PART I

Foundational concepts and issues

1 Introduction and overview

Introduction

This book is about language processing in the human brain and, more specifically, what happens to spoken language when certain areas of the brain are damaged. Language processing is what takes place whenever we understand or produce speech; a mundane task, but one of extraordinary complexity, whose mysteries have baffled some of the greatest minds across the centuries.

Neurolinguistics is the technical term for this field, introduced into academic usage by Harry Whitaker (1971), who founded the leading journal that bears this title. As Whitaker noted at the time, it is a key assumption of neurolinguistics that 'a proper and adequate understanding of language depends upon correlating information from a variety of fields concerned with the structure and function of both language and brain, minimally neurology and linguistics'. Today, some thirty years later, it seems necessary to add 'cognition' or cognitive science to the list of minimally necessary disciplines. A well-articulated cognitive science is needed to provide the hoped for integration of two otherwise very different fields of study: language and neurobiology.

Considerable progress and a vast body of research have accumulated since then. Yet leading advocates of the cognitive science perspective on language as a biologically grounded human ability (such as Chomsky, Pinker and Deacon, to mention just three) disagree on some fundamental questions. To what extent are our language learning capabilities 'hard-wired' into the human brain and unique to the species? How is 'innate linguistic competence' actually deployed in language learning? Is it closely bound to specific stages of neurological maturation or can it be re-invoked in maturity for second language acquisition or recovery of language competence after neurological damage? To what extent are the component skills activated in language processing separable from one another in function or in actual locus of operation in the brain? To what extent are language abilities separable from thinking or other mental activities?

Assuming at least some 'modularity' of language and its supporting cognitive, perceptual and motor competencies, a number of highly practical questions arise. Can recovery of language following brain injury be facilitated by therapy intervention strategies targeted at specific retained abilities in order to work around lost competencies, or can those lost competencies themselves be recovered?

Despite the controversies and profound uncertainties concerning the best way forward, there are good reasons for believing that a special relationship exists between human language on the one hand, and what makes human brains different from those of other mammals or our close primate relatives on the other. In this chapter we offer some arguments intended to establish a direct link between the brain and language, through an appeal to the concept of co-evolution of brain and language (Deacon, 1997a): the idea that language abilities arose as both a consequence and a cause of recent and rapid evolutionary brain changes, resulting in the emergence of homo sapiens. In chapters 2 and 3 we invite you to evaluate the language–brain relationship for yourself, as we describe the language faculty in broad outline from the separate perspectives of the linguist (chapter 2) and the aphasiologist (chapter 3). Linguists are trained to analyse patterns of language production and usage, with the aim of unravelling the complex code which enables speakers and listeners to map between sound and meaning. Aphasiologists observe the great variety of communication disorders that can arise as a consequence of damage to the language areas of the brain by strokes, tumours or traumatic injury. By and large, the classical studies of aphasia were conducted by neurologists and neuropsychologists who had no specialized linguistic training. Similarly, linguists formulated their theories of human language independently of any serious considerations of language loss in aphasia. Thus, Whitaker's (1971) assertion that progress in the study of language depends on some successful synergy between linguistics and neurology has always been controversial, and so the introductory chapters of this book should be regarded as a first approximation at defining a 'problem space' – the language–brain interface. In subsequent chapters, we explore in detail the various stages of language processing, from the decoding of phonological targets in the perception of speech, to word recognition, morphological analysis, syntactic parsing, semantic interpretation and understanding discourse. We consider the production of language and production disorders in aphasia only insofar as they throw light upon the nature of the brain's language processing mechanisms. At the 'higher' levels of language processing, a clear distinction between the mechanisms underlying language comprehension and language production is difficult to maintain, despite the fact that the task demands imposed upon listeners and speakers are very different. Speakers and listeners clearly must share a common linguistic knowledge base – a grammar in the broadest sense of the term – but just how that tacit knowledge is deployed in comprehending and speaking is a moot point.

Our concern is primarily with language comprehension and its disorders. However, the neural mechanisms that the brain has evolved for language processing are based, at least in part, upon novel synergies that have evolved between the motor control and the auditory perceptual systems. These synergies are needed for imitation learning of rapid gestural sequences for speech production and perception. Consider, for example, the utility of a vocal communication system that required 20-plus seconds to say: '*Look out, you are about to step on a snake!*'

We shall consider the evidence for the neural synergy between speech production and perception in subsequent chapters.

