Abstract

Recently developed diagnostic tools for coarsely analyzing brain function are shedding new light on theories of human linguistic processes (and brain function in general) developed over the last century. The long-held belief by some that bilingual persons have separate storage areas for each language has been shown to be false. Instead, all persons fluent in one or more languages store and process language in the same areas (multiple areas are involved) of their brain. However, persons with low fluency in one or more secondary languages use a separate area of the speech production region of the brain to process speech. As these persons develop fluency, this secondary area is scrapped and the "mainstream" speech pathway is used. Further, the concepts of "language storage area" and "language switching" are anomalies due to a false implicit assumption that mental processes are performed in sequential steps by dependent units of the brain. Instead, the brain and body are composed of many semi-autonomous units and few entirely dependent units. The conscious function of brain and body units is monitored by a supervisory attentional system and unconscious function is controlled by a basic executive system – both located in the brain. An interesting feature of the supervisory attentional system is that it is resource limited. It has been shown that due to this limitation, the system general cannot afford to process stored rules while listening to input and thus focuses nearly all attention on extraction of meaning: thus validating a leading model of language learning. With regard to language storage and memory in general, it turns out that storage is two-fold: we save both exemplars and schema. Exemplars are specific "snapshots" of captured input – regardless of the sensory system. Schemas are re-usable patterns which are used as-is or modified to a new use. Storing a sequence of snapshots of a gesture vs. storing the dynamics of a gesture is an example of exemplar vs. schema. It has been shown that fluency cannot be obtained by use of exemplars

alone. This situation is exacerbated by plasticity in the brain. On average (over humans), certain neural substrates in the brain become resistant to change during and after puberty. A particular example of this is an area used for storing dynamic spatial schemas. As a consequence, most persons learning a second language after puberty must resort to exemplars rather than schemas to process gestures. Similar results are known for some types of speech production. Consequently, developing fluency in a secondary language after puberty is problematic for most individuals. This result has serious consequences for those deciding the appropriate grade level to teach secondary languages in public schools.

Linguistic Processes of Bilingual Cognition

Research in bilingual ability and function has been historically motivated in several application areas, including: second language instruction (pedagogy), pathology of language disorders, and language translation. Economically, this last category is perhaps the most lucrative. In particular, recent advances in computer technology have spurned bilingual research in the race to produce effective automated translation devices.

Due to the varying motivations in bilingual research, the methods and models of investigators are quite varied. Historically there have been two broad categories – behavioral and functional. The behaviorist works with holistic models of bilingualism, often focusing on the psychology of interaction. The functionalist is interested in direct actions of the brain. Both of these approaches have greatly matured in the last decade giving rise to hybrid studies of behavior and physiology – 'the bilingual person'.

In a lucid article on the nature of individual bilingualism, Grosjean (1994) explains 5 major facets of bilingualism: (1) language knowledge and scope of use, (2) linguistic behavior with monolinguals and bilinguals, (3) psycholinguistics, (4) neurolinguistics, and (5) the bilingual persona. Grosjean's main points are summarized below. Within this framework, observations from investigators are interspersed to bring depth and balance to the presentation.

Language Knowledge and Scope of Use

Bilingualism is a foreign idea for those raised a monolinguistic culture or environment, and a matter of necessity for at least half of the human population. It does not mean native-like control in two or more languages, but rather the use of multiple languages in everyday life (Grosjean, 1994). Language-specific discourse is governed by social context: what is needed at work, at home, with a friend while shopping, etc. Most importantly, a bilingual person operates along a continuum of languages and is never fully monolingual at any particular time. The main language being used in any given social context is termed the "base language". A change of topic, situation, etc. can change the base language.

The fact that language choice is time-dependent and situational is a key factor in understanding the mechanics of language and bilingualism (Grosjean, 1999). This variable has been termed "language mode" and has been observed in studies of language production, perception, acquisition, and pathology (aphasia). When used in the psychological or neurological sense, language mode is defined as "the state of activation of the bilingual's languages and language activation". The situation is graphically depicted in Figure 1.

