One Lesson Learned: Frame Language Processing—Literal and Figurative— as a Human Brain Function

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What research is conducted on language processing and how that research is conducted are largely determined by researchers' assumptions about the functional organization of mental processes. These have changed significantly since the 1970s when the brain's role in language processing—although acknowledged—was practically inconsequential to psycholinguistic research or theory; this change is due in large part to considerable growth in knowledge of brain structure and function. I argue that when language is properly appreciated as one brain function among many, psycholinguistics will benefit from heeding certain factors that have received proportionately little attention within mainstream psycholinguistic research: (a) the hemispheres; (b) time and timing; (c) context liberally construed to include, for example, personality traits and mood; and (d) individual differences as a proxy for experience. I conclude with why it has not been so easy to answer such fundamental questions as where in the brain language is localized, and how activation of these language areas leads to understanding. The main message is that researchers of nonliteral language processing can benefit from the significant progress in the neurosciences in the past few decades more by thinking of language as brain function and as an experience than by viewing it merely as the (localizable) seat of nonliteral language. I recommend actively and seriously incorporating brain principles into thinking about all language processes and how best to investigate them.

Each time I write an empirical paper, I try to choose words that are theory neutral except when I am actually arguing in favor of a particular theory; however, as may not come as a surprise to those who have read this special issue, I never succeed. It

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is impossible to choose words that carry no baggage (methodological, theoretical, or otherwise). Likewise, what a scientist thinks to be true is inextricably bound in their research practice: it influences the questions asked, the methods used, the findings observed, the analyses chosen, the interpretations preferred, and the questions considered open, as well as how all of these are expressed in print. This is an inevitable consequence of the way human brains support perception, categorization, cognition, communication, memory, and action. Language processing is a human brain function (or, perhaps more accurately, a coordinated set of brain functions) and all that this inevitably entails. With the tail end of the Decade of the Brain barely visible, this statement is not particularly profound. However, it is important to realize that this is more than a research-justifying slogan to appease granting agencies or peer reviewers. The neurobiology of language has important consequences for all language researchers. This is the main lesson learned that I wish to pass on to researchers of nonliteral language processing. This, however, is not a rallying cry for psycholinguists to drop their methods or measures and become brain researchers. Nor am I advocating wholesale adoption of indirect (such as functional magnetic resonance imaging) or direct (such as magnetoecephalographic or event related brain potential [ERP]) indexes of brain activity as the only avenue to language processing enlightenment. Although I believe that every attempt should be made to match method to question, I also believe that all the available methods have something to offer and should—indeed must—be employed. True understanding requires an appreciation and integration of all types of data. Indeed, it is often the apparent dissociations in data patterns across different techniques that force researchers to reconsider assumptions that they may not even be aware shape their research efforts. What I ask instead is that their minds be bleached of outdated assumptions (as detailed next) that gained ascendancy when so much less was known about (human) brain structures and functioning than is known now.

Following a brief history of psycholinguistic views in the 1970s, I present a very brief précis of the main principles of brain organization that I believe can provide a new set of assumptions (and associated theoretical perspective) for contemporary psycholinguistic researchers and theorists. In particular, I argue that when language processing is properly understood as one brain function among many, language research and theory will naturally place greater weight on the fact that the brain has two halves (*hemisphere matters*), that language processing in the brain unfolds with time as an intrinsic variable (*timing matters*), that brain functioning is highly context dependent (*context matters*), and that both brain structure and function are experience dependent (*experience matters*). Each of these facets of brain processing and some of their implications on language research is elaborated in turn in the following four sections. I conclude with a discussion of why, despite significant advances in the neurobiology of language, it has proven difficult to an-

swer fundamental questions about where language is located in the brain, and the sorts of questions that researchers might wish to ask instead.

When I first started my investigations into language in the late 1970s, the mind was viewed as a very large symbol processing program and the brain as a computer. It thus seemed reasonable to view mental operations as information processing subroutines (symbol crunchers) that just happened to run their course in biological rather than silicon matter. Even a direct measure of electrical brain activity, such as the ERP, was viewed as a time series of reaction times following stimulus presentation, albeit recorded from electrodes attached to the scalp's surface, rather than the fingertips. Inferences about the flow of information processing stages through the series of subroutines involved in decoding, encoding, transforming, comparing, maintaining, and generating new information were to follow from modulations in the amplitudes and latencies of the brain's electrical potential at various time points after stimulus onset as a function of task demands based on the experimental manipulations. Naturally, everyone "knew" that different parts of the brain were responsible for the various computations, but it mattered little because what was sought was a psychologically satisfying description of language processing (computations on symbols with meaningful outcomes) that was independent of the physical medium in which the processing transpired. Indeed, if only it were possible to figure out what routines were run on which symbols and in what order, situating them in the brain seemed only one perhaps tedious, but simple, step away.

By far, the most influential account of the internal structure of the mind during these years came from Fodor's (1983) *Modularity of Mind: An Essay on Faculty Psychology.* Cognition was the product of a large number of autonomously functioning, highly specialized faculties or modules feeding into a general-purpose central processor. Each module received specific inputs from the sensory periphery and transformed these into "neuromental" representations that the central processor could then (re)combine as needed for the information processing problem at hand. Each module was dedicated to processing only one type of input and was completely blind to all other sources of information. The central processing unit (CPU) was responsible for integrating the outputs of the various modules to compute meaning. Moreover, the CPU was at the mercy of these dedicated processing modules in terms of what information it received and when; critically, it had no access to intermediate representations internal to modules, only to their final outputs. Processing modules were, thus, black boxes even to each other, with no avenues for cross talk. Context effects were relegated to late processing stages (and by inference to higher cortical areas when brain substrates were mentioned), time-limited by the completion of processing within the individual modules that fed into the CPU. By assumption, each module was associated with a fixed neural architecture, rendering ultimate localization of psychologically defined functions much easier.

Language was one of the macromodules—a mental faculty—acting independently of other cognitive systems like attention and memory. Levels of organization within the language system (e.g., orthography, phonology, morphology, syntax) likewise were effectively autonomously functioning submodules, informationally encapsulated from one another. Accordingly, there were no direct interactions between levels of organization within language either, and contextual meaning effects were expected to occur relatively late in the sequential analysis of serialized language inputs. The initial identification of a word by the lexical access module or the initial parse of a word string by the syntactic module, for example, were considered to be impervious to semantic or pragmatic concerns. Meaningful interpretation of linguistic inputs was a higher order, relatively late process that took place under the purview of the brain's central processor.

The language module, moreover, was considered unique and special: its representations and operations were somehow fundamentally different from those of other cognitive domains. And even though the identities of the responsible brain regions were orthogonal to the conduct of research on the properties of the language module, there presumably was a circumscribed and limited set of brain areas (within the left hemisphere) dedicated solely to language functions. A key component of this dedicated processor was a language acquisition device (LAD), which was ready by virtue of its unique organization shaped by evolution to embody linguistic universals that could be tweaked by the inputs of the particular language to which it was first exposed to process and produce any and all natural languages from birth. Language was the left hemisphere's responsibility. The right hemisphere's role in language was either minimized or, in later years, limited to the special processes invoked by figurative language. Psycholinguistic models of language processing—whether descriptive or computational—largely ignored the fact that the brain has two interconnected hemispheres, because it did not matter to the computations needed for making sense of or producing language. Or, perhaps, alternatively, because these were implicitly models of the "talking" (left) hemisphere, damage to which yielded a host of devastating aphasic syndromes. The brain substrates of at least certain LAD submodules were acknowledged, in the belief that their operating parameters were set early. Unlike most (although not all) other cognitive modules, these submodules (e.g. syntactic, phonological) were subject to a critical (age) period, during which certain inputs had to occur to eventuate in normal development and proper functioning. If received after the critical period, these same inputs could no longer set the appropriate parameters for the language submodules in question, leaving the language user with spotty syntactic skills or inaccurate pronunciation (stress, prosody), respectively. Localizing these submodules in the brains of patients with damage due to tumors or strokes, surgical separation of the two hemispheres, or with electrical stimulation via electrodes implanted for monitoring epileptiform seizure activity became the work of clinical and experimental neuropsychologists. In parallel, psycholinguists were charged

with characterizing the language submodules (how many there were, their sensitivities, their inputs, their intermediate representations, their outputs, their computations, and their relative order of action). Language learning was the sole province of developmental psycholinguist or researchers of bilingualism.

Psycholinguistic thinking over this same period was also very much colored by Chomsky's (1965) distinction between a language user's knowledge of his or her native language (competence) and its implementation in real time (performance). Competence was deemed the proper subject of linguistics, as it was relatively stable over time and not subject to the irrelevant vagaries of online language processing; anatomizing performance was the staple of psycholinguistics. Even among psycholinguists, however, systematic effects of nonlinguistic processes that may have redounded to variance in performance across sessions or individuals were largely ignored. Individual differences in perceptual–cognitive (attention, working memory), emotional–motivational, personality and other nonlanguage variables were considered tangential to the real task of determining just which processes, acting on which representations within the language sub- and macromodules, were responsible for language comprehension and production. Representations and the operations on them (processes) were regarded as conceptually distinct constructs fulfilling different roles in mechanistic accounts of language processing. Time was considered a tangential or dependent variable rather than an intrinsic variable. Even though reaction times were the main dependent measures for delineating mental chronometry, the concept of time in most psycholinguistic models was relatively static: even if some process were to run its course more or less quickly in one situation compared to another, it was, nonetheless, typically regarded as the same process unfolding with a different time course, and not as a qualitatively different process. Moreover, the working consensus was that language input could be analyzed into fundamental building blocks and then resynthesized into increasingly larger constituents according to universal combinatorial rules, with comprehension being the final product (and similarly for production)—from phonemes to syllables–morphemes, words, phrases, clauses, sentences and ultimately discourse. This belief in submodules (and within them constituent functional pieces) not only made it possible, but customary, to study submodules in isolation, leaving the investigation of final integration processes for a later time, when all the constituent submodules needed for meaningful integration were fully understood. This analytic–synthetic view of a symbol processing system with a limited number of autonomous input modules or submodules with highly specialized functions feeding into a more general processor spawned a particular class of approaches to language processing that were, for the most part, oblivious to brain structure and function.

