

To appear as chapter 18 in Montserrat Sanz, Itziar Laka, Michael Tanenhaus (eds.), *Language Down the Garden Path: The Cognitive and Biological Basis for Linguistic Structure*, Oxford University Press, 2012.

The mirror theory of language: a neuro-linguist's perspective^{*}

Yosef Grodzinsky
Department of Linguistics
McGill University

How many principles govern our mental life? This age-old question has occupied the minds of many: from Plato to Fodor, through Lichtheim and Hughlings-Jackson, modularists have debated holists regarding the number and type of principles that need to be assumed in order to explain complex behavior. This debate has lingered on: As I write these lines, many laboratories are engaged in experiments aimed at discovering similarities and differences between motor and linguistic aspects of human behavior. Is there anything new in the current format of the debate? Has it led to important discoveries? What is its future and how would it affect a future neuro- and psycholinguistics? In this brief note I will try to provide tentative answers to these questions, while looking at the mirror-neuron theory through the prism provided by Broca's area and its cognitive functions.

1. MODULAR VS. HOLISTIC THEORIES OF COGNITION: THE PAST

Neurolinguistics is perhaps the first cognitive discipline in which modularist claims were voiced in modern times. Broca's celebrated 1861 paper (for its English translation, see Grodzinsky & Amunts, 2006), in which he claimed to localize *le siège de la faculté du langage articulé*, unambiguously endorsed a modular thesis, arguing that aphasia (or *aphémie* as he called it) evinces a unique left hemispheric location for language production (*langage articulé*), a region that later became known as Broca's area. Thus the first modern neurocognitive module was borne (I am excluding Gall's phrenological

^{*} This paper began as a presentation in the Cognitive Seminar of the interdisciplinary Center for Neural Computation, the Hebrew University of Jerusalem. I am grateful to the participants for their extensive comments during the presentation, especially to Merav Ahissar, who invited me to present, and to Ari Rappoport. Thanks also to Galit Agmon who commented on the manuscript.

I would like to acknowledge the hospitality and support of the Edmund and Lily Safra Center for Brain Research (ELSC) in Jerusalem. Finally, I thank the following agencies for their continued support: NIH (grant #000494), SSHRC (standard grant #410-2009-0431), and Canada Research Chairs.

writings from discussion, even though they were clear antecedents to Broca's research program). Broca's remarks were met with skepticism: The anatomist Gratiolet argued against localization, bringing in (rather dubious) evidence that linguistic functioning can be retained after frontal damage (Zeki, 1993, ch. 2). His objections were followed by Hughlings-Jackson's (1874) more serious proposal that aphasia is not a loss of linguistic capacity, but rather, of a more general ability to concatenate symbols ("asymbolia"). For him, aphasia, apraxia, and agnosia were all manifestations of the same disturbance, an inability to sequence symbols into functionally meaningful units.

Both Broca's and Hughlings-Jackson's positions have since been repeatedly recapitulated, from varied perspectives and through different theoretical frameworks. At the neural level and cytoarchitectonic level, anatomists and physiologists realized that the brain must be compartmentalized. Ramón y Cajal and Golgi convinced the world that there are units called "neurons". Anatomists like Brodmann saw compartments at the cytoarchitecture and conjectured that these must have functional correlates (cf. Brodmann, 1908, see Grodzinsky & Amunts, 2006, for English translation). And Penfield recorded intra-operatively, and drew a functional map of the somato-sensory and motor cortices. Not that physiology lacked holists: Lashley (1950), for example, argued for the principles of "mass action", according to which all brain parts work together to accomplish any task, and "equipotentiality," indicating that all regions are equally likely to support any behavioral function, given the proper conditions.

Cognitivists, appearing on the scene a bit later, were likewise divided: while Chomsky, Fodor, and their followers argued for well-delineated cognitive domains, holists such as Rumelhart & McClelland (1986) and many others maintained the opposite, and so the current debate on modularity was renewed, way before the discovery of mirror neurons.

2. BEVER'S HOLISM

Tom Bever played an important role in the early cognitive debate, and in the attack on the modularity of language. In *The Cognitive Basis for Linguistic Structures* (1970), he made a bold attempt to derive (psycho)linguistic generalizations from perceptual principles. The huge impact his paper had on psycholinguistics stemmed not only from insights and empirical discoveries it contained, but also, from the fact that it tried to construct a theory

of language use that minimized the role of grammatical principles, with the hope of eventually creating psycholinguistic models from which grammar is completely cleansed out. Bever thus aligned himself with the holist tradition.

This view on sentence processing was espoused by Fodor, Bever & Garret's (1974) famous textbook. They argued that humans process sentences in a strategy-based manner (strategies being by and large domain-general), but still reserved a role for grammar in human mental life: it was to serve as a back-up, to be used for specialized, "nonpsychological" tasks. Fodor later changed his view, and in *The Modularity of Mind* (1983) argued for the modular nature of the cognitive system, syntactic knowledge used on line in language processing being a prime example of a module. This note, in keeping with Fodor's line of argumentation, first seeks to establish criteria for modularity, which it then uses to assess recent claims that language is *not* a module, and that linguistic behavior is a mere instantiation of an overarching "perception-action loop" that spans all higher perceptual-motor skills.