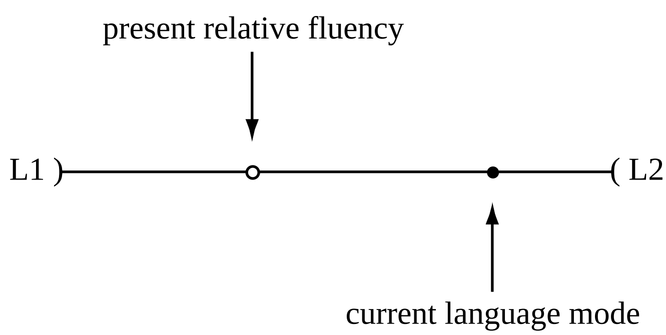

Figure 1. The relationship between individual fluency and operational language mode along a continuum of possible language knowledge for languages L1 and L2.

Historically, several researchers have not accounted for language mode in behavioral studies and thus it exhibits itself as a confounding variable (Grosjean, 1999). Using mode as a control variable is not particularly easy either. Grosjean (1999) sharply criticizes two popular approaches which are (falsely) assumed to "fix" language mode:

- “Language set” – all cues in the experiment are given in a single language. Problem: the bilingual operates on a continuum and thus the use of one language does not necessarily deactivate another.
- “Hidden language” – the interviewer or experimenter in a study attempts to hide or obscure their knowledge of a second language when interacting with a subject. Problem: such attempts are frequently voided by non-verbal queues.

Another phenomenon worth noting is that a bilingual’s competence in languages will change as needs in their surrounding environment change. This in turn will mean that neurological changes will occur within the persons brain (Grosjean, 1994). In the extreme, a person may nearly forget a language no longer in use.

Linguistic Behavior with Monolinguals and Bilinguals

When a bilingual converses with a monolingual in L2, they must deactivate or inhibit (Green, 1998) unwanted languages as much as possible. In the continuum of Figure 1, the language mode is pushed as far right as possible. Total deactivation is extremely rare. Examples of “interference” from the deactivated language include (Grosjean, 1994):

- “Phonetic interference” – misapplication or substitution of L1 sound for vowel, consonant, or blend in L2.
- “Lexical interference, type 1” – replacing a word in L2 with its similar-sounding or spelling equivalent in L1. Example: spelling the English (L2) “apartment” erroneously “appartment" in the pattern of the French (L1) “appartement”.
- “Lexical interference, type 2” – replacing a word in L2 with another L2 word that is a homonym for L1 word with original L2 word meaning. Example: replacing English (L2) word “horns” with English “corns” which is homonym of French L1 “cornes”.

- "Syntactic interference" – misapplication of L1 syntax in the L2 context.

There are additional language behaviors of the bilingual which are worth understanding. These typically occur during interaction with other bilinguals but can also happen in exchanges with monolinguals (Grosjean, 1994):

- "code switching" – a complete switch from the base language to another language for a complete word, phrase, or sentence.
- "borrowing" – taking a morpheme, word, or short expression from a non-base language and adapting it morphosyntactically and/or phonologically to the base language.

Note that the cultural adoption of a new word occurs primarily through the process of a culturally repeated borrowing.

Psycholinguistics

Psycholinguistics is largely concerned with holistic models of language processes. This approach is a rather practical one, since (a) until recently there has been no robust means of studying brain physiology of language, and (b) the concerns of psychology are historical behavioral instead of functional. Models developed under these conditions are then necessarily limited by an author's assumptions with regard to actual brain processing and the author's background in modeling component systems.

There is a large body of psycholinguistic literature that utilizes studies of bilingual aphasia and the concept of double disassociation to either prove or disprove a particular theory or model. In this context, double disassociation says that if lesions in mutually exclusive areas of the brain produce mutually exclusive deficits, then it is concluded that the different areas are involved in separate functions. For the human brain, this is a false conclusion (Hernandez, 1999).