Although it may still be possible in 2006 to theorize about language processes as a series of operations on symbols that could just as easily take place in a digital computer as in the human brain, it is not advisable to do so. The issue is not simply whether or not there are symbols in the brain, as this may be a matter of definition,

or even whether connectionist networks are the models of choice. Rather, the issue is that language processing is a brain function, and this matters for both psycholinguistic theory and practice.

STRUCTURAL AND FUNCTIONAL ORGANIZATION
OF THE BRAIN

With some 1,000 nameable parts, the brain has structure at multiple levels and these anatomic structures delimit the scope and manner of its functioning; the brain's functional organization, in turn, delimits the psychological functions that it supports. The division of the brain into two interconnected halves is neither irrelevant nor inconsequential to language researchers. Even if the exact roles each hemisphere plays in language may be controversial, any psychological theory of language processing that completely ignores this fact is not a theory of human language processing. *The hemispheres matter.*

Within each hemisphere there are a large number of highly interconnected clusters (groups) of neurons that share inputs, outputs, and response properties. Sensory and motor cortical areas, for example, are composed of anatomically and functionally segregated areas containing specialized sets of neurons. These areas, in turn, are connected to each to other in an intricate fashion that is neither complete nor random. If there were but one large undifferentiated cortical area instead, theoretical estimates show that the volume of cortex required to form the same neural circuits would be an order of magnitude larger (Mitchison 1991, 1992). Ouch!

Mental activity presumably emerges from the dynamic patterns of neural activity distributed across these functionally specialized groups of interconnected subcortical and cortical neurons. The brain's functional connectivity determines how sensory inputs are perceived and interpreted, thoughts are conceived, emotions are felt, commonalities and differences are appreciated, memories formed and maintained, and actions prepared and executed. What the brain represents and how it processes those representations are inherent in its structural and functional connectivity. The communicative currency within this network is electrochemical (electrically mediated, all-or-none action potentials and chemically mediated, graded synaptic potentials), with mechanisms in place for hormonal modulation. Neural representations—not symbols or connection weights per se—unfold dynamically as patterns of electrical and chemical activity in an ever-changing brain. Neural representations and processes are so inextricably intertwined that it may not be fruitful (or accurate) to theorize about them independently of one another.

The brain is heavily interconnected: local connectivity within a group is dense; connections between areas less so. Each group tends to be connected to a specific subset of other groups. Yet, whatever their location, any two cortical neurons are only a few synapses apart. Processing is hierarchical, each stage contributing to the subsequent stage of processing. Cells in different areas have different response

properties. Signal flow, however, is not strictly serial: higher areas receive inputs from areas immediately below them and in some cases directly from nonadjacent lower areas as well. The nonlinearity of feedforward connections undermines any simple notions of the time course of stimulus processing. Areas become activated, for all practical purposes, as soon as the areas connected to them: the time course of processing itself, thus, is integral to determining what is processed and in what order. *Brain timing matters.* Several such hierarchical sequences (processing streams) specialized for particular functions (e.g., ventral vs. dorsal streams) operate on the same inputs in parallel for vision, audition, action, etc. Psychological events, accordingly, are not best conceptualized as possessing either discrete temporal or spatial boundaries.

Most of the pathways linking areas are reciprocal. The ratio of incoming (feedback) to outgoing (feedforward) connections for many cortical areas is almost 1, suggesting significant give and take between brain regions. Compared to the estimated 14,000 feedforward neurons for each square millimeter of V1, for instance, there are an estimated 11,000 feedback neurons in V2 (Rockland, 1997). The high number of reciprocal connections into the lowest cortical areas provides the scaffolding for an abundance of top-down interactions, which may (and, as functional studies demonstrate, do) modulate even early, primary sensory and motor processes. *Context*—construed much more broadly than in conventional psycholinguistic research—*matters.*

Anatomical, neurophysiological, and pharmacological data suggest a preferred vertical flow of information through the cortical layers from layer IV to layers II–III and either layer V to VI or layer VI. Cells in different cortical layers have different response characteristics. As information flows through the cortical layers, neurons appear to sample from a larger input space (i.e., larger receptive fields), receive convergent inputs from the previous layer, and send diverging outputs to the next layer. Receptive fields tend to be larger and responses more complex outside of the layer IV. Additionally, there is substantial horizontal interconnectivity, combining inputs from neighboring regions and from more distant cortical areas. Excitatory horizontal projections arise predominantly from layers II–III and V pyramidal cells and project preferentially to supra- and infragranular layers (Douglas & Martin, 2004). The horizontal connectivity may be especially important in the experience-initiated reorganization of cortical maps (Buonomano & Merznich, 1998).

The cortical surface is replete with topographic maps of the outside world and of the body. Numerous retinotopic maps of visual space, for example, can be seen not just in occipital cortex but in temporal, parietal, and frontal cortex as well (Felleman & Van Essen, 1991; Hagler & Sereno, 2006; Schluppeck, Glimcher, & Heeger 2005; Sereno, Pitzalis, & Martinez, 2001; Silver, Ress, & Heeger, 2005); other maps are somatotopic (Chainay et al., 2004; Dechent & Frahm, 2003; Ostrowsky et al., 2002), tonotopic (Formisano et al., 2003), somatomotor, etc. A coarse map of movements associated with muscles and within each a mosaic of

finer movements about the same joints characterizes primary motor cortex (Nudo, Jenkins, Merzenich, Prejean & Grenda, 1992), and so on.

Cortical representations, however, are dynamic entities, continually modified by experience. *Experience matters.* The notion of the exact same stimulus (as with repetition) is antithetical to how brains re-present stimuli. The brain is, by design, a continuously changing, self-organizing structure. Brain structure (anatomical connectivity) is shaped by brain function (functional connectivity), which in turn shapes brain structure, and so on. Cortical representational area is approximated by the peripheral innervation pattern; however, although each peripheral neuron initially has about an equal cortical area for its representation, area is reapportioned as a function of usage.

Both the structural and functional organization of the brain are activity dependent. Electrical and chemical changes modulate the probability of activity in preexisting connections. Attended inputs that occur coincidentally (or nearly so) in time tend to be represented together in the cortex, whereas those that are temporally uncorrelated or anticorrelated tend to be represented separately. Electrical and chemical changes also may lead to structural changes at all levels of the nervous system, from the molecule to behavior, including growth or branching of axons and dendrites, addition or removal of synapses and receptors, gene transcription, and reorganization of cellular machinery. Functional dynamics, thus, not only represent the brain's information directly but also share the storage load by shaping anatomical connectivity throughout an organism's lifetime.

It is important that plasticity is not a special mechanism reserved for young brains during critical (or sensitive) periods, for brains experiencing abnormal early sensory or language inputs, or in response to gradual or abrupt damage, although younger brains are more plastic and many factors are known to modulate the extent of functional plasticity (Sereno, 2005). Plasticity is an intrinsic property of all brains (Buonomano & Merznich, 1998; Pascual-Leone et al., 2005). From this it follows that language is not just as a structured sensory input in need of interpretation but a processing experience that may at times (especially when attended) literally alter the form (and associated functioning) of the brain regions involved in interpreting it, at least in the short-run. Moreover, because experience can mold the matter that determines its function, it becomes cost effective, if not essential, to estimate what each brain knows (represents) and the consequences of that knowledge on its functioning, and to use this information about individual differences to account for variance in language behavior.

PSYCHOLINGUISTIC ASSUMPTIONS REVISITED IN LIGHT OF BRAIN FINDINGS

Overall, neuroscience data do support a view of the brain as a collection of large number of functionally specialized faculties. Functional segregation is one of the

major principles of brain organization, even if it is not always clear just what is the specific function of any given area. There is much less support for a central processor or controller to which the different modules funnel their outputs for integration. If there is a central neural processor that orchestrates the various modules, its brain locus remains a mystery. At a functional level, there is no overpowering evidence for a single reservoir of amodal knowledge. Functional integration, the other major principle of brain organization, seems to emerge instead from the temporally coordinated activity of many thin-skinned modules. Although individual modules do typically receive specific inputs from the sensory periphery, the directionality, for example, of these pathways is modifiable by experience. Visual cortex, for example, can process somatosensory inputs in congenitally blind individuals or even in seeing individuals after a brief period of visual deprivation (for review see Sathian, 2005, but also see Sereno, 2005). Neither autonomy nor information encapsulation has received much empirical support. In the brain, there is considerable built-in cross talk among submodules via both lateral and top-down connections; this holds equally for interactions among various nonlanguage modules, between nonlanguage and language modules, and within submodules of the language faculty. Stimulus evaluation processes, for example, do not, as a matter of course, cause a bottleneck for the motor system, because computations in the two systems can proceed in parallel and because the motor system has access to partially-digested information from the stimulus processing system (even if the information flow is not always continuous).

Language-related processes in hippocampal, medial temporal, frontal, and parietal brain areas are inextricably bound with attentional, working memory, and long-term memory mechanisms. Although an integral part of language processing, these sorts of processes are not unique to language, even if sequencing operations or mapping operations between inputs–outputs and stored knowledge may have been fine-tuned by evolutionary pressures from language processing operations. At minimum, the extensive structural and functional interconnectivity of brain parts indicate that no cell, cell assembly, area, region, or system is wholly autonomous. Purely language functions (if such exist), therefore, seem to be a part of a much larger, apparently integrated system, and it may not be prudent to study them in isolation from perception, attention, memory, and action. Functional data show substantial interactions even at the lowest levels of sensory processing. This, combined with the nonlinear nature of feedforward connections and high proportion of feedback connections to multiple levels in the central nervous system, raises doubts about the viability of constructing a full-blown language system from fundamental building blocks characterized in isolation.

