Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

Theories of Learning
in Applied Linguistics:
A Neurobiological Perspective

Daniel C. Strack

Introduction

Historically, crises caused by fundamental disagreements in academia have been precursors to groundbreaking new approaches. According to some scholars, applied linguistics is presently facing just such an identity crisis. Peter Skehan points to the "uneasy relationship" of theory and pedagogy, noting that "pedagogical applications derived from theoretical approaches have only a perfunctory quality, rather than being properly rooted in theory." (Skehan 1998: 2) With the growing tension between the real world findings of corpus linguistics and the analysis prevalent in mainstream linguistic theory, the situation looks to become even more complex. (Widdowson 2000) How can applied linguists hope to resolve conflicts when empirical research can so easily be subsumed by theoretical debate? Even on the pedagogically crucial question of whether conscious learning is possible, nothing can be taken for granted. Richard Schmidt observes, "A hundred years of research in psychology and centuries of argumentation in philosophy have not resolved the issue, and I cannot resolve it here." (1995: 28) If such controversies are left to psychology and philosophy, they may well prove intractable.

Neurobiological knowledge could be used to augment the findings

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

of applied linguistics and mediate conflicts when evidence from psycho-linguistic research does not correlate with linguistic theory. There is a "cognitive" tradition in applied linguistics, but this tradition has drawn more from psycholinguistics than neurobiology. Although neuro-biological issues have garnered sporadic attention, (e.g. Jacobs and Schumann 1992) cognitive scientist and linguist Sydney Lamb notes, "For most linguists the orientation of neurocognitive linguistics is still new and unfamiliar, even while the term 'cognitive' is being used with ever greater frequency." (1999: 13)

As linguists have depended principally upon psycholinguistics to supply "cognitive" insight, they might perhaps be excused for their present unfamiliarity with neurobiology. Neuroscientist and Nobel Prize winner Gerald Edelman is not as quick to defend the indifference he perceives in psychology itself. Edelman states, "psychology can no longer declare its autonomy from biology, and it must always yield to biology's findings." (1992: 177) On the other hand, Edelman has praised the work of cognitive linguists, Ronald Langacker and George Lakoff, and philosopher, Mark Johnson, stating that his own work on neurobiology "nicely complement[s] Langacker's, Lakoff's and Johnson's work, providing essential biological underpinnings for many of their proposals." (1992: 252) This is not surprising in that the values Lakoff and Johnson list as fundamental to cognitive linguistics recognize that "mind" cannot exist without "brain." They state that cognitive linguist-ics "seeks to use the discoveries of second-generation cognitive science to explain as much of language as possible," (1999: 496) while providing an account that is "neurally realistic," "based on converging evidence from as many sources as possible," and encompassing "empirical generalizations over the widest possible range of phenomena." (1999:

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

79-80)

This paper will focus on the biological processes that underpin language learning, and show how neurobiological insight may help resolve some of the apparent contradictions between standard linguistic theory and what is actually observed. Some problematic empirical evidence relating to error and language learning will be reviewed in section A, followed by a brief summary of the brain's neurobiological underpinnings in section B. After showing how an understanding of neurobiology can illuminate previously inscrutable language processes in section C, section D will make a case for applied linguistics to proceed with a "cognitive" approach that incorporates evidence not just from psycholinguistics, but from neurobiology, as well.

A. Presuppositions and Conflicting Evidence in Applied Linguistics

It has been claimed that children learning their native languages are not usually exposed to negative input (active error correction). (Wexler and Culiver 1980) To account for the speed at which children learn their native languages, some linguists posit a Language Acquisition Device (LAD), an innate knowledge of linguistic "rules" which children use to make sense of language in the absence of negative input. If, indeed, a LAD eliminates the need for negative input then explicit error correction should have no place in the second-language classroom. In response to this claim, some researchers posit that child language acquisition takes place during a critical period of development and so comparison with older second language learners is not justifiable. Even so, if there is a LAD, even one not functioning at full capacity due to the fact that a critical period has ended, then the principles, conditions and rules of language might prove inaccessible to

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

conscious awareness, rendering explicit error correction either irrelevant or inferior to implicit learning. Already the issue of language learning has become complex; we find three questions that have the potential to frame all dialogue:

1. **Is there a critical period in language learning?**
2. **If there is a critical period, how does it work?**
3. **Is there biological evidence of a Language Acquisition Device that might render explicit error correction irrelevant?**

It is important to identify how errors occur. If different aspects of language are processed in fundamentally different ways, then any theory of error would need to take these differences into account. The experimental psychologist Steven Pinker has posited that "modules" in the brain (namely phonology, lexicon, morphology, syntax and semantics) process the different aspects of language. (Pinker 2000: 23) Some applied linguists are explicit in their acceptance of modularity and base their examinations entirely upon the theory; others, while avoiding explicit commitments, simply phrase their arguments in modularity-friendly terms. Two more questions emerge:

4. **Is the brain modular in its processing of language?**
5. **Are the terms associated with modularity biologically meaningful?**

While these two questions seem only to be two different ways of phrasing the same query, the distinct wordings are useful in that they allow the topic to be analyzed from two divergent perspectives. Question 4 frames the question in straightforward biological terms

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

while question 5 addresses more subtle issues relevant to linguistic analysis. They are not entirely the same question and will not necessarily entail identical answers.