3. CURRENT HOLISM: THE MIRROR THEORY OF LANGUAGE

Chomsky's suggestion (1980) that there is a "language organ" in the human mind/brain drew much fire. Rizzolatti & Arbib's (1998, *passim*) recently attacked this position, arguing that a communicative connection between an actor and an observer begins as "the actor... recognize[s] an intention in the observer, and the observer...notice[s] that its involuntary response affects the behavior of the actor. The development of the capacity of the observer to control his or her mirror system is crucial in order to emit (voluntarily) a signal. *When this occurs, a primitive dialogue between observer and actor is established. This dialogue forms the core of language.*" (1998, p. 191, italics added). Rizzolatti & Arbib constructed a "pre-linguistic grammar" for monkey action, whose rules are said to bear a striking similarity to linguistic rules. This grammar, they then speculated, underwent expansion to become the grammar of human language. The origin of language and perception-action, as reflected in mirror-neuron governed behavior, are therefore one and the same, and the governing principles seem to be quite similar. More recently, Pülvermüller & Fadiga (2010) proposed that "*because language, music and body action have similar hierarchical syntactic structures, the principal underlying brain mechanisms might be the same*". (p. 357, italics added).

These perspectives are very much in the spirit of Bever's *Cognitive Basis*, though unlike Bever, they do not go into linguistic details, but rather, seek physiological support which I discuss below (see Grodzinsky, 2006a; Venezia & Hickok, 2009, for recent critiques). In the remainder of this short note, I will try to establish tests for modularity, and discuss the relation between language and the perception-action loop in light of these.

4. FOUR TESTS OF MODULARITY

If we are interested in whether two (or more) classes of behaviors belong in the same cognitive unit, we must ask whether they are governed by the same set of processes, rules, and structural constraints, and whether their cerebral representation, and the shape of the behaviors they produce, is the same (or at least similar). Osherson (1981) puts it very succinctly:

... let C_1 and C_2 be two classes of processes and structures that conform to two sets of interlocking and explanatory principles, P_1 and P_2 , respectively. If the properties of C_1 can be proved not to be deducible from P_2 , and likewise for C_2 and P_1 , then distinct faculties are (provisionally) revealed.

Fodor (1983) suggests several perspectives from which the modularity of cognitive systems from one another can be assessed: **a.** the computational perspective, in which we inquire whether the structural principles (*a k a* knowledge) that govern one system can be deduced from those of another; **b.** the implementational perspective, which examines identity or distinctness of the processes that implement this knowledge in use. **c.** the developmental perspective, in which one looks at similarities and differences in the way cognitive systems unfold in the developing child; **d.** the neurological perspective, which explores brain loci that support each system, and their anatomical and physiological properties. In light of these, I shall now discuss 2 recent holist claims: at the computational level, I shall try to evaluate Pülvermüller & Fadiga's (2010) claims for the structural unity of language, music and action, and at the neurological level, I shall try to assess Fazio et al.'s (2009) interesting study of aphasic patients' perception-action abilities and their correlation with their linguistic deficit.

5. TWO TESTS OF MODULARITY IN BROCA'S AREA

5.1. The computational perspective

A perspective of importance is the computational one – where structural principles are considered. Realizing that, Pülvermüller & Fadiga (2010) detail their argument for the unity of structural properties across the musical, actional, and linguistic domains:

The hierarchical structure of embedded or ‘nested’ sentences is paralleled in music and bodily interaction: a centre embedded sentence (“*The man {whom the dog chased} ran away*”) has the same nested structure as a standard jazz piece (theme {solos} modified theme) and complex everyday action sequences (open door {switch on light} close door). In each case, a superordinate sequence surrounds a nested action or sequence. Because language, music and body action have similar hierarchical syntactic structures, the principal underlying brain mechanisms might be the same. (p. 357)

This discussion suggests that the hierarchical structure that is found in a center embedded relative clause is akin to that found in a musical phrase or an action sandwiched between two others. It is founded on Pülvermüller’s (2010) modeling work, which focuses on the hierarchical structure found in relative clauses, and on a push-down stack that’s deemed necessary for its analysis.

Pülvermüller & Fadiga’s argument is of a form similar to Osherson’s: they assume L , a class of linguistic structures that conforms to a set of principles P_L ; they also assume M , a class of perception-action structures that conforms to a set of principles P_M . And when applying the computational test of modularity to these two systems, they conclude that structural properties of L are deducible from P_M and vice versa. As the property of embedding is common to both L and M , a single set of principles is said to govern the linguistic, musical and action syntax.

