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A Unified Model

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There are three obvious differences between first and second language learners. First, infants who are learning language are also engaged in learning about how the world works. In contrast, second language learners already have a full understanding of the world and human society. Second, infants are able to rely on a highly malleable brain that has not yet been committed to other tasks (MacWhinney, Feldman, Sacco, & Valdes-Perez, 2000). In contrast, second language learners have to deal with a brain that has already been committed in various ways to the task of processing the first language. Third, infants can rely on an intense system of social support from their caregivers (Snow, 1999). In contrast, second language learners are often heavily involved in social and business commitments in their first language that distract them from interactions in the new language.

Together, these three differences might suggest that it would make little sense to try to develop a unified model of first and second language acquisition. In fact, many researchers have decided that the two processes are so different that they account for them with totally separate theories. For example, Krashen (1994) sees L1 learning as involving "acquisition" and L2 learning as based instead on "learning." Others (Bley-Vroman, Felix, & Ioup, 1988; Clahsen & Muysken, 1986) argue that Universal Grammar (UG) is available to children up to some critical age, but not to older learners of L2.

Despite these differences, there are good reasons to want to develop a unified model. First, many of the tasks faced by L1 and L2 learners are identical. Both groups of learners need to segment speech into words. Both groups need to learn the meanings of these words. Both groups need to figure out the patterns that govern word combination in syntactic constructions. Both groups have to work to interleave their growing lexical and syntactic knowledge to achieve fluency. For both groups, the actual shape of the input language of the community is roughly the same. Thus, both the overall goal and the specific subgoals involved in reaching that goal are the same for both L1 and L2 learners.

Furthermore, the fact that L2 learning is so heavily influenced by transfer from L1 means that it would be impossible to construct a model of L2 learning that did not take into account the structure of the first language. Thus, rather than attempting to build two separate models of L1 and L2 learning, it makes more sense to consider the shape of a unified model in which the mechanisms of L1 learning are seen as a subset of the mechanisms of L2 learning. Although some of these learning mechanisms are more powerful in L1 than in L2, they are still accessible to both groups (Flynn, 1996). Therefore, it is conceptually simpler to formulate a unified model. We can use this same logic to motivate the extension of a unified model to the study of both childhood and adult multilingualism.

A first attempt at a unified account can be found in MacWhinney (2005a). The current chapter attempts to further systematize that account, relying on the Competition Model (Bates & MacWhinney, 1982; MacWhinney, 1987a) as its basic starting point. In particular, the Unified Model adopts the core Competition Model insight that, for the adult native speaker, cue strength is a direct function of cue validity. In the Unified Model, forms are stored in associative maps for syllables, lexical items, constructions, and mental models. During processing, the selection of forms is governed by cue strength within a competitive central syntactic processor.

Learning is grounded on self-organization within the associative maps. The processes of buffering, chunking, and resonance further modulate learning in these maps. Buffering works to provide short-term storage of material to allow the processor to compare competing forms and to extract consistent patterns as inputs to learning. Chunking works to facilitate the fluent integration of information between maps. Resonance works to consolidate representations within maps. The next sections explain the structuring of the associative maps, the operation of competition, and the roles of buffering, chunking, and resonance.

1. Self-organizing Maps

The Unified Model views long-term linguistic knowledge as organized into a series of self-organizing maps (SOMs) (Kohonen, 1990; Li, Farkas, & MacWhinney, 2004). Self-organizing maps base their computation on a two-dimensional square lattice with a set of neurons or units. These neurons are all fully connected to the input, so that, on a given processing trial, every neuron receives the same pattern of featural input. Within the sheet, neurons are only connected to their nearest neighbors. On a given trial, some input features will be active and others will be turned off. For example, when the learner hears the syllable /pa/, the feature for labiality of the consonant will be active and the feature for affrication will not. Learning involves three phases. In the first phase, all units receive activation from the input and each unit computes its current activation. In the second phase, units compete through local inhibition of their neighbors. The best matching unit then emerges as the winner in this competition. In the third phase, the weights of the responding units are adjusted to increase the precision of activation in future trials. An important result of the weight adjustment procedure is that neighboring units become increasingly responsive to similar input patterns. As a result, similar inputs tend over time to activate neighboring units in the map. This adjustment feature gives SOMs their self-organizing properties.

Figure 1 shows how the SOM used in the DevLex model of Li, Farkas, and MacWhinney shows increasing organization of activity bubbles for specific parts of speech over time. In this figure the upper left map shows the network after learning 50 words; the upper right shows the network after learning 100 words; the lower left shows the network after 250 words; and the lower right shows the network after it has learned 500 words. These figures show how, particularly during the first stages of learning, there is great plasticity with verbs moving from one edge of the sheet to the other. This movement occurs because, at first, particular areas are only weakly committed to particular parts of speech. For example, verbs may have made an initial beachhead in several areas. However, each of these beachheads is only weakly organized and lightly entrenched. Over time, one of these beachheads becomes the strongest and then ends up attracting all verbs to this area. As the network becomes more entrenched, less movement occurs. At the same time, the recall precision of the network increases, as does the size of the vocabulary it has learned.