Positing a phonology module further complicates an already challenging issue. Ian Watson remarks: "The subject of phonology is in itself so complex and riddled with controversy that it is difficult to know where to start to find a conceptual framework that will permit bilingual acquisition to be investigated." (1991: 25) One aspect he mentions is the relationship of speech perception and production: are they two sides of the same coin or two different coins? In his paper on phonological acquisition in bilingual children, he mentions a case in which empirical evidence strays from theory:

All of the perceptual studies reported above had subjects who in their productions were, at least for the variables tested, impressionistically indistinguishable from monolinguals. Their productions were not, however, identical when measured instrumentally. (Watson 1991: 45)

Watson noted that these findings, if unmitigated, would imply that bilinguals' systems are separated in respect to production but utilize a single common system for perception. Watson found this interpretation "unlikely" because it would imply that perception and production are separate; he explains that there must have been some problem with the experiment. Why would the dissociations implied by the evidence present a problem to be mitigated? Advocates of generative phonology recommend a single phonological module that facilitates both perception and production. (Pinker 2000: 110) In this case, the theoretical

— 5 —

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

assumptions of modularity and generative phonology disallow a straightforward interpretation of the empirical evidence. Momentarily setting theoretical questions aside, one might ask:

6. Is there any neurobiological evidence for either the unity or separation of perception and production?

Clearly, questions such as these will have great repercussions for a second language learning environment. If the perception and production aspects of language are unified, then student errors in one domain must be caused by some kind of unexplained interference within the modular associations themselves, beyond the student's conscious control. Consequently, if extensive language input does not solve the problem naturally, nothing will. In contrast, if the two aspects are separate, then problems with perception or production may potentially be addressed locally and more or less irrespective of the counterpart ability. Furthermore, if either perception or production should be distinct from the hidden unconscious phonological module, then conscious learning becomes possible, in turn paving the way for noticing, and possibly explicit error correction.

Temporarily setting problems of modular interference aside and proceeding further into Watson's examination, two new assertions are made concerning the perception and production of language in bilingual infants:

As the child's vocabulary increases, it rapidly becomes uneconomic to store words as wholes. At this point, words are analyzed into smaller units, probably first into syllables, then

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

segments. (Watson 1991: 32)

Watson gives no evidence for the first contention but these two points are often used in conjunction to assert biological motivation for generative phonology. (e.g. Pinker 2000: 93-94) The second assertion includes documentation, but the two claims are only noteworthy as they stand together. Without the implied biological motivation, the second assertion could simply be taken as evidence for metalinguistic understanding.

Having stated these two positions, Watson encounters another paradox. It seems that children can produce sounds that have not yet been phonologically categorized. (1991: 30-32) How is this a paradox? Normally, perception is thought to drive production and so how can an effect outrun its supposedly antecedent cause? Watson shrugs this apparent contradiction off by saying that it doesn't matter that these two aspects appear to be separate in infants because the performance "does not translate usefully into phonological knowledge." (1991: 30-31) The beginning of "linguistic activity" is thus deferred to a later age, making any conflict with the principles of generative phonology irrelevant. A very practical question presents itself:

7. Does neurobiological evidence show any "economic" necessity to break words down into syllables or segments?

In contrast to these assertions of an "economic" necessity for all language learners to break words down, Bialystok mentions anecdotal evidence from the second language classroom that apparently contradicts generative grammar theory: "Second language learners frequently

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

manage to reduce the demands for analysis by the use of highly practiced and conventionalized "chunks" or patterns of language." (1991: 127) This is problematic because a generative view asserts that language is a discrete combinatorial system, which is "infinite," and "compositional." (Pinker 2000: 365). True linguistic learning cannot take place in the absence of unconscious analysis for combinatorial use.

Bialystok solves this problem by asserting that second language students only "appear" to be learning by using chunks. (1991: 127) Although the students may seem to be putting such unanalyzed "chunks" into practical use, these "meaning units" are not legitimate aspects of language because they have not yet been analyzed apart for potential recombination. The analysis will occur internally and after the fact (and so the rote memorization of these unwieldy "chunks" does not serve a true linguistic purpose). Because it seems unlikely that students would stubbornly display such effort to no practical end, another question comes to mind:

8. **Wouldn't it be possible for second language learners to use con-ventionalized "chunks" for real communication even lacking com-binatorial analysis?**

While question 8 might at first glance appear not to be an issue of contention, it does, in fact, have crucial theoretical implications. Although many linguists would accept at least some use of unanalyzed "chunks" of language, opinions concerning the extent of their employ-ment may be seen as a continuum between "limited utility" and "comprehensive use," with many Universal Grammar advocates at the former end of the continuum and radical construction grammar advo-

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

cates at the latter. Using neurobiology as a standard to gauge the relative feasibility of "chunks" as opposed to "combinatorial analysis" is an exercise of crucial theoretical import.

