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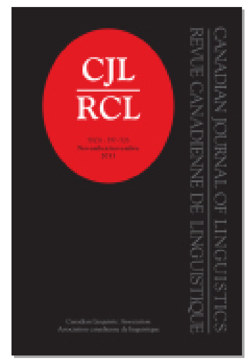

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Syntactic Dependencies as Memorized Sequences in the Brain

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1. INTRODUCTION

I consider how two areas in cognitive neuroscience — investigations of Working Memory and the study of syntactic representation and processing — can be unified. I entertain the possibility that the functional neuroanatomy of these seemingly independent systems may be more closely related than has been previously supposed. To see how this might be, consider dependency relations in syntax. It is clear that their computation requires a memory. For example, a sentence like (1) requires several memories, each with different properties.

(1) [Which of the papers that he_1 gave to *Ms. Brown*$_2$]$_3$ did every student_1 hope t'_3 that *she*$_2$ will read t_3

In (1), each pronoun links to a different antecedent. The pronoun *he* links to *every student*, while the pronoun *she* links to *Ms. Brown*. These linking relations can be coded as in (2a–b).

(2) *Links involved in example (1)*:

a. 1: (every student, he)
b. 2: (Ms. Brown, she)
c. 3: ([Which of the papers that he gave to Ms. Brown], t', t)

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In addition, the expression enclosed by square brackets [*Which of the papers that he gave to Ms. Brown*]$_3$ must be linked to two different positions, namely t'_3 (the intermediate extraction site) and t_3 (the lower extraction site); this can be coded as in (2c). This is a truly complex structure, aspects of which will be ignored here, including quantifier scope and precedence relations among syntactic operations (Fox 1999). Suffice it to note that we have at least three separate links, each with its own structural properties, and each requiring a memory to hold linked parts temporarily during processing.

I propose that sentences such as (1) involve several Working Memories, each entrusted with a different linguistic function. This proposal is based on an observation regarding a co-occurrence that has not been given sufficient attention. On the one hand, components of Working Memory reside in the Left Inferior Frontal Gyrus (LIFG), parts of which are known as Broca's region (or Brodmann's Areas 44, 45, and their vicinity). On the other hand this area, when lesioned, manifests in disruptions to the ability to analyze certain intra-sentential dependencies — somewhat similar to those in (1) — in comprehension. This anatomical juxtaposition is arguably not accidental. It is possible, then, that the scope of Working Memory is wider than current accounts would have it, and that it spans over syntactic computations. I explore this possibility, and try to unify considerations regarding Working Memory — which receive empirical support from a variety of memory tasks monitored in fMRI and PET — with a strictly syntactic approach to Broca's region, based on experimentation with Broca's aphasics.[1] This approach views Broca's region as housing mechanisms that compute transformations, and no other syntactic relations. The attempt to unify these two major approaches is an intellectual exercise that requires the reader to put disciplinary preconceptions aside. Linguists are asked to temporarily suppress certain grammatical considerations, while cognitive neuroscientists are asked to take grammar as a serious object of psychological inquiry. This undertaking is worthwhile, as it reveals new facts, and refines our understanding of the representation, neural implementation, and localization of language. It also underscores, in my view, the prospects of a cognitive neuroscience of syntax.

2. THE TRACE-DELETION HYPOTHESIS VERSUS WORKING MEMORY

The role of Broca's region in the processing of sentences has been extensively studied. I focus on two explicit attempts to characterize its functional role: the Trace-Deletion Hypothesis, and the recent proposal that Broca's region houses components of Working Memory (Smith and Jonides 1999). These proposals

[1] Positron Emission Tomography (PET) tracks changes in cortical metabolism associated with neural activity by scanning for local changes in the uptake of radioactive trace metabolites. Functional Magnetic Resonance Imaging (fMRI) is used to map cortical activation by tracking changes in local electromagnetic fields due to blood-flow perturbation following neural activity.

have more in common than initially meets the eye. Our tour will lead us to consider an unusually broad range of theoretical considerations, both linguistic and cognitive. It will involve experimental results based on normal grammaticality judgments, sentence comprehension, judgment tasks by aphasic patients, the time-course of sentence processing, and tasks carried out with neuroimaging instruments (PET and fMRI).

2.1. The Trace-Deletion Hypothesis and Broca's region (Left Interior Frontal Gyrus)

The starting point of the Trace-Deletion Hypothesis is the observation that movement is the line dividing impaired and preserved structures in Broca's aphasia. The idea is that, in this syndrome, traces of movement are invisible to the syntactic system.

(3) *Trace-Deletion Hypothesis*:
Delete all traces from agrammatic representation.

The Trace-Deletion Hypothesis predicts that, for an agrammatic, any task that recruits traces is bound to fail. The shape of the failure depends on phrasal geometry, certain semantic properties of the predicate, and task specifications. The Trace-Deletion Hypothesis has far-reaching implications regarding the role of Broca's region in sentence reception in aphasia as well as in health.

This account, coupled with an augmentative interpretive strategy, captures a massive body of comprehension and real-time performance data, including a host of cross-linguistic phenomena (Grodzinsky 1986, 1995, 2000). Here, I focus on how the Trace-Deletion Hypothesis handles the deficit as manifested in grammaticality judgments. This task probes patients' abilities, and through them the role of Broca's region, in a way that is more informative than comprehension tasks. I then explore the consequences of the lesion-based Trace-Deletion Hypothesis to the normal brain.

Consider, first, the examples in (4)–(6). Movement of a phrase is licit in (4b) and (5b) since it does not cross a like element, namely another NP. If another NP is crossed, then ungrammaticality follows, as in (6b) where the pronoun *it* is the relevant intervening NP.

(4) a. It is likely that [Mary will win].
b. Mary_1 is likely [t_1 to win].

(5) a. It seems that Mary is a fool.
b. Mary_1 seems [t_1 a fool].

(6) a. It seems that Mary_1 is likely [t_1 to win].
b. *Mary seems that it is likely [*t* to win].

A similar principle holds in (7). A question can be formed only if an interrogative element (known as a wh-element) does not cross another one. This principle is observed in (7a). When there is an intervening wh-element, as in (7b), with the second occurrence of *whom*$_2$, this results in ungrammaticality.

(7) a. Whom$_1$ did John persuade t_1 [to visit whom].

b. *Whom$_1$ did John persuade whom$_2$ [to visit t_1].

Both sets of facts have been claimed to fall under the same constraint, namely Relativized Minimality (Rizzi 1990), which requires that the distance between an antecedent and a trace be minimal relative to antecedent type. In other words, the presence of a potential antecedent that intervenes between a moved element and its trace blocks linking between the latter two. In the examples above, a violation of Relativized Minimality is apparent in (6b) because of the presence of *it*, and in (7b) because of the presence of *whom*$_2$. And these are indeed the sole ungrammatical strings in the paradigm.