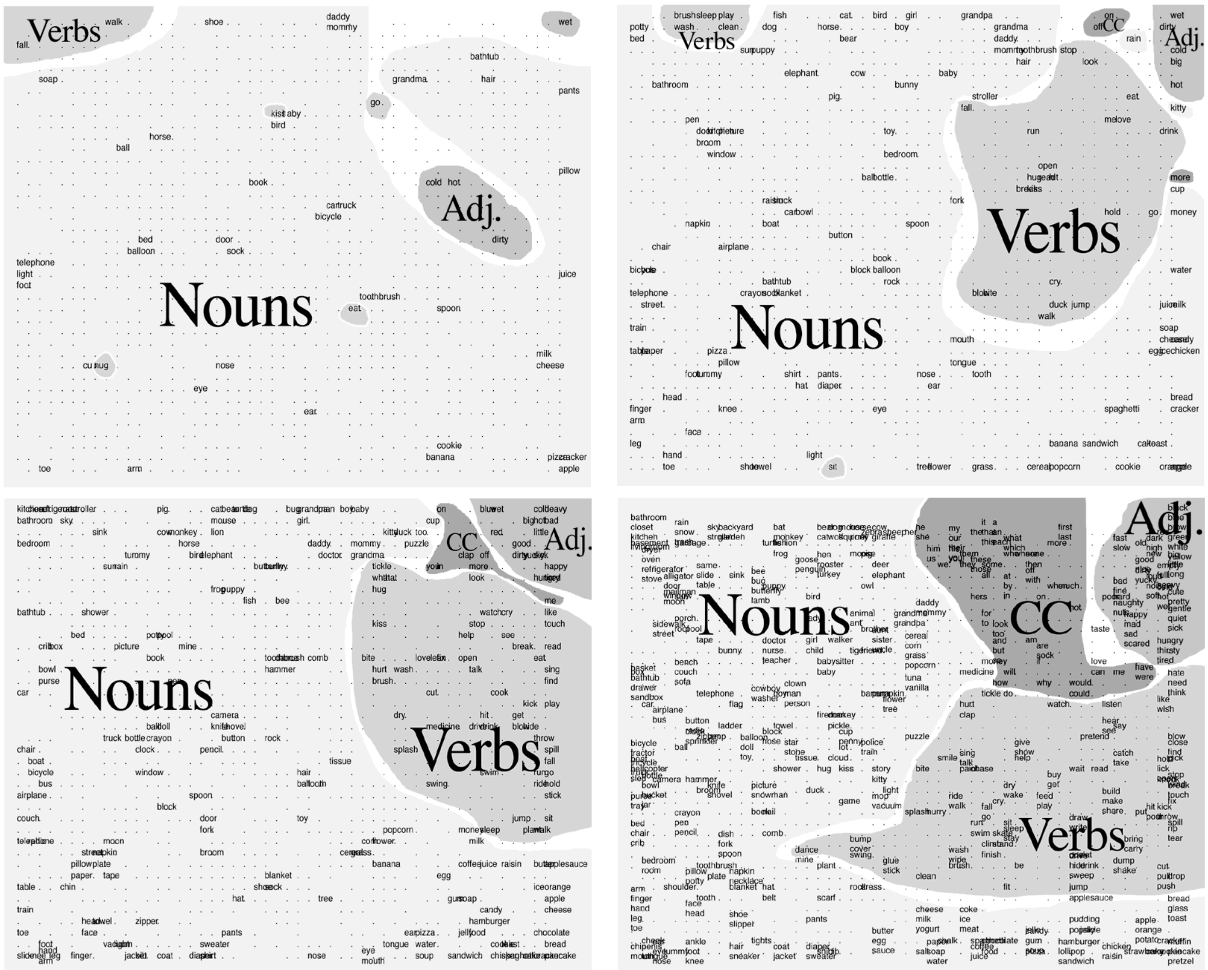

Figure 1: Part of speech organization in the DevLex network after learning 50 (upper left), 100 (upper right), 250 (lower left), and 500 (lower right) words. Adj=adjectives, CC=closed class.

Kohonen (1990) has shown that a two-dimensional SOM can accurately compute associations in a multidimensional space. Furthermore, the SOM has several structural and processing properties that correspond closely to those found in the brain.

1. SOMs rely on lateral inhibition during the competition of the winner with its nearest neighbors. The shape of this inhibition corresponds closely to the "Mexican hat" function observed in actual neural lateral inhibition.
2. SOMs maximize local connectivity. This corresponds to the observed preference for short connections in the brain.
3. SOMs provide an emergent form of localist representation. Over time, individual neurons come to become responsive to highly specific inputs, down to the level of the individual word or morpheme. This localist organization makes lexical items and parts of speech available for syntactic computation. However, this localism is emergent. If a particular unit is destroyed, the sheet may still be able to respond properly, although somewhat less accurately, to the input preferred by that unit.
4. SOMs demonstrate increased entrenchment and decreasing plasticity over time. As local organization progresses, it becomes more and more difficult to reverse or modify.
5. SOMs learn through unsupervised self-organization, rather than back-propagation. This corresponds to the observed pattern of unidirectional local connectivity in the cortex.

The two-dimensional structure of SOMs corresponds well with the sheetlike nature of cortical regions. Moreover, many cortical regions have been shown to possess a spatial organization (retinotopic, tonotopic, somatotopic) that corresponds in a SOM-like way to the physical structure of the input space.

The Unified Model postulates the existence of SOMs at the level of the syllable, the lexical item, and the construction. Let us look now in greater detail at how each of these maps functions in the Unified Model.

1.1 Syllabic maps

At the level of the syllable, there are initially two maps. The first map organizes recurring auditory input to auditory syllabic patterns, and the second organizes recurring motor sequences to articulatory syllabic patterns. During babbling, the child learns the equivalence between syllables organized in these two alternative ways. Once these equivalences are established, the system can be represented as a conjunction of two sets of inputs to a single central map. In accord with the models of Gupta & MacWhinney (1997) and Li & MacWhinney (2002), syllables are represented as serial chains with positions encoding syllable onset, nucleus, and coda. This representation allows the articulatory processor to convert syllables to a series of articulatory gestures. It also allows the auditory processor to detect formant changes through time across the syllable.

Languages differ markedly in the range of syllables encoded in these maps. Japanese uses no more than 70 different syllables. Mandarin Chinese has about 400 syllables. However, because a given syllable can be produced with up to five tones, the total inventory is about 1600. English has even more possible syllables, reaching perhaps 3000. It is likely that the syllabaries of languages like Japanese require no more than one level of SOM organization. However, systems like those for English or Mandarin can rely on hierarchicalization within SOMs, as suggested by Dittenbach, Rauber, & Merkl (2002). In a hierarchically-organized SOM, an area of high local competition projects to a full subordinate feature map which can then be used to further resolve the competition.

These properties of syllable-level SOMs help us understand the challenges faced by L2 learners at the level of phonology. Werker (1995), Kuhl (1991), and others have argued that during the first year children lose their ability to distinguish phonemic contrasts not present in their L1. This effect will arise in SOMs as a result of focusing on highly predictive features in the input at the expense of less predictive features (Regier, in press). A classic case of this type of loss is the inability of many Japanese speakers to distinguish between English /r/ and /l/ in perception. To perceive this contrast, English speakers rely on third formant (F3) transitions to the following vowel. However, because there is no role for F3 transitions in the smaller Japanese syllabary, native Japanese speakers are not even listening for this cue. Moreover, since production uses this cue to guide subtle aspects of tongue positioning, Japanese L1 speakers also have problems learning to distinguish these consonants in production.

This example illustrates how L1 entrenchment blocks effective L2 learning. In fact, adults can learn to recognize and produce this contrast (Bradlow, Akahni-Yamada, Pisoni, & Tokhura, 1999; Flege, Takagi, & Mann, 1995). The relevant features are still available in the auditory input (Lotto, Kluender, & Holt, 1997); learning just involves allowing these features to have their impact on the auditory SOM. The Competition Model holds that, in order to restructure the syllable maps, L2 learners must rely on repeated focused trials to link changes in the auditory syllabary with changes in the articulatory syllabary. Methods for inducing these changes include presenting clear cases (McCandliss, Fiez, Protopapas, Conway, & McClelland, 2002), facial visual feedback, and diagrams of tongue positions.