Psycholinguistic research aims to understand the immaterial, mental processes of language processing, but because only the final product of understanding is available for conscious reflection, the nature of the representations and operations on them must be inferred from some observables. These observables are directly or indirectly a brain product, and thus subject to its structural and functional organi-

zations; that is, the medium matters for inferring how it functions. It matters because it is the anatomical and functional organization of the cerebral cortex that affords it the means for balancing functional segregation and functional integration. It matters because despite the phenomenological sense that people experience the "real" world moment by moment as it is and the belief that they represent it veridically, what people really perceive and encode is a somewhat delayed reconstruction with considerable top-down (contextual) support (see Coulson, this issue) of deconstructed events distributed across the functionally segregated brain systems of two cerebral hemispheres. That it works as well as it does to give a sense of understanding attests to the intelligence of evolution.

THE HEMISPHERES MATTER

The superb language skills of the left hemisphere need no elaboration. It is, after all, mostly the left hemisphere that talks, although some formulaic, nonpropositional speech seems to be uttered involuntarily under right hemisphere control (Van Lancker Sidtis, this issue). The former, among other facts, has been the basis for the conventional view of the right hemisphere as the mute, nonverbal hemisphere. The right hemisphere, however, is clearly critical for integrative, pragmatic, prosodic, and emotive aspects of language comprehension (see the Katz and Van Lancker Sidtis articles, this issue). Whether or not these processes are disproportionately exercised by certain types of language, it is hard to imagine that they would not play at least some role during the comprehension of all (not just figurative) language. Certainly, it is not uncommon for neuroimaging studies to report language-related activations and (de)activations in both hemispheres even for language materials that would, by all accounts, be characterized as literal, although there is considerable variability in the spread and intensity of these activations (Gernsbacher & Kaschak, 2003; Josse & Tzourio-Mazoyer, 2004). Electrophysiological studies with normal infants and children during language acquisition, moreover, point to a course of developmental changes in the configuration of language-related brain systems, including at some point a crucial role for the right hemisphere (e.g., Mills, Coffey-Corina, & Neville, 1997). Similarly, it has been hypothesized that the division of labor between the two hemispheres, for language as well as other domains, may change with advancing age, with older adults showing reduced hemispheric asymmetry especially in prefrontal brain regions (Cabeza, 2002). Right hemisphere recruitment—short- and long-term—also has been observed in congenitally deaf native-signing adults (reviewed in Neville & Bavelier, 2002; Newman, Bavelier, Corina, Jezzard & Neville, 2002) as well as in normal hearing adults with aphasic symptoms exhibiting some recovery of language functions after brain injury (Altenmüller, Marchmann, Kahrs & Dichgans, 1997; Cappa & Vallar, 1992). At minimum, such evidence belies the view of the

right hemisphere as a nonverbal hemisphere. Moreover, the well documented anatomical, physiological, and chemical differences between the two hemispheres indicate that each is likely to perform even the same nominal functions somewhat differently (Gainotti, Sorbi, Miceli, & Amaducci, 1982), and thus to differ not just quantitatively but qualitatively (see Beeman, 1998; Beeman & Chiarello, 1998). There is every reason to believe that both hemispheres are processing at least some aspects of linguistic input in parallel to some extent with different outcomes (Van Lancker Sidtis, this issue). These differences, however, need not be language specific, and are likely to emerge from the outcome of competitive, as well as collaborative, mechanisms that have yet to be specified. Accordingly, I highly recommend whatever means available for probing the individual language capabilities of the two hemispheres, keeping in mind (and whenever possible capitalizing on) the known hemispheric differences in the nature and timing of sensory processing, attention, working memory, and long-term memory (e.g., Christman, 1989; Hellige, 1996; Markowitsch, 1995).

One approach to tapping the different capabilities of the two hemispheres that researchers have found to be surprisingly effective is the visual half field paradigm in combination with concurrent scalp ERP recordings. This typically involves presenting stimulus materials (words or pictures) lateralized two or so degrees peripheral to a central fixation point to take advantage of the contralateral organization of the visual system: stimuli in the left visual field initially go exclusively to the right hemisphere, and vice versa. Given that the information is quickly transmitted to the other hemispheres, it is remarkable that such a small timing difference has a reliable and persistent impact on the ensuing patterns of neural processing and behavioral outcomes. This combined methodology provides a systematic means of tracking the lateralized contributions of the different processes that lead to documented asymmetries in performance. In this way, it may be possible to go beyond descriptive statements about the mere presence or size of hemispheric asymmetries.

Coulson, Federmeier, Van Petten, and Kutas (2005), for example, used this combined methodology to compare the processing of unassociated and associated word pairs presented in isolation versus embedded within sentences, and found that, whereas both hemispheres were sensitive to message level information, the nature of lexical and sentential effects differed as a function of presentation field. Federmeier and Kutas (1999; Federmeier, Mai, & Kutas, 2006) showed that the two hemispheres differ not in whether or not they use message-level context information for word processing but in how. From such results, they have proposed that the data pattern for the left hemisphere (the same as that seen with central visual presentation) suggests that it—unlike the right—is actively predicting upcoming information. The right hemisphere pattern, by contrast, was more sensitive to plausibility, suggesting that it integrates each word into the sentence representation only on, and not prior to, its occurrence. Similar results with lateralized line draw-

ings imply that this hypothesized hemispheric difference is not reading specific (Federmeier & Kutas, 2002). Whether or not this hypothesis of the left hemisphere as an active preactivator (predictor) proves to be the whole story or even an accurate subplot, the combined visual half field–ERP approach has already revealed important similarities and differences in how the two hemispheres deal with language inputs to extract visual information, as well as to create meaningful representations. It also has illuminated the uncertain borders between perceptual and cognitive processes. Combined with hemispheric differences in the temporal course over which visuo-verbal information is retained (Federmeier & Benjamin, 2005), such findings may help to explain some of the reported hemispheric asymmetries in language comprehension including the literal–nonliteral distinction. More generally, such results enhance the likelihood that language inputs engage multiple brain mechanisms in parallel—at least one in each hemisphere—apparently extracting and maintaining different types of information—which are somehow orchestrated to yield a unified sense of understanding.

TIMING MATTERS

Even if language processing were restricted to a single hemisphere, there is little obvious resemblance between the phenomenological sense of a written, spoken, or signed word and its neural instantiation. The experimenter typically presents a word for a short duration (200–300 ms). The brain, however, experiences a cascade of neural changes distributed over time and space that go well beyond (seconds) the word's occurrence. What the mind experiences as a singular event—a printed word, for example—is, from a neural perspective, a set of attributes (color, intensity, contrast, spatial frequency, location). Moreover, despite the sense that people apprehend what a word means instantaneously (at least for words they know), the brain processes of word recognition and sentence comprehension take nontrivial amounts of time (at least 200 msec for words, and seconds for sentences). Even at the highest contrasts, retinal ganglion cells do not begin to transmit information until approximately 30 ms for rod-based processing and 50 ms for cone-based processing; these time differences are carried forward and typically accentuated with further processing deeper in the system (see Federmeier & Kutas, 2000). Word-related activity appears across several types of sensory receptors subserving multiple neural pathways, transmitting information at different speeds to different brain areas, so that information about a word is distributed across brain areas. Signals arrive in these various brain areas over multiple extended periods of time and are processed at different time scales. At any given moment after its occurrence, a simple sensory stimulus can appear across several brain areas, as a set of distributed attributes in various stages of analysis. Brain areas receiving information about the same external visual event typically differ in exactly what information they receive, from

where, at what time, and in how long they process that information. Information from cone vision, for example, travels to the primary visual cortex via the lateral geniculate nucleus, to the inferotemporal cortex via other thalamic nuclei, and to the frontal eye fields via the superior colliculus, etc. As visual information can also arrive at the inferotemporal cortex from the primary visual cortex, there is no single linear flow from the periphery to higher order areas. An area, such as the inferotemporal cortex, may receive the same information more than once, at different times, and with different amounts and types of preprocessing. Even seemingly straightforward psycholinguistic variables, such as word frequency or repetition, are likely to modulate processing at multiple times.

Language processes thus unfold at multiple time scales—from the milliseconds it takes to identify a phoneme to the seconds or minutes required to make sense of a sentence or discourse, not to mention the longer-term language-initiated changes in semantic memory function and organization. Time, moreover, is not just a dependent variable for experimenters to measure. Rather, it is an intrinsic variable for the brain. Even small differences in timing, which may or may not be reflected in different reaction times, can nonetheless be associated with quantitative or qualitative differences in the participating processes. A submillisecond lag between two postsynaptic potentials, for example, can determine whether or not a neuron fires, just as a long (neural) lag between two spoken words might be mistakenly attributed to a speaker's intent to cue a clause boundary or the focus role of a cleft noun or the punch word in a joke, etc. Faster versus slower processing of the same stimulus may, at times, reflect the engagement of qualitatively different neural mechanisms. At least in some cases, then, it is impossible to separate the timing of processing from its essential nature.

Brain time and external stimulus time, thus, are unlikely to be synonymous, with no simple mapping from the temporal course of brain processing to the time course of stimulus processing, as delineated within a psychological model of language. A brain-based view of language processing (and of time) thus has many implications for psycholinguistic research and models of language processing (see Federmeier & Kutas, 2000, for details). Given that even the punctate presentation of a single sensory stimulus results in extended activity in a distributed set of brain areas that receive information at different times, often more than once, it is difficult to exact a discrete moment when some process occurs (as if a digital switch were thrown), no matter how fine the temporal measurement taken. Lexical access, for example, is unlikely to be a momentary event. Adopting a neural perspective on word processing calls into question the validity and utility of discussing processes such as pre- or postlexical access (see also Coulson & Federmeier, in press). Neural processing honors all the differences between words and pseudowords that the brain has learned from experience (extracted from inputs) and not just those that a researcher assumes he or she is manipulating, and may reflect these differences at different places at different times; neither the potential multiplicity of temporal nor

spatial loci can readily be inferred from lexical decision times or from any dependent measure sampled only at a single time point.