Knowledge of the position of the trace is crucial for grammaticality judgments in these cases, since Relativized Minimality (or whatever other constraint one might imagine) is formulated over trace-antecedent relations. When Relativized Minimality is coupled with the Trace-Deletion Hypothesis, it follows that Broca's aphasics should be unable to judge the grammaticality of strings that violate this constraint. This is because in order for a trace to be computed in a representation, the location of the trace must be known. According to the Trace-Deletion Hypothesis, it is exactly this type of knowledge that is inaccessible to the Broca's aphasic. This prediction is borne out. When asked to judge contrasts such as those in examples (4)–(5) versus (6), patients made errors 30–50% of the time, compared to a set of controls whose error rates were significantly lower, at 15% and under (Grodzinsky and Finkel 1998). I return to these issues below.

2.2. Working Memory and Broca's region (Left Interior Frontal Gyrus)

What could the cognitive underpinnings of this deficit be? One could, perhaps, imagine a disruption that is directly linked to knowledge of traces of movement. But could the observed failures be linked to an identifiable, independently motivated, processing unit? Such a move, if possible, would not only unify a broad range of data under one account, but also bridge a gap between psychological and linguistic perspectives on language processing in the brain. It is therefore worthwhile to give this possibility a fair hearing. An idea that I explore here is that of rigging the aphasic deficit to Working Memory. The latter is a construct said to be closely linked to language processing, and some of its components are claimed to reside in Broca's area. It therefore seems reasonable to entertain the possibility that the range of results described by the Trace-Deletion Hypothesis can be explained by appealing to Working Memory. The Trace-Deletion Hypothesis, in other words, could be a consequence of a Working Memory failure. Before

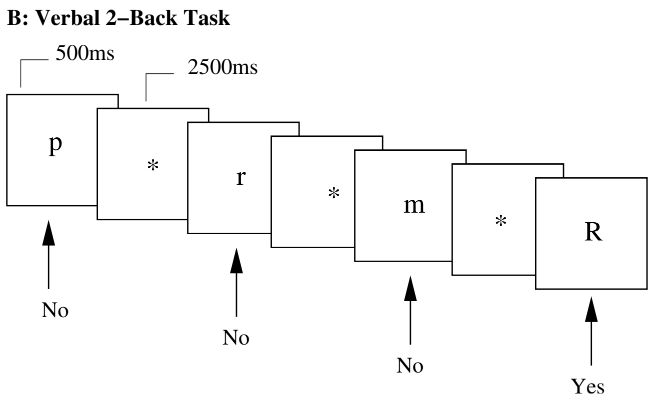

Figure 1: Structure of a 2-back experiment (from Smith and Jonides 1999:1657)

considering this possibility, let us examine the characterization of Working Memory, and some empirical arguments for its localization in Broca's region. This then leads to a direct comparison between a Trace-Deletion Hypothesis and a Working Memory approach to Broca's area.

The notion of Working Memory is not new. It has long been recognized that Broca's area is a specialized unit, aimed at holding information in temporary store during processing. Baddeley's (1986) model posits separate storage buffers for verbal and visual-spatial information. Verbal storage is decomposed into a buffer for short-term maintenance of information, which Baddeley claims to be phonological, and a subvocal rehearsal process that refreshes the contents of the buffer. A central concept in this approach is that of load, which is a linear property of stimuli, for which there are identifiable, linearly related cognitive and cerebral correlates. As Working Memory load grows, so grows effort, and the experimenter devises ever more sophisticated methods to measure it. Smith, Jonides, and their colleagues (Smith and Jonides 1999; Carpenter et al. 2000) have been using such a method, with the goal of localizing components of this system in the frontal lobes. They have explored this issue through extensive testing of neurologically intact subjects in PET and fMRI. Two central claims emerge. First, Working Memory is localizable, and some of its central components are in the Left Inferior Frontal Gyrus, or Broca's region. Second, Working Memory is incremental: the more load a task involves, the more intensely the neural tissue of Broca's region is harnessed to its service (rather than expanding to other regions).

The most direct evidence comes from experiments that use the *n*-back task. A subject is presented with a sequence of single letters every 2.5 seconds; for each letter s/he has to decide whether it is identical to the letter that either was mentioned in the instructions (0-back), or appeared one, two, or three items earlier in the sequence (by pushing a yes/no button). The structure of a 2-back experiment is illustrated in Figure 1.

A comparison with a set of controls suggests to the authors that this experiment isolates a frontal "rehearsal" circuit.[2] Other PET and fMRI studies have used 0-, 1-, 2- and 3-back tasks. All found activation in Broca's region and the premotor cortex, among other loci, although Broca's region and its vicinity seem the most stable in exhibiting activity across experiments (Awh et al. 1996; Cohen et al. 1994; Braver et al. 1997; Cohen et al. 1997; Jonides et al. 1997). Importantly, when spatial relations constitute the task, other areas light up, indicating that there may be distinct Working Memories, and that the current one may be specialized for the "verbal" domain.

As stated, the connection between these claims — which focus on the phonological shape of elements presented in lists — and considerations pertaining to grammatical structure, seems rather tenuous. Still, despite the absence of structural constraints of the type familiar in linguistics, it is tempting to inquire whether this processing component is linked to abilities that implicate structured linguistic materials. There are two reasons for such a move: anatomical and functional. Anatomically, certain Working Memory circuits are in the Left Inferior Frontal Gyrus, namely Broca's area and its vicinity.[3] Functionally, tasks in receptive language, which Broca's aphasics fail, require a temporary store. So perhaps there is a connection, after all, between Broca's area and Working Memory. If so, the notions entertained by psychologists could be reformulated so as to make direct contact with linguistic considerations.[4]

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[2]This experiment uses two different controls. In one, participants also see a sequence of letters, but here they decide whether each letter matches a *single* target letter, rather than a non-adjacently presented one. The difference between this and the 2-back condition should identify the localization of a component dedicated to temporary storage and maintenance of an item in a string for the purpose of immediate use. Indeed, the subtraction of this control from the 2-back condition yielded many of the areas of activation that have been obtained in item-recognition tasks, including the left frontal speech regions and the parietal area. A second control required participants to rehearse each letter silently. Subtracting this rehearsal control from the 2-back task should remove much of the rehearsal circuitry since rehearsal is needed in both tasks; indeed, in this subtraction, neither Broca's region nor the premotor area remain active. Hence, this experiment is considered to have isolated a frontal rehearsal circuit.

[3]Smith and Jonides (1999) attempt to identify a region smaller than Broca's area. We are not sure that this level of precision is possible, given the variation in the locus of BA 44,45. See Amunts et al. (1999) for a detailed neuroanatomical analysis of this issue, and a new perspective regarding this variation.