Language is used not only to convey our thoughts and feelings to others, but also to represent them to ourselves. But thinking is not equivalent to talking to oneself, and the linguistic expressions with which we clothe our thoughts are merely signposts to meaning, not explicit representations of those meanings. Linguistic expressions are under-determined with respect to the message the speaker intends to convey.

Trying to understand how the brain processes language may always lie just beyond the realm of scientific feasibility. But for the sake of thousands of people every year who suffer the traumatic effects of language loss through aphasia we are obliged to make our best effort. Cognitive neurolinguistics has its origins about as far back as one chooses to trace them, from Aristotelean speculations in the third century BC on the nature of words and ideas, or from Broca's (1861) famous observation that 'the seat of articulate language lies in the left posterior frontal convolution', or from Chomsky's programmatic reformulation of the goals of linguistics as a branch of cognitive science in the 1960s. But the most significant developments in the field have occurred in only the past three decades. Psycholinguists and neuroscientists have devised behavioural and neuroimaging techniques to fractionate the different stages of language processing: from the instant the auditory system reacts to the acoustic signal of speech, to the few hundred milliseconds that it takes to complete linguistic decoding of the speaker's message. Most recently, powerful neuroimaging techniques have potentially greatly enhanced our powers of observing 'real-time' language processing. The extent to which this potential will be realized in the near future largely depends upon how well the new imaging techniques can be harnessed to the 'on-line'[1] methods and theories of language processing developed by psycholinguistics over the preceding three decades. There is cause for cautious optimism that we may be on the threshold of new insights into language and the human brain–language relationship, which enables us to communicate with one another a range of ideas, worries, conjectures, desires or demands, unknown to other species, regardless of whether we believe them capable of entertaining such things.

Co-evolution of language and the brain

It is uncontroversial, in scientific circles at least, that the human brain has undergone very rapid growth in recent evolution. The brain has doubled in size in less than one million years. The cause of this 'runaway' growth (Wills, 1993)

[1] 'On-line' refers to observational methods that are intended to capture sentence processing as it takes place in 'real time', as distinct from 'off-line' observational methods, which are not time-sensitive, that tap into comprehension or production processes after the fact, or after they have taken place. Grammaticality judgements or judgements of semantic well-formedness are examples of 'off-line' tasks.

is a matter of conjecture and endless debate. A strong case can be made that the expansion of the brain was a consequence of the development of spoken language and the survival advantage that possessing a language confers. The areas of the brain that underwent greatest development appear to be specifically associated with language: the frontal lobes and the junction of the parietal, occipital and temporal lobes (the POT junction – more of this later).

It is easy, perhaps all too easy, to reconstruct plausible scenarios illustrating the survival advantages that possession of a hands-free auditory/vocal means of communication with the symbolic power to represent almost any imaginable situation would confer on a social group. Perhaps it was the superior linguistic abilities of homo sapiens, with brains and vocal tracts better adapted for speech and language, that led to the rapid displacement and extinction of the Neanderthals in Europe, some 40,000 years ago (Mellars, 1996). Language is of such importance in our daily lives and culture that it is almost impossible to imagine how our species could survive without it.

But perhaps the most surprising thing about the evolution of language and the brain structures required to support it is – as indicated earlier – how rapidly they were acquired by our species. It is well known that quite dramatic phenotypical changes can take place under adaptation pressures in relatively short periods of evolutionary time. However, there appears to be no parallel in other species to the rapid increase in cranial capacity accompanied by the signs of an evolving material culture that one finds in the human archaeological record. What drove this massive yet selective increase in brain tissue, confined mainly to the cerebral cortex and to some regions more than others? According to the co-evolution hypothesis, it was the voracious computational requirements of a symbolic representational system, i.e. of a language. It is not difficult to appreciate this point. Just look up from the book and cast an eye around the myriad of recognizably distinct objects in your immediate field of view. A large proportion of them have names. All the others can effectively be provided with names by verbal constructions such as: 'low radiation energy sticker' for the object fixed to the screen monitor casing of my PC. Language, as every language user knows, involves a kind of doubling of our perceptual universe. For every object of experience, there is at least a name or a naming construction to represent that object. Once the germ of a representational system has implanted itself in the mind/brain, there is no quarantining its spread to the whole realm of imaginable experience. This is evident from the period of explosive vocabulary growth that occurs in normal human infants around two to three years of age, for which there is no parallel in even the most loquacious of the signing chimps that have been studied (Savage-Rumbaugh and Levin, 1994). The voracious growth of a representational system is also movingly illustrated in the diary of Helen Keller, the remarkable woman, rendered blind and deaf in infancy, who suddenly discovered the representational function of tactile signs at an age when she was old enough to consciously appreciate their communicative significance. Everything suddenly required a name.