Given the nonlinear nature of feedforward connections and the prevalence of feedback connections, there is no simple notion of the temporal course or ordering of processing from higher to lower areas. Although there is a forward flow to sensory processing in the nervous system, it is open to influences from all directions, often in response to the current context and processing goals. There is unlikely to be a single answer to questions like "Does syntactic processing precede semantic processing?" or "When does a particular psycholinguistic variable exert its effect?" Psycholinguistic variables, like psycholinguistic events, are often multifaceted, and thus can affect brain processing at different times, in different places, in different ways. Electrophysiological analyses, for example, show multiple, different effects of word frequency in the waveform including modulations of ERP component latencies and amplitudes, some of which are also subject to sentence context effects (King & Kutas, 1998; Münte et al., 2001; Rugg, 1990; Van Petten & Kutas, 1990). Moreover, as the relevant brain processes take place over different time scales, with substantial opportunities for interactions, it cannot be taken for granted that higher order, slower events can be predicted from a precise temporal accounting of lower order, faster events. In ERP studies, for example, it is not possible to predict the response to a sentence simply by summing the responses to individual words, because sentence processing is associated with a slow potential that spans phrases, clauses, and sentences, and is sensitive to variables other than those that modulate ERPs to isolated words, such as working memory capacity, among others (Kutas & King, 1996). Moreover, aspects of the response to a word vary as a function of the sentential context in which it occurs. Results from lexical decision tasks and word pair priming studies—no matter how many researchers perform—are unlikely to ever provide researchers with the fundamental building blocks for a full-blown theory of even sentence (much less language) processing. Mindful of language processing as a brain function, researchers may be less inclined to entertain naive notions of "scaling up" from the processes of word recognition to those of sentence comprehension.

A psycholinguist's particular conceptions of time are important at both practical and theoretical levels. Most psycholinguistic designs include only one presentation rate and stimulus duration. It thus seems that researchers assume that the same mechanisms are invoked during language processing regardless of input rate (within limits, of course). This may be the case. However, only systematic variation of timing parameters (including stimulus duration and rate of stimulus presentation in combination with other stimulus and environmental parameters known to influence early visual or auditory processing, as well as other cognitive variables) can answer this set of empirical questions. The answers are undoubtedly neither singular nor simple. The answers are, however, bound to have significant ramifications for how reaction time measures in an interference paradigm, for instance,

may be interpreted, and more generally for theories of human language processing. Psycholinguistics will employ different types of designs and perhaps ask different questions when working from the assumption that the timing of a process may be a critical part of the context determining what is being processed and in what order. Researchers of nonliteral language processing, for example, can move beyond the simple question of order—that is, whether metaphorical language processing only kicks in after literal processing mechanisms have failed to make sense of the input—and use the various and sundry tools available for indexing time and the time course of processes (including gating, speed-accuracy tradeoff, stop-signal paradigm, eye-tracking, ERPs, and magnetocephalogram) to compare and contrast the consequences of various temporal and nontemporal variables on the processing of literal and nonliteral stimulus materials.

CONTEXT MATTERS

Timing is but one type of context, which, although perhaps difficult to define, is impossible to ignore as a key variable in language processing. Neural processing is context sensitive. Indeed, context sensitivity is evident not merely at the level of systems, regions, and areas, but even at the level of single cell responses. A given single cell in primary visual cortex, for example, will respond to a stimulus in its classical receptive field differently as a function of stimuli outside its receptive field. In fact, a stimulus or event that could not by itself trigger a cell to fire can nonetheless modulate the response to a stimulus that does. Context effects of this sort abound (Albright & Stoner, 2002; Allman, Miezin, & McGuinness, 1985; Fitzpatrick 2000; Zipser, Lamme, & Schiller, 1996). Evidence of context-sensitivity combined with demonstrations that brains construct, rather than store, veridical records of the external world (see Coulson, this issue) has engendered serious (renewed) questioning of the continued wisdom of probing single cells with simple, rather than with more complex, natural stimuli—that is, with simple bars, gratings, light flashes, or light-emitting-diode movements instead of natural scenes (Kayser, Kording, & Konig, 2004). These are equally valid concerns in the language domain with regard to what are the best language materials with which to preferentially tax distinct language mechanisms and what constitutes the stimulus and what constitutes context.

Research on nonhuman animals has revealed that the picture that neuroscientists see of the functional organization of various neural systems depends in large part on the nature of the stimuli with which the brain has been probed. Stimulation with different classes of simple stimuli alone or even in simple combinations has led to strikingly different conclusions about the functional organization of sensory systems than has stimulation with more complex stimuli such as objects, scenes, or environments (Kayser et al., 2004). For example, stimulating the visual

system with oriented lines led to the conclusion that some V1 cells have preferred orientations (i.e., respond most strongly to lines of a particular orientation). Probing with more natural visual scenes (with orientation contrasts), however, reveals that even the activity of cells that show no orientation tuning when probed with a single stimulus is, nonetheless, modulated when exposed to a number of different orientations, as if the relevant stimulus was not orientation per se but rather orientation context. Perhaps this stems from the fact that the visual system, like all brain systems, adapts to the properties of its inputs, which are complex scenes that it parses in ways that researchers are still discovering.

During my (academic) lifetime, most neuroscientists seem to have adopted a reductionist approach to deciphering brain structure–function mappings: start small and simple with basic features, and then scale up by systematically combining elemental features into increasingly more complex combinations such as an object or a visual scene. This approach has revealed much about the differential responsivities of cells in various visual areas to various features of visual inputs; for example, it led to the discovery of cells with preferred orientations, and differences between cells lower and higher in the visual hierarchy. Indeed, this view continues to shape how many vision researchers conceptualize the hierarchical nature of visual processing. It is what leads them to characterize the cells in V1 as feature detectors when, in fact, all they know for certain is that these cells can detect certain features. The tide is turning, however, as it should, for it has become increasingly clear that the brain's response to natural visual scenes cannot be accounted for by any straightforward combination of the responses to simple visual stimuli. And, ultimately, it is how people process natural scenes and not just spots, lines, checkerboard grids, and the like that researchers wish to understand. So far, the visual system's performance cannot be predicted from the performance of its basic constituents, because individual neurons do not provide functionally independent fragments of the world that can be reassembled like pieces of a jigsaw puzzle to reveal the world out there. Stimuli present at other points in space or time, as well as attention, memory, and self-movement, among others, often affect a visual neuron's response to a stimulus within its receptive field (Fitzpatrick, 2000). Evidence for modulatory influences outside the classical receptive field and the constructive nature of vision call for a context based approach to the study of vision (Albright & Stoner, 2002), and is unquestionably a valuable lesson for language researchers as well. As eloquently discussed by Coulson (this issue), language researchers quickly run into a brick wall trying to figure out what a sentence—literal or figurative—means by simply combining the meanings of the individual words.

As already noted, in ERP studies the electrical response to sentences is not predictable from the responses to individual words; responses to individual words ride atop slow potentials that span phrases, clauses, and sentences, and responses to prosodic boundaries (Kutas & King, 1996), not to mention other differential electrical activity accompanying sentence processing that does not contribute to the av-

erage ERP waveform (Roehm, Schlesewksy, Bornkessel, Frisch & Haider, 2004). However, even the responses to individual words change from one presentation to another, for a whole host of reasons, but certainly due to interactions with a prior word in the sentence or sentence-level processes. These considerations would seem to challenge the view that it is best to investigate subprocesses in isolation with the hope of scaling up to higher levels of analysis. That said, even experiments that have gone beyond the single word to include whole sentence or discourse processing of the literal or the nonliteral have yet to come close to the types of communicative interactions outside the laboratory that researchers are most interested in explaining. Just as combined stimulation of the classical receptive field and nonclassical receptive field leads to neurons conveying more information about the stimuli, greater selectivity, and increased efficiency of information transmission (Kayser et al. 2004), presenting natural language with its fits and starts, pauses, repetitions, and incomplete sentential structure in a communicative context and tracking the ensuing consequences may help researchers understand the computations invoked during "real" meaning construction.

Taking a brain perspective on language processing according to which context can affect the brain electrically, chemically, and structurally at multiple time scales opens researcher's minds to contexts that traditionally have not been considered important or even relevant for the nitty-gritty of language processing. Among these are genetic predispositions or moods that intuitively seem to affect not just what people think but how well, and as I discuss next—perhaps also how. Although moods have long been known to influence the content of memories, they have traditionally not been considered key to how language inputs are actually processed. Yet changes in neurotransmitter distribution and neuromodulatory changes can alter which neurons will fire, under what circumstances, and how long they take to begin or stop reacting to a particular input. More precisely, such changes have the potential of determining whether stimuli in a series are treated as independent events or as subparts of a single temporally extended event, among other effects. Background information about words and their meanings are obvious candidates as context, and have been heavily investigated. Neurally inspired research on literal language processing in the recent past, however, encourages a wider casting of the context net to embrace, among other factors, personality states or traits with or without a genetic predisposition and mood.