The influence of L1 syllabaries on L2 acquisition is not restricted to Japanese speakers learning /r/ and /l/. Even for languages as close as German and English, the transfer of L1 syllabaries to L2 words can lead to strong L1 accents in L2. Consider the pronunciation by

German learners of English of the word “German” as “Tsherman” or the use of German guttural /r/ for English flapped /r/. In general, L2 articulatory learning begins with massive transfer of L1 articulatory patterns to L2 (Flege & Davidian, 1984; Hancin-Bhatt, 1994). This transfer is at first successful in the sense that it allows for a reasonable level of communication. However, it is eventually counter-productive, since it embeds L1 phonology into the emergent L2 lexicon. In effect, the learner treats new words in L2 as if they were composed of strings of L1 articulatory units. This method of learning leads to short term gains at the expense of long-term difficulties in correcting entrenched erroneous phonological transfer.

Forms that are unmarked in L1 transfer much more strongly than forms that are marked in L1 (Demuth, 1995; Eckman, 1991; Major, 2001). This is exactly the type of pattern we would expect to emerge from the operation of a cue-based SOM model. For example, if your goal as an L2 learner of English is to articulate an /r/, and your native Spanish language uses both a marked trilled /r/ and an unmarked tap /r/, you are most likely to make use of the unmarked tapped /r/, even in initial position with English words like “rich,” rather than relying on the marked trilled /r/. This pattern of reliance on the unmarked form extends also to lexicon and syntactic constructions, as we will see below.

Some researchers (DeKeyser, 2000; Long, 2005) have attributed these effects not to transfer and entrenchment, but to the operation of a biologically determined critical period (Lenneberg, 1967). Critical periods arise when presence or absence of a certain input causes irreversible deviations in the normal course of development (Waddington, 1957). These periods require a sharply defined age of termination, after which normal development is no longer possible. Extending this notion to cover the effects of entrenchment in cortical maps is problematic. We know that synapses and neurons are continually created and lost in most cortical regions, even including segments of the motor system (Strick, in press). Given this, it is better to talk about the persistence of L1 accent in terms of entrenchment of particular features, rather than the end of some global critical period (Hurford, 1991).

Children who are exposed to two languages from birth are able to separate out two syllabaries early on. This separation relies on both segmental and prosodic cues (Mehler & Christophe, 1994). For example, it is easy to use even foot length to distinguish Spanish from English or to use tone to distinguish Chinese from Portuguese. Children learning two languages have up to 14 months of experience in distinguishing their languages by the time they come to saying their first words. The fact that languages can be consistently separated in audition as early as six months (Sebastián-Galles & Bosch, 2005) makes findings of early language separation in production (De Houwer, 2005) understandable in Competition Model terms.

When the child's two languages are roughly equal in dominance or strength, each system generates enough system-internal resonance to block excessive transfer. However, if one of the languages is markedly weaker (Döpke, 1998), then it will not have enough internal resonance to block occasional transfer. The situation is very different for L2 learners, since the balance between the languages is then tipped heavily in favor of L1. In order to permit the growth of resonance in L2, learners must apply additional learning strategies that would not have been needed for children. These strategies focus primarily on optimization of input, promotion of L2 resonance, and avoidance of processes that destroy input chunks.

1.2 Lexical Maps

In the DevLex model of Li, Farkas & MacWhinney (2002), lexical items (words) are represented as links between sounds and meanings. The lexical map encodes the phonological shape of words as a sequence of syllables. The semantic map encodes the meaningful side of words as a series of embodied images (Barsalou, 1999). Basically, words are viewed as associations between forms and functions.

The DevLex model (Li, Farkas, & MacWhinney, 2004; Li, Zhao, & MacWhinney, in press) has been used to model a wide variety of phenomena in early lexical learning, including the vocabulary spurt, acquisition of parts of speech, semantic association, early lexical confusions, and the age of acquisition effect. It has also been used to model early lexical modularity in simultaneous bilingual acquisition (Hernandez, Li, & MacWhinney, 2005; Li & Farkas, 2002). Unlike most models of early lexical development, DevLex models use realistic parental input gathered from the CHILDES database for English and Chinese corpora. This input is coded using the PatPho system (Li & MacWhinney, 2002) for phonology, the HAL system for lexical cooccurrence (Li, Burgess, & Lund, 2001), and the WordNet system (Harm, 2002) to provide additional semantic detail.

In the DevLex simulations of the simultaneous learning of Chinese and English, the emergent feature maps show a clear separation between the two languages with Chinese words organized to one side of the map and English words organized to the other. L2 learning in DevLex takes a very different form. The L2 learner can achieve rapid initial progress by simply transferring the L1 conceptual world *en masse* to L2. This amounts to an intermingling of L2 forms in a basically L1 map. When learners first acquire a new L2 form, such as “silla” in Spanish, they treat this form as simply another way of saying “chair”. This means that initially the L2 system has no separate conceptual structure and that its formal structure relies on the structure of L1. Kroll and Tokowicz (2005) review models of the lexicon that emphasize the extent to which L2 relies on L1 forms to access meaning, rather than accessing meaning directly. In this sense, we can say that L2 is parasitic on L1, because of the extensive amount of transfer from L1 to L2. The learner's goal is to reduce this parasitism by building up L2 representations as a separate system. Learners do this by strengthening the direct linkage between new L2 forms and conceptual representations.

Given the fact that connectionism predicts such massive transfer for L1 knowledge to L2, we might ask why we do not see more transfer error in second language lexical forms. There are four reasons for this.

1. First, a great deal of transfer occurs smoothly and directly without producing error. Consider a word like *chair* in English. When the native English speaker begins to learn Spanish, it is easy to use the concept underlying "chair" to serve as the meaning for the new word *silla* in Spanish. The closer the conceptual, material, and linguistic worlds of the two languages, the more successful this sort of positive transfer will be. Transfer only works smoothly when there is close conceptual match. For example, Ijaz (1986) has shown how difficult transfer can be for Korean learners of English in semantic domains involving transfer verbs, such as *take* or *put*. Similarly, if the source language has a two-color system (Berlin & Kay, 1969), as in Dani, acquisition of an eight-color system, as in Hungarian, will be difficult. These effects underscore the extent to which L2 lexical items are parasitic on L1 forms.
2. Second, learners are able to suppress some types of incorrect transfer. For example, when a learner tries to translate the English noun *soap* into Spanish by using a cognate, the result is *sopa* or "soup." Misunderstandings created by "false friend" transfers such as this will be quickly detected and corrected. Similarly, an attempt to translate the English form *competence* into Spanish as *competencia* will run into problems, since

competencia means competition. Dijkstra (2005) notes that, in laboratory settings, the suppression of these incorrect forms is incomplete, even in highly proficient bilinguals. However, this transfer effect may be less marked in non-laboratory contexts in which language-internal L2 associations are more fully activated by concurrent reciprocal activation.