Pülvermüller & Fadiga’s seem to have identified a principle (or structural property) that is found across domains. Are they right, then, in concluding that language, music and action have similar syntax, and in conjecturing that “the principal underlying mechanisms might be the same”? We are not yet in a position to decide, for we must first ensure that the property at issue – embedding (and center embedding) in relative clauses – is indeed “principal”, namely characteristic of each domain. Only if it is can cross-domain similarity with respect to it be used to drive a holist argument. As Pülvermüller & Fadiga do not discuss this important question, I will in what follows.

How can we decide whether a putative property is characteristic of a cognitive domain? How characteristic is embedding of natural language syntax? Before we get into specifics, let's reflect for a moment on another cognitive domain – face recognition. Researchers in this area agree that a mere phenomenology of faces, and of the way people look at these to decide if they are familiar, is not sufficient for an understanding of the underlying ability. Additional, less immediate, properties need be taken into account: the common inability to recognize faces when they are upside-down, the “Thatcher illusions” in which viewers fail to notice the inversion of face-parts when the whole face is upside-down, the common success in face recognition even when the image is compressed along one axis, and the like (see Sinha et al., 2006 for an inventory of relevant properties). Without these, the quest for a theory of face recognition, and the underlying brain mechanisms, is hopeless. Linguists have likewise long recognized the importance of properties of language that are found beyond those that meet the eye (or the ear) for our understanding of language (e.g., Ross, 1967; Rizzi, 1990, and many, many others).

To begin with, note that relative clauses are not the only embedded ones. What makes them special is that they are subject to constraints from which other types of embedding are exempt. To see that, consider (1a)-(2a). These sentences contain a [bracketed] embedded clause, but only (2a) is a relative clause. Next, consider the relation between question formation and embedding in English. Questions are formed by the conversion of the element we are inquiring about into a question expression (*which dog*), and then placing it at the front of the sentence. This works in (1b), but not in (2b), which is ungrammatical hence marked with an asterisk. Note that the question intended in (2b) is semantically coherent, as seen from the paraphrase in (2c). Thus relative clauses represent a special type of embedding, one that is subject to a syntactic constraint from which other types of embedding are exempt:

- | | | |
|-----|--|----------------------|
| (1) | a. The man believed [the dog chased Mary] | |
| | b. Which dog did the man believe [chased Mary]? | <i>grammatical</i> |
| (2) | a. The man whom [the dog chased] ran away | |
| | b. *Which dog did the man [whom chased] run away? | <i>ungrammatical</i> |
| | c. Which is the dog such that the man whom it chased ran away? | <i>possible</i> |

A second, perhaps related, property concerns a constraint on possible meanings of relative clauses. At issue are ambiguities that arise when two positions in a sentence host different quantifiers. Thus (3), a sentence that contains an embedding, can have either the meaning in (3a) or that in (3b).

- (3) Some man believes that every dog was chased
- a. Some (particular) man believed that every dog was chased *possible*
 - b. For every dog, some man (or another) believes that it was chased *possible*

The ambiguity here is between a reading in which a single man has a belief about all the dogs in the discourse (3a), and a reading where the belief about each chased dog is held by a distinct man (3b). Curiously, as Rodman (1976) famously observed, this ambiguity is not attested in relative clauses:

- (4) Some man who chased every dog knew Mary
- a. Some (particular) man who chased every dog knew Mary *possible*
 - b. For every dog, some man (or another) who chased it knew Mary *impossible*

Here, only a reading that is parallel to (3a) – that a single man who chased every dog had the property of knowing Mary. The one parallel to (3b) – that for every dog there was a distinct man who had the property of knowing Mary – is unavailable. Importantly, both instances contain an embedded clause – a complement clause in (3) and a relative clause in (4).

Whence the difference between the two types of embedding with respect to both question formation (1)-(2) and ambiguity with multiple quantifiers (3)-(4)? Why are relative clauses more constrained, and are the phenomena in (1)-(2) related to those in (3)-(4)? Linguists have long debated these phenomena (for discussions from both syntactic and semantic perspectives, cf. Rodman, 1976; Farkas, 1981; Reinhart, 1997; Johnson, 2000, among others). I will not dwell on these. My point is simple: a discussion of relative clauses is severely lacking if it fails to consider these intricacies, because to understand the structure of language, one needs figure out not only what can be said, but also what cannot. In this respect, research on language is similar to the study of face recognition discussed above. Pülvermüller & Fadiga's account, that tries to extrapolate

from one property of relative clauses – center embedding – to language in general, seems to stop short of covering the necessary ground in the language domain, unfortunately, even if one restricts discussion to embedded relative clauses.

Similarly, a quest for parallels between rules of language and those of music or action must examine whether these domains contain phenomena akin to those in (1)-(4). I am not aware of such parallels. Analogies between language and music that have been discovered do not involve syntax or semantics (cf. Lehrdahl & Jackendoff, 1983, *passim*). Unfortunately, neither Rizzolatti & Arbib, nor Pülvermüller & Fadiga discuss such phenomena. A complete evaluation of the holist claim thus awaits further exploration, leaving the modular perspective unaffected, it would appear.