Schizotypy as a Prevailing Context

Individuals in the general population, for example, vary along a continuum in the degree to which they exhibit relatively stable, schizotypal personality traits that are qualitatively similar to symptoms of schizophrenia, albeit quantitatively much less severe (Verdoux & van Os, 2002). These traits include ideas of reference (incorrectly believing that certain events have particular personal significance); odd be-

liefs or magical thinking (superstitiousness, belief in telepathy or the paranormal); unusual perceptual experiences (sensing another person's presence or hearing a voice when no one else is about); odd speech (vague, circumstantial, or overelaborate); suspiciousness or paranoid ideation; constricted affect; odd behavior; lack of close friends; and social anxiety associated with paranoid fears (American Psychiatric Association, 1994). Brief instruments such as the Schizotypical Personality Questionnaire (SPQ) provide estimates of the degree of schizotypy. Healthy individuals with a schizophrenic family member not only score higher on schizotypy scales (e.g. Kendler, McGuire, Gruenberg, & Walsh, 1995), but also are more likely to exhibit neurophysiological and neuropsychological abnormalities typifying schizophrenia (reviewed in Tsuang, Stone, & Faraone, 2000). Furthermore, a higher than normal prevalence of these same abnormalities has been reported in healthy individuals absent a schizophrenic relative but scoring high on schizotypy (Ettinger et al., 2005; Kimble et al., 2000; Klein, Andresen, Berg, Bruger, & Rockstroh, 1998; Lubow & De la Casa, 2002).

Of specific interest here is the finding that high schizotypy is associated with abnormal patterns of semantic processing reminiscent of schizophrenics. Individuals rated high on magical ideation and/or paranormal beliefs, for instance, are more likely to respond to words with an unusual associate (Duchêne, Graves, & Brugger, 1998) and to show behavioral priming for weakly related category members (Kerns & Berenbaum, 2000) or for indirectly related words, at least following left visual presentation (Pizzagalli, Lehmann, & Brugger, 2001). Such results suggest that high schizotypy is accompanied by heightened sensitivity to relationships between words or concepts that, by general norms, are rated as only weakly related, or not at all. Although this picture is complicated by reports of increased activation of strongly related items or decreased inhibition of related items, the general conclusion that high schizotypy scores are paralleled by atypical patterns in the way categories activate their exemplars stands. Research in my laboratory (by Michael Kiang, MD) provides support for both the major theoretical positions on the possible mechanisms for the abnormal pattern of semantic processing observed, namely a greater than normal scope of activation that encompasses weaker semantic associates, as well as less effective use of context to activate related items and to inhibit unrelated ones.

In one study, for example, when given 1 min to name as many fruits as they could, individuals from a nonclinical population scoring high on schizotypy generated more atypical fruits (in initial position and overall; Yoon et al., 2004) than lower schizotypy scorers even though the groups did not differ in the total number of fruits named (Kiang & Kutas, in press). One low schizotypy participant, for example, produced the relatively high typicality response set: apple, orange, banana, pear, peach, plum, pineapple, mango, strawberry, cantaloupe, melon, grapefruit, grapes, tangerine. A high schizotypy participant produced the low typicality response set: cherimoya, banana, apple, orange, tangerine, grape, passionfruit, kiwi,

jackfruit, lime, lemon, cherry, strawberry, persimmon, cantaloupe, Persian melon, plum, nectarine, peach, avocado. On average, these schizotypy groups did not differ in their knowledge of word meanings (as indexed by the Peabody Picture Vocabulary Test). They did, nonetheless, differ in what fruits came to mind and were expressed under time pressure—the sort of time pressure that is not unlike that experienced during daily routine language use. Such results attest to the importance of the genetic context within which language output is produced.[1] One can imagine various arguments for how varying degrees of schizotypy might interact with the processing of certain trope types as well.

It could be argued that the association between schizotypy and atypical production in a category fluency task merely reflects an effect of personality on semantic content rather than on semantic processing per se. In a different study, however, we found that high schizotypy was associated with a reduced category effect as inferred from relative N400 amplitudes in a category verification task (Kiang & Kutas, 2005). In that study, ERPs were recorded as individuals from a normal population made yes–no category membership judgments to one of three types of target nouns presented following a category name: high typicality exemplars, low typicality exemplars, or nonexemplars (e.g., A type of fruit—apple/prune/table). Nonexemplars elicited the largest N400s, high typicality exemplars the smallest, and low typicality members intermediate amplitudes in all participants. The size of the N400 category effects (nonexemplar minus either high or low typical exemplars), however, was inversely correlated with SPQ scores: higher schizotypy was associated with smaller N400s for nonexemplars as well as larger N400s (or less positivity) to both types of exemplars. This pattern of results is consistent with the hypothesis that individuals high in schizotypy do not make effective use of context either to activate members or to inhibit nonmembers (also see Kimble et al., 2000). It is perplexing that this reduction in N400 category effects was more highly correlated with the SPQ Interpersonal factor than the Disorganized factor (which includes Odd Speech). Nonetheless, on the view that semantic knowledge plays a critical role in how language is processed and the evidence that semantic memory organization in nonclinical populations with schizotypy is functionally altered in one way or another (with the details of just which factors are crucial yet to be worked out), it would seem wise to assess at least this if not other personality factors as a potential source of variance in studies of language processing. Blasko and Kazmerski's (this issue) research on the relation between relational aggression and differential behavioral and electrophysiological responsivity to sarcasm under-

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[1] The experiment also tested naming for four-footed animals, articles of clothing, and vehicles. See article for discussion of why this group difference was seen only for the fruit category. In short, we argued that it was easier to see a slight shift from the norm for fruits in particular because there is overall less interindividual variability not only in the set of responses generated but also in the order that they are generated for the fruit category relative to most other categories.

scores the utility of factoring personality variables (whether acquired or innate) into the analysis of nonliteral language processing as well.

Mood as Context

In this same vein, a growing literature in both the language and nonlanguage domains challenges any clean separation between reason and emotion. Substantial evidence indicates that an individual's affective state or mood can, and often does, modulate sensory–perceptual, cognitive, and motor processes that have no obvious affective component. Fredrickson and Branigan (2005), for example, found that an induced mood (positive, negative, or neutral) influenced whether participants were more attuned to the global (shape) or to the local (feature) level of an image when asked to decide which of two images was similar to a particular target image in which the global and local levels were at odds (e.g., triangle made of three squares). Participants in a happy mood were more likely than those in a neutral or negative mood to match on the basis of global similarity (triangle made of triangles) as opposed to local similarity (square made of triangles). Although these results are silent as to which processes—perceptual, attentional, or decision-related—are modulated by mood induction, they unequivocally implicate at least one of them. Whether those in a happy mood are really more inclined to see the forest for the trees or are merely more inclined to respond at the global level, that mood has an impact at any stage of analysis would seem to have implications for language researchers, especially when comprehension calls for mappings between two or more domains. The pattern of results also suggests that mood may differentially affect language (and other) processing in the two cerebral hemispheres, which have been hypothesized to contribute differentially to affective processing (see Heller, Nitschke, & Miller, 1998; Van Lancker Sidtis, this issue).

Induced-mood effects have also been observed in higher order cognition such as problem solving and language processing. Individuals in a happy mood, for example, are more likely than those in a neutral or negative mood to solve difficult problems by lighting on less obvious (and therefore, by definition, more creative) solutions. Isen, Daubman, and Nowicki (1987), for example, found that given a candle, a box of tacks, a book of matches, and the instructions to fix the candle to the wall in such a way that no wax drips to the floor when the candle is lit (Duncker's candle problem), participants in an induced happy mood were more likely to find the solution than individuals in a neutral or negative mood. Again, although the mechanism of action for such background mood effects remains unclear, a positive mood does seem to open the mind to more options, rendering less salient alternatives more available than in the same mind in a relatively neutral or negative mood.

A similar looseness of mind can be seen in production tasks. Individuals in a positive (relative to neutral) mood produce not only more associates, but more un-

usual associates (Isen, Johnson, Mertz, & Robinson, 1985) and generally exhibit greater sensitivity to more distant relations between words (Isen et al., 1987). Given three words (bee, comb, dew) and asked to come up with a fourth that can be combined with each of them (honey bee, honeycomb, honeydew), participants rendered happy via a comedy film or a gift of candy were generally more successful than a negative mood group, a no mood-manipulation group, or even a group aroused via mild exercise (Isen et al, 1987). On the basis of such findings, Isen et al. (1987) concluded that people in a positive mood are more able to combine materials in new ways and to see relationships between remotely associated items. Even when participants were unable to come up with the right word, those in a positive mood were more accurate and those in a negative mood were less accurate in indicating whether such a word triad was coherent and thus, in principle, soluble (Bolte, Goschke, & Kuhl, 2003). Mood manipulations similarly have been shown to influence perceptual and conceptual categorization. Participants in a positive mood, for example, gave higher membership ratings to less canonical category members (e.g., pickle as a type of vegetable) than participants in a neutral mood (Isen & Daubman, 1984). More generally, participants in an induced positive mood are characterized by more pronounced cognitive flexibility, creating large inclusive categories when the task calls for appreciating similarities and small exclusive categories when performance hinges on appreciating differences (Murray, Sujan, Hirt, & Sujan, 1990).

Researchers do not yet know whether or not moods affect generation of word associates, judgments of semantic coherence, and category membership via the same cognitive or neural mechanisms. Initial studies using the N400 component, however, indicate that positive mood modulates some aspect of semantic analysis and contextual integration. In one study of written sentence processing, for example, pictures from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2005) served to induce either a positive or negative mood as participants read sentence pairs designed to lead to an expectation for a particular category member as the final word of the second sentence. Sentences, however, ended either with that expected exemplar, or with an unexpected member from the same category, or with an unexpected word from a different, albeit related, category, for example, "They wanted to make the hotel look more like a tropical resort. So, along the driveway they planted rows of ... " palms (expected), pines (within category violation), tulips (between category violation). Remarkably, the pattern of effects in the region of the N400 (300–500 ms) was modulated by the induced mood, at least in women. Participants in a neutral mood responded to expected exemplars with the smallest N400s, to between category violations with the largest N400s, and to within category violations with intermediate N400 amplitudes, whereas women in a positive mood responded to both between and within category violations with equivalently reduced N400s. A positive mood apparently facilitated the integration of distantly related words into a sentence even when the resulting interpretation

was not particularly plausible. The implications for investigations of nonliteral language processing are obvious. At minimum, it would seem advisable to assess preexperiment baseline moods via Depression Adjective Checklist (Lubin, 1965) or Positive-Affect-Negative-Affect Scale (Watson, Clark & Tellegen, 1988). At a practical level, these results suggest that it may be important to equate stimulus materials across critical contrasts on their affective content. The functional organization of semantic memory and its use during lexical and sentence processing are clearly not immune to fluctuations of mood. Indeed, overall it seems that a positive mood, in particular, enables access to the very information that psycholinguists consider crucial for nonliteral language processing—the less obviously related pieces that can fuel the creation of novel associations. It is, at present, unclear whether positive experiences have only a short term modulatory effect on semantic processing or accumulate to exercise a more trait-like effect, as seen in individuals who tend to be suspicious of others (Schul, Mayo, & Burnstein, 2004) or who rate high in schizotypal traits or other personality traits (introvertedenss, field dependence/independence, etc.) that have yet to be systematically investigated. Certainly, the brain mechanisms for such factors to have an impact are in place whether these are construed as context or as a brain-modifying experience.