For the same reasons that "chunking" presents a challenge to a combinatorial view of language, regression errors in language learning also present problems for those who would advocate an unconscious LAD. Bialystok comments:

> It is commonly observed that second-language learners dem-onstrate considerable variability in their apparent control over the forms of the new language. Correct forms seem to slip in and out of the learner's speech, defying any accurate measure of progress with the second language. (Bialystok 1991: 136)

Children, as well, are observed to backtrack into mistakes, which poses a dilemma for a generative view of language. Once analysis has taken place, why would learners at any level make regression errors? Bialystok mentions a possible explanation: the LAD must have multiple levels at which to function, with symbolic representations, formal representations and semantic representations functioning independent-ly, so that it can deal with an individual's progress uniquely as the learner's skills develop: "In time, each of these will become analyzed to a higher level." (Bialystok 1991: 118) As some levels lag behind others in sophistication, errors occur. Pinker has a different explanation: "Human memory profits from repetition. If children have heard *sang* less often than adults have, their memory trace for it will be weaker and their ability to retrieve it will be less reliable." (Pinker 2000: 197) This statement, however, implies that the LAD must be given the same

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

information over and over before it will do its job, leaving the theoretically powerful universal grammar at the mercy of frail human memory.

When confronted with evidence counter to claims for an autonomous generative grammar, neither scholar considered questioning the existence of a LAD; instead, the device itself needed only to be scaled up for Bialystok or scaled down for Pinker. Momentarily setting aside these theoretical explanations, the issue may be addressed without reference to any LAD:

9. Is there any neurobiological explanation for the way in which both young native speakers and second language learners regress into errors?

Looking back over the questions suggested, it is apparent that all of the problematic evidence conflicts with theoretical assumptions that were held from the outset. Furthermore, the conflicts are all mitigated either by adjusting aspects of the theory or carefully redefining language itself; the legitimacy of the starting hypotheses are never questioned. Not coincidentally, the presuppositions being defended are not separate, unrelated issues, but rather interconnected, supporting arguments in a theoretical pyramid.

We will return to these questions again in section C and attempt to answer them from a neurobiological perspective. Before that, however, an overview of neurobiology with respect to development, memory and language will introduce the main concepts and terminology necessary to answer these questions.

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

B. Noticing Neurons: Understanding the Biological Basis of Language

Evidence will be taken from the work of neuroscientists and cognitive scientists that either study neurobiology directly or emphasize neurobiological evidence in their research. These researchers include Mark F. Bear (Professor of Neuroscience, Brown University), Barry W. Connors (Professor of Neuroscience, Brown University), Antonio Damasio (Department of Neurology Head, University of Iowa's College of Medicine), Terrence W. Deacon (Associate Professor of Biological Anthropology, McLean Hospital, Harvard University), Gerald M. Edelman (Director of Neurosciences Institute, Department of Neurobiology Chair, Scripps Research Institute), Sidney Lamb (Professor of Linguistics and Cognitive Science, Rice University), Michael A. Paradiso (Professor of Neuroscience, Brown University) and Giulio Tononi (Senior Fellow in Theoretical and Experimental Neurobiology, Neurosciences Institute). While some of these scholars might disagree with one another on more subtle matters such as mechanisms of consciousness or non-human cognition, there is agreement on neurobiological fundamentals, including much of the information presented in the following overview.

Specialized cells called neurons form the network that accomplishes the various goals of the body by transmission of electrochemical stimulus. A prototypical neuron has three basic parts: the *soma* (cell body), the *axon* (an output fiber) and *dendrites* (input fibers). Neurons are connected to other neurons, forming electrochemical circuits that consist of "conducting wires (the neurons' axon fibers) and connectors, known as *synapses* (which usually consist of an axon making contact with the dendrites of another neuron)." (Damasio 1999: 324) Neurons generate nerve impulses that are called *action potentials*. While the

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

action potentials of one neuron will be different from those of other neurons, the multiple action potentials resulting from the firing of a single neuron are consistent in size and duration. (Bear et al 2001: 74) Generally evidencing greater similarity to a burning fuse than to an electrical charge, (Bear et al 2001: 89-91) these electrochemical impulses do not carry "information." (Edelman 1992: 27) The *spikes* (action potentials) generated by neurons are similar to the clicks of a Geiger counter in the presence of radiation; in response to strong stimulus a neuron fires rapidly and weak stimulus will produce less frequent or intermittent spikes. These firings are not in any way "encoded" and are functionally distinct from the highly calibrated succession of electrical pulses that travel along telegraph wires or through digital processing equipment.

The network of neural subsystems instantiates itself according to the basic cellular processes of division, migration, death, adhesion and induction. Although the timing of these events is coordinated according to genetic constraints, "...individual cells, moving and dying in unpredictable ways, are the real driving forces" of neural development. (Edelman 1992: 60) The overall configuration of the brain is genetically coordinated but from early embryonic stages, "neurons extend myriads of branching processes in many directions" and connectivity is established at the synapse level as a result of individual development. (Edelman and Tononi 2000: 83) Neurons do not simply branch out to complete the system; a mature and functional neural system requires some little-used connections to be eliminated while more active connections are strengthened. Edelman has called this selection process Neural Darwinism. Deacon notes, "Nature prefers to overproduce and trim to match, rather than carefully monitor and coordinate the devel-

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

opment of innumerable cell populations." (1997: 197)

A neuron will only generate an action potential at the near-synchronous firing of many inputs coming from other neurons. (Deacon 1997: 202) Furthermore, the magnitude of the input stimulus can increase the *firing frequency* of the action potentials; the more intense the stimulus, the greater the chances that a connection will be selected to "live" and become entrenched. There are two rules of thumb that sum up this neuronal selection process: "neurons that fire together, wire together," and "neurons that fire out of sync, lose their link." (Bear et al 2001: 731)