5.2. The test of functional anatomy

A second important modularity test pertains to functional anatomy: are the functions under consideration supported by the same brain regions? Do lesions to a given region produce similar functional deficits across domains? Are brain areas that support each function anatomically distinguishable? Holists have long used this test to argue against the modularity of language. Thus Schuell (1965), reluctant to view aphasia as a language deficit, referred to it as apraxia for speech; Kimura (1973a,b) likewise argued that the proximity of Broca's area to supplementary motor cortex, the cooccurrence of apraxia and aphasia, and the correlation between the dominant hemisphere and dominant hand indicates that at the very least, language production and motor planning go hand in hand. The mirror neuron theory and its extension to language, due to Rizzolatti, Fadiga, and their colleagues (Rizzolatti & Arbib, 1998; Rizzolatti & Craighero, 2004, Fadiga et al., 2006) was the next step.

Here are the main empirical arguments of the mirror-neuron theory of language in a nutshell:

- a.** Monkey's F5, the region in which mirror neurons are mostly found, is thought to be the precursor of the human Broca's region, in which major linguistic functions are believed to reside (Petrides et al., 2005).
- b.** Broca's region, that contains mirror neurons for speech, moreover contains mirror neurons for action observation (Rizzolatti & Craighero, 2004).

c. Broca's aphasic patients are deficient sequencing both perceived actions, and linguistic objects such as words and sentences; lesions to this region, moreover, distinguish comprehension of actional and non-actional (Fazio et al., 2009).

Fadiga and his colleagues, in a series of impressive experiments, have explored this path extensively, testing speech in healthy adults by blocking or enhancing Broca's area with TMS, and investigating language in patients with lesions in this area (cf. Fadiga et al., 2002; Roy et al., 2008, D'Ausilio et al., 2011).

Space limitation preclude extensive discussion of all these arguments, so I will restrict myself to work pertaining to language, not speech, namely to the study of action and language sequencing in Broca's aphasia, as investigated in a creative experiment conducted by this group (Fazio et al., 2009). Their idea was to see whether Broca's area is entrusted not only with linguistic, but also with action-perception functions, through experiments with patients who suffer from Broca's aphasia without apraxia. Support for the mirror theory would come from a demonstration that these patients are equally impaired in language and action-perception. They thus tested the sequencing abilities of 6 patients in both action-perception and language, and compared them to neurologically intact controls. For perception, they prepared videos of actions and events that involve motion (e.g., a person opening a notebook and writing, a door closing), sampled 4 discernible and representative snapshots from each, and requested the patients to order these snapshots so that they make up a coherent sequence. The snapshots were moreover divided into 2 conditions: scenarios with human action (e.g., a person opening a door or bowing), and those that contained a physical event (e.g., a bicycle falling). For language, they prepared written word-pieces (e.g. *cam/mi/na/re*: to walk) and sentence-fragments (e.g., *press/the button/to open/the door*) which they scrambled. They then asked the patients to sequence these fragments into coherent linguistic objects. If Broca's area governs the sequencing of both linguistic and actional perceptual representations, one would expect the patients to fail on both tasks.

Fazio et al. assume that "sequencing" is a cognitive function, and investigate whether it governs both linguistic and perceptual abilities, in keeping with Osherson's dictum: they assume L , a class of linguistic behaviors governed by a set of processes P_L ; they also assume M , a class of perception-action behaviors governed by a set of

principles P_M . They seek to show that the underlying process is one and the same ($P_L = P_M = \text{sequencing}$), which is moreover localized in Broca's area, as a lesion in this locus results in a parallel sequencing impairment in language and action-perception.

They report that their patients evinced impairment in both tasks, failing to properly sequence the action snapshots as well as the language fragments. Errors were, moreover, structured in 3 interesting respects: first, there was a group (patients/controls) by condition (human action/physical event) interaction; second, the patients' action sequencing deficit on human *transitive* action snapshots correlated with their linguistic sequencing one; this was not the case with intransitive actions. As humans but not physical objects have goals, this pattern of selectivity suggests a loss to the abilities to sequence goal-oriented activities, which is reminiscent of mirror neuron firing patterns in the monkey. The cross-species similarity that Fazio et al. notice leads them to conclude that Broca's area, "the putative human cytoarchitectonic homologue to monkey area F5... may form a crucial node of the human mirror-neuron system" (p. 1986). As the language and action-perception deficits correlated, they conclude that this brain region

"...might have specialized in encoding complex hierarchical structures of goal-directed actions, and to eventually apply these pragmatic rules to more abstract domains. Therefore, the language-related functions sub-served by Broca's region could be the most eloquent part of a more general computational mechanism shared by multiple domains." (p. 1987).

Fazio et al.'s imaginative experiment thus takes us from a language deficit to a sequencing deficit to a generalized role of Broca's area. If they are right, then this region, traditionally the bastion of the human "language organ", is turning out to be a special case of a more general ability, very much in the spirit of Hughlings-Jackson's asymbolia.