While the origins of language remain obscure, the co-evolution hypothesis claims that once the seeds of a symbolic representational system were sown, the

brain responded with a vigorous and unprecedented increase in its processing and storage capacity. According to the co-evolution hypothesis, the brain as a system which supports representational computation cannot remain 'a little bit pregnant' with language. 'Representational computation' is perhaps an awkward way of saying 'thinking with language'. Representational computation conveys the idea that thinking supported by linguistic expressions involves a second-order level of manipulation, not just of objects, events or states of affairs, as perceived or imagined in 'the mind's eye', but also the manipulation of *symbolic representations* of those objects, events or states of affairs. Thus, perception and episodic memory provide a first-order 'internal' representation of the 'external' world. But language users have access to a second-order and publicly shareable level of symbolic representation, whereby objects of perception are coded as linguistic expressions.

In addition to linking the evolution of language to symbolic reasoning – an idea which has a respectable philosophical pedigree in European philosophy (von Humboldt, 1999 (1836); Cassirer, 1953, 1962; Werner and Caplan, 1963) though not widespread acceptance in contemporary cognitive science – the co-evolution hypothesis asserts that a quantal increase in the brain's processing capacity was required to accommodate this second-order representational system. Also, that although the evolutionary adaptation of the brain took place in incremental steps, the pace of change was such as to produce a qualitative new step in speciation. Furthermore, the co-evolution hypothesis asserts, controversially, that thinking-with-language is a unique facility of human brains. Deacon's (1997a) book-length exposition of the co-evolution hypothesis is a bold and controversial idea. It has met with a very mixed reception from linguists, depending on their theoretical orientation (Hudson, 2001; Hurford, 1998; Poeppel, 1997). As a scientific hypothesis, it is rather too difficult to prove or to refute. We offer it here primarily to set you thinking along the paths we wish to explore in this book. Norman Geschwind in the 1960s (see chapter 3) was the first to offer a clear account of how recently evolved cortical structures that distinguish humans from primates enabled the formation of extensive networks of cross-modal associations, which in his view provided the neural-computational basis for vocabulary formation, and hence the evolution of a natural system of symbolic representation.

An alternative view of co-evolution

Another reason for believing that the joint study of brain–language relationships will be productive derives from the study of language itself and how it is acquired. Language, as we shall presently discover (if you have not done so already), is the most complex of human artefacts,[2] re-invented by each successive generation of language learners, who are quite unaware of the enormity

[2] artefact: tool or human construction. Language is a cognitive rather than a physical artefact; a vessel for containing or carrying meanings.

of their accomplishment. Linguists like Noam Chomsky have long argued that young children can only accomplish the remarkable feat of learning their native language by virtue of inheriting some specialized neural machinery specifically designed for that task. The reference here is to Chomsky's *principles and parameters* (P&P) model of grammar (Haegeman, 1991; Radford, 1997). The principles are structural properties to which all languages supposedly conform, constituting a *universal grammar* (UG). The parameters define the ways languages can vary from one another. The idea is that if a large part of the structural complexity of human language is pre-programmed into structural principles, then language learners have only to discover the parameter settings appropriate for their language community. Thus, the 'principles' set limits on how human languages may vary, confining natural languages to a restrictive set of possible types, thereby narrowing the 'search space' of the language learner. Furthermore, if a special 'parameter setting' mechanism for language learning can be invoked, then it is easier to see how first language acquisition could be under the control of 'instinctive' maturational mechanisms, by analogy to such behaviours as nest building in birds or 'learning to walk' in mammals. In this way, a language faculty can be conceived as a special-purpose module of the mind/brain, dedicated to the demands of spoken language communication and acquired through special learning mechanisms linked to the maturation of perceptual, motor and cognitive systems of the infant brain.

Clearly a great deal of investigative groundwork is needed to isolate the principles and parameters that underlie natural languages and to then show how such principles and parameters may be incorporated into a model of first language acquisition.[3] But this is precisely what linguists and psycholinguists in the Chomskian paradigm seek to do. We cannot evaluate the P&P theory until we have elaborated at least a first approximation model of language structure, which we will begin to do in chapter 3, and elaborate with respect to a specific theory of agrammatism in chapter 14. The P&P theory of language is in fundamental respects antithetical to the idea, advanced in the previous section, that language is an undifferentiated 'symbolic system'. Nevertheless, P&P theory also provides an alternative formulation of the co-evolution hypothesis that the emergence of natural language drove the most recent 'runaway' stage of evolution of the human brain, albeit a formulation with a very different conceptual foundation as a modular 'faculty of language'.