Linked together, neurons form somewhat localized brain units, but "there are no single "centers" for vision, or language, or for that matter, reason or social behavior. There are "systems" made up of several interconnected brain units." (Damasio 1994: 15) While these distributed systems facilitate certain recognizable cognitive functions, the contribution of a given brain unit to the operation of the system hinges not only on the structure of the unit but also on its *place* in the system. (Damasio 1994: 15) Sharp functional distinctions between regions in cortical processing do not exist. (Bear et al 2001: 648)

In neurological terms, when an object is perceived visually, there is a *neural pattern* (or *mental image*) that registers at various processing stages between the eye and the brain. Mental images need not be visual: auditory images, olfactory images, gustatory images and so-matosensory images all leave their marks on the system in one form or another. (Damasio 1999: 318-319) As mentioned before, these images are not "contained" in a single action potential. They are formed through the correlation of the action potentials of multiple neurons into "*maps.*" Such mapping processes are crucial to the operation of

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

complex brains. "Maps relate points on the two dimensional receptor sheets of the body (such as the skin or the retina of the eye) to corresponding points on the sheets making up the brain." (Edelman 1992: 19) Damasio notes that these mappings do not need to be point-for-point, utterly faithful facsimiles of the original perception; the brain constructs maps according to its own parameters, (1999: 322) the only real constraint being that these parameters must be adaptive enough to succeed within their specific system. (Edelman 1992: 204, 220).

These mappings are not found in a single location of the brain but are "distributed" over a number of locations. (Damasio 1994: 106-107) Damasio describes how disparate aspects of a conceptualization of your Aunt Maggie might be distributed throughout the brain:

> There are dispositional representations for Aunt Maggie's voice in auditory association cortices, which can fire back to early auditory cortices and generate momentarily the approximate re-presentation of Aunt Maggie's voice [...] Aunt Maggie as a complete person does not exist in one single site of your brain. She is distributed all over it, in the form of many dispositional representations, for this and that. (Damasio 1994: 102-103)

One great advantage of the human brain's distributed memory system is its relative immunity to catastrophic loss if some neurons die. (Bear et al 2001: 749) It is true that drinking alcohol kills neurons, but one drink will not likely cause the drinker to forget the word "aardvark." The highly parallel and redundant nature of mental images assures that it is impossible for one neuron to contain the word or for

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

a single neuron to allow access to it. (Lamb 1999: 173) Heavy drinking over a long period of time is another matter, as evidenced by the widespread brain damage often caused by Korsakoff's syndrome, a neurological disease associated with chronic alcoholism. (Bear et al 2001: 760) One disadvantage of the highly distributed memory system is relative instability of logic when compared to the precisely specified logical determinacy of systems such as Turing Machines. (Edelman 1992: 225) Indeed, the reason that computers commonly exceed human capacities for chess and mathematical calculation is found in fundamental structural difference rather than memory capacity; the machines were built to be rigorously logical and humans were not.

Neural control of bodily movement is facilitated by *motor sequences*, which are also mappings. These motor sequences are necessary for kicking a ball, playing the piano or speaking. Motor sequences that are related to these tasks are "constructed or linked during consciously guided learning until a smooth, apparently effortless sensorimotor loop is executed speedily, reliably and unconsciously." (Edelman and Tononi 2000: 188) While motor sequences, including speech, are constructed using overt, conscious control, they are entrenched through repetition, eventually becoming global mappings for largely unconscious coordinated action.

In the case of sound perception, there is a certain amount of preprocessing that happens even before the sound image reaches Wernicke's area, one of the regions often associated with language comprehension. Intensity and frequency adjustments occur with the mechanical interaction of the tympanic membrane and the ossicles even before neural processing is initialized in the cochlea. Beginning with the cochlea, axons project stimulus toward the primary auditory cortex

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

in an array called *acoustic radiation*. (Bear et al 2001: 355-372) The primary auditory cortex registers the incoming *sound images* on *tonotopic maps*. (Bear et al 2001: 380-381) These maps are probably composed of strips of neurons, called *isofrequency bands*, each band handling fairly similar characteristic frequencies. "In addition to the frequency tuning that occurs in most cells, some neurons are intensity tuned, giving a peak response to a particular sound intensity." (Bear et al 2001: 381) Some neurons even key in on clicks, bursts of noise, frequency-modulated sounds and animal vocalizations.

