The Neurobiology of Learning

Perspectives From Second Language Acquisition

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To Arnold Scheibel

In the early 1980s, Bob Jacobs, then a graduate student in Applied Linguistics at UCLA, began to take neuroscience courses at the Brain Research Institute. There he studied neuroanatomy with Dr. Arnold Scheibel and became both a TA for Dr. Scheibel's classes and an RA in his laboratory. In the 1985–86 academic year when Dr. Wolfgang Klein from the Max Plank Psycholinguistic Institute was a visiting professor at UCLA, Bob arranged for us to meet with Dr. Scheibel on a regular basis to discuss issues of brain and language. As a result of these discussions, Dr. Scheibel offered to teach neuroanatomy to students in Applied Linguistics. The first course was taught in the fall 1987, and it began a long exciting relationship between our Applied Linguistics students and Dr. Scheibel. Applied Linguistics students have been taking neuroanatomy with Dr. Scheibel every other year since then.

Dr. Scheibel is a dynamic teacher who loves his subject. His lectures are like watching Nova three times a week. Learning neuroanatomy is no easy task. A friend, who is an oncological surgeon, recalls his neuroanatomy studies in medical school as similar "to memorizing Amtrak schedules." Indeed a good deal of memorization is necessary, but Dr. Scheibel makes sure we see the brain from multiple perspectives: by dissecting sheep brains, human brains, and working through diagrams in brain atlases, The Human Brain Coloring Book, and in computer visualizations of the substrate.

Slowly but surely the students become comfortable navigating the neural landscape, and then a whole new world opens. They learn about the brain and they learn a science. When humanities students become proficient in a science, it is very empowering—particularly in neuroscience which provides a biological basis for all human activity and which frequently leads to interest in evolution, genetics, and complexity.

Successfully learning neuroscience requires distributed cognition, and it couldn't be done without Dr. Scheibel's generous help beyond the neuroanatomy class. He has served on many of our Applied Linguistics MA thesis committees, PhD qualifying paper committees and PhD dissertation committees. He puts us in touch with other neuroscientists with expertise in our areas of interest. Dr. Scheibel also organizes a monthly meeting of individuals interested in the neurobiology of higher cognitive function. The group has been meeting for about 15 years. When students have finished the neuroanatomy class, they are welcome to join the group and to explore with other neuroscientists a wide range of issues involving brain function.

It is the relationship with Dr. Scheibel that allowed us to write this book. He guided us to the knowledge of neurobiology that we use here to understand SLA, and he has been tolerant and supportive of our linguistic speculations that go beyond the neural data. However, while our inspiration and guidance are his gifts to us, any mistakes are ours.

It is to this wonderful scholar, teacher, gentleman, and friend that we dedicate this book.

Foreword

There has been a tendency in language acquisition circles to dismiss neuroscience because, as the claim goes, supposedly not enough is known about the brain to make significant contributions to our understanding of how language is acquired. Unfortunately, such claims often reflect an overriding ignorance of underlying neural mechanisms—a dismissive attitude about the neurosciences that must end. This book constitutes a timely contribution to the existing literature by presenting a relatively comprehensive, neurobiological account of certain aspects of second language acquisition. Moreover, the present volume avoids the corticocentric bias that characterizes many brain-language publications—both cortical and subcortical structures receive their appropriate attention here. The chapters in this volume demonstrate, without any apology, that enough is presently known about the brain to inform our conceptualizations of how humans acquire second languages. It thus provides a refreshingly novel, highly integrative contribution to the (second) language acquisition literature.

Historically, the language acquisition mirror, as it were, has reflected behavior back into the "black box" of theoretical mechanisms with little concern for the neurobiological plausibility of those mechanisms. The acquisition literature is replete with such supposed mental mechanisms (e.g., buffers, filters, organizers, Language Acquisition Device, Universal Grammar). Although such cognitive metaphors may help researchers *describe* acquisition at a phenomenological level, they are ultimately of limited *explanatory* value without an underlying neural foundation. With this book, the perspective comes full circle: we are now looking out from the brain itself, letting the neurobiology itself indicate potential signposts along the road of second language acquisition. Such an approach is not for the neurobiologically timid, however, as it requires one to learn the language of the brain for effective academic discourse. It is a long, complex, but intellectually stimulating neural pathway.