[4]There have been attempts to link this perspective to sentences, for example Smith and Geva (2000) extend their account to this domain. They cite a correlation that has repeatedly been found between severely reduced digit span and "poor sentence comprehension", and suggest that the scope of Working Memory is likely wider than phonology. While this proposal is not readily interpretable in linguistic terms, the attempt to think about the relationship between Working Memory and syntactic movement is commendable.

2.3. Geometric similarities between movement and 2-back

There are important and precise geometric similarities between the description of Working Memory as it emerges through the above experiments, and movement (understood as the displacement of syntactic constituents). Recall that, according to the Trace-Deletion Hypothesis, Broca's aphasics are unable to process traces of movement. What is the form of strings whose grammatical status is unknown to aphasics? In (6) and (7) we saw violations of Relativized Minimality, which abide by the following schema:

(8) a. $\ldots X_1 \ldots t_1 \ldots Y \ldots$
b. $*\ldots X_1 \ldots Y \ldots t_1 \ldots$

In these structures, movement is licit if the moved element *X* does not cross a like element *Y*, as in (8a).[5] But if movement results in crossing a potential antecedent, then the structure is ungrammatical. This corresponds to (8b) where the moved element *X* is separated from its trace by an element similar to it, namely *Y*.

Reflect for a moment on the resources necessary for this relation to be computed during sentence analysis. At the very least, some memory system is needed, one that keeps track of a "free" constituent which is encountered as parsing proceeds, so that later, when an appropriate position is identified downstream, a connection can be established between that position and the memorized constituent.[6] It takes no more than a modicum of imagination to see how such a constraint might emanate from the same system recruited for the 1-back task, where an element must be stored and held in memory until an additional item is input, so that a comparison between it and the memorized one can be made. Moreover, a lesion to the system computing Relativized Minimality occurs in Broca's area, the alleged anatomical locus of the temporary Working Memory store.

2.4. 1-back vs. 2-back in Broca's aphasia and normal Working Memory

The similarity between movement and the *n*-back experiments actually goes further. Violations of Relativized Minimality involve an element (*Y* in (8b)) that interferes between an antecedent and its trace (*X* and *t* in (8b)). Reinterpreted in memory terms, Relativized Minimality might mean that a (moved) element will not be held in memory for later linking to a trace, if a like element is encountered on the way. The trace-antecedent connection is blocked in such cases. When other structural considerations are suppressed, this appears to be the very situation encountered in the 2-back task: two positions (*r* and *R* in Smith and Jonides'

[5] Structures that contain no movement at all, such as (i), are also licit:

(i) [… X … Y …]

[6] As Edwin Williams points out (personal communication), for the analysis of sentences with multiple dependencies, there are probably multiple Working Memories operating concurrently in sentence processing.

schema given in Figure 1) must be matched across an intervening third position (*m*). Aphasic patients, lesioned in the Left Inferior Frontal Gyrus, fail on an analog of a 2-back task. However, when asked to check if a locality relation between two adjacent positions is violated, they readily detect these violations. Consider the following illustrative examples, where the relevant adjacent elements are enclosed in square brackets. One way in which a relation between two adjacent positions may be violated is when the requirements of case are not satisfied. For example, in English, as shown in (9), the nominative form of the 3rd person pronoun (*they*) is the usual form in matrix subject position; replacing it with the accusative form (*them*) yields ungrammaticality.

(9) a. [They] [were] chased by the police.

b. *[Them] [were] chased by the police. (Linebarger et al. 1983:223)

Similarly, as shown in (10), in Russian the accusative form of 'the field' is licit (*polje*), but the instrumental form is not (*poljem*). Conversely, in (11), the instrumental form is licit, but the accusative form is not.[7]

(10) a. Seljak [obradjuje] [polje].
farmer cultivate field.ACC

b. *Seljak [obradjuje] [poljem].
farmer cultivate field.INSTR
'The farmer is cultivating the field.' (Lukatela et al. 1988)

(11) a. *Seljak [trci] [polje].
farmer run.through field.ACC

b. Seljak [trci] [poljem].
farmer run.through field.INSTR
'The farmer is running through the field.' (Lukatela et al. 1988)

Another type of example that involves two adjacent positions arises with number agreement. In (12) the non-plural form for the noun (*customer*) is ungrammatical in this context. In (13), the plural form of the auxiliary (*were*) is ungrammatical in this context.[8]

(12) a. *The banker noticed that [two] [customer] deposited the cheques late.

b. The banker noticed that [two] [customers] deposited the cheques late.

(13) a. *The baker told the help that [the bread] [were] rising.

b. The baker told the help that [the bread] [was] rising.

(cf. Shankweiler et al. 1989:12)

[7] Abbreviations used in this article include:
ACC accusative
INSTR instrumental

[8] I am not aware of any data pertaining to sensitivity to case and agreement violations involving non-adjacent elements; these are a crucial test for this account.

In all three judgment experiments, Broca's aphasics performed well, in contrast to their diminished abilities in judging Relativized Minimality violation. (See Mikelic et al. 1995 for a presentation of more evidence along these lines.)

Performance drops sharply when Broca's aphasics move from the 1-back to the 2-back task. This sharp drop runs contrary to the incremental nature of Working Memory. But the story has a twist. A careful reading of the neuroimaging literature reveals something special about the step from the 1-back to 2-back task. The change in intensity of reaction in Broca's region monitored for neurologically intact people — as observed in fMRI — is much steeper when one moves from a 1-back to a 2-back task than anywhere else in this setup. The same result is obtained in PET (Cohen et al. 1997; Jonides et al. 1997). This result is unexpected from the standard Working Memory perspective. As Cohen et al. acknowledge, their conception of Working Memory predicts that increased neural activity should be linearly related to increase in memory load. This is not the case.[9] The non-linearity of the reaction measured in Broca's region in the 2-back task correlates with the posited deficit in Broca's aphasia, where sensitivity to Relativized Minimality (which prohibits anything intervening between an antecedent and its trace) is compromised. This is precisely what one would expect after the destruction of an isolable component whose participation in processing is obligatory. Cohen et al. (1997) themselves consider the possibility that there is a qualitative difference between the 0- and 1-back tasks, and the 2- and 3-back tasks, which may be responsible for the "the step function observed within PFC [pre-frontal cortex]". On this view, the 2-back and the 3-back tasks may "depend on the maintenance of information about the sequential order of stimuli, whereas the 0- and 1-back conditions do not" (Cohen et al. 1997:605–606). This comment brings the aphasia data immediately to mind and suggests that the Working Memory unit whose activity was monitored in the Left Inferior Frontal Gyrus for the 2-back task is the same component that is wiped out by damage to Broca's region resulting in Broca's aphasia.

The discussion has centred on results from grammaticality judgments in Broca's aphasia. It is important to emphasize that the Working Memory account works in a similar way for the broad array of comprehension results available for Broca's aphasia. The patients fail to link a semantic role (θ-role) properly to a moved antecedent; in most instances, there is another potential antecedent intervening between the trace and the moved element. Such a failure is exactly what a 2-back disruption predicts.[10]

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[9] Cohen et al. (1997) cite another experiment where the results were a monotonic function, rather than a step function (Braver et al. 1997). Such results are less stable than one would desire, and so their significance is, at present, unclear.