We briefly sketch here in somewhat stark terms some differences in perspective between language as a symbolic system (as expounded by Deacon, 1997a) and the P&P theory of language, which represents, if any one position can, the textbook orthodoxy of linguistic theory. We will elaborate the major theoretical issues currently in dispute in chapter 4, in the attempt to build a biologically grounded theory of language processing. Deacon's model of language has been

[3] Second language learning appears to be different in fundamental respects from first language acquisition. Parameter setting may only be available as a window of opportunity during the critical period of first language learning; or once set, parameters may not be re-set.

described as linguistically naive. This may be true, but in adopting positions opposed to the prevailing orthodoxy in linguistic theory, he finds allies in alternative models of language and language learning which have psycholinguistic credibility.

By enumerating the differences between the two perspectives we will generate some clear expectations as to where to look for significant theoretical alternatives, for contending hypotheses about how the brain might organize itself for language. Firstly, there is the issue of **modularity** which expresses itself at the level of both broad and fine-grained mental architecture. At the level of broad mental architecture, Deacon's view of language as a symbolic system draws no clear distinction between cognition and language processing. By contrast, while the P&P model is not very explicit on how the distinction should be drawn, it is recognized that there is a necessity to do so, if language is to be consistently viewed as a modular component in an integrated cognitive system. The existence of mental disorders specific to language processing (aphasia and aphasic disorders) would seem to argue in favour of modularity in the broad. But as we shall see, the history of aphasia is a battlefield littered with fallen standards of both houses in this unresolved dispute.

At the fine-grained level, within language itself, Deacon's 'symbolic system' of language also draws no hard and fast distinctions between components of linguistic competence, such as the computational aspects (syntax) and the encyclopaedic (lexical) aspects of the speaker's internal grammar. But in the P&P model, as indicated previously, the principles that govern structure building operations in the syntactic component of the grammar are quite distinct from the constraints that apply in the lexicon in word formation. We might expect, therefore, that language disorders in aphasia might fractionate along fault lines between modular components of the language faculty as described by P&P theory. Again, the modular view appears to be supported on superficial inspection of the syndrome of 'agrammatism' in Broca's aphasia compared with the pattern of lexico-semantic impairment observed in Wernicke's aphasia. But on closer inspection the association between the linguistic competence model and patterns of aphasic performance turn out to be deeply problematical, as we shall see. The P&P theory has been productive of a great deal of research into aphasia in recent years, but so too have non-modular language processing theories based on neural network models explicitly framed in opposition to the perceived prevailing linguistic orthodoxy.

Related but distinct from the question of modularity are issues of *learnability* and how language abilities are embedded in the biological makeup of brain's capacity for language. Deacon's theory postulates a somewhat elusive propensity for 'symbolic processing' underlying our unique linguistic capabilities. He is at pains to demonstrate that some apes, like the celebrated Kanzi (Savage-Rumbaugh and Levin, 1994), have this capacity also, to a limited extent. But this is quite a different standard of proof from showing that human infants (or the infants of some other species) have the capacity to spontaneously acquire languages whose syntax conforms to specific properties specified by a theory of UG, and, equally

critically, an *inability* to learn the grammars of artificial languages whose syntactic rules violate principles of UG (Smith, Tsimpli and Ouhalla, 1993).

Or to consider an example much closer to the themes of this book: a theory of UG might be expected to predict that at least some acquired language disorders in aphasia should reflect specific patterns of language impairment that are more or less isomorphic with the specific components of a grammar competence model. Grodzinsky's (2000) trace deletion (or chain disruption) hypothesis of agrammatism is such a case in point, which we will consider in detail in chapter 14.

Chomsky and the generative grammarians may be correct. On the other hand, we should also consider the possibility that human languages are just too complex, too diverse, or too contrary, to be reducible to a core set of principles and parameters. However, if the co-evolution hypothesis (in either of its competing versions) is correct, then we might hope to find independent confirmation of its validity by studying what Eric Lenneberg (1967), another pioneer in the field, called the *biological foundations of language*. This involves examining neurological structures that underpin language comprehension and production, correlating language acquisition with brain maturation in infancy, investigating loss of language caused by damage to various brain regions, and correlating the evolution of different brain structures across the species with the evolution of language. Some progress has been made in these endeavours. In this book we will focus primarily on two sources of evidence: (a) what can be learned about language and the brain from psycholinguistic and neurolinguistic studies of language processing in 'normal' language users (such as, dear reader, you and I), and (b) from clinical and experimental studies of those who have suffered neurological disorders or diseases which have impaired some or all aspects of their spoken language.