Indeed, the impulse for this speculative account of language acquisition began nearly four decades ago with Lenneberg's (1967) landmark publication of *Biological Foundations of Language*, which helped set the general stage for this kind of interdisciplinary undertaking. Within the field of second language

acquisition, the major impetus for the neural perspective was provided by the seminal neurofunctional contributions of Lamendella (1977), who claimed that "observation of overt behavior in itself cannot be an adequate basis for understanding the organization of the internal systems that produce behavior" (p. 160). Supplementing Lamendella's functional emphasis, Jacobs (1988) focused more on the underlying neuroanatomical substrate itself, questioning the neural plausibility of linguistic concepts such as Universal Grammar. Finally, the foundation for the current volume developed with a series of subsequent publications by Schumann and his colleagues (Jacobs & Schumann, 1992; Schumann, 1994, 1997; Pulvermüller, 1992; Pulvermüller & Schumann, 1994). Although each of these authors approached the neural underpinnings of language from a slightly different perspective, all had the unwavering conviction that language acquisition researchers need to incorporate a degree of neuroscientific reality into their perceptions of the language acquisition process. Although this neural emphasis is not without its detractors (cf. Eubank & Gregg, 1995), there is no denying the significant advances of recent neuroscientific investigations relative to language acquisition, many of which are discussed in the current volume.

The details in this volume will invariably be modified with future research, but the fundamental insights presented here should guide second language acquisition researchers for years to come. This is very much a work in progress, a work that could only have been realized within an atmosphere inherently supportive of truly interdisciplinary undertakings, such as the UCLA Applied Linguistics and TESL Department, which has led the field of applied linguistics for more than thirty years. More specifically, the Neurobiology of Language Research Group responsible for this volume could not have flourished without the continued, unparalleled guidance of two scholars: John Schumann and Arnold B. Scheibel. They provided the neural underpinnings of this volume, the glia of productive collaboration. It is my sincere hope that this book will further promote such interdisciplinary undertakings by a new generation of neurobiologically knowledgeable investigators.

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Preface

At a colloquium on the Neural Biology of Learning held during the 2002 Conference of the American Association for Applied Linguistics, Nick Ellis pointed out the need to draw more links between the neurobiological mechanisms and second language acquisition. This, of course, is the goal of the research program proposed here. However, it must be noted that constraining links to actual neural mechanisms results in fewer degrees of freedom than inferring acquisition and processes mechanisms from behavior. This is because the "behavior to mechanism" approach allows the imaginative invention of mechanisms that fit that data but that are not necessarily neurobiologically plausible. Schumann (1990) examined five cognitive models in an effort to offer a cognitive account of the Pidginization/Acculturation Model. All five models fit. The cognitive models were neither specific enough nor consistent enough to yield a preference. The brain, on the other hand, anchors mechanisms in actual material, and we know this material is this source of the cognition involved in SLA. Middle level psycholinguistic, neurolinguistic, and cognitive accounts are, of course, extremely helpful. One can't just probe around in the neural tissue looking for learning mechanisms. Psychological theories focus research. But to be productive the psychological models must be answerable to their neuroanatomy and neurophysiology. Given these considerations, we probably have to recognize that developing links between neural mechanisms and SLA may be more difficult, but we believe that this is more than compensated for by the knowledge that the brain is the ultimate mechanism subserving the acquisition of knowledge and skill, and therefore, it is where we should be looking.

The point of this book is not to apply findings in psycholinguistics, neurolinguistics and cognitive studies of language to SLA but rather to promote a neurobiology of language that starts with the brain and moves to behavior. We do not believe the mechanisms we propose are the final word on the issue. We envision a research program that gets modified and expanded as more and more is learned about the brain. We expect that debates will be generated by neurobiologically oriented researchers in SLA about what anatomical and physiological mechanisms are the best candidates to subtend language acqui-

sition. It may be difficult or, even for a long period of time, impossible to test the proposals this research generates. Because of the complexity of the brain and the limitations of current noninvasive imaging technology, empirical research on the hypothesized mechanisms may be some time off. But enough is now known about the brain that it is time to attempt to constrain our theorizing about learning and processing mechanisms by knowledge of the brain. The cognitive tools that have been proposed so far (such as nodes, analyzers, buffers, schemas, filters, operating principles, learning strategies, monitors, and processes such as fossilization, defossilization, pidginization, monitoring, noticing) must have neural correlates, and it is time for the field to attempt to specify them.