Underlying the logic of double disassociation is the requirement that each function has a linear or binary activation function. In reality, the activation function is sigmoidal which mathematically violates the double disassociation assumption.

Many psycholinguistic models found in the literature either explicitly or implicitly assume that brain function is sequential and/or single-tasking in nature. This is certainly not the case (Green, 1998; Hernandez, 1999). Another popular error is the omission of time and phase relationships (for a counter-example, see Skehan, 1998). Therefore, to be successful in psycholinguistic modeling today, the researcher needs the mathematical background of an engineer or physicist and the biological training of a neurologist.

Dijkstra (Dijkstra & Van Heuven, 2002) has long proposed a sequential word recognition model called BIA. In light of current evidence for non-sequential processing and the dynamic models of David Green (2002), Dijkstra has refashioned his model under the name BIA+ with limited dynamics and an adaptation of his notation to Green's model (Van Hell, 2002). Dijkstra's model further supposes that visual word recognition is performed in a fashion analogous to graphic pattern matching but there is both neurological (Kim, 1997) and psycholinguistic (Green, 2002) evidence that visual word recognition involves phonology.

Henser (2000) provides an interesting comparison between two leading semiotic models of thought: (a) the "mental-ese" or Communicative Thesis of Jerry Fodor at Rutgers, and (b) the "natural language" or Cognitive Thesis of Peter Caruthers at Sheffield. To support his opinions of these models, Henser pre-supposes that thought is a centralized executive process – an argument that is contrary to neurological evidence (Hernandez, 1999). Henser further uses the phenomenon of inner speech to justify his view that thought occurs in native language. This stands in contrast to Rodriguez-Fornells' (2002) study of sub-lexical processes of input in the phonological system. Inner speech cannot be inner thought because it is input-driven. Further evidence of this lies in the practices of popular speed-comprehension reading courses which teach the student to process text without inner speech (no conscious process of text) and entirely scan for meaning (Skehan, 1998). Rodriguez-Fornells (2002) has shown that this processing route is faster than routes through the phonological system and thus explains the success of speed-comprehension reading programs.

Another curious topic not mentioned by any of the authors discussing inner speech is the lack of a visual analogy to inner speech. That is, humans have a physical mechanism for mentally sounding out speech – this resides in Broca's region of the brain (Rodriguez-Fornells, 2002), the same region that produces audible speech. However, there is no analog for vision. In particular, humans cannot (except in extreme cases of psychosis) produce internal visions of images afforded by sight. This is probably due to the lack of a system to produce images – a system analogous to the voice box.

MacWhinney (2002) has written extensively about a "Competition Model" for language acquisition. The model is largely symptomatic in nature and the discussion is phenomenological. The main features of the model are essentially Green's inhibitory control model (Green, 1998) under change of notation. MacWhinney also argues for a "bottom-up" activation of lexical elements which are not supported by neurological studies (Hernandez, 1999).

Michel Paradis has made many contributions to the field of bilingual studies – especially the Bilingual Aphasia Test (BAT) (Fabbro, 2001). Paradis and his students (e.g., Paradis, 2001; Tomioka, 2002) have also been the main proponents of a separate-storage model for languages in the brain. This model is predicated on a sequential language processing model in a single-task system. The popularity of this model in the 1980's led neurological researchers to search for a region in the brain responsible for switching between the multiple storage areas and language modes. One such study was performed by Abutalebi (2000) which relies on double disassociation in addition to assuming sequential processing. The absence of separate language storage centers and the lack of a language switching center are supported by the neurological research of Hernandez (2000).

In the third chapter of his textbook on language use and learning, Skehan (1998) carefully develops a model that serves as a framework for understanding language acquisition and use. The main tenant of the model is: we process only what we notice. In this view, consciousness is nothing more than awareness under the control of a supervisory attentional system.