6. BROCA'S AREA IS NONETHELESS MODULAR AND LINGUISTIC

Fazio et al.'s experiment is a real challenge to modularists. Most would agree with the logic behind their inquiry, but I suspect that after careful scrutiny, only few would agree with their conclusion. Below I detail some arguments against the conclusion that Broca's aphasic patients suffer from a generalized sequencing impairment and that an overarching sequencing function resides in Broca's area. Finally, I discuss results that lend empirical support to Broca's old idea: that Broca's area is a language region.

6.1. Fazio et al. revisited

Extended reflection on Fazio et al.'s results yields alternative interpretations. For that, we need to delve into details. To begin with, consider the design: Fazio et al. compare error rates on the language and action-perception tasks. But do we know that the tasks were on a par? I find this question exceedingly difficult to answer. Let us try to compare the tasks, in the hope of finding dimensions of similarity.

Simply put, to sequence a set of elements is to identify for each its immediate successor. In this experiment, each trial has a unique solution. Once the first element is found (a hard task in itself) its immediate successor requires pairwise comparison between the remaining elements, until an optimal choice is made. This action is then iterated until the inventory is empty. This is a rather difficult task, which is made even more difficult when we consider that it involves action snapshots, not a real video, which forces participants to use visual imagery in order to complete the frames that were not sampled. Two mitigating factors are (i) the absence of a typology of the elements that feature in the event, as they all appear in every snapshot, as the only differences between snapshots seem to be related to motion; and (ii) the fact that well-formedness is done locally and successively between pairs of images, and may thus not tax memory all that much.

In the language task, matters are different: sequencing requires a typology of the elements (words) into lexical categories and semantic types; no imagery is necessary; there may not be a unique solution (cf. press/the button/to open/the door vs. to open/the door/press/the button); and lastly, the determination of well-formedness cannot always be local, as in many instances, it can only be done on the whole string. These two tasks therefore appear quite different.

Moving on to the results, it turns out that error rates in scene sequencing and in sequencing linguistic objects are correlated. This is interesting. But in light of the above discussion, this result is difficult to interpret, as a different notion of “sequencing” is invoked by each task.

A second salient result is the group (healthy/aphasic) by error rates per condition (human/physical) interaction. This result may be very important, but we must first be sure that both conditions are equally difficult. This may not be so. As Fazio et al. themselves note, there may be differences in difficulty caused by the nature of the scene at issue: all

depicted physical events involve a single object (e.g., a bicycle falling), and most naturally translate into intransitive statements, whereas the human action scenes are mixed (a man reaching for a bottle vs. a man bowing). As far as one can tell, sequencing transitive scenes may be harder to parse and sequence than intransitive ones. Indeed, it appears (indirectly) that the intransitive human action scenes yielded lower error rates. Therefore, a fair comparison would pit errors in sequencing snapshots of physical events against errors in *intransitive* human actions. And yet, Fazio et al.’s central result – the group by condition interaction effect – was obtained when error rates in *all 14* human action scenes were pitted against error rates in the 5 physical event scenes. Thus, one cannot rule out the possibility that the transitivity of 8/14 transitive actions accounts for the increased error rates on the human action condition, rather than their being human actions, as Fazio et al. suggest.

6.2. What the deficit in Broca’s aphasia is not

The difference in patients’ error rates in human actions and physical events may be an important result. Is it consistent with the extant literature? I am not sure. To take one example, in Grodzinsky (1995), a task somewhat similar to Fazio et al.’s language sequencing task was used. Patients were asked to sequence sentence fragments (e.g., *the priest | covers | the nun; the book | is covered by | the newspaper*) so that the resulting sentence would match a picture. They received several sentence types (5), in which syntax (active/passive) and animacy (human/object) were systematically manipulated. A sketch of the results, shown in the rightmost column, indicates that performance was unaffected by the nature of the actors. It was affected, however, by the syntactic properties of the sentence in question. Performance dropped to chance in passive (which, incidentally, contained no embedding) regardless of whether or not participants were human.

(5)	a. The priest covers the nun	<i>Active-human</i>	OK
	b. The nun is covered by the priest	<i>Passive-human</i>	Chance
	c. The book covers the newspaper	<i>Active-object</i>	OK
	d. The newspaper is covered by the book	<i>Passive-object</i>	Chance

We can now return to Pülvermüller & Fadiga’s work and their claims that regard the sentence level. They suggest that “the important role of Broca’s area in understanding the

grammar of sentences is paralleled in nonlinguistic modalities” (p. 357), citing Fazio et al.’s experiment, and a pionerring experiment that tested relative clauses in aphasia (Caramazza & Zurif, 1976). Even if we accept the way Fazio et al. interpret their data, it is still not clear how exactly the pattern they see is related to relative clauses, especially in light of the fact that the language tests in Fazio et al.’s study contained no embeddings.