For several reasons, we have decided not to simplify the neurobiological information we provide. At a certain level of an abstraction (e.g., that supplied in neurobiology discussions in *The Science Times*), what we say is manifestly true. For example, the hippocampus is involved in declarative memory; the basal ganglia subserves procedural memory. But accounts at this level really explain nothing, and they tend to end discussion rather than opening it up. We see the debate to be in the details—circuits within these areas, circuits among them, local and global physiology, and so on. We envision a field in which these issues are debated with research evidence brought to bear from both language acquisition and neuroscience. As students of SLA become more knowledgeable about the neural substrate, such debates will ensue. But will SLA adopt a biological perspective? We would hope so. SLA is about learning; learning is mediated by the brain. Therefore, neurobiology is as central as linguistics to our enterprise. Additionally, information about the brain is expanding exponentially. Each year at the meeting of the Society for Neuroscience, between 8 and 10,000 presentations are made. A good many of these are directly relevant to learning, and many others provide information that is indirectly relevant: neural development (re, critical periods), motor systems (re, the organization of cognition and articulation), vision (re, reading), prefrontal systems (re, planning, descending control), and so forth. For SLA to ignore this information is to deliberately impose a handicap on its endeavors. But because doing SLA research from the neurobiological perspective requires an investment—one must learn some neurobiology—each researcher has to decide whether overcoming the handicap is worth the investment. The investment is basically a course in neuroanatomy and one in the cell biology of learning and memory. These are available in departments of neuroscience or medicine and will become more generally available to applied linguistics programs as the authors of this book

and their followers receive their degrees and become university professors. There was a time when SLA itself was an innovation in the applied linguistics scene. Before the early 1970s, the major expertise expected of professors in Teaching English as a Second Language programs (the precursors of applied linguistics programs) was in linguistics and language teaching methodology. Then departments began hiring faculty because of their expertise in SLA, and courses in this area became wide spread. Because knowledge of the structure and function of the brain is directly relevant to linguistics, teaching, and learning, we would not be surprised if neurobiological training became common in the curricula of applied linguistics, second language acquisition, TESL, and foreign language education programs.

This book constitutes the collaborative efforts of members of the Neurobiology of Language Research Group in the Applied Linguistics and TESL Department at UCLA. Members of this group are trained in neurobiology and then use this knowledge to develop biological accounts of various aspects of applied linguistics. The chapters that comprise this volume were originally written as academic papers—MA theses and PhD qualifying papers. Before the students began these projects, we decided to prepare them as components in what would be a book on the neurobiology of learning. This is that book.

John H. Schumann

Contents

Introduction

John H. Schumann

In a seminal paper in second language acquisition, Long (1990) argued that any theory of second language requires the specification of a mechanism to account for the acquisition and development of second language (L2) knowledge and skills. This book is about just such mechanism(s). Like all research on language acquisition and processing mechanisms, this book contains much speculation. Traditional psycholinguistic, neurolinguistic, and cognitive approaches to second language acquisition (SLA) operate by observing linguistic behavior in experimental, clinical, or naturalistic settings, and based on patterns in those data, mechanisms are inferred. These inferences are speculations. Additionally, they are generally abstract characterizations of learner behavior. But to the extent that they actually specify what goes on in the learner's mind/brain, they remain speculations. However, speculation from behavior to mechanism is so standard, ubiquitous and expected in psycholinguistic, neurolinguistic, and cognitive studies that it is frequently unnoticed. Thus, if research procedures and methods of data analysis raise no objections, then the speculations from behavior to mechanism are seen as reasonable and appropriate. However, in this book, we work in the opposite direction. On the basis of well-researched neural mechanisms for motivation, procedural memory, declarative memory, memory consolidation, and attention, we speculate about what language learning behavior could be subserved by these mechanisms. Figure 1 illustrates the difference.

In this book, we explain learning on the basis of domain-general neural mechanisms. Much language acquisition research, particularly in SLA, has followed traditional linguistics in postulating a domain-specific mechanism, a Language Acquisition Device (LAD) or a Universal Grammar (UG). However, after several decades of research within this paradigm, is not clear that UG exists, and if it does exist, it is not clear that it applies to SLA. Additionally, research on the brain has found it very difficult to identify any areas or circuits

Speculation Direction

Psycholinguistic, Neurolinguistic, Cognitive Studies
Behavior ──────▶ Mechanism

Neurobiology of Learning
Mechanism ──────────▶ Behavior

FIG. 1. Speculation direction.

that might constitute UG. On the other hand, neuroscience has produced considerable research that identifies the mechanisms for motivation and memory. These components have been shown to underlie a wide variety of learning tasks, and therefore, we chose to pursue the very conservative hypothesis that these mechanisms are ones that subtend second language learning.