With respect to linguistic communication, there is unanimity in assertions that "specialized language areas have evolved in the human brain that endow us with an incredibly flexible and creative system for communication." (Bear et al 2001: 673) Deacon states, "Without question, children enter the world predisposed to learn human languages," (1997: 102) and cites neurobiological, anthropological and clinical evidence to suggest that the brain has been "significantly overbuilt for learning symbolic associations." (1997: 413)

These observations notwithstanding, there is also agreement that linguistic processing should not be defined narrowly in terms of spoken language comprehension and production, but communication facility within a broad conceptual system. (Lamb 1999: 238) For instance, in some cases in which American Sign Language users are impaired in a way analogous to Broca's Aphasia "...the ability to move the hands is not impaired (i.e., the problem is not with motor control); rather, the deficit is specific to the use of hand movements for the expression of language." (Bear et al 2001: 650) This demonstrates that linguistic communication is possible in the total absence of the sound images normally associated with linguistic processing, even though areas of the

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

brain known to facilitate spoken language are in use. Such flexibility is built into the system by the ways that individual neurons act and interact: "Each brain is formed in such a way that its wiring and dynamics are enormously variable at the level of its synapses. It is a selectional system, and each brain is therefore unique." (Edelman and Tononi 2000: 213)

C. Resolving Conflict with Empirical Data: A Neurobiological Approach

There is an unfortunate misunderstanding among linguists that neuroscientists commonly disagree with one another at the most basic levels. In fact, as we have seen in the preceding section, neurobiological researchers are in agreement on a wide range of issues. It is time to address the questions posed earlier with respect to neurobiology.

1. Is there a critical period in language learning?

From a neurological perspective, there most definitely is a critical period in language learning. Without neuronal branching, the neural system would not exist and without selection and entrenchment, the neural system would be ill equipped to do anything practical. Furthermore, the number of synapses a neuron is capable of sustaining has a limit called *synaptic capacity*, which decreases as a neuron matures. Bear et al note that in the striate cortex, "the synaptic capacity of immature neurons exceeds adult cells by about 50%," and that (in macaque monkeys, which are similar to humans in many respects) "synaptic capacity in the striate cortex was remarkably constant from infancy until puberty," after which synaptic capacity declined sharply. (2001: 721)

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

2. If there is a critical period, how does it work?

Critical periods can be genetically explained by the *topobiological* nature of gene differentiation, (Edelman 1992: 58-63) and Edelman notes that for language, a critical period would likely be "related to extensive synaptic and neuronal group selection occurring up to adolescence, after which time such changes occur much less extensively and in a different fashion." (1992: 130) Remarking on the advantages of the relatively slow neural development seen in humans as compared to other species, Deacon observes that "Immaturity of the brain is a learning handicap that greatly aids language acquisition." (Deacon 1997: 141)

Although critical periods do end, neural plasticity does not ever completely disappear: "the environment must modify the brain throughout life at some level, or there would be no basis for memory information." (Bear et al 2001: 737) About general neural plasticity, Bear et al observe, "Early in development, gross rearrangement of axonal arbors is possible, while in the adult, plasticity appears to be restricted to local changes in synaptic efficacy." (2001: 736) While some linguists have asserted that the idea of a critical period "clearly implicat[es] an innate mechanism" for language learning, (Eubank and Gregg 1995: 39) this need not be the case. Critical periods are at least partially motivated by the general topobiological framework mentioned above. Neuroscientists can account for critical periods straightforwardly in neurobiological terms; perhaps linguists should spend less time generating highly speculative critical period theories to match equally speculative linguistic hypotheses, and more time correlating the body of empirical findings in applied linguistics with neurobiological critical period knowledge already available.

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

3. Is there biological evidence for a Language Acquisition Device that renders explicit error correction irrelevant?

All of the neuroscientists mentioned agreed that the brain, in its entirety, is an excellent language acquisition device, but this fails to respond to the heart of the question. None of the researchers mentioned any candidate structures that could be construed as a LAD. On the contrary, all stressed that phrenology (an emphasis on discrete localized function) is not an option, and that different cognitive skills are distributed throughout the brain's various systems. Lamb sums things up: "there is no reason for supposing that the brain has genetically built-in structures dedicated specifically to language." (1999: 371) Although genetically predetermined structures specific to language are not ruled out, until neurobiological proof affords itself, there is no necessity to posit them. Finally, aside from the decided lack of biological evidence for a LAD, Deacon argues that genetic specification of precise neural connections in the brain would be too costly in terms of genetic resources. (1997: 197)

In fact, learning in the absence of explicit error correction may be explained without hypothesizing an innate LAD. Terry Regier, in his constrained connectionist modeling of basic spatio-linguistic understanding, has offered a cogent explanation. (Regier 1996) As children learn their first words of language, for each word learned, they may understand an implicit negation of that word's meaning for all other words. While such an oversimplistic view of language does not reflect the way that the meaning of a word tends to overlap somewhat with the meanings of similar words, it matches well with Deacon's comment concerning neural development that nature tends to overproduce and trim to fit. As Regier's connectionist model takes cues from the actual

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

systems of human perception for biological motivation, the high corre-lation between his model and actual human language understanding cannot strictly be considered incidental.

4. Is the brain modular in its processing of language?

The modules that Pinker suggests (namely, phonology, lexicon, morphology, syntax and semantics) will not likely be found in any clearly demarcated form because of the distributed nature of neural processing. Making a similar observation, Deacon notes that while researchers have made claims for grammatical modularity by citing studies of Broca's aphasia in English speaking patients, the results become much less clear when studying the speech of Broca's aphasics whose native language is Italian (a highly inflected language). (1997: 307) His conclusion:

So if there is a grammar module, then the parts of this module map in very different ways to different grammatical operations, depending on the relative importance of positional or inflectional tricks for cuing grammatical decisions in different languages. This sort of module is a will-o'-the-wisp. (Deacon 1997: 307)

Lamb echoes this opinion, noting that the linguistic system is not a unified system, but a "complex of subsystems" that are "closely related to one another," although these relationships are not simple ones. (1999: 37)

The most likely candidate for modularity would seem to be phonology, in that the primary auditory cortex does seem to be adapted specifically for the reception of sound images into tonotopic maps.