EXPERIENCE MATTERS

Sensory Deprivation and Functional Reorganization

It is clear, then, that brain function and structure are experience dependent in some way or ways, at least under the appropriate conditions. The experiences that have received the most intensive investigation are those due to sensory deprivation, especially early, such as congenital deafness or blindness, as these result in noticeable reorganization in cortical areas involved in sensory (and sometimes language) processing. The deafferented auditory cortex in deaf individuals, for example, responds to visual images of sign language (MacSweeney et al. 2002; Nishimura et al. 1999; Pettito et al. 2002), perhaps due to the linguistic (if not just the visual) nature of the stimuli. The deafferented occipital cortex in blind individuals also has been implicated in language processing to some extent as well, either via the release of suppression of existing connections or establishment of new ones. Both neuropsychological and transcranial magnetic stimulation (TMS) data suggest that an intact occipital cortex may be necessary for Braille reading. TMS stimulation of the occipital cortex in blind participants somehow distorts tactile perceptions and increases the number of errors in Braille identification. Functional magnetic resonance imaging (fMRI) activations during auditory verb generation, verbal memory (Amedi, Raz, Pianka, Malach, & Zohary, 2003), semantic judgment (Burton,

2003; Noppeney, Friston, & Price, 2003), and speech processing tasks (Roder et al., 2002) in blind individuals also have been taken as evidence for visual cortex involvement in language processing. Amedi et al. (2003), for example, observed V1 activation in the left hemisphere of blind individuals retrieving abstract words from long-term memory; the magnitude of the activity correlated positively with the number of words recalled. TMS disruption of these same areas (calcarine sulcus, occipitotemporal cortex) was accompanied by increased numbers of errors during verb generation (Amedi, Floel, Knecht, Zohary, & Cohen, 2004).

Even sighted individuals have been reported to show some fMRI activations in occipital cortex bilaterally during a semantic generation task (Press et al., 2004). Moreover, temporary visual deprivation of sighted individuals by blindfolding for only an hour or so also seems to enhance visual cortex excitability as demonstrated via TMS and fMRI activations (Boroojerdi et al., 2000). Moreover, TMS stimulation of the occipital cortex disrupts Braille reading in sighted individuals following 24 hr or more of blindfolding, but not 24 hr after the blindfold is removed. The effects of early sensory deprivation are stronger and more enduring, but still it is noteworthy that short-term deprivation can influence some language tasks by altering visual cortex functioning.

Methodological Consequences

Although brain plasticity is also generally acknowledged by researchers of first and second language acquisition, bi- or multilingualism, and recovery of language function after brain damage, it has received little, if any, direct mention within mainstream psycholinguistic theories of language processing—that is, theories of processing by young, healthy adults. Brain plasticity, of course, does indirectly influence certain methodological choices because it insures that the same physical stimulus from the experimenter's point of view is never exactly the same stimulus from the brain's point of view. Word frequency and word repetition effects, for example, attest to this fact. Accordingly, word frequency is a variable that is of concern in just about every psycholinguistic study, although it is far from obvious exactly what is the relevant frequency to match or control for. For similar reasons, psycholinguists typically avoid stimulus repetition as much as possible—or should. Given the sensitivity of the brain to structure in its inputs, there are multiple levels at which repetition effects might occur. However, as there is no one-to-one mapping between behavioral modifiability and brain plasticity, it is an empirical question whether or not any particular experience will leave a perceptible trace. It seems that it is less likely to if the experience is outside the attentional focus. The role of different amounts and types of attention on different aspects of language processing could certainly benefit from a thorough and systematic analysis, as well.

Individual Differences

It goes without saying that "average" individuals differ widely in their experiences. How this normal range of individual differences plays out at neural and behavioral levels has received relatively little systematic attention in the psycholinguistic literature to date, although researchers of metaphors, proverbs, and idioms seem to be more likely to at least check that participants understand or know the tropes under investigation. Typically, experimenters aim to minimize individual differences by recruiting "like" subjects or occasionally by matching them on general IQ or verbal IQ scores. Viewing language processing as a brain function, however, underscores just how paltry such attempts are. A brain view on language processing brings individual differences of all sorts front and center. Language is both processed by and affects processing in large portions of the brain—areas whose connections store the knowledge that language input uses for its interpretation. The very existence and strength of these connections is a function of experiences. It would seem, then, that understanding when, how, and to what end such information is used would benefit from more extensive and thorough estimates of what individuals (experimental participants) have experienced (i.e., what they know both explicitly and implicitly).

To this end, it might prove useful to develop some standard procedures for characterizing healthy experimental participants, just as neuropsychological batteries have been used to assess patients with brain damage. In an ideal world, researchers would know everything about an experimental participant from their gene sequence to their temperament to their aspirations. They would test their senses (visual and hearing acuity), their motor response speeds, their category and verbal fluency, their ability to switch, their ability to inhibit, and their ability to learn and recover from errors. Experimenters would estimate participants' attentional and memory spans (Daneman & Carpenter, 1980; Engle & Kane, 2004; Hannon & Daneman, 2001; Vogel et al. 2005); their susceptibility to suggestion, their background general and culture knowledge (Author Recognition Test and Magazine Recognition Test; Stanovich 2000; Stanovich & West, 1989), including their areas of expertise and the speed with which they can access such information; the nature of the errors they make, ability to learn new things, ability to form images, and draw inferences; their sensitivity to novelty; their degree of hemisphericity (Morton, 2003); as well as various personality traits. They would keep track of their gender, their handedness, and their family history of left handedness. The list is so daunting that it may seem better left to researchers whose primary research interest is in individual differences. I recommend an intermediate position, however.

More and more evidence in the cognitive neuroscience of language processing suggests that individual differences do matter in the specific patterns of results obtained and, by extension, to the inferences drawn about how language is processed. Moreover, individual differences have proven to be important sources of variance

not just in patient populations or in the elderly. Even undergraduates differ significantly in handedness, verbal ability, working memory capacity, susceptibility to suggestion, ability to form visual images, and suspiciousness, among others. These differences do, at times, translate into reliably different patterns of behavioral and/or brain activity—the very measures that psycholinguists typically rely on to make inferences about responsible mechanisms and to adjudicate among alternative theories. Kutas, Van Petten, and Besson (1988) for example, found that the N400 to visual words in sentences was right-lateralized only in right handed participants with no family history of left-handedness; the N400s of right-handers with a first-order left-handed relative were bilaterally symmetric. Coulson and Lovett (2004) found that handedness, verbal skills, and gender were important in determining the pattern of ERPs obtained to the sentence final punch words of one-line jokes. Specifically, as in previous studies, they observed larger late positivities to jokes relative to straight endings with the same cloze probabilities; the laterality of the positivity was influenced by participant handedness and gender. Joke processing was also associated with a frontal negativity but only in right handers, and a slightly enhanced N400 but only in left handers with low verbal skills.

The literal language processing literature is rife with examples of different behavioral and electrophysiological patterns for individuals with high versus low verbal ability and verbal working memory spans (Bornkessel et al., 2004; King & Just, 1991). Comparing biclausal structures differing only in the first word ("AFTER/BEFORE the scientist submitted the paper, the journal changed its policy"), Münte, Schiltz, and Kutas (1998) found that BEFORE sentences with reversed chronological order elicited slow negative potentials over left anterior sites, relative to AFTER sentences, and that the magnitude of this negative difference was significantly correlated with verbal working memory capacity. Such effects may reflect individual differences in prefrontal cortex dopamine receptor concentrations. Vos and Friederici (2003) observed different patterns of both behavioral and ERP responses to disambiguating words in syntactically complex object-first relative clauses and object-first complement clauses; only high span readers, for example, responded to disambiguating words with a P600 (for other studies in which participants with different working memory span show different ERP patterns, see Fiebach, Vos, & Friederici, 2004; St. George, Mannes, & Hoffman, 1997; Vos, Gunter, Kolk, & Mulder, 2001).

Blasko and Kazmerski's work (this issue) shows individual differences in the way that healthy participants process metaphors and sarcasm, as well. Working memory span and vocabulary scores appear to be important determinants of how quickly and accurately metaphors are understood, and in how much difficulty individuals encounter when deciding that a metaphoric statement is literally untrue (as compared to false statements without metaphoric interpretations, e.g., "The beaver is a lumberjack." vs. "The rumor was a lumberjack.") as reflected in reaction times

and N400 amplitudes. Such data from individuals with different working memory capacities are essential for keeping theoreticians honest; metaphoric processing may indeed be automatic, but clearly not for all metaphors in all people at all times. In this sense, nonliteral language processing is no different than literal language processing.