Our approach is to describe the neurobiology for motivation, procedural knowledge, declarative knowledge, memory consolidation, and attention and then to speculate on how these neural mechanisms implement the acquisition and use of language. Our discussions range from the gross and cellular neuroanatomical to the behavioral levels. In the final chapter, we attempt to formulate a comprehensive neurobiology of SLA.

A word about the chapters. Psychological theory almost universally assumes that across individuals brain structure is homogeneous. Thus, most psychological research on learning proceeds on the notion that all brains are the same. The first chapter challenges this assumption because, from the perspective of neurobiology, brains are as different as faces. At the microlevel of neural structure and even at the gross level of sulci and gyri, each brain is unique. In the chapters on motivation, memory, and attention, we describe the neural systems as though they are uniform interindividually. However, it must be kept in mind that this uniformity is just a heuristic; the structure of each of the systems will vary across individuals. This variation has important implications for second language acquisition because it means that there are many ways to acquire language. In the second language teaching profession there has been a constant search for the "right way" to teach a language. A search for the right way entails the traditional psychological assumption of homogeneity. But because homogeneity does not exist in human brains, there can be no right way.

The second chapter describes how motivation can be reduced to the notion of "stimulus appraisal" and how it can be related to specific neural structures. Additionally, it shows how the concept of motivation is merely a higher order symbolic construction of what is achieved through the brain's reward system. All organisms have reward systems that tell them which stimuli to approach and which stimuli to avoid; this chapter attempts to show how motivation, as construed in second language research, can be understood as simply appraisal of the stimulus situation and the decision to approach or avoid. Additionally, the chapter indicates that motivation is not independent of cognition (as it is frequently treated in SLA research), but instead it is part of cognition, and therefore, there can be no "cognitive" approaches to SLA that do not include motivation.

Chapters 3, 4, and 5 deal with memory: procedural, declarative, and the processes of memory consolidation. A careful reading of these chapters and attention to the neurobiology will give the reader a detailed account of how these memory processes, which have been described in previous accounts of second language acquisition as metaphors, are implemented in the neural substrate. An important contribution that the neural perspective can provide is how these memory systems (declarative and procedural) are related and how information may be transmitted from one to another. This allows us to discuss, from a biological perspective, issues that have plagued the field such as the relationship between learning and acquisition, the phenomenon of fossilization, and the possibility of defossilization.

Chapter 6, on attention, has a dual task. The first is to come to grips with the notion of "attention" itself. At the level of psychology, attention has frequently been dealt with as a rather uniform phenomenon instantiated in a single mechanism, but from the perspective of the brain, attention appears to be distributed across many mechanisms. Joaquin Fuster (personal communication) suggested that the brain does not have an attention mechanism, but rather it has attention components in many mechanisms. The second task of this chapter is to describe the biology of those attention components. Therefore, this chapter is both a critique and a characterization of attention.

We have arranged the chapters in this book according to theme. We begin with an account of how all brains differ. This notion is essential in understanding variable success in second language learning. The second chapter is an account of motivation as the process which initiates and sustains learning. As just mentioned, chapters 3, 4, and 5 all concern memory, and 6 involves attentional processes that, like motivation, are important in modulating memory formation. Additionally, several themes from the SLA literature are treated in multi-

ple chapters. For example, learning versus acquisition is discussed biologically in chapters 3 and 4; fossilization and defossilization are discussed in chapters 3 and 6, L2 rule learning is treated in chapters 3 and 4; L2 lexical acquisition is treated in chapters 4 and 5; and appraisal/motivation is discussed in chapters 1, 2, and 6.

TAXONOMY OF MEMORY

A major aspect of the neurobiology of learning involves memory, and three chapters of this book are devoted to memory processes. Therefore, it may be useful to provide taxonomy of memory here in the introduction in order to guide the neurobiology for discussions that are presented in chapters 3, 4, and 5. Figure 2 provides the standard hierarchical taxonomy of memory. Memory has been defined in both functional and temporal terms. With respect to the latter, memory has been broadly classified into working (short-term) and long-term memory (Fabbro, 1999; Fuster, 1995).