[10] One potential exception is the passive; but there, too, an implicit argument known to be active in Broca's aphasia (Balogh and Grodzinsky 2000) may be the intervening potential antecedent.

Note that the time course of sentence processing tasks and the *n*-back task are not the same. In natural speech, words come in at a rate of about 3 to 4 per second. In contrast to this, the *n*-back task is presented at a slow rate, with 2.5 seconds elapsing between every two items. This time course difference should not diminish the force of the structural similarity. It is reasonable to assume that Working Memory works more efficiently when harnessed to service sentence processing, aided and abetted by structural considerations that may help it operate faster than it does with lists.

To recapitulate, these results suggest that the 2-back task and dependency relations in sentence comprehension both probe the same Working Memory component of Broca's region. This hypothesis remains to be investigated with both neurologically intact and aphasic subjects. A related question is whether the Working Memory component is on a par with the memory invoked to explain effects of difficulty in processing embeddings (Gibson 1998).

3. FOUR CONSTRAINING RESULTS

Recent evidence from sentence-level tasks allows us to distinguish between a general, non-linguistic account based on Working Memory, and a linguistic account that attributes the computation of movement to the Left Inferior Frontal Gyrus. The relevant evidence comes from two sources: (i) error-inducing tests in aphasia on the basis of comprehension and grammaticality judgments; and (ii) parallel fMRI experiments that monitor regional activation in the healthy brain. Here is the logic behind these empirical endeavours.

Consider first the aphasia experiments. If Broca's aphasics suffer from a Working Memory deficit, they would fail on tasks that involve the analysis of sentences with intra-sentential dependency relations, where the distance between the two codependent elements is increased. Success and failure would only depend on distance, as measured by the number of interveners, and not on grammatical constraints. The syntactic account (the Trace-Deletion Hypothesis) makes the opposite claim: syntactic movement, rather than distance, is the sole predictor of success and failure.

The Working Memory account and the syntactic Trace-Deletion Hypothesis can be distinguished empirically. The former predicts that failure should be independent of the grammatical properties of the dependency, and would occur as long as the sequential properties make it on a par with the respective *n*-back task. By contrast, under the syntactic account, the deficit should be constrained to contexts where movement has applied. Consequently, sentences containing other dependency relations would not lead to a deficit, even if sequentially the dependency relation at issue is on a par with an error-inducing *n*-back sequence. On this latter view, for example, aphasic patients would fail to detect violations of grammaticality in sentences in which an NP intervenes between a moved NP and its trace (violations of Relativized Minimality) not because they cannot link two non-adjacent positions in a sequence, but rather, because of the relevant syntactic constraint.

Now consider parallel fMRI experiments that monitor regional activation in the healthy brain. The logic is similar, modulo the dependent measure, namely regional activations that correlate with properties of stimuli. Precisely the cases for which the Working Memory account would expect errors in aphasia are the ones that would lead, in a healthy brain, to fMRI-monitored activations in Broca's region. The Trace-Deletion Hypothesis, by contrast, would expect Broca's region to be activated only by sentences that contain movement.

I briefly present results from error-monitoring experiments with aphasics, as well as Blood Oxygen Dependent Level (BODL) response monitored in fMRI in healthy brains. These results indicate that syntactic movement resides in Broca's region. First, in grammaticality judgment of structures that contain violations of Relativized Minimality, Broca's aphasics fail to detect NP- and wh-movement violations, but succeed in detecting head-movement violations (Grodzinsky and Finkel 1998). Second, in tests of comprehension, in which the distance (measured in terms of the number of words) between gap and antecedent is parameterized, no effect of increased distance is observed for Broca's aphasic patients (Friedmann and Gvion 2003). Third, fMRI tests of grammaticality judgment and comprehension in healthy subjects show that movement activates Broca's region (Ben-Shachar et al. 2003, 2004).

Moreover, contrary to the expectations of the Working Memory account, the deficit does not generalize to all dependency relations. First, in tests of comprehension in Broca's aphasia with sentences that contain a dependency relation but not movement (e.g., sentences with bound reflexives), patients successfully comprehend these structures (Grodzinsky et al. 1993). Second, in tests of grammaticality judgment in Broca's aphasia, where sentences contain a movement relation and/or binding, Broca's aphasic patients exhibit differential behaviour (Santi and Grodzinsky 2004, to appear). Third, in fMRI tests that pit movement against Binding, movement activates Broca's region, thereby replicating previous results, and binding activates frontal regions in the right hemisphere (Santi and Grodzinsky 2004, to appear).

3.1. Grammaticality judgment in head movement

Consider again the grammaticality judgment experiment discussed above. Recall that two sets of constructions from that study were presented: NP-movement and wh-movement. The patients performed rather poorly on both, unable to detect violations of grammaticality. One control was a set of sentences that contained head movement, which in English involves auxiliary verbs (traditionally known as "Affix Hopping"). These were cases of the following form:

(14) a. They could have left town.

b. *Could* they *t* have left town?

(15) a. John *did* not *t* sit.

b. John *has* not *t* left the office.

Observe that, similar to auxiliary movement in English, an auxiliary is barred from crossing a like element — another auxiliary in this case, as evidenced by (16).

(16) a. **Have* they could *t* leave town?

b. *John *did* not have *t* left the office.

Rizzi (1990) has proposed that this type of movement of heads, while differing from movement of phrasal constituents in certain respects, is nevertheless constrained by Relativized Minimality. If Relativized Minimality is impaired in Broca's aphasics, or, alternatively, if a Working Memory deficit impairs their ability to carry out 2-back tasks, a deficit in this set of structures is expected as well. Our test included the cases in (14)–(15), and their ungrammatical counterparts in (16).[11] However, the table in (17) shows a sharp contrast between the patients' abilities to detect violations of movement constraints in phrasal constituents as in examples (4)–(7), where they performed miserably, and their relative agility in detecting violations of head-movement as in examples (14)–(16).

(17)

	Condition	*Examples*	*X′ (% error)*
a.	NP movement	(4)–(6)	28.2
b.	Superiority	(7)	40.9
c.	Auxiliary	(14), (16a)	15.9
d.	Negation	(15), (16b)	13.4

Performance on (16a–b) was not different from chance, whereas performance on (16c–d) was well above chance; in addition, the two sets of conditions were significantly different from one another. Unlike movement of phrasal constituents, head movement is relatively preserved in Broca's aphasia. And, while certain analytic issues regarding these results need consideration that is beyond the scope of this presentation (see Grodzinsky and Finkel 1998 for detailed discussion), two conclusions follow. First, this relation is distinct from phrasal movement at least at some level, a distinction that might have potential implications to generalizations such as Relativized Minimality (see Chomsky 2000 for discussion of this point). Second, this result leads to a reformulation of the Trace-Deletion Hypothesis, that is, to a restrictive account of the involvement of Broca's region in the computation of dependency relations. It supports operations involved in establishing dependencies in which the antecedents are phrasal constituents (Grodzinsky 1995, 2000). Consequently, the Working Memory of the Left Inferior Frontal

[11] There was a set of controls that contained no movement, but violations of lexical requirements. Patients made errors less than 10% of the time under these conditions.