3. Third, error is minimized when two words in L1 map onto a single word in L2. For example, it is easy for an L1 Spanish speaker to map the meanings underlying “saber” and “conocer” (Stockwell, Bowen, & Martin, 1965) onto the L2 English form “know.” Dropping the distinction between these forms requires little in the way of cognitive reorganization. On the other hand, it is difficult for the L1 English speaker to acquire this new distinction when learning Spanish. In order to control this distinction correctly, the learner must restructure the concept underlying “know” into two new related structures. In the area of lexical learning, these cases should cause the greatest transfer-produced errors.
4. Finally, learners tend to avoid the transfer of marked lexical forms, just as they avoid the transfer of marked phonological forms. In the lexicon, this often means that learners will use generic forms and superordinates rather than more specific terms. For example, an English speaker learning Spanish will refer to a creek as a “river” using the Spanish word “río” rather than the more specific form “riachuelo.” This pattern of learning will minimize error, although it fails to achieve full expressivity.

1.3 Construction Maps

The combination of lexical items into sentences is controlled by constructions (Goldberg, this volume; Lieven & Tomasello, this volume). In the Competition Model, constructions are patterns that specify how a predicate (verb, adjective, preposition) can combine with its arguments. MacWhinney (1975, 1982) characterized the child's initial learning of syntax in terms of the acquisition of item-based constructions (Hudson, this volume). These are specific constructions linked to specific individual predicates. For example, we can say that the verb "pour" is linked to the construction: pourer + "pour" + thing_poured + receptacle. Or we can say that the adjective "nice" is linked to the construction: "nice" + thing_described. Although these item-based constructions are limited in scope, they can be combined recursively to produce full productivity in language. For example, constructions based on "nice," "for," and "my" can be combined to produce "for my nice kitty." For recent explications of the details of item-based learning, see MacWhinney (2005b). For older, more detailed accounts, see MacWhinney (1987a, 1987b).

Although we have not yet implemented a SOM-based model for the learning of constructions, we can sketch out the general way in which it will work. Constructions that are linked to individual items can be learned as features of items on the current DevLex semantic map. These additional features encode the expectations of individual predicates for arguments. Because the DevLex map uses cooccurrence information for training, this type of information is already available. For item-based constructions, we just have to add semantic role information to the input vector. In other words, instead of just telling the network that "nice" goes with "kitty," we will also tell it that "kitty" is functioning as "thing described." In addition, the map will encode the other semantic features of the "thing described" This information will then be sufficient for the syntactic processor to activate plausible nouns after the predicate "nice" during comprehension or to relate the predicate to its arguments positionally during production.

Building on the information acquired during the learning of item-based patterns, learners can then organize groups of item-based constructions into lexical group constructions. The extraction of this second level of constructions requires encoding in a separate map that associates groups or types of predicates to types of arguments. For example, verbs such as “pour” or “throw” use the construction Agent + V + Object + Goal as in “Bill poured the water into the tub.” Other verbs such as “fill” or “paint” use the construction Agent + V + Goal + Transferred, as in “Bill filled the tub with water.” The impact of lexical group constructions on processing has been examined in a variety of recent studies in sentence processing (Holmes & Stowe, 1989; MacDonald, 1994; MacDonald, Pearlmutter, & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998; Trueswell & Tanenhaus, 1994; Trueswell, Tanenhaus, & Garnsey, 1994; Trueswell, Tanenhaus, & Kello, 1993). This work has yielded results that are closely in accord with Competition Model claims regarding cue validity and competition (Elman, Hare, & McRae, 2005).

There is a third level of argument generalization, above the levels of the item-based pattern and the group-based construction. This is the level of the global construction. Whenever group-based constructions can be generalized across predicate groups, global constructions can emerge. In English, the SV and VO global patterns work together to produce prototypical SVO order (MacWhinney, Bates, & Kliegl, 1984). Other languages promote different combinations of global patterns. In Hungarian and Chinese, for example, SV, OV, and VO orders operate to express alternative varieties of object definiteness, producing SVO and SOV orders. Italian combines SV and VO patterns with secondary, but significant use of VS (Dell'Orletta, Lenci, Montemagni, & Pirelli, 2005) to produce SVO and VSO orders.

Among the various global patterns, there are two that seem to be nearly universal. The first is the ordering of the topic before the comment to produce Topic + Comment order. This pattern is used extensively in languages as typologically diverse as Hungarian (É.-Kiss, 1981), Italilan

(Moro, 2006), and Chinese (Barry, 1975). The second universal global cue is the global animacy cue. All other things being equal, nearly all languages tend to prefer animate subjects. This cue reflects the fact that there is a consistent association of the grammatical subject with the agential, human perspective (MacWhinney, 2005c). However, from the viewpoint of the child acquiring language, the association of animacy or topicality with the role of the subject can be induced directly from the statistical fact that subjects are typically agential and topical.

Thus, animacy is a strong cue to SV interpretation of NV in English, but also a strong cue to VS interpretation of VN in Welsh. Second, the marking of agentiality or perspective is typically cued most strongly by the contrast between animate and inanimate nouns. Third, the semantics of the perspective varies across the specific verb or verb group involved. Most verbs treat the perspective as the animate causer, but some verbs like "frighten" treat the cause as the perspective, even when it is not animate. Other verbs, such as those in the passive, create perspectives that are neither causal nor agential.

1.3.1 Transfer in Comprehension

There are now over a dozen Competition Model studies that have demonstrated the transfer of a "syntactic accent" in sentence interpretation (Bates & MacWhinney, 1981; de Bot & van Montfort, 1988; Frenck-Mestre, 2005; Gass, 1987; Harrington, 1987; Kilborn, 1989; Kilborn & Cooreman, 1987; Kilborn & Ito, 1989; Liu, Bates, & Li, 1992; McDonald, 1987a, 1987b; McDonald & Heilenman, 1991; McDonald & MacWhinney, 1989). These studies have shown that the learning of global constructions in a second language is a gradual process. The process begins with L2 cue weight settings that are close to those for L1. Over time, these settings change in the direction of the native speakers' settings for L2. The Competition Model view of language interaction is further supported by evidence of effects from L2 back to L1. Sentence processing studies by Liu, Bates, and Li (1992) and Dussias (2001) have demonstrated the presence of just such effects. Although the Competition Model requires that the strongest transfer effects should be from L1 to L2, the view of competition as interactive leads us to expect some weaker amount of transfer from L2 back to L1.

1.3.2 Transfer in Production

Pienemann et al. (2005) claim that "only those linguistic forms that the learner can process can be transferred to L2." They argue that this view of transfer contrasts sharply with the Competition Model view that every L1 structure that can find an L2 match will transfer. Pienemann et al. present the case of the learning of the German V2 rule by speakers of L1 Swedish as evidence in favor of their analysis. The V2 rules in Swedish and German allow speakers to front adverbs like "today" or "now." This produces sentences with the verb in second position with forms such as "Today likes Peter milk." The surprising finding is that Swedes do not produce this order from the beginning, starting instead with "Today Peter likes milk" and "Peter likes milk today."

