TESTING PARADIGMS IN APHASIA RESEARCH: METHODOLOGICAL REMARKS[1]

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Language is embedded in cognition and as such it is neither a unified nor isolated phenomenon. Many neurobiological and computational processes are involved in language processing. For example, speech perception and reading require perceptual transformations in the auditory and visual cortices. Speaking requires motor control processes mediated by the motor cortical areas, basal ganglia and cerebellum (Kutas et al. 2000). Auditory language comprehension, which can be compromised in aphasic patients to different degrees, is carried out by three language subsystems (phonological, semantic and syntactic subsystems), and is supported by memory and attentional processes.

The phonological subsystem of auditory comprehension carries out phonetic and phonological processes. Neuroimaging evidence suggests that this subsystem involves certain temporal areas as well as the superior-dorsal region of Brodmann area (BA) 44 (Friederici 1998). The semantic subsystem in auditory comprehension activates several areas, depending on the nature of the semantic task: while passive listening activates temporal region BA22/42 bilaterally, different semantic tasks activate left BA47, BA45/46 and BA44 (Friederici 1998). The syntactic subsystem involved in sentence comprehension activates the following areas in the dominant hemisphere: Broca's area, the angular gyrus, the

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supramarginal gyrus, and the superior temporal gyrus, also known as Wernicke's area (Caplan 2002, Friederici 1998). Syntactically more complex sentences also activate non-perisylvian regions. Furthermore, there are indications that some subcortical structures related to rule-based elements of processing, such as the basal ganglia, are also implicated in syntactic comprehension, although more research is needed on this issue (Caplan 2002).

As a higher cognitive function, language is supported by other cognitive systems, such as memory and attention. This further means that the parietal lobe, which is implicated in attentional processes, and the hippocampal, medial temporal, and frontal lobe structures, as implicated in memory processes (Kutas et al. 2000), also support language processing. Thus, many areas of the brain are involved in language processing. In computational terms, it means that the processing of language requires resources from more than one cognitive domain.

Until recently, the role of memory, attention, and perception in comprehension and other language processes had been overlooked. Two steps were necessary to overcome this problem: first, it was essential to recognize that each of these cognitive domains makes their respective resources available to information processing, and second, it was necessary to define the nature of systems such as working memory (WM) that link cognitive information from different domains (van der Zee & Nikanne 2000). Indeed, growing interest in the role of WM in language comprehension[2] has already created a dynamic field which incorporates theoretical knowledge, methodology and empirical findings

[2] Neuropsychological, experimental, and developmental evidence strongly suggest that WM is crucial in language comprehension.

from several disciplines (see for example, Caplan, Vijayan, Kupeberg, West, Waters, Greve & Dale 2001; Embick, Marantz, Miyashita, O'Neil & Sajai 2000; Felser, Clahsen, Münte 2003; Friederici, Steinhauer & Frish 1999; Just, Carpenter, Keller, Eddy & Thulborne 1996; Kang, Constable, Gore & Avrutin 1999; Keller, Carpenter & Just 2001; Kotz & Friederici 2003; Münte & Heinze 1994; Stowe, Withaar, Wijers, Broere & Paans 2002; Swaab, Brown & Hagoort 1997; Vos, Gunter, Schriefers & Friederici 2001 among others). While there is general agreement that without WM it would not be possible to temporarily store intermediate representations on which subsequent processes operate (which is crucial in any kind of syntax), research on the impact of WM on the comprehension of syntax has resulted in contradictory findings (Caplan & Waters 1999, 2002; Crosson et al. 1999; Just & Carpenter 1992; Martin & Romani 1994; Miyake, Carpenter & Just 1994, 1995; Vos et al. 2001). This is not a trivial matter, since it leaves open issues of theoretical framework, interpretation of empirical findings and choice of appropriate research methods. This is particularly evident in research on Broca's aphasia, a language disorder caused by a (usually focal) brain damage, where still predominantly off-line behavioral methodology has a strong influence on theory.

1. Currently used testing paradigms

Due to methodological constraints of behavioral paradigm applied in the research on aphasia, many important questions pertaining to the nature of the deficit are left out, which provides only a partial insight into disorder. As pointed out by Zurif et al. (1993), the most influential proposals on the comprehension deficit in Broca's aphasia (e.g. Grodzinsky1986, 1990; Hickok

1992) are merely 'descriptive generalizations' because of the limited testing paradigms on which they rely. These paradigms are unable to help answer the question of whether the deficit is a partial loss of syntactic knowledge or a deficit in real-time processing of that knowledge. Indeed, most studies on the syntactic comprehension deficit in Broca's aphasia often rely on a single, and sometimes several off-line behavioral paradigms, such as sentence-picture matching, act-out, and grammaticality-judgement paradigms (e.g. Linebarger et al. 1983, Grodzinsky 1995, Hickok et al. 1993, Hickok & Avrutin 1996, Thompson et al. 1999, among others). Only recently have on-line methods such as Event Related Brain Potentials (ERP) and neuroimaging techniques Computerized Tommography (CT), Positron Emission Tomography (PET), Functional Magnetic Resonance Imaging (fMRI) been applied in studying syntactic comprehension deficits in Broca's aphasics (Karbe et al. 1998, Marchand, D'Arcy & Connolly 2002)[2].