Moving on to relative clauses, note that Caramazza & Zurif ‘s early work was restricted to one type of relative clause (6a). However these constructions manifest a richer variety, dividing into 4 basic types: by the position of the [bracketed] embedded clause (center-embedding (6-7a) or right-branching (6-7b)), and by the position of extraction – the place inside the embedded clause to which the relative head (the man in (6-7a)) is related. It can function as either object (6a-b) or subject (7a-b) of the [bracketed] embedded clause. These properties enable a rich picture of relative clause comprehension in health and in brain disease. Indeed, this set of sentences has been subject to extensive testing with Broca’s aphasic patients, revealing a robust selectivity pattern (Grodzinsky, 1989; Sherman & Schweickert, 1990, and many others; see Draai & Grodzinsky, 2006a,b, for a review and a retrospective quantitative analysis of 32 patients’ comprehension scores).

(6) a. The man whom [the dog chased] knew Mary	<i>Center embedded Object relative</i>	Chance
b. Mary knew the man whom [the dog chased]	<i>Right branching Object relative</i>	Chance
(7) a. The man who [chased the dog] knew Mary	<i>Center embedded Subject relative</i>	OK
b. Mary knew the man who [chased the dog]	<i>Right branching Subject relative</i>	OK

The results are clear cut, as the rightmost column indicates: Broca’s aphasic patients are selectively impaired, but their deficit is not related to embedding or an embedding contrast (i.e., when (6a-7a) is compared to (6b-7b) no difference is found). That is, when embedding is manipulated their performance pattern is unaffected. The pattern of selectivity emerges when the data is partitioned by displacement. Namely, performance on (6a-b) is at chance and significantly worse than the near-normal performance on (7a-b). Related results are obtained in fMRI in health: Santi & Grodzinsky (2010) conducted an adaptation study with the 4 types of relative clauses. The results: the anterior part of Broca’s area, Brodmann’s area 45 of the left hemisphere, is selective to the same

distinction. A more posterior part, Area 44, was activated for both embedding and relative type. Crucially, no brain area was selectively activated by embedding type. It is difficult to see how this set of results would be accounted for by Pülvermüller & Fadiga's proposal, and moreover how they would generalize to action or music.

The deficit in Broca's aphasia, then, does not seem to be directly related to sequencing, to embedding, or to the contrast between human action and physical events. We might wonder what it is, and what it tells us about the role of Broca's region in cognition.

6.3. *What Broca's area does*

I hope to have convinced a reader that the mirror-neuron theory of language, at least in its present form, is insufficiently specified to establish precise action-language parallels, and to account for patterns of impairment and sparing in aphasia. I have also hinted that imaging evidence presents a picture in which subtle linguistic distinctions are evident. A full-fledged discussion of alternative perspectives on Broca's region is obviously beyond the limited scope of this note (for my own position, see Grodzinsky, 2000, 2006b; Grodzinsky & Friederici, 2006; Grodzinsky & Santi, 2008). I will only mention two additional facts that bear direct relevance to the current discussion:

a. Broca's aphasic patients who speak different languages exhibit differential performance on passive sentences and relative clauses, in a way that correlates with the syntactic properties of their language. As we have seen, patients generally have little trouble comprehending active sentences, and they are at chance in passive sentences in languages like English (as well as French, Spanish, and Hebrew). However in German and Dutch, their performance in passive is well above chance, not distinguishable from their comprehension level of actives (e.g., Friederici & Graetz, 1987; Burchert & de Bleser, 2004):

- | | | |
|-----|---------------------------------|--------|
| (8) | The woman was pushed by the man | Chance |
| (9) | Der Vater wird vom Sohn geküsst | OK |

Details aside, it is difficult to imagine how this contrast can be accounted for without an allusion to syntactic differences between English/Hebrew/Spanish passive and Dutch and German. Once the difference in basic word order between these classes of languages is

considered, the contrast in performance follows (Grodzinsky, 2006b).

Another cross-linguistic puzzle arises with relative clauses. Above I discussed the subject-object asymmetry in relative clause comprehension (10a-b). This result is obtained in English, Hebrew, and Spanish (see Drai & Grodzinsky, 2006a for a review). Yet in Chinese, the opposite pattern is observed (Law, 2000; Grodzinsky, 2000).

- | | | |
|------|---|--------|
| (10) | a. The cat that [chased the dog] was very big | OK |
| | b. The dog that [the cat chased __] was very big | Chance |
| (11) | a. [__ zhuei gou] de mau hen da
<i>Chased dog that cat very big</i>
The cat that chased the dog was very big | Chance |
| | b. [Mau zhuei] de gou hen xiao
<i>Cat chased that dog very small</i>
The cat that chased the dog was very big | OK |

This mirror-image performance pattern across languages correlates with an important syntactic contrast between English and Chinese – the position of the relative head. Once again, a precise account of these complex facts is not likely to emerge unless subtle distinctions are introduced.

b. When healthy participants listen to sentences, Broca's area is selectively activated by different syntactic relations; embedding is not one of them (Ben Shachar et al., 2003; Friederici et al., 2006; Makuuchi et al., 2009; Santi & Grodzinsky, 2007; Shetreet et al., 2009). Once again, it is difficult to imagine how these patterns can be explained by allusion to non-linguistic factors.