This finding is only surprising, if one believes that learners transfer whole syntactic frames for whole sentences. However, this is not the position of the Competiton Model. Instead, the Competition Model holds that individual predicate-argument constructions are transferred one by one. Moreover, transfer will begin with unmarked forms. In this case, the unmarked form produces "Peter likes milk today." Later, when learners attempt to transfer the marked form, they begin with the movement of "today" to first position and then adjust the position of the subject as a second step.

The opposite side of this coin is that, when L2 structures can be learned early on as item-based patterns, this learning can block transfer from L1. Pienemann et al. present the example of learning of Japanese SOV order by speakers of L1 English. These learners almost never generalize English SVO to Japanese. Of course, the input to L2 learners consistently emphasizes SOV order and presents no VO sequences, although these do occur in colloquial Japanese. As a result, learners view Japanese verbs as item-based constructions with slots for objects in preverbal position marked by the postposition "o" and topics in initial position marked by the postpositions "wa" or "ga." After learning a few such verbs, they construct a "feature-based" construction for SOV order. This is positive learning based on consistent input in L2. If L1 were to have a transfer effect at this point, it would be extremely brief, since L2 is so consistent and these item-based constructions with their associated case marking postpositions are in the focus of the learner's attention.

1.4 Morphological Maps

Learning of the morphological marking or inflections of a second language is very different from learning of the other areas we have discussed. This is because, in morphosyntax, it is typically impossible to transfer from L1 to L2. For example, an English learner of German cannot use the English noun gender system as a basis for learning the German noun gender system. In German, the sun (*die Sonne*) is feminine and the moon (*der Mond*) is masculine. The spoon (*die Löffel*) is feminine and the fork (*der Gabel*) is masculine. There is nothing in English that tells us how these nouns should be assigned to gender. If a learner of German has an L1 with a real gender system, such as Spanish, there can be transfer. But if the L1 is English, then transfer will be marginal. Similarly, a Spanish learner of Chinese cannot use L1 knowledge to acquire the system of noun classifiers, because Spanish has no noun classifiers. Also morphophonological alternations such as the shift of final /f/ to /v/ in "knives" are immune to transfer. For example, there is nothing in English that can help us decide that the plural of *tükör* (mirror) in Hungarian is *tükrök*, rather than the more regular form *tükörök*.

Although arbitrary forms and classes cannot transfer between languages, the grammatical functions underlying affixes can. For example, the underlying concept for words like “with” (comitative), “for” (benefactive), and “by” (agential) can be used in acquiring affixes and grammatical markings in L2. However, not all concepts are available for transfer to all languages. Consider the learning of article marking in English by speakers of Chinese, Japanese, or Korean. These languages have no separate category of definiteness, instead using classifiers and plurals to express some of the functions marked by the English definite. For learners from these languages, the semantic complexity of the subcomponents of definiteness in English constitutes a major learning barrier.

Earlier models using the back propagation algorithm showed how children could learn the morphology of German (MacWhinney, Leinbach, Taraban, & McDonald, 1989) and English (MacWhinney & Leinbach, 1991). However, these models failed to treat derivational suffixes as separate lexical items (MacWhinney, 2000). A recent extension of this model by Goldsmith & O’Brien (2006) explicitly models learning as the association between stems and affixes. However, that model relies on stems and affixes that have been hand extracted by the researcher. To solve this analytic problem Pirelli & Herreros (2006) used two-layer SOMs to extract affixes in English, Italian, and Arabic without hand analysis of the input forms. If the SOM is given input that matches the actual token frequencies of Italian, it learns to separate participles of the –tto class like stato and fatto from participles of the –sto class like visto and chiesto. For English, their model serves to extract both regular /-ed/ and the various irregular patterns such as *lend-lent* or *sing-sang*. For Arabic, they demonstrate extraction of a variety of non-concatenative patterns the alter the vowels and consonants of the stem. A next step in this work will be to show how the extraction of these alterations can be linked to learning of the stems as lexical items. Forms extracted in this way could then serve as input to models of the type developed by Goldsmith & O'Brien. In the DevLex framework, this learning would occur in the main lexical map, but connections would be maintained between that map and the extraction of affixes in this secondary map.

2. Competition

We have now completed our examination of the role of SOMs in the learning of both L1 and L2. However, by themselves, these maps do produce vocal output or conceptual interpretations. Rather, SOMs are repositories in long-term memory of associations and forms that can be used through the online processor to produce and comprehend the patterns of speech. The actual work of integrating information yielded by the SOMs is placed on the shoulders of the competitive processor. In comprehension, the competitive processor combines the patterns and cues used by constructions to derive a directed graph with labeled grammatical relations (Sagae, MacWhinney, & Lavie, 2004) that can then guide final interpretation. In production, the competitive processor receives activations from constructions and lexical items that it uses to structure the form of the output phonological buffer (Dell, Juliano, & Govindjee, 1993)

The competitive processor continually integrates information from both the lexical and phonological level during recognition (Elman & McClelland, 1988). Similarly, it adjudicates incrementally (Kempen & Hoenkamp, 1987; O'Grady, 2005) between conflicting grammatical relation attachment decisions (MacWhinney, 1987b), guided continually by lexical expectations

(MacDonald, Pearlmutter, & Seidenberg, 1994). The Competition Model account of sentence processing is extremely close in many details to that developed by O'Grady (this volume).

The study of the process of resolution of competing grammatical attachments has been the chief focus of experimental work in the Competition Model tradition. This work has focused on measurement of the relative strength of various cues to the selection of the agent, using a simple sentence interpretation procedure. Subjects listen to a sentence with two nouns and a verb and are asked to say who was the actor. In a few studies, the task involves direct-object identification (Sokolov, 1988, 1989), relative clause processing (MacWhinney & Pléh, 1988), or pronominal assignment (MacDonald & MacWhinney, 1990; McDonald & MacWhinney, 1995), but usually the task is agent identification. Sometimes the sentences are well-formed grammatical sentences, such as *the cat is chasing the duck*. Sometimes they involve competitions between cues, as in the ungrammatical sentence **the duck the cat is chasing*. Depending on the language involved, the cues varied in these studies include word order, subject-verb agreement, object-verb agreement, case-marking, prepositional case marking, stress, topicalization, animacy, omission, and pronominalization. These cues are varied in a standard orthogonalized ANOVA design with three or four sentences per cell to increase statistical reliability. The basic question is always the same: what is the relative order of cue strength in the given language and how do these cue strengths interact?