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

Unfortunately for a language module theory, it processes all kinds of sounds, not just language, so it could not strictly be called a phonology module. The other great facilitator of spoken language processing, Wernicke's area, often seems to play a role among deaf people that is highly analogous to the role it plays among the hearing. (Bear et al 2001: 650) Can a "phonology module" that is also capable of processing non-phonological sign language accurately be called a phonology module? As will become apparent in question 5, modules for lexicon, morphology, syntax and semantics are also highly unlikely.

5. Are the terms associated with modularity biologically meaningful?

At first glance, different areas of the brain seem to facilitate certain cognitive functions, but do the functions fall along traditional linguistic lines? Lamb remarks, "The fact that [patterns of analytical linguistics] can be found in the *products* of mind doesn't necessarily mean that they are direct reflections of anything *in* that mind." (1999: 229) Although the brain is very good at language, it is also good at things other than language. Specifically, Deacon points out:

> Though breaking up language analytically into such complementary domains as syntax and semantics, noun and verb, production and comprehension, can provide useful categories for the linguist, and breaking it up according to sensory and motor functions seems easier from a global neuronal viewpoint, we should not expect the brain's handling of language to follow either of these categorical distinctions. (Deacon 1997: 298)

Edelman has a similar skepticism about the modularity of syntax,

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

in particular, although for a different reason: he sees general cognition as a framework for semantics. He views syntax as a subsequent epigenetic phenomenon that occurs as rules "developing from memory" are "treated as objects of manipulation." (1992: 130) Lamb mentions that analytical linguistics, because of its specific formal agenda, partitions language with respect to "taxonomic convenience" rather than functional precision. (1999: 32) Despite the tendencies for Deacon and Edelman to downplay semantics in favor of more general neural function, both scholars still seem to understand semantics as a driving force in language. (Deacon 1997: 135-136; Edelman 1992: 130) Lamb explains that the idea of lexical connections is biologically meaningful, "not because they *have* meanings, but because they *have connections*" with the conceptual. (1999: 122)

6. Is there any neurobiological evidence for either the unity or separation of production and perception?

In fact, neurobiologically speaking, the two aspects do seem to be somewhat separate, although there must also be some overlap. Incoming sound requires preprocessing in preliminary auditory cortices before moving through the primary auditory cortex to Wernicke's area in the brain. In contrast, phonetic coding of meaning for speech begins with association in regions including Broca's area, thereafter proceeding to various motor cortices for the initiation of motor sequences that trigger physical movement of the lungs, vocal chords, tongue and mouth. To the extent that Wernicke's area and Broca's area stimulate the same conceptual neural maps, there will be a correlation of activity, but there is a great functional difference between a sound image to be interpreted and a motor schema to produce a sound through speech.

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

Regarding this neurobiological dissociation of early sensory and motor cortices, Lamb notes, "...understanding is perceptual while producing language is a motor activity, like drawing a picture or dancing. If this is so, language has both a production subsystem and perceptual subsystem as separate systems." (1999: 126)

Because the act of saying a word produces sound that can then be heard by the ear, speech will result in a reciprocal sound image within the speaker's ear. Consequently, a strong synchronous firing is likely to link the neural patterns of the sound image and the motor sequence, even though the respective maps may be located in separate areas of the brain. (Lamb 1999: 271) Since most people can easily repeat words they've just heard, we understand that these correlative connections have indeed been made. This does not change the fact that the actual functions are not two sides to the same coin; they are two different coins, or more accurately a coin and a machine that can mint a similar coin.

7. Does neurobiological evidence show any "economic" necessity to break words down into syllables or segments?

The assumption that it is uneconomical for the brain to store different forms of words intact assumes that the brain is strapped for memory resources. Is this an accurate assessment? Edelman estimates "there are about 1 million billion connections in the cortical sheet," and, in taking into account how these connections might be combined, the number of potential connections would be "on the order of ten followed by millions of zeros" (1992: 17) Damasio's more conservative estimate notes that one human brain contains several billion neurons with at least 10 trillion synapses among these. (1994: 259) For Deacon,

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

however, raw neural capacity is not the decisive issue in answering questions of "economy":

> Time is a critically important factor, especially in an informa-tion processing device that tends to operate almost entirely in parallel (instead of funneling all operations through a single processing unit, as do most desktop computers) [...] Maintaining a signal within a circuit long enough to analyze its part in some extended pattern would tend to get in the way of processes that require rapid and precise timing. (Deacon 1997: 292-293)

Lamb goes so far as to speculate on the availability of neural wiring over a lifetime, once for a "maximally curious and energetic" person (in terms of overall cognition), and again with reference to language for the expected lifetime neural demands of a 20 language polyglot (1999: 341-343); after auditing the neural balance sheets, he echoes Deacon's optimism concerning the brain's ample resources, stating simply, "the abundance hypothesis seems to be confirmed." (1999: 343) The main neural constraint on language would appear to be processing time rather than memory capacity.