Gyrus is constrained by the grammar, and so is sensitive only to phrasal constituents. Head movement, while having the same geometric features as the rest of the cases from the Working Memory perspective, has different grammatical properties, and is unaffected by damage to Broca's region.[12] The computation of this relation is therefore separate, and since it must rely on memory, we are forced to the conclusion that it is a memory of another type.

This view is more focused and precise than before, yet it has an obviously missing part. Dependency relations typically involve an antecedent and a referentially dependent element. In the case of NP antecedents, the latter may either be a trace or an anaphoric expression. The Trace-Deletion Hypothesis contends that traces are involved. But does the deficit extend to anaphoric relations? An answer to this question will be given below. But first, we might examine the Working Memory hypothesis from a different direction, that is, from the perspective of the linear distance between traces and their antecedents.

3.2. Parameterized distance between antecedent and gap

Friedmann and Gvion (2003) derived a clear prediction from the Working Memory account: if the distance (i.e., the number of words) that separates a trace from its antecedent is increased, performance should be affected. Initial hints to that effect already existed (Schwartz et al. 1987; see Grodzinsky 2000 for discussion), yet Friedmann and Gvion conducted a systematic study, parameterizing the distance between traces and their antecedents Their aphasic subjects were presented with Hebrew subject and object relative clauses, with variable (two to nine phonological words) trace-antecedent distance. Some examples are given in (18) and (19), where the relevant intervening string of words is counted off. I adopt the convention of bracketing and counting of each intervening phonological word.

(18) *Subject relatives*:

a. Distance 2

Ze *baxur*$_i$ [im]$_1$ [zakan]$_2$ she-*t*$_i$-malbish et ha-xayal

this guy with beard that dresses ACC the-soldier

'This is a guy with a beard that dresses the soldier.'

b. Distance 5

Zo ha-*baxura*$_i$ [im]$_1$ [ha-mixnasaim]$_2$ [ha-xumim]$_3$ [ve-ha-xulca]$_4$ [ha- levana]$_5$ she-*t*$_i$-mexabeket 'et ha-yalda

this the-woman with the-pants the-brown and-the-shirt the-white that hugs ACC the-girl

'This is the woman with the brown pants and the white shirt that hugs the girl.'

[12] Wernicke's aphasics performed in a way that was hardly distinguishable from Broca's. See Grodzinsky and Finkel (1998) for discussion.

(19) *Object relatives*:

a. Distance 2
Ze ha-*baxur*$_i$ [she-ha-yeled]$_1$ [tofes]$_2$ t_i
this the-guy that-the-kid catches
'This is the man that the boy catches.'

b. Distance 5
Ze ha-*xayal*$_i$ [she-ha-rofe]$_1$ [im]$_2$ [ha-xaluk]$_3$ [ha-lavan]$_4$ [mecayer]$_5$ t_i
This the-soldier that-the-doctor with the-robe the-white draws
'This is the soldier that the doctor with the-white robe draws.'

The result obtained in this study was clear: the comprehension abilities of Broca's aphasics did not change with distance. That is, subject-gap relatives were comprehended at above-chance levels, regardless of distance, and object-gap relatives yielded chance performance. Friedmann and Gvion (2003) thereby replicated previous results to that effect (Grodzinsky 1984, 1989), and extended them, lending further support to the Trace-Deletion Hypothesis. We now know that increasing the distance (when distance is defined as the number of intervening phonological words) does not affect comprehension, contrary to the prediction of the Working Memory account.

3.3. fMRI studies of movement in health

Above, I reviewed evidence regarding the movement deficit in Broca's aphasia. Recent results from fMRI experiments in health complement the picture. The relevance of these experiments is clear. As pathological data show that Broca's region is critically needed for the calculation of Movement, the fMRI technique should monitor activation in this region as these operations take place in health. There are by now a number of such experiments featuring several receptive tasks with sentence-pair stimuli. These studies evince a Blood Oxygen Level Dependent response pattern that is unique to syntactic movement operations. I briefly review one series of studies that presented healthy subjects with minimal pairs of sentences, one involving syntactic movement, the other not, *ceteris paribus*. The relevant stimuli are given in (20)–(22).

(20) ± *Movement* (other "complexity" held constant):

a. I told John that the nurse slept in the living room. (−Movement)
b. I helped *the nurse* that John saw ___ in the living room. (+Movement)

(21) ±*Topicalization*:

a. Danny gave the book to the professor from Oxford. (−Movement)
b. *To the professor from Oxford* Danny gave the book. ___ (+Movement)

(22) ±*Wh-movement*:

a. The waiter asked if the tourist ordered avocado salad in the morning. (−Movement)

b. The waiter asked *which salad* the tourist ordered ___ in the morning. (+Movement)

In all instances, activation was observed in left Broca's region, and in Wernicke's region bilaterally (Ben-Shachar et al. 2003, 2004). While the results above were obtained in Hebrew, similar effects have been observed in English (Caplan 2001), and in a variety of experiments in German (mostly from scrambling, Fiebach et al. 2002; Friederici et al. 2003; Röder et al. 2001). These studies, then, provide further support for the Trace-Deletion Hypothesis.

3.4. Comprehension of reflexive binding

A way to pit the Trace-Deletion Hypothesis and the Working Memory accounts is to test the role of Broca's region in processing dependency relations other than movement. Naturally, anaphoric dependency is the first relation that comes to mind. In Grodzinsky et al. (1993), we tested Broca's aphasics on a variety of constructions involving binding relations in a sentence verification test. Relevant to the present context is their test of reflexives and their antecedents.[13] The stimuli were of the following form:

(23) *This is A. This is B.* Is A touching herself?

Sentences such as those italicized in (23) were included in the stimuli to satisfy discourse requirements. Each sentence was presented with a picture which matched or failed to match the linguistic content. For example, for the stimulus in (23), a picture was shown with two characters, A and B, and A was touching herself (correct response "yes"). A second presentation had the same two characters, except now A was touching B, resulting in a mismatch (correct response "no"). Stimuli were mixed with others that contained pronouns ("her") in the same positions, which counterbalanced the experiment. While the patients made multiple errors elsewhere, exceeding 50% in certain cases which are not currently relevant, they were almost error-free, and significantly above chance, in the reflexive condition, as (24) shows.

(24) *This is A. This is B.* Is A touching herself?