In English, the dominant cue for subject identification is preverbal positioning. For example, in the English sentence *the eraser hits the cat*, we assume that *the eraser* is the agent. However, a parallel sentence in Italian or Spanish would have *the cat* as the agent. This is because the word order cue is not as strong in Italian or Spanish as it is in English. In Spanish, the prepositional object marker "a" is a clear cue to the object and the subject is the noun that is not the object. An example of this is the sentence *el toro mató al torero* (The bull killed to-the bullfighter). No such prepositional cue exists in English. In German, case marking on the definite article is a powerful cue to the subject. In a sentence such as *der Lehrer liebt die Witwe* (The teacher loves the widow), the presence of the nominative masculine article *der* is a sure cue to identification of the subject. In Russian, the subject often has a case suffix. In Arabic, the subject is the noun that agrees with the verb in number and gender and this cue is stronger than the case-marking cue. In French, Spanish, and Italian, when an object pronoun is present, it can help identify the noun that is not the subject. Thus, we see that Indo-European languages can vary markedly in their use of cues to mark case roles. When we go outside of Indo-European to languages like Navajo, Hungarian, or Japanese, the variation becomes even more extreme.

Cue strength is a psychological construct measured in Competition Model experiments in which cues are set in conflict with each other. To measure cue strength, Competition Model experiments rely on sentences with conflicting cues. For example, in *the eraser push the dogs* the cues of animacy and subject-verb agreement favor "the dogs" as agent. However, the stronger cue of preverbal positioning favors "the eraser" as agent. As a result, English-speaking adult subjects strongly favor "the eraser" even in a competition sentence of this type. However, about 20% of the participants will choose "the dogs" in this case.

Cue validity, availability, and reliability are properties of the linguistic input. To measure the validity of cues in the various languages we have studied, we rely on text counts where we list the cues in favor of each noun and track the relative availability and reliability of each cue. A fully available cue (availability = 1.0) is always there when you need it, although it may or may not be always reliable. Cue availability can be further defined to refer to the presence of the cue in some contrastive form. For example, if both of the nouns in a sentence are animate, then the animacy cue is available, but not contrastively available. A fully reliable cue (reliability = 1.0) is always correct when you use it, although it may or may not be always available. Of course, the best cue is one that is fully available and fully reliable. Thus, we can talk about cue validity as the product of availability and reliability, since perfect availability and reliability will yield perfect validity. A fully valid cue would always be present when you need it and always give you the right answer.

By looking at how children, adult monolinguals, and adult bilinguals speaking about 18 different languages process these various types of sentences, we have been able to reach these conclusions, regarding sentence comprehension:

1. When given enough time during sentence comprehension to make a careful choice, adults assign the role of agency to the nominal with the highest cue strength.
2. When there is a competition between cues, the levels of choice in a group of adult subjects will closely reflect the relative strengths of the competing cues.
3. When adult subjects are asked to respond immediately, even before the end of the sentence is reached, they will tend to base their decisions primarily on the strongest cue in the language.
4. When the strongest cue is neutralized, the next strongest cue will dominate.
5. The fastest decisions occur when all cues agree and there is no competition. The slowest decisions occur when strong cues compete.
6. Children begin learning to comprehend sentences by first focusing on the strongest cue in their language.
7. As children get older, the strength of all cues increases to match the adult pattern with the most valid cue growing most in strength.

8. As children get older, their reaction times gradually get faster in accord with the adult pattern.
9. Compared to adults, children are relatively more influenced by cue availability, as opposed to cue reliability.
10. Cue strength in adults and older children (8-10 years) is not related to cue availability (since all cues have been heavily encountered by this time), but rather to cue reliability. In particular, it is a function of conflict reliability, which measures the reliability of a cue when it conflicts directly with other cues.

This list of highly general findings from Competition Model research underscores the heuristic value and scope of the concepts of cue strength, cue validity, and competition.

3. Buffering

Self-organizing maps provide long-term storage for linguistic forms. However, the information that is retrieved from these maps during online processing can often involve ambiguities and competitions. Although there is usually one form or interpretation that is dominant, a second or third interpretation may also be viable and competitive. Such secondary forms may end up as the correct selections, once all the information is fully integrated. To permit this integration, the brain has to have mechanisms for preserving competitors in short-term storage.

Each SOM is associated with a buffer that preserves the activation of current competitors. These buffers allow for short-term storage of the auditory signal, activated lexical items, and competing grammatical role attachments. Baddeley (1992) and others have characterized lexical working memory in terms of a phonological loop or store. Gupta and MacWhinney (1997) showed how phonological storage can facilitate the learning of forms in the lexical map. Several authors (Ellis & Sinclair, 1996; Harrington, 1992; Service & Craik, 1993) have shown how working memory buffers of this type can facilitate the learning of new linguistic forms.

It is not yet clear whether how closely this acquisitional function of working memory is linked to its role in the online processing of specific syntactic structures (Gibson, Pearlmutter, Canseco-Gonzalez, & Hickok, 1996; MacWhinney & Pléh, 1988). However, in a lexically-driven processing model such as the Competition Model, the same processes that facilitate SOM storage during word learning can also operate during sentence processing to preserve lexical activation in maps. During online processing, storage would not involve full vocal rehearsal; rather, it would involve achieving a precise level of control for continued access to competing forms on the lexical maps.

The operation of short term buffering modulates the role of cue validity during both processing and acquisition. For example, the processing of subject-verb agreement for inverted word orders in Italian is not fully learned until about age 8 (Devescovi, D'Amico, Smith, Mimica, & Bates, 1998), despite its high cue validity and high cue strength in adult speakers. One of the core findings of Competition Model research has been that, when adult subjects are given plenty of time to make a decision, their choices are direct reflections of the cumulative validity of all the relevant cues. In this sense, we can say that off-line decisions are optimal reflections of the structure of the language. However, when subjects are asked to make decisions on-line, then their ability to sample all relevant cues is restricted. In such cases, we say that “cue cost” factors limit the application of cue validity. These cue cost factors can involve various aspects of processing. However, the most important factors are those that require listeners to maintain agreement cues and distant role binding cues in working memory.

It is easy to interfere with normal language processing by imposing additional loads on the listener or speaker. Working within a standard Competition Model experimental framework, Kilborn (1989) has shown that even fully competent bilinguals tend to process sentences more slowly than monolinguals. However, when monolinguals are asked to listen to sentences under conditions of white noise, their reaction times are identical to those of the bilinguals. Similarly Blackwell and Bates (1995) and Miyake, Just, and Carpenter (1994) have shown that, when subjected to conditions of noise, normals process sentences much like aphasics. Gerver (1974) and Seleskovitch (1976) report parallel results for the effects of noise on simultaneous interpretation.