Skehan cites several researchers in his development of the concept of noticing. For input to be noticed, it must have one or more of the following attributes:

- High Frequency
- Salience
- Instruction of a meaningful language task
- Tasks with selective effects; e.g., a group of tasks is presented which each subliminally cause the assimilation of the same fact, pattern, or rule
- Task demands; i.e., a focus on a particular form may be associated with the nature of a particular task which, as a result, makes targeted noticing more likely to occur

Further, there are two internal, individualized factors which influence noticing:

- Readiness
- Processing capacity

Skehan also introduces the important elements of exemplars, schemata, and rules in the human memory system. Exemplars are specific examples of input that we store for comparison and/or re-use. For most individuals, knowledge of the letter "A" is via exemplar. Exemplars are placed in an associative memory system that is activated by a connectionist-style network (Grosjean, 1994). Schemata are behavior patterns that are used semi-consciously and consequently reduce the processing load on the supervisory attentional system. For example, the experience of driving to work "on autopilot" – especially when unintended, is an example of using a schema. A person fluent in L1 has thousands of schemata for speech production. The human memory system also stores rules for use by one or more analytical processing centers of the brain. Figure 2 summarizes Skehan's model of language comprehension processes.

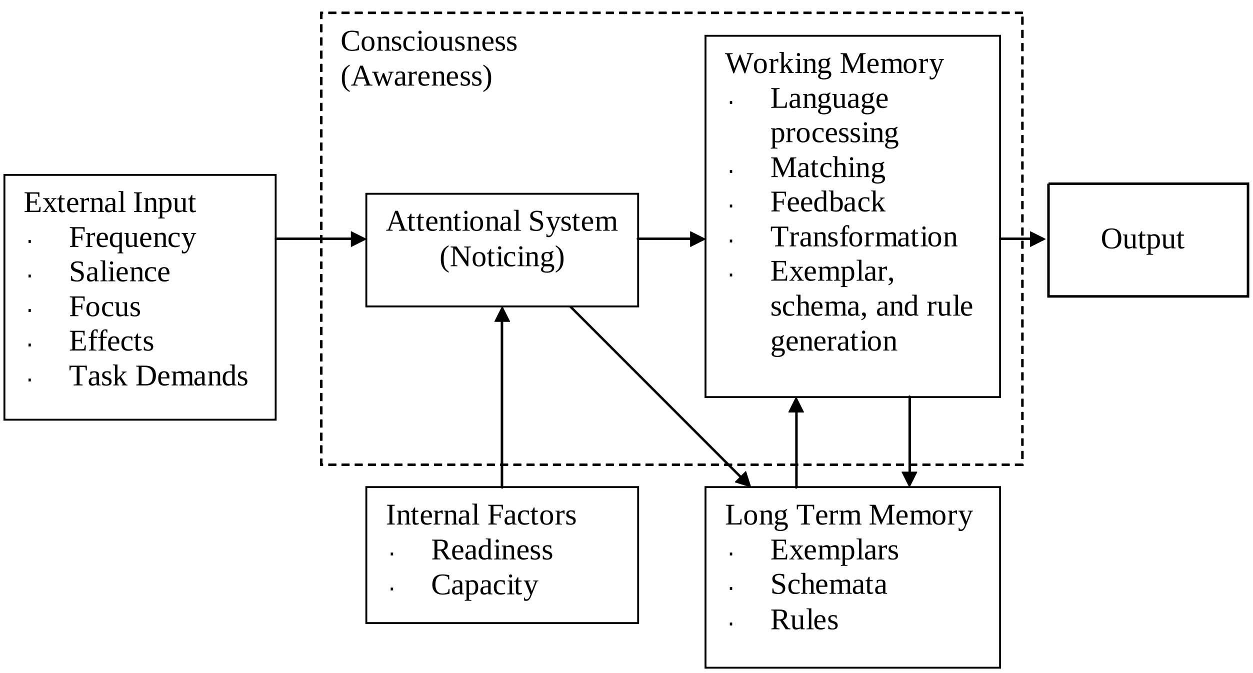

Figure 2. Summary drawing of Skehan's (1998) linguistic processing model.