Match (% error)		*Mismatch*		*X′*
19.4%	(7/36)	8.3%	(3/36)	13.89%

Given this finding, one might be tempted to conclude that the deficit in Broca's aphasia does not pertain to all dependency relations. Rather, it is restricted to movement, as the patients' performance in antecedent-reflexive binding seems near-normal. Yet this conclusion is premature, as the result itself is less decisive than one would like it to be. First, as pointed out by Grimshaw and Rosen

[13]Blumstein et al. (1983) tested aphasics on pronouns and reflexives, but their study does not bear directly on the current issue. See Grodzinsky et al. (1993) for discussion.

(1990), this type of experiment features a perfect correlation between the locality of a reflexive and reflexive action. On this view, all subjects have to do is associate the character who performs an action on herself with the antecedent in order to get at the correct answer. This criticism is testable, through the introduction of an additional response option in a picture that associates the reflexive action with a non-local antecedent. Such a test was carried out with children, who gave clear-cut positive results, and demonstrated knowledge of the locality of reflexive binding (Grodzinsky and Kave 1994). With aphasics, however, this experiment was not conducted, leaving open the possible interpretation entertained by Grimshaw and Rosen. A second problem with this study is the number of antecedents and their positions. Although there were two potential antecedents in each stimulus, only one of them (A) was intra-sentential. As a consequence, patients' ability to check binding with a local antecedent was tested, but not their ability to reject intra-sentential non-local antecedents. This makes the comparison between sentence-level tasks and the *n*-back task less direct.

These conclusions all set the stage for a set of experiments on binding relations and movement, which aimed at solving these problems and providing a clear answer to the question above. I will sketch the theoretical context, and proceed to describe these experiments and their results briefly.

4. Experiments That Contrast Binding and Movement

4.1. Movement and local binding

A well-known syntactic puzzle, one which syntacticians love to pull out of their bag of tricks, documents a locality constraint imposed on the relationship between reflexives and their antecedents — as shown in (25) and (26) — and then proceeds to show that this constraint must be violated, as shown in (27).

(25) *Local binding of reflexives*:

a. [Pierre likes himself]
b. *[Pierre likes herself]

(26) *Local binding of reflexives*:

a. Pierre believes [Natasha likes herself]
b. *Pierre believes [Natasha likes himself]

(27) *Long-distance binding of reflexives*:

a. *Which heiress does [Pierre believe [likes himself]]
b. Which heiress does [Pierre believe [likes herself]]

The examples in (25) and (26) suggest that a reflexive must have an antecedent (or must be bound) within its local domain: that is the explanation for the ungrammaticality of (25b) and (26b), in which the (masculine) reflexive has either no antecedent within the sentence, or one that is too far outside the parentheses (since the only potential local one is feminine). Yet observe how the judgments seem to be reversed in (27). Sacrificing accuracy for simplicity of exposition, we will replace the notion "local antecedent" with "nearest potential antecedent". Thus in (27a), the nearest potential antecedent for the reflexive *himself* is *Pierre*, and binding is nevertheless not possible even though they are of the same gender. This contrasts with (27b), where the reflexive *herself* is not bound by the nearest potential antecedent (*Pierre*), but rather by the farthest one, namely *which heiress*. This result yields an apparent paradox. On the one hand, in (27) the reflexive must be bound by what appears to be the furthest antecedent; that is, long-distance binding is in effect. On the other hand, in (25) and (26), the reflexive must be bound by the nearest antecedent; that is, local binding is in effect.

Note that the source of this paradox is not reducible to the fact that the long-distance binding in (27) occurs in the context of questions. That this is so is shown in by examples where local binding is in effect even in the context of a question, as in (28), the interrogative version of (26).

(28) a. Which prince believes [Natasha likes herself]?

b. *Which prince believes [Natasha likes himself]?

In what sense is the long-distance binding attested in (27) different from the local binding attested in (28)? Observe that in (26), the subject of the main clause (*Pierre*) is questioned, but that in (28) it is the subject of the embedded clause (*Natasha*) that is questioned. This difference seems crucial, because sentences containing questions, as everyone knows, are said to contain a transformational relation between two positions: the extraction site and the site where the question expression is found. We can accordingly annotate the sentences in (29)–(30) as follows:

(29) a. **Which heiress*$_i$ does Pierre believe [t_i likes himself]

b. *Which heiress*$_i$ does Pierre believe [t_i likes herself]

(30) a. **Which prince*$_i$ t_i believes [Natasha likes himself]

b. *Which prince*$_i$ t_i believes [Natasha likes herself]

While the wh-antecedent in (29) has changed its serial position relative to its extraction site, this is not the case in (30). Taking this into account provides a potential resolution for the seeming paradox between local and long-distance reflexive binding. Observe that the extraction site in (29), which corresponds to the silent category *t*, is the closest NP to the reflexive and crucially, is closer than the overt NP (*Pierre*). Suppose the silent category *t* counts as a potential antecedent for the reflexive. Suppose further that silent categories preserve the gender of their moved elements. The effects in (29) follow if empty antecedents (traces) are subject to the locality constraint. Consider (29a), where the gender on the trace is feminine but the reflexive is *himself*; the mismatch results in ungrammaticality.

In (29b), the opposite happens. We have accounted for the phenomena (though somewhat sketchily), and resolved the paradox.

4.2. Modularity: The distinctness of binding and movement

The solution of the paradox is not without consequences, even for the extremely narrow range of facts we have considered. There is a more comprehensible and parsimonious way of stating the solution by establishing an intrinsic ordering between the two dependencies. For example, one could say that movement "takes place" *after* the locality constraint on reflexives and their antecedents is satisfied. On this view, the underlying (pre-movement) representation of (27) is (31).

(31) a. *Pierre believes [*Which heiress* likes himself]

b. Pierre believes [*Which heiress* likes herself]

Given this representation, the facts follow. Within the local domain, only a feminine antecedent can bind a feminine-marked reflexive to give a matching grammatical result. It is only after binding requirements are satisfied that movement applies, to yield (29). But for this view to hold, the two relations, binding and movement, cannot be one and the same. They are ordered. They are also subject to different constraints. This implies distinctness. Thus, trace-antecedent relations, and the relation between reflexives and their antecedents, while sharing important properties — both are structural dependencies among (potentially) non-adjacent constituents — cannot be reduced to one rule. Not all dependency relations in the syntax are one and the same. Obviously, more support is needed to make this conclusion compelling, but in the present context we will not go any further. Suffice to say that the standard linguistic view (for which more evidence can be adduced) is that movement and binding are distinct.

The contrasts we just saw are explained through the postulation of ordering of syntactic operations. Locality conditions of the binding of reflexives apply first, prior to extraction, and movement applies second. Advantage of this set of phenomena was taken, to investigate how processes that underlie these rule systems — how algorithms that implement them in language use — are represented in the language regions of the left cerebral hemisphere. I will try to show that the distinction between these two rule systems is reflected very clearly in brain structure, and explore the consequences of this result to the Working Memory view of the Left Inferior Frontal Gyrus.

