanation for age-of-acquisition effects. Consider the cases of a child learning L2 at age 9 and a young adult learning L2 at age 24. The child has experienced years of consolidation and entrenchment [32], leading to progressively more automatic control of L1 in increasingly more committed neural substrates [33]. The young adult starts learning L2 against a background of an even more entrenched L1. Both the child and the young adult start learning L2 words as parasitic associates to L1 forms. In the terms of the DevLex model, this means that L2 items will be interspersed with the L1 forms on which they depend, rather than clustering in a separate region of lexical space, as in Figure 2.

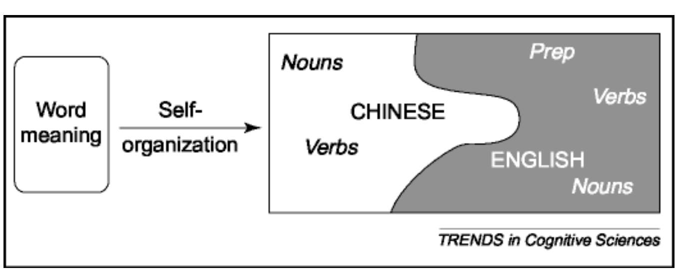

Figure 2. Emergence of lexical representations in DevLex from Chinese–English bilingual input. Through self-organization, the network comes to separate the Chinese lexicon from the English lexicon, implicating distinct lexical representations

Because the bilingual child retains greater plasticity and faces somewhat lesser L1 entrenchment, the model predicts a slow but continual reorganization of lexical space. For the young adult, on the other hand, movement on the lexical map may no longer be possible. Nonetheless, by invoking explicit [34] metacognitive procedures such as rehearsal, recoding and imagery, dedicated adult learners can induce resonance in L2. They can recognize this new stage subjectively when they find that they are starting to ‘think in the new language’. Once resonance sets in, a new set of neural relationships forms that allows L2 to develop its own nonparasitic integrity, even without full reorganization.

Adult L2 learners rely heavily on positive transfer or overlap with L1. At the phonological level, there is evidence that higher similarity between a native language and English leads to better perception and production of English vowels in non-native speakers [35] . However, when phonemes mismatch, the L2 adult learner might fail to detect the mismatch [16] and will have trouble developing motor programs to articulate correctly the subtly different sounds. At the lexical level, words that are orthographically similar across languages (tomato–tomate) are easier to process [36] and show fewer differences in neural activity than those that are not [37].

The DevLex model predicts that the neuronal organization of language in adult bilinguals should reflect these contrasting life histories. Early, balanced simultaneous bilinguals should have the clearest evidence of language separation. This separation will not be evident at a gross neuroanatomical level, but rather at the level of local cortical processing maps for audition, articulation, lexical form, sensory mappings, motor mappings, grammatical processes and sequential structures. Children with less balanced or later L2 input will perform like native speakers on many tasks, but will show residual asymmetries, suggesting that L2 is still partially parasitic on L1. Adult second-language learners will show relatively little L1–L2 separation at a local level. However, unlike late child learners, who rely primarily on implicit processes, adult L2 learners might recruit non-language areas to promote L2 resonance in an attempt to defend against the effects of L1 entrenchment.

Neurolinguistic evidence

Neurolinguistic studies tend to support the above analysis, although the picture varies markedly with the type of methodology used and the subject group being examined. ERP/EEG methodology provides one way of studying the on-line competition between L1 and L2. Tokowicz and MacWhinney [38] used ERPs to study sentence processing in college students who were beginning to learn Spanish. They presented subjects with Spanish sentences that had constructions that varied grammatically in L1 and L2. The sentences were either: (i) grammatically good in English, but bad in Spanish, (ii) good in Spanish, but bad in English, (iii) good in both languages, or (iv) bad in both languages. The Competition Model predicts the highest late-negative ERP response when sentences are bad in both languages, because this is a case of cue summation for learners whose L2 is parasitic on L1. The results supported the prediction [38]. Interestingly, the ERP results were a better indicator of these beginning learners' sensitivity to grammatical violations than were their paper-and-pencil grammaticality decisions, which were nearly random.

Cortical stimulation studies of early bilinguals [39] provide a very different type of evidence that languages are separated at the level of individual neurons. This method is able to probe small local differences in the topology of cortical organization of the type suggested by the DevLex simulations (Figures 1 and 2). However, separation at the neuronal level does not necessarily entail separation at a higher level of cortical organization.