There is general agreement among researchers that attentional resources are limited and that in order to comprehend language input, the majority of resources are allocated to decoding semantics (meaning), not form (Skehan, 1998; Kempe, 1998). In particular, learners focus attention on meaning but unconsciously internalize structure (Paradis, 2001). This in part validates Krashen's "Input Hypothesis" or "Comprehension Hypothesis" model of language learning (Schutz, 2002; Krashen, 2002). The other components of Krashen's model are all present as generalizations in Skehan's framework (Figure 2). In fact, Skehan's (1998) only complaint about Krashen's work is that it does not provide enough detail for psycholinguistic analysis.

A natural conclusion to reach from the paucity of available attentional resources is that a critical role of instruction is to channel attention. Given that short-term resources are limited in both time and memory, there is also a role for conversation to play in the reduction of load: the off-loading of short-term memory items to another person. This particular fact validates the small-group learning or collaborative construction models used successfully in many classrooms. In an extreme interpretation, human discourse is *explained* by the need to circumvent capacity limitations of working memory (Skehan, 1998).

Green (1998) has developed a compelling model of psycholinguistic processes which are in turn a subset of general processes in the brain. The main focus of his model is a supervisory attentional system which he supports through references to the neurolinguistics literature. Thus, Green's work is both complementary and expansive in comparison to the work of Skehan. The inter-relationships of components in Green's model are shown in Figure 3.