In a sentence-picture matching task, a subject is required to judge if the meaning of a sentence is correctly represented by a single picture, or, in the case when semantically reversible sentences are tested, to select from a pair of pictures the one that best represents the meaning of an auditorily presented sentence (Schwartz et al. 1980, Berndt et al. 1996, Inglis 1999). Since semantic reversibility is crucial in assessing comprehension, a set of distributed pictures usually contains a picture that represents a correct assignment of thematic roles

[2] An on-line behavioral paradigm, lexical cross-modal lexical priming (CMLP), is used in studies that hypothesize that a slow lexical access causes the syntactic comprehension disturbances in Broca's aphasia (Prather et al. 1991, Zurif et al. 1993).

to sentence nouns, and a distracter picture showing a reversal of thematic roles assigned to the nouns in a sentence, resulting in an incorrect meaning of the sentence.

However, as pointed out by Hickok, Zurif & Canseco-Gonzalez (1993), the sentence-picture matching task imposes unnecessary cognitive demands onto a subject. In addition to sentence parsing, this type of task requires parsing and comparing of two or more pictures - a computational burden that is not present in sentence comprehension in the everyday use of language. Another problem pointed out by the same authors is that sentences in this type of task are presented out of context, which is problematic in cases where sentence meaning depends on a discourse. In this case, a subject has to 'mentally create' an appropriate context in order to be able to interpret a discourse-linked sentence, again imposing an unnecessary computational burden (Hickok et al. 1993).

Another testing paradigm, the grammaticality-judgement paradigm, has been used in the assessment of recognition of grammaticality of sentential structure (Linebarger et al. 1983). Studies based on this paradigm have shown that Broca's agrammatic patients, in spite of their comprehension deficits, can correctly judge the grammaticality of sentences (Linebarger et al. 1983). According to other researchers, however, judging a grammatical structure is less computationally demanding than building up the correct syntactic representations of a sentence in real time, which also requires properly assigning thematic roles and correctly interpreting the sentence (Zurif et al. 1993).

Also, research on hemispheric specialization indicates that the ability to correctly judge the grammaticality of sentences is probably related to the right hemisphere (which is presumably intact in right-handed Broca's aphasics), while the left hemisphere supports syntactic processing. Gazzaniga's research related to 'split-brain' patients has shown that the right hemisphere could perform grammaticality judgments, but it was deficient in syntactic processing implicated in comprehension (Zurif et al. 1993).

Another often-used paradigm in testing Broca's comprehension deficit is the act-out paradigm. In an act-out task, a subject 'acts out' an auditorily presented sentence with toys (animals or dolls) (Caplan & Futer 1986, Hickok & Avrutin 1996, Thompson et al. 1999, Inglis 1999). In other words, a subject is required to manipulate a toy to demonstrate, or 'enact', the action of a verb in a spoken sentence. However, this type of task reduces the discourse from a set of potentially infinite number of possibilities to a limited number of alternatives manageable within the testing paradigm. It also imposes certain non-linguistic cognitive (memory) and non-cognitive demands (Inglis 1999). A non-cognitive factor, but equally important to the cognitive ones discussed above, is that Broca's aphasia following left hemisphere damage is often accompanied by right hemiplegia, in which case restricted motor agility of the right arm in a patient dramatically reduces the outcome of such a task. For these reasons, a task should require zero or minimum of non-linguistic efforts.

A version of such an act-out task that can be applied in testing Broca's aphasic subjects is Hickok et al.'s (1993) truth-value judgment task. In this version of the act-out paradigm, a scenario is acted out by the experimenter, after which a sentence is read. The subject is required to decide whether the sentence correctly represents the situation acted out or not, and to say (or point to a sign indicating) either ‘true’ or ‘false’. In this case, the subject attends to a sentence rather than a picture, and accepts or rejects a *sentence*, instead of a correct or incorrect *picture*, which is the case with the sentence-picture matching task. This simplifies the sequence of cognitive and non-cognitive subtasks a patient needs to perform in order to successfully complete the task. Since a patient *watches* the experimenter acting-out the task, it takes less time for a sentence to be acted out. Instead of storing a sentence in memory, planning and performing motor movements of the act-out, and constantly comparing the sentential representation in memory with the motor movements of the act-out, the patient focus on the comparison and decide immediately upon the experimenter’s acting out to which toy to point. Not only is the amount of time that a patient needs to store sentential sequences within WM shorter, but his / her motor activities are reduced to simple pointing, leaving her / him a chance to fully concentrate on the sentence, and not on a motor task. Thus, this version of the act-out task is less demanding cognitively (less memory, less attention) and non-cognitively (smaller motor effort), and contains a minimal interference of cognitive and non-cognitive requirements (pointing). In other words, this version of act-out task avoids the factors that would be confounded with syntactic processing in the previous version of the task as well as in picture-matching task.