Language Processing as an Experience

Viewed from the perspective of language as a brain function, one realizes that language is not just something that human brains process to understand, but a physical force that may alter the brain and its functioning. Indeed, psychologists are acutely aware that verbal instructions can have a significant impact on what participants view to be the task and how they should perform it. Words can alter what people look at (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Spivey, 1995), what they attend, and their choice of strategies in an experimental setting. Accordingly, researchers craft instructions with care so as to say what they mean and insure that each participant receives the same instructions, cognizant that they cannot completely control what the participants take them to mean. My sense, however, is that researchers do not routinely think much more deeply about the impact of their words on brain processing beyond that. Although words may be a source of misinformation about a past event (Loftus, 2005), and thus may affect memory for whether there was or was not any broken glass at the scene of an accident, it is generally considered unlikely to alter one's perception of reality—of the sensory here and now or of one's actions, except as a response to language content. This, however, is an invalid assumption.

In a dark room, a stationary light, nonetheless, appears to move (autokinesis effect). Remarkably, when participants are told what direction such a light might move (Sherif, 1935) or what words the moving lights might spell out (Rechtschaffen & Mednick, 1955), at least some participants actually report seeing the lights moving in particular directions or spelling out certain words. Words, thus, seem to influence what some people report seeing. Olfactory perception, likewise, is subject to verbal suggestion. O'Mahoney (1978), for example, informed a television or radio audience that a certain sound frequency could produce the perception of odors and found that some people reported detecting certain odors; others even reported allergic reactions to them. More recently, Herz and von Clef (2001) showed that the same physical stimulus—that is, an odorant—was sometimes perceived as a negative odor and at other times as positive odor, in large part due to the accompanying verbal label. At two different sessions, 1 week apart, participants were provided with five different odors (violet leaf, patchouli, pine oil, and menthol combined with 1:1 mixture of isovaleric and butyric acids), asked to sniff them, rate them on various hedonic scales, and to elaborate on their perceptual and interpretive responses. Unbeknownst to the participants, at the different

sessions the same odors were given different verbal labels, which affected both the hedonic ratings and participant's descriptions of the chemically identical odorant, although to varying extents for different odors. In a similar study employing event-related functional magnetic resonance imaging, de Araujo, Rolls, Velazco, Margot, and Cayeux (2005) replicated the susceptibility of odor (isovalric acid) pleasantness ratings to verbal labels "cheddar cheese" or "body odor" label and showed further that odors (and clean air) rated as pleasant were associated with greater activation in the rostral anterior cingulate/medial orbitofrontal cortex. A similar pattern was also observed in the amygdala bilaterally for the test (but not the clean air control) odor. The mere sight of a word, thus, affects what people think they smell and how pleasant they consider it, modulating activation in brain areas known to be sensitive to olfactory stimulation. Placebos may exact their influence via similar mechanisms. In sum, it seems that words influence sensory perception in all modalities, albeit to varying degrees for different stimuli in different people.

Without more work, researchers cannot elaborate on the mechanism(s) by which words influence perceptions, or how low (early) within each sensory system these influences reach, and what stimulus, brain, and personality factors affect the degree of susceptibility to verbal labels. It does seem, however, that words cue memories of various sorts and these memories have a top-down influence on the interpretation of sensory inputs, so that the same physical stimulus is sometimes perceived one way and at other times another. It is not a far stretch to imagine a similar mechanism of top-down *verbal framing* on the perception and interpretation of sensory inputs that happen to be linguistic.

Language and perception/cognition have long been thought to be related—indeed, it continues to be controversial just how much and the direction of their influence on each other, that is, that language and thought are functionally independent or, alternatively, that language shapes thought (Katz, Cacciari, Gibbs & Turner, 1998). Thus, language modulation of sensory–perceptual processing is neither surprising nor new. Over the past decade however, it has been clearly established that language—even a single word—directly affects the motor system, and not just trivially, via language production (oral or hand movements). In a series of experiments, Gentillucci and his colleagues (Gentilucci et al., 1991; Goodale, Meenan, Bulthoff, Nicolle, & Murphy Racicot, 1994; Jakobson & Goodale, 1991; Jeannerod, 1988) showed that words written on objects can, for instance, influence the dynamics of reaching and grasping movements toward those objects. To grasp an object, people first shape their fingers and then close in on the object. Object properties such as its size and shape influence both the selection of the type of grip and grasp kinematics. Recent work shows that words—about which participants are given no instructions—written on objects that are the targets of various arm/hand movements influence the control of the executed movements. For example, in one study, when the words *large* or *small* were written on objects to be

grasped, the initial size of the hand opening for grasping was altered accordingly, whereas when the words *near* or *far* were written on objects, the initial reach kinematics were affected (Gentilucci, Benuzzi, Bertolani, Daprati, & Gangitano, 2000). In another experiment, adjectives were less effective in altering the required movement, but verbs not only influenced control of the action but did so differentially, even though neither verb was directly related to the actual action that the participants were asked to perform. Specifically, the verb *sposta* (in English, *place*) speeded reaching velocity whereas the word *alza* (*lift* in English) influenced the placing movement.

These data underscore the importance of viewing language (linguistic input) from the brain's perspective: not just as a "special" sensory input that it must process for meaning or as an output that it must generate, but also as an experience that modifies (either short- or long-term) the brain circuitry that is somehow touched by its analysis. All linguistic input, thus, has both bottom-up and top-down effects and these effects are not limited to language processing. For the moment, it remains an open question whether the top-down effects of language on sensory–perceptual and motor processing are coincidental or whether they are a natural consequence of how the brain comes to give meaning to linguistic inputs (e.g., sensorimotor grounding).

In an embodiment view of language organization in the brain, language is embodied in the sense that it is built on the sensory and motor substrates that serve the human body; language processes effectively piggyback on existing sensory and motor maps of the body that have been found throughout the cerebral cortex. In this view, the neural structures responsible for the sensory features or motor actions expressed verbally also play a role in figuring out what the utterance means. Support for this hypothesis comes from studies showing that reading or listening to action-related sentences not only modulates the activity of the motor system, but does so in an effector-specific fashion: Statements about hand actions activate the hand motor area and statements about foot actions activate the foot motor area, etc. Buccino et al. (2001), for example, recorded motor-evoked potentials (MEPs) from hand or foot muscles following single pulse TMS of the hand or foot motor area in the left hemisphere delivered at the end of the second syllable of verbs in spoken sentences that described actions performed with either the hand or the foot, respectively. Hand MEPs were modulated by sentences referring to hand actions and foot MEPs by sentences referring to foot actions. Interestingly, MEPs in these same muscles are also modulated by observations of another's execution of the same actions (presumably via the mirror neuron system; Fadiga, Fogassi, Pavese, & Rizzolatti, 1995; Strafella & Paus, 2000). Mirror neurons are neurons that discharge not only during the performance of a goal-directed movement by an individual monkey or human but also when that same animal observes another individual performing a similar action (Ferrari, Gallese, Rizzolatti & Fogassi, 2003; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, &

Fogassi, 1996). Similar to monkeys, fMRI data localize the human mirror neuron system in the inferior parietal lobule (ventral premotor cortex, posterior portion of inferior frontal gyrus, and inferior parietal lobule). Observations of hand, foot, and mouth actions have revealed that the mirror system is somatotopically organized. Whether or not the human mirror neuron system is the substrate for the evolution of human language, as some have proposed, it attests to the close anatomical, and perhaps functional, link between motor systems and language processing.

CONCLUSIONS

Some readers may have expected me to answer some fundamental questions about literal language processing that they could then apply to the study of nonliteral language processing. Questions such as: (a) How many language areas are there? (b) Where are they located? (c) What are their functions? and (d) Is there any principled order to their circuitry?

Localizing "Language Brain Areas" and Their Functions

Appreciation of language as a brain function may help clarify why it has proven especially difficult to answer these fundamental questions, and why I believe that these may not be the best questions to ask. Asking how many language areas there are presupposes that there is a denumerable number of brain areas dedicated to language (and presumably to no other domain). At minimum, it presupposes that such brain areas and their precise functions can be reliably identified. There are no unequivocal criteria for defining functional maps of the brain, although a reasonable anatomical map of the cortex can be built from cytoarchitectonic, myeloarchitectonic, and receptoarchitectonic distinctions, and there are many relatively well-defined brain areas (e.g., Schleicher et al., 2005). Nonetheless, creating accurate brain function maps is hampered by the fact that brain areas and their functions may change with time, context, and experience (e.g., Toga & Thompson, 2003). It is hampered by the fact that a cell tells a very different tale, depending on the stimulus and context within which its function is probed. It is hampered by the fact that researchers are uncertain about what are the right levels or terms for defining mental brain functions.

Activity dependence notwithstanding, however, most aphasics do not recover the full extent of their prestroke language capabilities. Those compromised areas thus might be the ones dedicated to language processing. Perhaps they are, but just which areas are these? And, are they really essential and specific to language processing? Do they really leave nonlanguage functions untouched when damaged? Setting aside for the moment what researchers mean by *language*, neuroimaging data of various sorts have revealed considerable variability in the brain regions that

lead to particular aphasic syndromes. Although damage to the left hemisphere is much more likely than damage to the right hemisphere to result in some set of aphasic symptoms, damage to either hemisphere impacts aspects of both language comprehension and production, and not just in individuals with atypical sensory experiences or language histories (such as those who are congenitally deaf or blind). At the same time, however, it seems that not all Broca's aphasics have damage to Broca's area (or more accurately areas) as traditionally defined (see discussion in Kutas & King 1996) and not all patients with damage to Broca's area present with Broca's aphasia.[2] A similar argument holds true for Wernicke's area (BA 22 in the superior temporal-parietal lobe junction), and the angular gyrus, and the arcuate fasciculus—all parts of the classical language areas in the left hemisphere. In short, if one's only criterion for defining a language area were loss of (some) language function after damage to that area, they would be forced to tolerate some uncertainty in the specific brain loci so identified and in the consequences of their damage on language (and nonlanguage) behaviors.