Language areas in the brain

Language is predominantly lateralized to the left hemisphere in the vast majority of people, even the majority of left-handers. While the functional asymmetries of the left and right hemispheres are well known and have been much debated in the popular and technical literature (Hellige, 1993; Chiarello, 1998), anatomically, the structures of the brain appear to be quite symmetrical. But the one known region where a structural asymmetry has been found occurs in the *planum temporale*, which is part of *Wernicke's* area, the second language area, known after its discoverer Karl Wernicke in 1874. The planum temporale of the left temporal lobe was found to be larger than its right hemisphere counterpart in 84 per cent of cases (Galaburda, Lemay, Kemper and Geschwind, 1978). The reason why this rather unique asymmetry was not observed by previous generations of anatomists, though it is quite visible to the naked eye, is that the planum temporale is located within the fold of the sylvian fissure, out of sight from surface inspection of the temporal lobe.

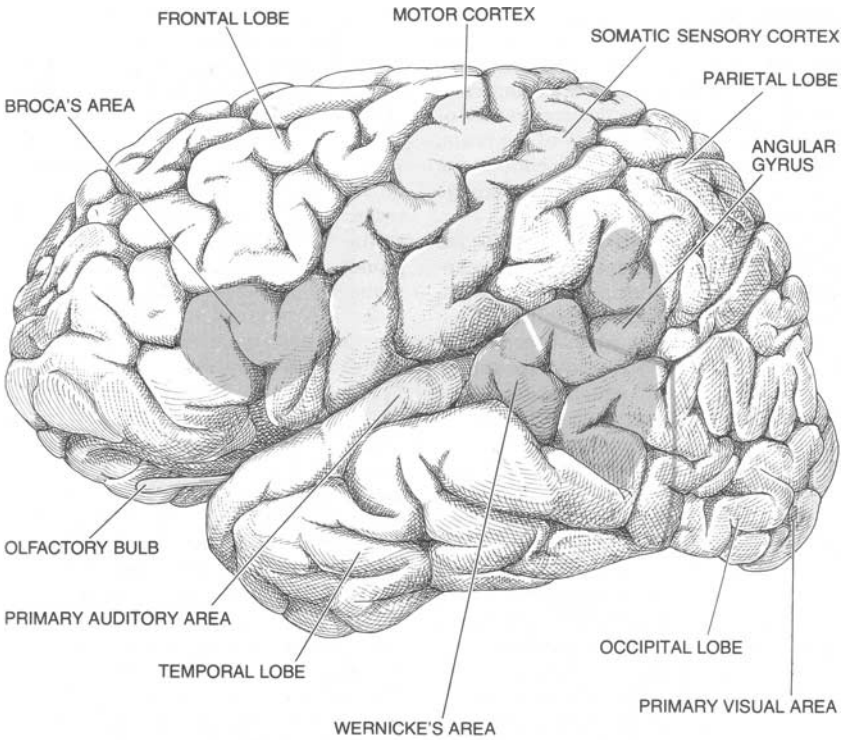

Figure 1.1 *The cerebral cortex: the language areas and major anatomical landmarks*

The functional significance of this long-overlooked cerebral asymmetry is no doubt related to the fact that the planum temporale overlaps with Wernicke's area.

Aphasia as evidence of the brain's representation of language

The study of aphasia, or the loss of language functions caused by damage to the 'language areas' of the brain, has been our major historical source of evidence for the study of brain–language relationships. We can trace the clinical study of brain–language relationships to Paul Broca's (1861) famous discovery of the language area that bears his name, located in the posterior region of the left frontal lobe of the cerebral cortex. The precise role of Broca's area in normal language functioning remains controversial to this day (see chapter 9).

Disease or injury to the recently evolved regions of the cerebral cortex may be revealing of how language is organized in the brain. We can have various types of injury. Focal damage to a limited region may occur as a consequence of a 'stroke', when a blood vessel bursts or an artery is blocked and there is oxygen deprivation to some local region of the brain. Alternatively, damage may be more