Recall that reflexives depend on another NP within the sentence for reference. Grammatical conditions determine whether this dependency is possible. First, the antecedent NP must be local. Second, reflexive and antecedent must agree in person, gender, and number. Third, for a non-local NP to be a proper antecedent, it must originate in a local position, even if it moves later. In a sentence that has two full NPs and one reflexive, all these considerations apply. As long as there is a link between the reflexive and an NP antecedent, the sentence is grammatical.

Consider the sentence pairs in (32) and (33). They differ only in the relative ordering of the embedded subject: *the man* in (32) versus *which man* in (33). Grammaticality is orthogonal: the (a) examples are grammatical ("yes"), while the (b) examples are ungrammatical ("no").

(32) a. [$_{NP_1}$The woman] believes [$_{NP_2}$*the man*] likes *himself* "yes"

b. [$_{NP_1}$The woman] believes [$_{NP_2}$*the man*] likes *herself* "no"

(33) a. [$_{NP_1}$*Which man*] does [$_{NP_2}$the woman] believe *t* likes *himself* "yes"

b. [$_{NP_1}$*Which man*] does [$_{NP_2}$the woman] believe *t* likes *herself* "no"

Consider now how this paradigm works. In (32a), NP_1 *the woman* cannot link to the reflexive due to excessive distance; NP_2 *the man* links to the reflexive as it is local and agrees with it in gender and number. As a result, the sentence is grammatical, and the correct answer is "yes". In (32b), NP_1 *the woman* cannot link to the reflexive due to excessive distance; NP_2 *the man* cannot link to the reflexive due to an agreement mismatch. As a result, the sentence is ungrammatical, and the correct answer is "no".

In (33a), NP_1 *which man*, though non-local, links to the reflexive through a double link. First, there is a local link between the reflexive and the trace of movement *t*. Second, there is a movement link from the trace *t* to NP_1 *which man*, and agreement is satisfied. As for NP_2 *the woman*, it cannot link to the reflexive due to an agreement mismatch, as well as excessive distance. Although NP_2 *the woman* is the overt NP closest to the reflexive, the trace *t* counts as an NP for syntactic purposes, and so is the closest NP. As a result, the sentence is grammatical, and the correct answer is "yes". Finally, in (33b), a link between the (local) trace *t* and the reflexive cannot be established due to an agreement mismatch between *herself* and NP_1 *which man*. As for NP_2 *the woman*, it cannot link to the reflexive *herself* due to excessive distance, even though it is the closest overt NP. The trace *t*, which counts as an NP for syntactic purposes, is closer. As a result, the sentence is ungrammatical, and the correct answer "no".

4.3. The experiment as a trace-deletion task

We constructed a grammaticality judgment test of a set of cases, similar to those in (32) and (33), which contain a reflexive, two potential antecedents, and in which considerations of locality and movement enter into the determination of the grammatical status of the sentences. The same sentences are presented in two sets of conditions, featuring the two dependency relations for which we seek to characterize the aphasics' abilities: binding and movement. This set of cases allows for a direct comparison between the two dependency relations, hence an evaluation of the scope of the Trace-Deletion Hypothesis. As stated, this hypothesis predicts that only cases involving movement, namely (33), would cause problems to the patients. In contrast, we expect that (32) would not cause problems, since the dependency relation is one of binding rather than movement.

4.4. The experiment as an *n*-back task

Now, consider the cases in (32) and (33) from a Working Memory perspective, as discerned through the 2-back task. In (32a), a 1-back suffices to decide that the sentence is grammatical, because the nearest potential antecedent permits a grammatical reading. The situation changes, however, in the other cases. The sentence in (32b) can be deemed ungrammatical only after both potential antecedents have been examined and rejected (each on different grammatical grounds). This requires both a 1-back and a 2-back comparison. In (33a), the correct antecedent is the farthest, hence again, both 1-back and a 2-back comparisons are necessary, but more importantly, perhaps, the determination of grammaticality presupposes the ability to carry out a movement analysis of this sentence. Finally, (33b) is rejected for the same reasons that that lead to acceptance of (32a). Thus, although all cases look the same serially, the pairs (32) and (33) appeal to different kinds of knowledge, and require, perhaps, different sets of structure-sensitive processes. If Working Memory is involved in the aphasic deficit in a way that makes no structural distinctions, it is expected to make no distinction between binding and movement, since from a Working Memory perspective, both seem to require the same processing resources. I will now briefly present results from two recent experiments that pitted the Trace-Deletion Hypothesis against the Working Memory hypothesis.

4.5. The aphasia experiment

We tested six Broca's aphasics, all diagnosed on the basis of clinical neurological findings, neuroimaging, and the Boston Diagnostic Aphasia Examination (BDAE). Anatomically, they all had lesions that included Broca's region. They all performed above-chance in comprehension of active sentences and subject relatives, and around chance on passive sentences and object relatives. We tested them in a grammaticality judgment task, using a procedure that was previously demonstrated as understood and doable by the patients (Grodzinsky and Finkel 1998). The resulting structure of the test is presented in (34).

(34) *Structure of grammaticality judgment task: Locality violations*:

		+Grammatical		*−Grammatical*
−MOV	a.	It seems to Sally that *the father* rewards *himself*	c.	It seems to *Sally* that the father rewards *herself*
	b.	The man think that *Mary* likes *herself*	d.	*The man* think that Mary likes *herself*
+MOV	e.	*The father* seems to Sally ◀ to reward *himself*	g.	The father seems to *Sally* ◀ to reward *herself*
	f.	*Which man* does Mary think [*t* likes *himself*]	h.	Which man does *Mary* think [*t* likes *herself*]

Using non-movement counterparts as controls (34a–d), our test consisted of grammatical and ungrammatical instances of NP- and wh-movement (+MOV), all crossed with binding, where the violations always involved an incorrect gender on the reflexive (34e–h). The question was whether or not the patients would be able to detect distant violations, and if so, would their ability be diminished by the presence of a trace. The resulting structure of the test is presented in (34).

We obtained very clear results: Broca's aphasics were quite good at accepting grammatical sentences, and detecting violations (reflexive/antecedent gender mismatches) without movement (Santi and Grodzinsky, to appear). The presence of movement diminished performance. Interestingly, right-hemisphere-damaged patients (n = 3) were nearly at ceiling on all conditions.

4.6. The fMRI experiment

We also conducted an fMRI study with healthy subjects (Santi and Grodzinsky, to appear). The materials here were slightly different, reflecting constraints that are imposed by this technology. The sentences either contained Movement (MOV), or a Binding relation (BIND), or both. As this was a grammaticality judgment task, each sentence type had an ungrammatical counterpart, leading to the design in (35).