Lesion studies with bilingual aphasics have not provided clear evidence that L2 is more vulnerable to neurological insult [40]. However, recent work in neuroimaging has supported the view that processing in a less proficient L2 leads to more widespread neural activity than that observed when processing a stronger L1 [41–44]. Furthermore, imaging studies have reliably demonstrated that L2 processing relies on attentional and strategic control areas not involved in L1 processing [45].

In a recent fMRI study [46], Chinese monolinguals performed a lexical decision task for nouns, verbs or class-ambiguous items. Verbs in Chinese are distinct from verbs in English in that they take no markings for tense or number. Thus, Chinese has no affixes to mark, for example, the distinction between run, runs, running and ran. In addition, there are many items that can serve as both nouns and verbs. As an apparent result of this fuzzy category boundary in Chinese, neuroimaging reveals strong overlapping regions of activity for processing nouns and verbs. In a parallel study [47], early Chinese–English bilinguals performed lexical decisions for nouns and verbs in each language. Like Chinese monolinguals, these bilinguals showed large areas of overlapping activity for the processing of Chinese nouns and verbs. However, when the bilingual subjects were processing English, there was increased activity for verbs relative to nouns in the left inferior frontal gyrus (Brodmann areas 45 and 47), in the precuneus bilaterally, and in the culmen of the right cerebellum. Late Chinese–English bilinguals have not yet been tested in this way, but our prediction is that distinctions in neural activity between the two languages will be less clear for later bilinguals. Together, these various imaging results suggest that subjects with contrasting L1 experiences process L2 in different ways.

Another source of support for the emergentist account comes from an fMRI imaging study of Korean adoptees by Pallier et al. [48]. The subjects in this study were eight young adults who had been adopted by French families when they were between 3 and 8 years old. All of them reported having totally forgotten Korean and all had achieved a fully native-like control of French. When these subjects were placed in the scanner and given word stimuli, their activation patterns for Korean and other unfamiliar languages (Polish or Japanese) were indistinguishable, but all were different from that to French. Their activation patterns to French were similar to those of native French speakers, although they were confined to a more restricted area of the cortex. These results indicate

Box 2. Questions for future research

There is much to be done to test and clarify the predictions of the Competition Model. Some of the current questions that require investigation are:

- At the neuronal level, we expect to see a local separation of languages in the feature maps of early bilinguals. Current fMRI methodology cannot detect this local separation, but might it be observable through other methods?
- The theory of resonance holds that both adults and children should benefit from mnemonic associations between sounds and meanings. Work on the keyword method with adults [49] supports this view, but does a similar process operate in young children?
- Are there fundamental neuronal or processing differences between the temporary resonance used to learn new words and the long-term resonance that arises in more advanced learners?
- The parasitic nature of late L2 learning might force learners to rely more on the strategic control of activation of the two languages. How is this managed in real time by the attentional system?
- Are there some contexts in which L2 learners can overcome entrenchment and avoid parasitism by avoiding all use of L1? The studies of the Korean adoptees by Pallier et al. seems to show an example of this type. Are there others?
- What are the details of the effects of entrenchment for different linguistic domains, including segmental phonology, prosody, tone, auditory recognition, word order, grammatical declension and conjugation, lexical learning, turn-taking and pragmatics?
- How can we best use the ERP framework of Tokowicz and MacWhinney [38] or similar reaction-time methods [50] to examine syntactic competition in early bilinguals, child bilinguals and proficient late bilinguals?
- The conceptual representations across a bilingual's two languages are only partially overlapping [24]. Can models like DevLex account for the emergence of overlapped, but non-identical concepts that are linked to partially separated lexical maps?

that, as late as the age of 8, Korean had not yet ‘crystallized’ in their brains. Once Korean input was no longer available, L1 resonance quickly diminished with a resulting rapid drop in L1 entrenchment. Freed from the effects of competition and entrenchment, these adopted children were able to learn L2 with little difficulty (see Box 2 for other future research questions).

Conclusions

Elizabeth Bates was the foremost spokesperson for the emergentist approach to language learning and language loss. By stressing the idea that ‘modules are made, not born’, she provided the underpinnings for a detailed account of first- and second-language learning. Computational models based on her ideas have shown that parts of speech separate on topological maps of the monolingual lexicon. These same models show how simultaneous learning of two languages can lead to the acquisition of fully separated lexical modules. By relying on the constructs of competition, parasitism, resonance and entrenchment (Box 1), we can construct a full picture of the fundamental ways in which adults and children differ in their learning of a second language, without invoking hard-wired modules or critical periods based on unproven biological capacities.

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