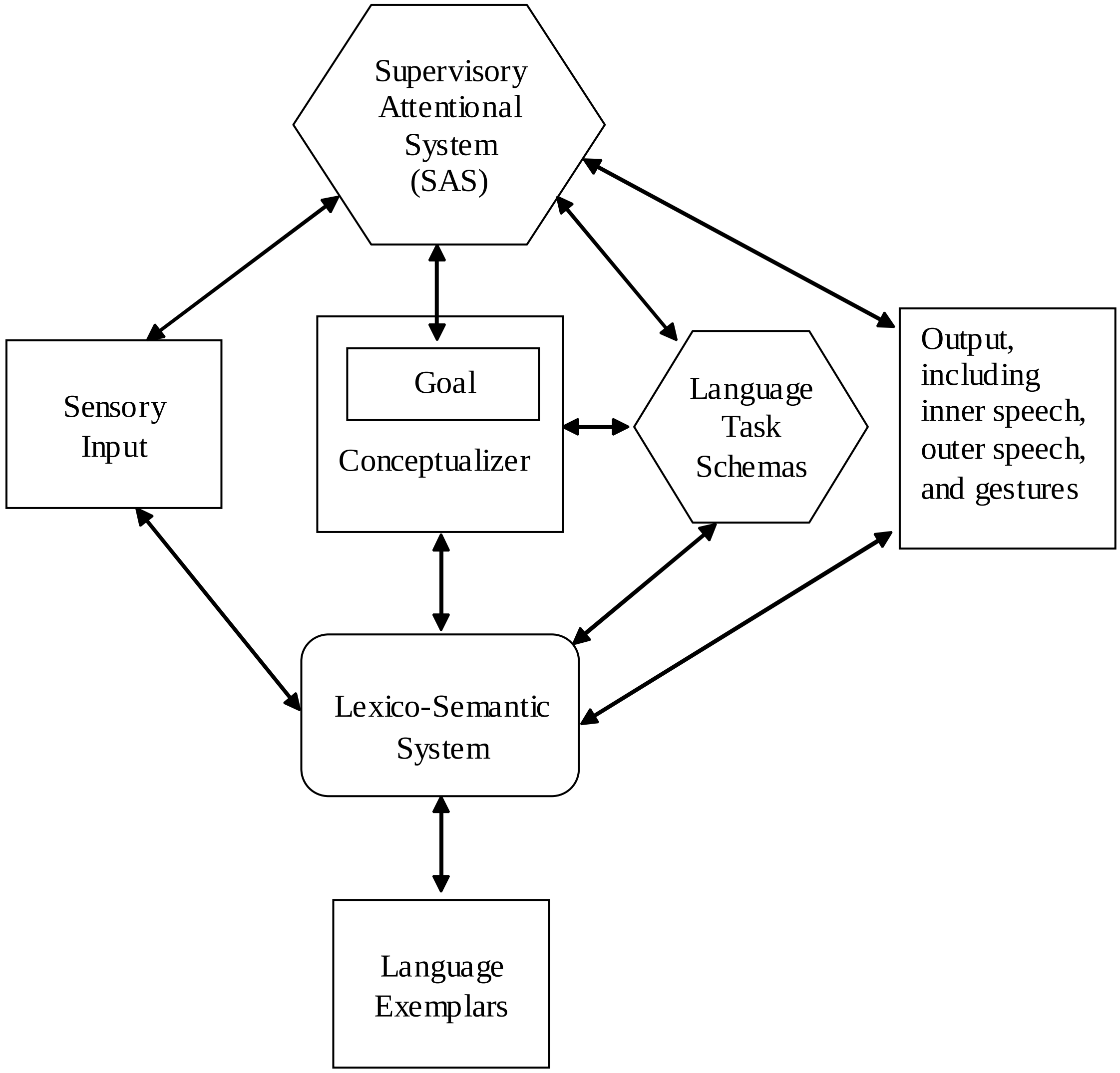

Figure 3. A lexico-symantic system with multiple levels of control. Driven by a goal, a conceptualizer builds representations based on schemas to achieve some effect through language. Adapted from Green (1998).

Green argues that the bilingual does not have separate language systems but rather language-specific schemas for language tasks. This approach is compatible with empirical observations that neural systems of second language acquisition are shaped by the native language (Tan et al, 2003). Green's model of inhibitory control follows Skehan's argument that any attentional resource directed towards form is a luxury. Thus in Green's model: fluency, complexity, and accuracy all compute during output. This matches numerous observations that skilled learners don't process words but integrate them instead (Skehan, 1998).

Computational Linguistics

Computational models of language processes are largely driven by market demands for inter-language tools. Jones and Somers (1997) classify the various approaches used by practitioners into six major categories: Analogy, Connectionist, Corpus, Example-based, Statistical, and Hybrid. Analogy methods are perhaps the most encompassing, drawing upon psycholinguistic theory to design computational models. Connectionist methods are the most visible and/or advertised, being constructed from artificial neural networks (connectionist is synonymous with neural network) which were heavily touted during the public fascination with artificial intelligence of the late 1980's and early 1990's. A connectionist network is exemplar-based by design but contains trained (tuned parameters) levels of exemplar activation for a given response. Recent mathematical research has shown that neural networks systems are equivalent to statistical regression (of order varying by network design) or Bayesian inference (depending on network design).

Corpus-based methods use a database approach to identify or compose direct translations. Implementation of corpus methods are often focused on optimal search strategies and consequently, prevailing computer science theories of tree-based retrieval. Example-based methods refer to any approach that is constrained to translation by example – in contrast to systems that utilize rules. Exemplar-based connectionist systems are necessarily included in this category.

Statistical approaches to computational linguistics refer to models based on statistics and not necessarily constructed with any known psycholinguistic processes in mind. However, given the equivalence between connectionist and statistical approaches, this distinction is rapidly fading. Further, since statistical models are more developed (e.g., statistical mechanics of information theory) and easier to analyze in comparison to their counterparts in artificial neural networks, there has been a shift in emphasis to the former over the last decade.

Neurolinguistics

A number of interesting results from empirical studies of the brain and bilingualism have shaped our knowledge of language processes and the brain. Many of these results come from non-invasive Functional Magnetic Resonance Imaging (fMRI) techniques which have only become available to researchers in the last 5-7 years. Previous non-invasive studies utilized PET (Positron Emission Tomography) which has a lower spatial resolution than fMRI. Grosjean (1998) points out that in cases of conflicting brain scan results, the effects of image resolution should be closely examined. Neuro-chemical studies have also provided some interesting results, not the least of which is that a hormone released into the brain during times of "happiness" is also responsible for increased neurological capability of knowledge acquisition.