(35) *Structure of grammaticality judgment task: Movement vs. binding*:

a.	−MOV	+Grammatical	The girl supposes the cunning man hurt Christopher
	−BIND	−Grammatical	*The girl supposes the cunning man swam Christopher
b.	−MOV	+Grammatical	The girl supposes *the cunning man* hurt *himself*
	+BIND	−Grammatical	**The girl* supposes the cunning man hurt *herself*
c.	+MOV	+Grammatical	*Which older man* does Julia suppose *t* hurt the child
	−BIND	−Grammatical	**Which older man* does Julia suppose *t* swam the child
d.	+MOV	+Grammatical	*Which older man* does Julia suppose *t* hurt *himself*
	+BIND	−Grammatical	*Which older man does *Julia* suppose *t* hurt *herself*

Here, too, the results were clear: a Movement effect was obtained for the posterior part of left Broca's region (Brodmann Area 44), and for parts of left Wernicke's area. A [±Binding] contrast was obtained in distinct cerebral loci. First and foremost, deactivation for [−Binding] was monitored in the right Middle Frontal Gyrus. Second, activation for [+Binding] was monitored in the left anterior portion of Broca's region (Brodmann Area 45), in a locus more anterior and markedly distinct from the one for which the Movement effect was recorded. While the

Binding contrast is subtle and requires further thought and testing (see Santi and Grodzinsky, to appear, for discussion), its distinctness from the Movement effect is clear. Support for the Trace-Deletion Hypotheis is obtained: Broca's region is Movement-modulated, and although it undoubtedly hosts certain Working Memory mechanisms, there is a portion of it whose behaviour is structure dependent.

5. Implications and Remaining Questions

5.1. A structure-sensitive Working Memory

It is always difficult to convince people to cross disciplinary boundaries, which is what I tried to do in this paper. But if some preconceptions can be set aside, then linguistics and cognitive neuroscience can meet midway. Here, we seem to have come full circle. Beginning with a non-structural hypothesis, we ended up with a result that strongly ties Broca's region to grammar. We have identified a Working Memory whose only role is keeping track of moved phrasal constituents. It plays a critical role in the processing of movement, but not other dependencies; it makes contact with phrases, and excludes heads. Of the multiple memory systems required for sentence analysis in real time, we seem to have isolated one which is located in Left Inferior Frontal Gyrus, whose activity is manifest in 2-back but not 1-back tasks in the intact brain.

This is a generalized, yet restrictive characterization of a Working Memory, possibly one of many such devices. It should come as important news to linguists and cognitivists alike. For linguists, this is major corroboration from neurology to the view that movement is distinct from other dependency relations, and that head movement is to be set apart from the rest. Moreover, it is a demonstration that underlying syntactic mechanisms can be tapped in tasks that are outside sentential contexts. To cognitivists, this result sets a new constraint on Working Memory, and shows how results from imaging studies converge on lesion data. Thus, not only does it cast new light on the precise nature of Working Memory, but also suggests new ways of studying it.

5.2. Ruling out another non-structural explanation

One seemingly possible explanation for the results of the aphasia experiment described above relies on simple proximity. Versions of this are known as the Minimal Distance Principle proposed by Chomsky (1969) for children, and espoused by Blumstein et al. (1983) for aphasics. A more specific version of this is the Most Recent Potential Filler strategy (Frazier et al. 1983). On this view only the closest potential antecedent is checkable. If it cannot serve as an antecedent, the aphasic patient rules it out, without looking at more distant antecedents. The Minimal Distance Principle would account for patients' performance on the single-antecedent cases, and for cases of binding without movement, as in (29). In this latter set of cases, if the closest antecedent is not a potential binder, the sentence is indeed ungrammatical. Yet, observe the prediction of an approach based on the Minimal Distance Principle for the binding-plus-movement sentences in (36). In these, the patients should always reject the grammatical case (36a), while accepting the ungrammatical (36b). This is because, in the absence of considerations that pertain to dependencies, what matters is whether or not the closest potential antecedent, *the woman*, agrees with the reflexive. In (36a) it does not, hence the patients are expected to say "no" all the time, whereas in (36b) the opposite should occur.

(36) a. $[_{NP_1}$*Which man*$]$ does $[_{NP_2}$Mary$]$ think $[_{NP}t]$ likes himself "yes"

b. $[_{NP_1}$*Which man*$]$ does $[_{NP_2}$Mary$]$ think$[_{NP}t]$ likes herself "no"

Performance should thus be below chance in both cases, which does not happen. As the table in (37) demonstrates, Broca's aphasics, while being above chance on the non-movement cases (upper row), are around chance on both the grammatical the ungrammatical cases of movement (lower row):

(37) *Movement vs. Grammaticality in performance* (% correct, SD):

	+Grammatical		*−Grammatical*		X' (±)	
−MOV	87	(8.23)	67	(16.36)	77	(16.25)
+MOV	66	(20.11)	53	(20.57)	57.5	(20.9)

5.3. Further predictions

As a general point, the conclusions of this report have crisp and wide-reaching predictions for normal functional imaging and for aphasia. Two cases come immediately to mind. First, Broca's region is expected to be very active not just in *n*-back tasks, but also in tasks involving sentence processing with movement, but not binding. Second, aphasics are expected to fail the 2-back task. To judge by Smith and Geva's (2000) report on digit span, this may indeed be the case.

The foregoing discussion has an important limitation. It has ignored issues pertaining to hierarchical relations, and focused only on the sequential nature of dependencies in strings. Hierarchy, a central property of syntactic objects, must interact with Working Memory in intricate ways. This, however, is beyond the scope of this preliminary report. I should just mention a few relevant constructions that need to be tested.

Two such cases (also relevant to the Minimal Distance Principle) involve the contrast between hierarchically local but linearly non-adjacent binding of a reflexive, apparent in the case of a complex NP binder, as in (38). Another pertains to the complex issue of reflexives in double object constructions, as in (39).

(38) a. [An uncle]$_1$ of Mary's adores [himself]$_1$

b. *An uncle of [Mary]$_2$'s adores [herself]$_2$

(39) a. [John]$_1$ showed Mary to [himself]$_1$ in the mirror

b. John showed [Mary]$_2$ to [herself]$_2$ in the mirror

5.4. Processing load and Broca's region

Finally, the results speak to the notion of processing complexity in language. The non-incremental nature of the activity as monitored in neuroimaging devices, and more saliently, the sharp drop in performance in aphasia and the dissociation between performance on different types of dependency relations, casts doubt on the centrality of notions that make no direct contact with structure. The results show that conceptions of processing complexity, load, and capacity limitation — which have been introduced to describe the role of Broca's region in language (Just et al. 1996; Carpenter et al. 2000) — may be valid just in case they are equated with grammatical concepts such as syntactic movement. That is, they must have an irreducibly syntactic character.

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