4. Chunking

Chunking plays a major role in general models of cognition, such as Newell's SOAR model (Newell, 1990) or Anderson's ACT-R model (Anderson & Lebiere, 1998). It also figures heavily in accounts that emphasize the role of implicit learning (Cleermans & McClelland, 1991). Ellis (1996, 2002) has argued that chunking can help us understand the growth of fluency in second language learning. However, the exact way in which this operates has not yet been fully described. One way in which chunking can operate is by the simple composition of units into a new whole. For example, in Spanish, L2 learners can chunk together the plan for *buenos* with the plan for *dîas* to produce *buenos días*. They can then combine this chunk with *muy* to produce *muy buenos días* "very good morning."

Second language learners often fail to pick up large enough phrasal chunks. For example, if learners of German often learn the word *Mann* "man" in isolation. If, instead, they would learn phrases such as *der alte Mann, meines Mannnes, den junge Männern,* and *ein guter Mann*, then they would not only know the gender of the noun, but would also have a good basis for acquiring the declensional paradigm for both the noun and its modifiers. If they analyze a phrase like *der alte Mann* into the literal string "the + old + man" and throw away all of the details of the inflections on "der" and "alte," then they will lose an opportunity to induce the grammar from implicit generalization across stored chunks. If the learner stores larger chunks of this type, then the rules of grammar can emerge from analogic processing of the chunks stored in feature maps (Bybee & Hopper, 2001; Ellis, 2002; MacWhinney, 1982; Tomasello, 2003).

Although the formation of chunks through composition is certainly an important process, this process by itself cannot produce full fluency. There are simply too many possible chunks to learn. One solution to this problem is to extend the original formulations of chunking theory (Chase & Simon, 1973; Newell, 1990) to allow for the formation of more schematic chunks (Gobet, 2005). The theory of Construction Grammar fits in well with this new emphasis, since high-level constructions are schematic in just this flexible way. In addition to retrieving constructions as chunks, learners must work out methods that produce new constructional chunks on the fly in real time. Thus, instead of storing Spanish *muy buenos días* (very good days) as a rote chunk, learners must be able to smoothly integrate the combination of *buenos días* with the additional predicate *muy* without hesitation or delay. Thus, rather than thinking of chunking as only a method for creating new long term memory units, we need to think of it as a method for integrating phrases on line.

Practice in producing combinations can be either fairly limited or quite general. For example, the chunk *muy buenos dias* only generalizes to a few other forms such as *muy buenas noches* (very good night), *muy buenas tardes* (very good afternoon) or, perhaps, *muy poco dinero*, (very little money). However, a phrase such as *quisiera comprar* (I would like to buy ..)

can be used with any manner of noun to talk about things you would like to buy. In each of these cases, having produced one initial combination, such as *quisiera comprar una cerveza* (I would like to buy a beer) may be halting at first. However, soon the result of the creation process itself can be stored as a chunk. In this case, it is not the actual phrase that is chunked, but rather the process of activating the predicate combination (*quisiera comprar*) and then going ahead and filling the argument. In other words, we develop fluency by repeated practice in making combinations.

Once we have developed fluency in the combination of well-learned words, we can still experience disfluency when we try to integrate newly-learned words into established constructions. For example, even if we have learned to use the frame *quisiera comprar* fluently with words such as *una cerveza* (a beer) or *un reloj* (a clock), we may still experience difficulties when we need to talk about "a round trip ticket to Salamanca" (un billete de ida y vuelta para Salamanca). In this selection, we might have particular problems when we hit the word "para" since the English concept of "for, to" can be expressed in Spanish using either por or para and our uncertainty regarding the choice between these two forms can slow us down and cause disfluency or error. In general, for both L1 and L2 learners, disfluencies arise from delays in lexical access, misordering of constituents, and selection of agreement markings. Fluency arises through the practicing of argument filling and improvements in the speed of lexical access and the selections between competitors.

5. Resonance

Since the days of Ebbinghaus (1885), we have understood that the learning of the associations between words requires repeated practice. However, a single repetition of a new vocabulary pair such as *mesa – table* is not enough to guarantee robust learning. Instead, it is important that initial exposure be followed by additional test repetitions timed to provide correct retrieval before forgetting prevents efficient resonance from occurring (Pavlik, in press). Because robustness accumulates with practice, later retrieval trials can be spaced farther and farther apart (Pimsleur, 1967). This is the principle of "graduated internal recall." The Unified Model argues that the success of this method can be attributed to its use of resonant neural connections between cortical areas. While two cortical areas are coactive, the hippocampus can store their relation long enough to create an initial memory consolidation. Repeated access of this trace (Wittenberg, Sullivan, & Tsien, 2002) can serve to further consolidate the memory. Once the initial consolidation has been achieved, maintenance only requires occasional reactivation of the relevant retrieval pathway. This type of resonance can be used to consolidate new forms on the phonological, lexical (Gupta & MacWhinney, 1997), and construction levels.

A fuller form of resonance occurs during covert inner speech. In the case of inner speech, we are using resonance not to acquire new forms, but to activate conceptual interpretations and plan actions. Vygotsky (1934) observed that young children would often give themselves instructions overtly. For example, a two-year-old might say, "pick it up" while picking up a block. At this age, the verbalization tends to guide and control the action. By producing a verbalization that describes an action, the child sets up a resonant connection between vocalization and action. Later, Vygotsky argues, these overt instructions become inner speech and continue to guide our cognition. L2 learners go through a process much like that of the child. At first, they use the language only with others. Then, they begin to talk to themselves in the new language and start to "think in the second language." At this point, the second language begins to assume the same resonant status that the child attains for the first language.

Once a process of inner speech is set into motion, it can also be used to process new input and relate new forms to other forms paradigmatically. For example, if I hear the phrase "ins Mittelalter" in German, I can think to myself that this means that the stem "Alter" must be "das Alter." This means that the dative must take the form "in welchem Alter" or "in meinem Alter." These resonant form-related exercises can be conducted in parallel with more expressive resonant exercises in which I simply try to talk to myself about things around me in German, or whatever language I happen to be learning. Even young children engage in practice of this type (Berk, 1994; Nelson, 1998).

Resonance also helps us understand code-switching. If a language is being repeatedly accessed, it will be in a highly resonant state. Although another language will be passively accessible, it may take a second or two before the resonant activation of that language can be triggered by a task (Grosjean, 1997). Thus, a speaker may not immediately recognize a sentence in a language that has not been spoken in the recent context. On the other hand, a simultaneous interpreter will maintain both languages in continual receptive activation, while trying to minimize resonant activations in the output system of the source language.

Like La Heij (2005), I would argue that multilingual processing relies more on activation and resonance than on inhibition (Green, 1986). We know that the brain makes massive use of inhibitory connections. However, these are typically local connections that sharpen local competitions in SOMs. Inhibition is also important in providing overt inhibitory control of motor output, as in speech monitoring. However, inhibition by itself cannot produce new learning, coactivation, and inner speech. For these types of processing, resonant activation is more effective.