Working memory has traditionally been defined as memory that is held for short period of time (less than 20 seconds) in order to achieve success at a task. However, Fuster (personal communication) asserted that working memory has functions beyond its temporal duration. According to Fuster (1995), working memory can be defined by two criteria: a future perspective with emphasis on the execution of a future task, and its subservience to action such that it is memory for the sole pur-
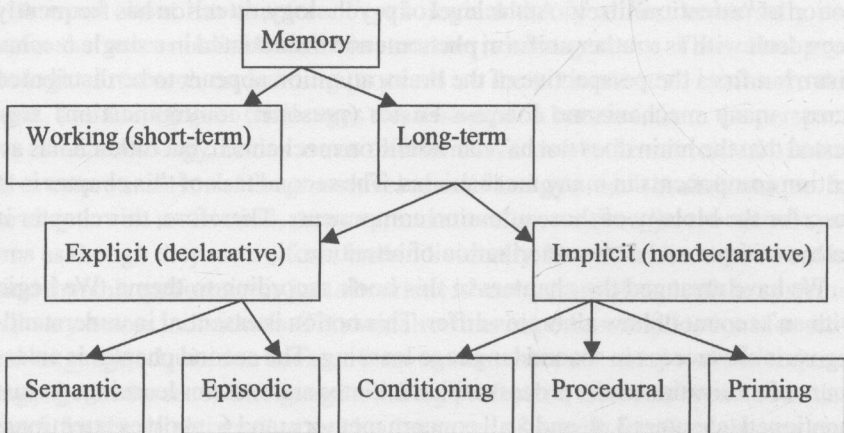
FIG. 2. Hierarchical classification of memory (based on Fabbro, 1999. Adapted with permission).

pose of accomplishing a task. Because the distinction between working memory and short-term memory is difficult to make, they are shown as one item in Figure 2. *Long-term memories* are those lasting for extended periods of time, from days, to weeks or for as long as months or years (Squire & Kandel, 2000).

Functionally, there are two major types of memory: declarative (or explicit) and nondeclarative (or implicit; see Fuster, 1995 for a review). These classifications sometimes assume different names such as memory with knowledge (i.e., declarative) and memory without knowledge (i.e., nondeclarative; Eichenbaum & Bodkin, 1999). Broadly defined, declarative memories are memories for facts and events, and nondeclarative memories are memories for habits, motor and perceptual skills, and emotional learning (Fuster, 1995; Squire & Kandel, 2000).

Declarative memory can be subclassified into semantic memory or memory for facts or encyclopedic knowledge of the world. These memories are not tied to any particular experience (Fabbro, 1999; Fuster, 1995; Squire & Kandel, 2000). The second category of declarative memory consists of episodic memories or recollections of past events or experiences, including the relevant temporal and spatial details of those events (Fuster, 1995). It is generally assumed that declarative memories can be recalled consciously (Aglioti, 1999; Fabbro, 1999; Milner, 1999; Tulving, 1972). All declarative memory is subtended by the hippocampal system and the neocortex.

Nondeclarative memory is subclassified into conditioning, procedural memory, and priming (Fabbro, 1999); or into skill and habit learning, emotional conditioning, and classical conditioning (Aglioti, 1999). Nondeclarative memories are subserved by both the hippocampal and the basal ganglia systems. Among these, procedural memory is largely supported by the basal ganglia (Graybiel, 1998; Hikosaka, Rand, Miyachi, & Miyashita, 1995; Joel & Weiner, 1998).

Declarative memory and nondeclarative memory have distinct characteristics. The classification depends on whether conscious introspection about the contents of the particular memory trace is present (Fabbro, 1999). Nondeclarative memory content cannot be accessed through conscious effort. Declarative memory, on the other hand, can be consciously recalled, represented, or verbalized (Aglioti, 1999; Fabbro, 1999). Nondeclarative memory, unlike declarative memory, is relatively inflexible and only available in contexts that are identical or very similar to the original learning situation (Aglioti, 1999). However, this also means that nondeclarative memory is more robust. It is spared and preserved in the elderly, whereas declarative memory deteriorates dramatically with aging (Aglioti, 1999). Finally, nondeclarative memory precedes declarative memory both phylogenetically and ontogenetically (Aglioti, 1999; Paradis, 1994).