Admittedly, much is unaccounted for. And much more is still out there, awaiting discovery. But the small exercise above, I hope, illustrates that neuroscientists cannot study language without a linguistic tool kit. My hope is, therefore, that physiologists and linguists, who agree on the basic logic and have similar research programs, would enhance the sharing of experimental methods and analytic tools for exploration and understanding. There must be a way to incorporate our joint knowledge and agendas, and harness them to the service of a common enterprise, for only joint work will make real breakthroughs in our understanding of brain mechanisms for action, perception, and language.

REFERENCES

- Ben-Shachar, Michal, Talma Hendler, Itamar Kahn, Dafna Ben-Bashat & Yosef Grodzinsky. 2003. The neural reality of syntactic transformations: evidence from functional magnetic resonance imaging. *Psychological Science*, 14. 433–40.
- Bever, Thomas G. 1970. The cognitive basis for linguistic structures. In: J.R. Hayes, Editor, *Cognition and the development of language*, Wiley, New York.
- Burchet, Frank & Ria De Bleser. 2004. Passives in agrammatic sentence comprehension: A German study. *Aphasiology*, 18: 29-45.
- Caramazza, Alfonso & Edgar B. Zurif. 1976. Dissociation of algorithmic and heuristic processes in sentence comprehension: evidence from aphasia. *Brain & Language*, 3, 572–582.
- Chomsky, Noam. 1980. *Rules and Representations*. New York: Columbia University Press.
- D'Ausilio, Alessandro, Ilaria Bufalari, Paola Salmas, Pierpaolo Busan, Luciano Fadiga. 2011. Vocal pitch discrimination in the motor system. *Brain & Language*, 118, 9–14.
- Drai, Dan & Yosef Grodzinsky. 2006a. A New Empirical Angle on the Variability Debate: Quantitative neurosyntactic analyses of a large data set from Broca's Aphasia. *Brain & Language*, 96.2, 117-128.
- Drai, Dan & Yosef Grodzinsky. 2006b. The Variability Debate: More statistics, more linguistics. *Brain & Language*, 96.2, 157-170.
- Fadiga, Luciano, Laila Craighero, Buccino, G., & Giacomo Rizzolatti. (2002). Speech listening specifically modulates the excitability of tongue muscles: A TMS study. *European Journal of Neuroscience*, 15, 399–402.
- Farkas, Donca. 1981. Quantifier scope and syntactic islands, in R. Hendrick, C. Masek, and M. Miller, eds., *Papers from the 17th Chicago Linguistic Society Meeting*, 59-66.
- Fazio, Patrik, Anna Cantagallo, Laila Craighero, Alessandro D'Ausilio, Alice C. Roy, Thierry Pozzo, Ferdinando Calzolari, Enrico Granieri, and, Luciano Fadiga, 2009. Encoding of human action in Broca's area. *Brain*, 132.7, 1980-1988.
- Fodor, Jerry. 1983. *The Modularity of Mind*. Cambridge, MA: MIT Press.
- Fodor, Jerry, Thomas Bever & Merrill Garrett. 1974. *The Psychology of Language*. NY, NY: McGraw Hill.
- Friederici, Angela & Patty Graetz. 2007. Processing passive sentences in aphasia: Deficits and strategies. *Brain and Language*, 30: 93-105.
- Friederici, Angela, Christian Fiebach, Matthias Schlesewsky, Ina Bornkessel & Yves von Cramon. 2006. Processing linguistic complexity and grammaticality in the left frontal cortex. *Cerebral Cortex*, 16, 1709–17.
- Grodzinsky, Yosef. 1989. Agrammatic comprehension of relative clauses. *Brain & Language*, 37, 480-499.
- Grodzinsky, Yosef. 1995. Trace deletion, θ -roles, and cognitive strategies. *Brain & Language*, 51, 467-497.
- Grodzinsky, Yosef. 2000. The neurology of syntax: language use without Broca's area. *Behavioral and Brain Sciences*, 23.1., pp. 1-71.
- Grodzinsky, Yosef. 2006a. The language faculty, Broca's region, and the mirror system. *Cortex*, 42.4, 464-468.
- Grodzinsky, Yosef. 2006b. A blueprint for a brain map of syntax. In Grodzinsky, Y. and K. Amunts (eds.). *Broca's Region*. New York: Oxford University Press.