Perhaps, then, researchers should add to this accounting all the areas whose activity is somehow altered during language processing (broadly construed) in healthy individuals with normal sensory experiences and areas that direct stimulation of which disrupts language processing. By this criterion, the count would jump dramatically to include regions of olfactory, visual, somatosensory, and motor cortex among others. As described, language processing is insidious, wending its way into the recesses of every lobe into areas whose activities are traditionally linked to nonlanguage processing. Are the sensory and motor areas that show activations with language stimuli critical for understanding or are they epiphenomenal? By this criterion, in any case, researchers would be hard pressed to maintain the assumption that these language sensitive areas are specific to language. Although most of these may not be essential for production, they may ultimately be shown to be essential for a true understanding of the broad range of expressions that a human language comprehender may encounter, depending on how meaning is constructed. This extensive and distributed localization of areas involved in language may not be surprising however, given the general finding that the same neurons that mediate experience—perception and action—also mediate memory for that experience.[3] Indeed, researchers would further expect that the relative contributions of different areas would change dynamically with the language task and the comprehender's knowledge, as it seems they do.

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[2]Broca's area (BA 44 and 45), as usually depicted, varies substantially from source to source but certain minimal areas are universally included: namely, a substantial amount of the cortex along the inferior frontal gyrus, almost all of the pars opercularis, and also parts of the more anterior pars orbitalis.

[3]Note that I do not mean to imply that various brain areas are equipotential with respect to various language functions or that there are no structurally, and to some extent functionally, well defined brain areas.

Localizing areas specific to language also requires determining not just what a brain area is sensitive to, but what its function really is. This endeavor would be helped by a consensus as to what the relevant language functions for localization should be, as well as on what constitutes unequivocal evidence for a functional link. This sort of consensus (and mapping) has turned out to be notoriously difficult to achieve even for much simpler functions than language. As information is inherent in the (continuously changing effective) connections between neurons, the brain does not make it easy to separate language as representation from language as process.

Initial attempts to localize global language functions such as speaking, listening, reading, repeating, naming, and joking with any specificity met with little success; these then are not the appropriate level at which brain functions are implemented for easy localization. Some researchers would claim greater success at localizing meaning, syntax, phonetics, phonology, morphology, and discourse using tasks such as phoneme detection, lexical decision, generating related words in a particular word class, word class judgments, ambiguity resolution, grammaticality or sense judgment, paraphrasing, abstract or concreteness judgments, cross-language translation, judgments about metaphoricity, etc. (Bevalier & Neville, 2002). However, rarely have task analyses been precise enough to allow an unequivocal pronouncement of what functions such tasks actually exercise.

Even if one were to take these tasks at face value, one would be forced to relinquish any notion of a one-to-one mapping between the classical language areas and specific language functions. Both Broca's and Wernicke's areas appear to contain functional subdivisions, although the functional details are controversial (Bookheimer, 2002; Martin, 2003). Broca's area, for example, is unquestionably involved in language production and control of articulation. Still, it is unclear whether speech apraxia is a manifestation of its malfunctioning or that of the underlying insula. Posterior regions of the left frontal operculum (BA 44) may subserve articulatory-based working memory (Hickok & Poeppel, 2004) or sequencing more generally. More medial aspects of Broca's area may mediate syntactic processing (Grodzinsky, 2000) or syntactic or more general aspects of working memory (Fiebach, Schlesewsky, & Friederici, 2001). Anterior aspects of Broca's area have been linked to semantic processing (Gabrieli, Poldrack, & Desmond, 1998) or selection processes, more generally (Thompson-Schill et al., 1998). Broca's area, thus, has been linked to language at the level of sound, structure, and meaning, especially (although not just) for production. Broca's area, however, is also activated by nonlanguage tasks leading to the proposal that it is not language specific and may be involved in more general processes such as segmentation, planning, working memory, or selection processes, among others.

The traditional Wernicke's area, the posterior superior temporal gyrus (STG) seems to be important for phonological decoding (Buchman, Garron, Trost-Cardamone, Wichter, & Schwartz, 1986; Poeppel, 2001). The STG is more gener-

ally sensitive to the acoustic properties of speech (Binder et al., 2000; Scott, Blank, Rosen, & Wise, 2000), although left and right STG may mediate somewhat different aspects of acoustic processing (Ivry & Robertson, 1998). Anterior portions of the STG also may have a role in syntactic processing (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004; Meyer, Friederici, & von Cramon, 2000). More inferior parts of the temporal lobe seem to have a role in the interface between sound and meaning (Binder et al., 1997; Dronkers et al., 2004), although not just for language (Lewis et al., 2004). More inferior areas, in the inferior temporal gyrus and fusiform gyrus, seem to be involved in reading, naming, and concept retrieval. Finally, the visual word form area in the posterior fusiform, although consistently activated in reading tasks (review in Cohen et al., 2002), is also active in other tasks (Price & Devlin, 2003). Clearly, the functional story with regard to Broca's and Wernicke's areas is not yet in. Still, it would seem safe to conclude, in contrast to more conventional views, that both regions are involved in comprehension and production and that there is no obvious boundary that separates the processing of lexical access or syntactic parsing from semantic or pragmatic processes. In sum, the network of areas engaged during (if not essential for) language processing is widespread, complex, and dynamic.

As already noted, at a practical level it has also proven quite difficult to localize functions because brain processing is so context sensitive, with context intimately involved in the constructed and stored perceptions. Researchers have much to learn about how context—local or otherwise—contributes to meaning construction, but certainly it seems sensible to probe the system with the sort of complex wholes to which human brains have become adapted rather than (just) isolated parts that have no neural reality, and, if parts are used, then the inferences drawn need to be appropriately tempered.

Perhaps, researchers should seriously reconsider the possibility that there may be no language specific functions, per se, to localize. Perhaps, many core linguistic facts—usually attributed to competence—can indeed be explained by the action of general brain computations that are not inherent to language. Kluender (1998, 2005), for example, has argued for an approach that assesses just how far generic brain processes of working memory and attention can get in explaining basic word order effects, dependencies between discontinuous sentence elements, and other syntactic phenomena without resorting to the construction of innate linguist competence. Ueno and Kluender (2003) hypothesized that many of the processing difficulties associated with moved constituents (including filler-gap dependencies) may index deviations from a general preference for canonicity. Coulson (this issue) likewise appeals to general neural interpolation mechanisms in perceptual processing as an analogy for meaning construction in language.

So, in conclusion, how many language areas are there and where are they located? If there are any language specific areas, they will be far more than the handful making up the classical language circuit connecting Broca's and Wernicke's ar-

eas, given that routine language processing seems to engage sizable chunks of the cortex in both hemispheres, as well as subcortical regions (see Van Lancker Sidtis, this issue). The language functions of the right hemisphere are arguably as critical for comprehension as those of the left and, I maintain, not limited to nonliteral language processing, although it is possible that its functions are more taxed or more tuned to deal with certain types of nonpropositional than propositional language. Clearly, more direct within (well-characterized) individual comparisons of literal versus nonliteral, as well as of different nonliteral language types, will help researchers better understand each hemisphere's contribution to online language processing and at the same time provide us with a neurologically defensible means of defining the functional or anatomical distinctions or gradients between literal and nonliteral language. As the two hemispheres are heavily interconnected and working in tandem, any viable theory of human language processing will have to explain not only their individual capacities, preferences, and contributions but their coordinated action—no small feat. Nonetheless, the slight head start given to one hemisphere over the other by virtue of lateralized stimulus presentation has proven amazingly effective in revealing the differential sensitivities of the two hemispheres to different psycholinguistic factors and thus would seem to be a relatively inexpensive way of honoring the cerebral divide. As a first step, it could be very informative to detail the circumstances under which the central field pattern resembles that seen with right visual field presentation, left visual field presentation, or some additive, underadditive, or overadditive combination of the two.

A viable theory of language processing by the two hemispheres also will need to accommodate the changes that occur in hemispheric functioning, language processing, and other brain functions with development and (normal and abnormal) experiences. Individuals differ in many respects and at least in some cases these differences not only influence what people know but in how they use what they know to make sense of language input. Information availability and accessibility would seem to be crucial factors to determine what information is activated, when and for how long, what is stored and available for subsequent use as background information for making sense of an utterance or a piece of text. Rather than ignoring individual and group differences in working memory capacity, general and expert knowledge, physical and intellectual experiences, personality, emotional traits and states, age, biological gender, etc., the time has come to use these factors to peel away performance variance from whatever core of language competence remains. Literal or figurative, these experiences are the background context used to construct meaning. How? To the extent that what people understand is shaped by their personal sensory and motor experiences, as some have suggested, then this should be especially evident in individuals with atypical sensory or motor experiences. Under this view, much could be gained from studying metaphorical processing given the appropriate contrasts in individuals with congenital deafness or blindness or those heavily practiced in some sensory or motor skills. Evidence of

changes, even after short-term sensory deprivation, suggests that it might be possible to test notions of embodiment by temporarily changing the brain's representation of its body.

What are the functions of language brain areas? Together, these areas support language comprehension and production (see Demonet, Thierry, & Cardebat, 2005, for a review of neuroscience techniques for studying language and core findings). Individually, they support a host of less obvious functions most, if not all, of which are unlikely to be language specific. It is difficult to imagine that language processing is totally insulated from other cognitive processes, such as attention and memory, when the likelihood that an experience will take hold is very much a function of the accompanying attention. Practice is good, but practice with attention is golden. Is there any principled order to their engagement? Yes, there is an order to the neural flow through the relevant circuitry but it is not fixed in space or time, but rather adapts to language processing tasks and communication goals and the brain–body that presides over communication. Clearly, the production and comprehension of figurative language are important aspects of brain functioning, which therefore can be most effectively investigated if researchers are mindful of their relation to other brain functions, as well as of the ways that the interconnected hemispheres, timing, context, and experience are known to matter.

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