Now let's take a brief look at the areas of the brain that are relevant to our discussion. Figure 3 is an attempt to capture all these areas in a single view. A brain cut down the middle is shown so that we can see the inside of the brain and part of the overlying right cerebral cortex. The areas that are particularly relevant to chapter 2, on motivation, are the amygdala, the nucleus accumbens, and the orbitofrontal cortex (OFC). Additionally, the neurotransmitter dopamine plays an important role in motivation. The cell bodies of origin for dopamine are in the midbrain and are indicated on the figure as the ventral tegmental area and the substantia nigra pars compacta. Procedural memory, as discussed in chapter 3, focuses on the caudate, the putamen, and the globus pallidus. Declarative memory, chapter 4, involves the hippocampus, and memory consolidation, chapter 5, is achieved through interaction between various areas in the neocortex and the hippocampus. As is seen in chapter 6, attention is distributed throughout the brain, but three regions can be identified as among those that are important to the substrate for this process: the dorsolateral prefrontal cortex, the parietal cortex, and the anterior cingulate. All these areas are rarely discussed in relation to language. Most people, if they are familiar with some aspect of language and the brain, have heard about Broca's area and Wernicke's area. These two regions certainly have something to do with language processing because Broca's area is part of the motor system and Wernicke's area is part of the auditory system. But when the task is to describe language learning, the central areas become those that subserve motivation, memory and attention; and therefore, it is these areas and their interconnections that are the central focus of this book.
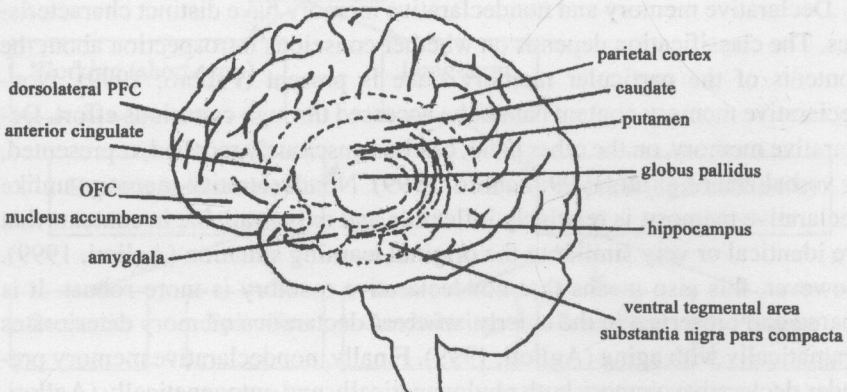

FIG. 3. Areas of the brain involved in learning (see text for explanation).

1 The Neurobiology of Aptitude

John H. Schumann

SOURCES OF VARIATION ACROSS BRAINS

The major thesis of this chapter is that all brains are different—as different as faces (Edelman, 1987, 1989, 1992) and that these differences have consequences for learning. The sources of variation among humans' brains are both genetic and epigenetic. I first examine the way genetic inheritance generates differences.

Each child receives roughly half the genes from its mother and half from its father. But the composition of the set of the parents' genes is different for each child, with the result that siblings are about 50% similar (Dunn & Plomin, 1990). Thus, we share about half our genes with our brothers and sisters. Of course, identical (monozygotic) twins are genetically the same, but fraternal twins (dyzygotic) share no more genetic material than ordinary siblings.

In terms of IQ, this genetic variation produces the following results. Identical twins' IQs correlate at about .86, fraternal twins have a correlation of about .60 and regular siblings have an IQ correlate of about .48. Environmental influences are estimated at .32 for regular siblings and .11 for monozygotic twins. Therefore, genetic influence on IQ for non-twins seems to be about .50 and environmental influence about .30 (Hamer & Copeland, 1998, Segal, 1999).

Edelman (1987, 1989, 1992) explained that genes do not specify the targets of all neurons (brain cells). Instead, they control the expression of adhesion molecules that cause cells to bind together and move along certain trajectories. These processes are largely stochastic and depend on the local mechanicochemical milieu in the embryo. A cell's ultimate location and connectivity is thus the result of the activity of the adhesion molecules and the chemical influences on the cell's history. This activity, called developmental selection, leads to brains that are similar in overall construction but which vary considerably at the level of