The ability of the brain to structurally reorganize at the substrate level or in the large is known as *neuroplasticity* (UCP, 1997). Frequently in the literature, the inability of a certain region to reorganize is termed *plasticity*. Stapp (1997) has shown that there is a critical period for L1 (first language) acquisition from 8 months to 6 years with early exposure to and development continuing through age 6. This corresponds (Stapp, 1997) to the development of associated cognitive and motor systems circuitry developed over same period, with the major growth cycle occurring between ages 3 and 4. Delayed exposure to L1 leads to language handicaps (dysfluency). Further, second language acquisition between the ages of 5 and puberty is strongly correlated with second language fluency while the latter is rarely obtained beyond puberty.

Stapp goes on to distinguish between acquisition and mimicry, the generation of sounds without regard to content. In the study, it is shown that mimicry is an individual talent and not related to age of acquisition. It would seem for some, mimicry is a boundless enterprise (McFerrin, 2000).

Kim et al (1997) demonstrated that distinct cortical areas in the region of speech production were associated with native and second languages. However, Perani (1998) went on to show that this bipartite system only existed in individuals where fluency in the second language was low – and instead a homogeneous system in individuals with fluency in the second language. This has led to the proposition that the brain develops a trial system during language learning and then as fluency approaches this learned system is incorporated into "mainstream" processing.

This result by Perani (1998) and later Hernandez (1999) have shown that bilingual fluency is not always dependent upon age or the issue of plasticity with age. But rather, the situation is turned upon its head: fluency dictates physiological structure in the brain (Abdulla, 1999). Perani and colleagues also rightly point out that it is still an open question whether individual plasticity is the cause or the consequence of an individual's ability to gain fluency in a second language after puberty.

Rodriquez-Fornells et al (2002) have demonstrated that there are two pathways for decoding written text:

a. the faster orthography to lexical system (the latter of which has spelling rules), and
b. the graphemic to phonological sub-system (which also has spelling rules) to lexical system.

In particular, while the attention supervisory system is specifying a choice of language schema the phonetic system can filter candidates prior to accessing semantic information. Bilinguals with low fluency in the base language were shown to use this approach in the study.

However, Tan et al (2003) have examined the physiological development of linguistic systems in individuals whose first language has only word-to-phonetic conversion rules instead of rules for letter-to-sound conversion (in this case, Chinese). They found that late-language learners of English (which has letter-to-sound conversion rules) used word-to-phonetic conversion rules exclusively – whose processing is located in a distinct location of the brain. They reached the reasonable conclusion that first language acquisition "tunes" the brain and sets the processing model for secondary languages. Perani (1998) and Hernandez (1999) would point out that the subjects in this study were all low-fluency English learners and thus the conclusion should be restated: earlier language acquisitions tune learning modes of later acquisitions but the issue of plasticity in letter-phonetics remains an open question.

Newman et al (2002) have studied another interesting facet of linguistics: the acquisition of sign language. They have found that regardless of fluency in American Sign Language (ASL), acquisition prior to puberty results in brain development in both Broca's (speech production) region in the left hemisphere and in the right hemisphere region of the angular gyrus. However, ASL acquisition after puberty only results in left hemisphere development of Broca's region.

The RH angular gyrus is known to be associated with processing dynamic spatial relationships and plasticity is thought to occur prior to puberty after the main episodes of cognitive development in childhood. Consequently, the fluent late-learners who do not utilize the RH angular gyrus during conversation are necessarily using exemplars of sequential signing positions to process meaning. The situation is comparable to recognizing a spiral motion as one-motion (dynamic model) in contrast to recognizing a spiral motion from a sequence of object positions (exemplar model).

Newman's result has enormous implications to language and culturally-specific gestures. These non-verbal communications are as much a part of language as the spoken word (Grosjean, 1999). The learning of gestures without dynamic information (only as positional sequences) is problematic and thus gesture fluency is at risk for those learning languages or cultures after childhood.

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