Resonance can facilitate the sharpening of contrasts between forms. Both L1 and L2 learners may have trouble encoding new phonological forms that are close to words they already know. Children can have trouble learning the two new forms “pif” and “bif” because of their confusability, although they can learn “pif” when it occurs along with “wug” (Stager & Werker, 1997). This same phonological confusability effect can impact second language learners. For example, when I came to learn Cantonese, I needed to learn to pay careful attention to marking with tones, lest I confuse *mother, measles, linen, horse,* and *scold*, as various forms of /ma/.

Resonant mappings can rely on cues generated by synaesthesia (Ramachandran & Hubbard, 2001), onomatopoeia, sound symbolism, postural associations (Paget, 1930), lexical analysis or a host of other provisional relations. It is not necessary that this symbolism be in accord with any established linguistic pattern. Instead, each learner is free to discover a different pattern of associations. This nonconventional nature of resonant connections means that we cannot use group data to demonstrate the use of specific connections in lexical learning. However, we do know that constructive mnemonics provided by the experimenter (Atkinson, 1975) greatly facilitate learning. For example, when learning the German word *Wasser*, we can imagine the sound of water running out of a faucet and associate this sound with the /s/ of *Wasser*. For this word, we can also associate the sound of the German word to the sound of the English word *water*. At the same time, we can associate *Wasser* with additional collocations, such as *Wasser trinken,* which themselves resonate with *Bier trinken* and others. Together, these resonant associations between collocations, sounds, and other words help to link the German word *Wasser* into the developing German lexicon. It is likely that children also use these mechanisms to encode the relations between sounds and meanings. Children are less inhibited than are adults in their ability to create ad hoc symbolic links between sounds and meanings. The child learning

German as an L1 might associate the shimmering qualities of *Wasser* with a shimmering aspect of the sibilant; or the child might imagine the sound as plunging downward in tone in the way that water comes over a waterfall. The child may link the concept of *Wasser* tightly to a scene in which someone pours *ein Glas Wasser* and then the association between the sound of *Wasser* and the image of the glass and the pouring are primary. For the first language learner, these resonant links are woven together with the entire nature of experience and the growing concept of the world.

A major dimension of resonant connections is between words and our internal image of the human body. For example, Bailey, Chang, Feldman, and Narayanan (1998) characterize the meaning of the verb "stumble" in terms of the physical motion of the limbs during walking, the encountering of a physical object, and the breaking of gait and posture. As Tomasello (1992) has noted, each new verb learned by the child can be mapped onto a physical or cognitive frame of this type. In this way, verbs and other predicates can support the emergence of a grounded mental model for sentences. Workers in L2 (Asher, 1977) have often emphasized the importance of action for the grounding of new meanings. The new literature in cognitive grammar exemplified in this Handbook provides good theoretical support for that approach. Item-based constructions are central in this discussion, since they provide a powerful link between the earlier Competition Model emphasis on processing and cue validity and the newer theories of grounded cognition (MacWhinney, 1999).

Orthography provides a major source of resonance in L2 learning. When an L2 learner of German learns the word *Wasser,* it is easy to map the sounds of the word directly to the image of the letters. Because German has highly regular mappings from orthography to pronunciation, calling up the image of the spelling of *Wasser* is an extremely good way of activating its sound.

When the L2 learner is illiterate or when the L2 orthography is unlike the L1 orthography, this backup system for resonance will not be available. L2 learning of Chinese by speakers of languages with Roman scripts illustrates this problem. In some signs and books in Mainland China, Chinese characters are accompanied by romanized pinyin spellings. This allows the L2 learner a method for establishing resonant connections between new words, their pronunciation, and their representations in Chinese orthography. However, in Taiwan and Hong Kong, characters are seldom written out in pinyin in either books or public notices. As a result, learners cannot learn from these materials. In order to make use of resonant connections from orthography, learners must focus on the learning of Chinese script. This learning itself requires a large investment in resonant associations, since the Chinese writing system is based largely on radical elements that have multiple resonant associations with the sounds and meanings of words.

6. Age-related effects

At this point, it may be helpful to review how the Unified Competition Model accounts for age-related changes in language learning ability. As DeKeyser and Larson-Hall (2005) note, the default account in this area has been the Critical Period Hypothesis (CPH) which holds that, after some time in late childhood or puberty, second languages can no longer be acquired by the innate language acquisition device, but must be learned painfully and incompletely through explicit instruction.

Following Birdsong (2005), the Unified Competition Model attributes the observed facts about age-related changes to very different sources. The model emphasizes the extent to which learning in SOMs produces ongoing entrenchment. This entrenchment operates differentially across linguistic areas, with the strongest entrenchment occurring in output phonology and the least entrenchment in the area of lexicon, where new learning continues to occur throughout the lifespan. To overcome entrenchment, learners must rely on resonant processes that allow the fledgling L2 to resist the intrusions of L1, particularly in phonology (Colomé, 2001; Dijkstra, Grainger, & Van Heuven, 1999). For languages with familiar orthographies, resonance connections can be formed between writing, sound, meaning, and phrasal units. For languages with unfamiliar orthographies, the domain of resonant connections will be more constrained. This problem impacts older learners severely because they have become increasingly reliant on resonant connections between sound and orthography.

Because learning through resonant connections is highly strategic, L2 learners will vary markedly in the constructions they can control or which are missing or incorrectly transferred (Birdsong, 2005). In addition to the basic forces of entrenchment, transfer, and resonant learning, older learners will be affected by problems with restricted social contacts, commitments to ongoing L1 interactions, and declining cognitive abilities. None of these changes predicts a sharp drop at a certain age in L2 learning abilities. Instead, these effects predict a gradual decline across the life span.

7. Conclusion

This concludes our examination of the Unified Competition Model. This model relies on a particular version of Construction Grammar that emphasizes the role of storage in lexical maps and the online integration of constructional chunks during both L1 and L2 processing. In accord with other functionalist accounts in this volume, the model emphasizes the role of cue availability and reliability in determining the course of acquisition. The model views age-related changes in L2 learning in terms of entrenchment, competition, and transfer, rather than the expiration of a critical period. Because of this, the model can provide a unified account for learning both L1 and L2.

Many of the pieces of this model rely on separate theories that have been worked out in some detail. For example, we have a good model of cue competition in syntax for both L1 and L2. We have good models of L1 lexical acquisition in SOMs. We have good data on phonological and lexical transfer in L2. We have clear data and models regarding the ways in which processing load impacts sentence processing in working memory. We are even learning about the neuronal bases of this load (Booth et al., 2001). Other areas provide targets for future work. In particular, we need to link the item-based construction approach outlined here to the broader theory of embodied cognition (MacWhinney, 2005c; Pecher & Zwaan, 2005). The Unified Model provides us with a high-level road map to guide our ongoing explorations of these topics.

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