- Grodzinsky Yosef & Katrin Amunts, eds. 2006. *Broca's Region*. New York: Oxford University Press.
- Grodzinsky, Yosef & Angela Friederici. 2006. Neuroimaging of syntax and syntactic processing. *Current Opinion in Neurobiology*, 16.2, pp. 240-246.
- Grodzinsky, Yosef & Andrea Santi. 2008. The Battle for Broca's Region. *Trends in Cognitive Sciences*, 12.12, pp. 474-480.
- Hughlings-Jackson, John. 1874/1931. Selected Writings of John Hughlings Jackson. JH Jackson, J Taylor, SG Holmes, eds. London: Hodder and Stoughton.
- Johnson, Kyle. 2000. How far will quantifiers go? In R. Martin, D. Michaels, and J. Uriagereka, eds. *Step by Step: Essays on Minimalist Syntax in Honor of Howard Lasnik*. Cambridge, MA: MIT Press.
- Kimura, Doreen. 1973a. Manual activity during speaking— I. Right-handers. *Neuropsychologia*, 11.1, 45-50.
- Kimura, Doreen. 1973b. Manual activity during speaking— II. Left-handers. *Neuropsychologia*, 11.1, 51-55.
- Lashley, Karl. 1951. The problem of serial order in behavior. In L.A. Jeffress, ed., *Cerebral Mechanisms in Behavior*. New York: Wiley.
- Law, Sam-Po. 2000. Structural prominence hypothesis and Chinese aphasic sentence comprehension. *Brain and Language*, 74, 260-268.
- Lehrdahl, Fred & Ray Jackendoff. 1983. *A Generative Theory of Tonal Music*. Cambridge, MA: MIT Press.
- Makuuchi, Michiru, Jorg Bahlmann, Alfred Anwander & Angela Friederici. 2009. Segregating the core computational faculty of human language from working memory. *Proceedings of the National Academy of Sciences of the United States of America*, 106(20), 8362-8367.
- Pulvermüller, Friedemann. 2010. Brain embodiment of syntax and grammar: Discrete combinatorial mechanisms spelt out in neuronal circuits. *Brain and Language*, 112.3, 167-179.
- Osherson, Daniel. 1981. Modularity as an issue for cognitive science. *Cognition*, 10, 231-232.
- Petrides, Michael, Cadoret, G. & Mackey, S. 2005. Orofacial somatomotor responses in the macaque monkey homologue of Broca's area. *Nature*, 435, 1235-1238.
- Pulvermüller, Friedemann & Luciano Fadiga. 2010. Active perception: sensorimotor circuits as a cortical basis for language. *Nature Reviews Neuroscience*, 11, 351-360.
- Reinhart, Tanya. 1997. Quantifier Scope: How labor is Divided Between QR and Choice Functions. *Linguistics and Philosophy*, 20.4, 335-397.
- Rizzi, Luigi. *Relativized Minimality*. Cambridge, MA: MIT Press.
- Rizzolatti, Giacomo & Michael Arbib. 1998. Language within our grasp. *Trends in Neurosciences*, 21.5, 188-194.
- Rizzolatti, Giacomo & Laila Craighero. 2004. The mirror-neuron system. *Annual Review of Neuroscience*, 27, 169-192.
- Ross, John R. 1967. Constraints on Variables in Syntax. MIT dissertation.
- Rodman, Robert. 1976. Scope phenomena, 'movement transformations,' and relative clauses, in Barbara Partee (ed) *Montague Grammar*. New York: Academic Press.
- Rumelhart, David & Jay McClelland. 1986. *Parallel distributed processing: explorations in the microstructure of cognition*. Cambridge, MA: MIT Press.

- Roy, Alice, Laila Craighero, M. Fabbri-Destro & Luciano Fadiga. 2008. Phonological and lexical motor facilitation during speech listening: A transcranial magnetic stimulation study. *Journal of Physiology – Paris*, 102, 101–105.
- Santi, Andrea & Yosef Grodzinsky. 2007. Working memory and syntax interact in Broca’s area. *NeuroImage*, 37, 8–17.
- Santi, Andrea & Yosef Grodzinsky. 2007. fMRI Adaptation Dissociates Syntactic Complexity Dimensions. *NeuroImage*, 51, 1285-1293.
- Schuell, Hildred. 1965. *Minnesota Test for Differential Diagnosis of Aphasia*. Minneapolis, MN: University of Minnesota Press.
- Sherman, Janet. C., & Schweickert, Janel. 1989. Syntactic and semantic contributions to sentence comprehension in agrammatism. *Brain and Language*, 37, 419–439.
- Shetreet, Einat, Naama Friedmann & Uri Hadar. 2009. An fMRI study of syntactic layers: sentential and lexical aspects of embedding. *NeuroImage*, 48, 707–16.
- Sinha, Pawan, Benjamin Balas, Yuri Ostrovsky, Richard Russell. 2006. Face recognition by Humans: 20 Results all Computer Vision Researchers Should Know About. *Proceedings of the IEEE*, 94.11, 1948-1962.
- Venezia, Jonathan & Hickok, G. 2009. Mirror neurons the motor system and language: From the motor theory to embodied cognition and beyond. *Language and Linguistics Compass*, 3, 1-14.
- Zeki, Semir. 1993. *A Vision of the Brain*. Oxford: Blackwell.