8. **Wouldn't it be possible for second language learners to use con-ventionalized "chunks" for real communication even lacking com-binatorial analysis?**

Going beyond Bialystok's guarded reference to linguistic "chunks" or "meaning units," there is strong evidence that some aspects of language become deeply entrenched by frequent repetition in produc-tion. These "overlearned" linguistic items do indeed seem to operate

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

irrespective of grammatical analysis. Bear et al note that "...there are certain "overlearned" things Broca's aphasics can say without much hesitation, such as the days of the week." (2001: 643) While Bialystok and others treat this sort of example as an atypical process that may or may not have linguistic value, there is no neurobiological reason to believe that all language is not learned in "chunks" of varying length and grammatical complexity. In fact, Edelman asserts: "to build syntax or the bases for grammar, the brain must have reentrant structures that allow semantics to emerge *first* (prior to syntax) by relating phonological symbols to concepts." (1992: 130) Deacon explains:

> Indeed, grammatical cues, such as are embodied in small "function words," may be the primary agents for initially tagging and distributing sentence "chunks" to be separately processed. For this reason, it is precisely these features of language that need to be subject to minimal symbolic analysis. They serve a predominately *indexical* function. And as we have seen, indices can be interpreted in isolation as automated, rote-learned skills. (Deacon 1997: 299)

Lamb posits just such an arrangement, characterizing it as "sequence control without constituent structure," (1999: 255) and gives extensive neurobiological rationale for making such claims. In fact, he explicitly recommends an "exemplar" understanding of the linguistic "chunks" mentioned above. (Lamb 1999: 263) Actually, for construction grammar advocates including William Croft (Croft 1998) and Adele Goldberg (Goldberg 1995), the observation that foreign language students often attempt to learn language by memorizing large "chunks" is

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

not in any way problematic; according to their views, it simply shows the way in which language is actually learned.

9. Is there any neurobiological explanation for the way in which both young native speakers and second language learners regress into errors?

It has already been stressed that human neural wiring is a highly distributed process. Edelman remarks that ongoing behavior of an animal makes memory "a process of continual recategorization." (1992: 102) Deacon observes, "Learning is, at its base, a function of the correlations between things, from the synaptic level to the behavioral level." (1997: 83) Edelman further notes that "The maps that speak back and forth are massively parallel and have statistical as well as precise features" (1992: 29) and "perceptual categorization, which is one of the initial bases of memory, is probabilistic in nature." (1992: 194) In this view, learning is characterized by probabilistic correlation rather than precise specification.

To put it another way, neural mapping, the basic organizing principle of memory, is association of perception according to spatio-temporal contiguity, which is not actually logical at all. This dynamic process, in logical terms, is the fallacy "guilty by association," but the illogicality in the argument's form does not stop it from being effica-cious. Neurons that fire together, wire together and so logically unrelated aspects of sensory perception can become associated through correlation. Less well-entrenched routines have weaker mutual asso-ciations among constituent neurons and therefore a lower statistical probability of being available at the crucial moment. Also, when a neuron fires there is resource depletion; the chemical resources that

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

allow for the firing do not remain at constant levels, resulting in further potential instability for less well-entrenched routines. Just because a language item is consistently available does not mean it is being accessed in the same way from one instance to the next.

For these reasons, the processing of a sentence is not a short ride through a predetermined interpretational circuit in a language governing center but a far-reaching and fairly unpredictable resonance among disparate brain units in three-dimensional space and time. Within such an electrochemical cascade, regression into error for both young native speakers and second language learners can be explained in terms of statistical probability. Neural Darwinism displays bias toward linguistic efficiency; language is streamlined as usage events succeed or fail to result in communication in real time social context. Nevertheless, until overlearning has occurred, a single correct utterance is no guarantee of future perfection.

To summarize section C, there is indeed a critical period in language learning and it is crucially interrelated with neuronal branching and selection processes. The quick pace of language learning in the absence of explicit error correction may be explained according to basic neuronal processes without reference to language modules or a LAD; indeed, there is no neurobiological evidence to support their existence. Consequently, the terminology often associated with modularity, while analytically useful, may not be biologically meaningful. Although perception and production necessarily overlap in association cortices, motor functions of production and sensory functions of perception are relatively discrete. There is no "economic" necessity to break words or phrases down to conserve memory. Not coincidentally,

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

overlearned "chunks" of language are essentially linguistic in nature and an exemplar-based understanding of language is the most neurally plausible option. Finally, regression into error for children and second language learners can be explained straightforwardly in neural terms by the unstable, probabilistic nature of perception and linguistic association.

In that this type of relevant neurobiological knowledge is readily available, highly theoretical speculation that fails to take known processes into account is unwarranted; so, too, are attempts to mitigate problematic evidence in light of such speculation.

D. Realigning Applied Linguistics to match Neurobiological Processes

Needless to say, sections B and C above do not represent the final word on the issues in question, but taking a neurobiological perspective into account is infinitely better than NOT taking such a perspective into account.

Skehan, in his book, *A Cognitive Approach to Applied Linguistics* (Skehan 1998), calls for a realignment of theory with empirical evidence. He mentions a great number of cases in which theory does not match up well with observation. Many of the problems he identifies from a psycholinguistic perspective have been echoed in this paper. Having listed all of these discrepancies between empirical evidence from applied linguistics and mainstream linguistic theory, however, he essentially ignores the mutually exclusive nature of the competing viewpoints by proposing a "dual mode system." Arguing that both rule-based systems and exemplar-based systems are insufficient, he states: "The question then becomes one of explaining how the two systems might work together harmoniously." (Skehan 1998: 89) Skehan

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

reasons that an exemplar-based system, "with its emphasis on mean-ing," would be too inflexible to accommodate "underlying system change." (1998: 89) But what "underlying" system is he talking about? In neural terms, we have already seen that there is no "underlying system," only largely inextricable subsystems. The purported difficul-ty of "underlying system change" is a dilemma only if one has already posited an underlying system. Skehan deftly critiques the theoretical pyramid only to mitigate his own findings by invoking evidence taken from presuppositions in the pyramid itself.

Nevertheless, research aiming for a "cognitive" view of language acquisition cannot hope to account for everything in terms of neural processes. Skehan duly notes that the classroom is a social environ-ment and so affective concerns must also be figured into the equation. Still, it is unfortunate that although Skehan's book is titled *A Cognitive Approach to Applied Linguistics*, he makes almost no reference to neurobiology. When he advocates a cognitive approach, he explicitly refers to a *psycholinguistic* approach. (Skehan 1998: 2) Although there is a tendency to equate "cognitive" with "psychological," the findings of psycholinguistic study represent but one portion of the potentially useful evidence that may be brought to bear on perennially intractable problems of applied linguistics. Although psycholinguistic evidence is important and cannot be brushed aside, ultimately, any theory of language that is not defensible with respect to neurobiology is not a viable theory.

Conclusion

Theories of language learning are only useful insofar as they detail how language is actually learned and thereby facilitate effective learn-

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

ing. Theoretical stances that subsume both the neurobiological un-
derpinnings of language and empirical evidence from language acquisi-
tion research do not serve the goals of applied linguistics. Although
knowledge of neurobiology could play a mediating role in the resolution
of longstanding disputes, applied linguists have made little reference to
the actual electrochemical processes by which language is facilitated.
A change of perspective may allow applied linguists freedom to extend
the limits of theory, rather than being restrained by it.

References

Bear, M., B. Connors and M. Paradiso. 2001. *Neuroscience: Exploring the Brain, Second Edition.* Baltimore, MD: Lippincott Williams & Wilkins.

Bialystok, E. 1991. "Metalinguistic Dimensions of Bilingual Language Proficiency." *Language Processing in Bilingual Children.* (Bialystok, E. ed.) London: Cambridge University Press.

Croft, W. 1998. "The Structure of Events and the Structure of Language." *The New Psychology of Language.* (Tomasello, M. ed.) New Jersey: Lawrence Erlbaum Associates.

Damasio, A. 1994. *Descartes' Error: Emotion, Reason, and the Human Brain.* New York: G. P. Putnam.

Damasio, A. 1999. *The Feeling of What Happens.* New York: Harcourt, Inc.

Deacon, T. 1998. *The Symbolic Species.* New York: W.W. Norton and Co.

Edelman, G. 1992. *Bright Air, Brilliant Fire: On the Matter of Mind.* New York: Basic Books.

Edelman, G., and G. Tononi. 2000. *A Universe of Consciousness.* New York: Basic Books.

Eubank, L. and K. Gregg. 1995. "Et in Amygdala Ego?: UG, (S)LA, and Neurobiology." *Studies in Second Language Acquisition,* 17, 35-57. Cambridge: Cambridge University Press.

Goldberg, A. 1995. *Constructions: A Construction Grammar Approach to Argument Structure.* Chicago: University of Chicago Press.

Daniel C. Strack
Theories of Learning in Applied Linguistics: A Neurobiological Perspective
Bulletin of the Institute of Language Teaching Waseda University, 57, March 31, 2002

Jacobs, B. and J. Schumann. 1992. "Language Acquisition and the Neurosciences: Towards a more Integrative Perspective." *Applied Linguistics*, 13. Oxford: Oxford University Press.

Lakoff, G. and M. Johnson. 1999. *Philosophy in the Flesh.* New York: Basic Books.

Lamb, S. 1999. *Pathways of the Brain.* Amsterdam: John Benjamins Publishing.

Pinker, S. 1994. *The Language Instinct.* London: Penguin Books.

Pinker, S. 1999. *Words and Rules: The Ingredients of Language.* New York: Harper Collins Perennial.

Regier, T. 1996. *The Human Semantic Potential.* Cambridge, MA: MIT Press.

Schmidt, R. 1995. "Consciousness and Foreign Language Learning" *Attention & Awareness in Foreign Language Learning.* (Schmidt, R., ed.) Honolulu: UH Manoa, Second Language Teaching and Curriculum Center.

Skehan, P. 1998. *A Cognitive Approach to Language Learning.* Oxford: Oxford University Press.

Watson, I. 1991. "Phonological Processing in Two Languages." *Language Processing in Bilingual Children.* (Bialystok, E. ed.) London: Cambridge University Press.

Wexler, K. and P. Culicover. 1980. *Formal Principles of Language Acquisition.* Cambridge, MA: MIT Press.

Widdowson, H. 2000. "On the Limitations of Linguistics Applied." *Applied Linguistics*, 21. Oxford: Oxford University Press.