However, Thompson et al. (1999) tested comprehension of wh-questions in four Broca’s agrammatic patients by using both the sentence-picture matching and the act-out paradigms (with the experimenter acting out the task), and found ‘little difference’ in obtained comprehension patterns. Thus, although the two paradigms impose different processing demands, 'the same sentence parser is operating under both experimental conditions' (Thompson et al. 1999, p. 181).

Thompson et al. (1999) may be correct in assigning the similarity of the results obtained in two paradigms to the role of the parser. However, they do not consider the possibility that something else in addition to the parser operates in both experimental conditions – spatial working memory (SpWM). Namely, both conditions test auditory comprehension. However, in addition to auditory they both present visual material, which is then spatially manipulated to different degrees. It is not clear then whether (or to what extent) the obtained results reflect auditory comprehension, or whether they reflect SpWM processes facilitated by auditorily presented material. This cannot be deduced, given that none of the studies that used one of these two paradigms contains tests of SpWM.

2. The functional definition of Broca's area

Given the shortcomings of the behavioral off-line testing paradigms, and the fact that the ultimate goal of any research on aphasia is to reveal workings of the brain, it is not surprising that a unified theory of aphasia has not been developed. Also, although the localization hypothesis on language, i.e. the view that language is processed only by a few specific brain areas that are involved in nothing but language processing (Bates 2001), has been debated within different theoretical paradigms over years, it is still predominant view in aphasia research. The localizationist view has lost some of its appeal due to new findings provided by imaging techniques such as PET and fMRI. The new findings are not consistent with the classical approach, according to which there exist 'language zones' (see Zurif et al. 1993, and Zurif 1995 for a criticism of this view). They strongly indicate that language is widely distributed in the brain (Kutas et al. 2000), which is enabled by ‘multiple *relative* specializations’ of different brain areas (Keller et al. 2001). At the moment, there is no satisfactory functional definition of Broca’s area, but it is plausible to assume that it has multiple *relative* specializations.

More specifically, the original localization theory, according to which it is possible to associate brain areas with cognitive functions, assumed that Broca’s area was involved in speech production. The theory has been challenged on different grounds over time, only to reappear recently, reinstated by syntacticians who claim that Broca’s area is in fact the locus of syntactic computation (Grodzinsky 2000). Since this area is damaged in Broca’s aphasic patients, careful analyses of syntactic processing in this population were conducted in an attempt to correlate damage to component(s) of Broca’s area with types of syntactic deficits. Thus, most of the current research on Broca’s aphasia is based on the idea that damage to a component of Broca’s area - pars opercularis (BA 44) and pars triangularis (BAs 45, 47) (Diamond et al. 1985) - wipes out part of syntax.

Embick et al. (2000), for example, claim that the exclusive role of Broca’s area is to regulate comprehension of specific intrasentential dependencies. Evidence from lesion studies suggests that these dependencies are related to *syntactic movement*, a specific process of forming complex syntactic structures (Grodzinsky 2000).

Based on the functional Magnetic Resonance Imaging (fMRI) experiments conducted with healthy native Hebrew-speaking population, Ben-Scachar, Palti & Grodzinsky (2003) found a finer distinction in neurological areas involved in syntactic movement: both the left inferior frontal gyrus and left anterior insula are sensitive to movement operations, but

> […] based solely on our fMRI results we cannot determine which of the activated brain regions is indeed critical for processing movement sentences. Results from lesion studies make a strong case for the critical role of Broca's region in this respect (Ben-Scachar, Palti & Grodzinsky 2003).

Friederici, Rüschemeyer, Hahne & Fiebach (2003) conducted fMRI experiments with a neurologically intact, German-speaking population and found that the anterior portion of the inferior frontal gyrus (BA 44 on the border to BA 45) and BA 47 are implicated in processing of long-distance dependencies, while 'the posterior-inferior portion of BA 44, i.e. the inferior tip of the pars opercularis and deep frontal operculum on the border to ventral premotor cortex, is involved in on-line syntactic structure building processes (Friederici et al. 2003, p. 171).

The representatives of an alternative approach claim that Broca's area is not the locus of syntax per se. For example, Zurif claims that it houses processing resources implicated in 'lexical (re)activation and its syntactic ramifications' (Zurif 1995, p. 394).

Based on Event Related Brain Potential (ERP) experiments conducted with neurologically intact native speakers of German, Fiebach et al. (2001) propose that Broca's area actually houses syntactic WM, a particular type of processing cost implicated in comprehension of syntactic structures. While speculations on the involvement of Broca's area in an aspect of WM clash with the traditional view according to which it is BA46 that is implicated in verbal WM (Petrides et al. 1993), Fiebach et al.'s (2001) finding on two distinct types of processing costs implicated in comprehension of complex syntax has been supported by further evidence from German (Fiebach et al. 2002, Felser et al. 2003). Note that, according to their view, the concept of syntactic WM corresponds to the resources required for a specific type of syntactic processing that is being subserved by Broca's area.

Kennedy & Small (2002) conducted a cross-domain behavioral study in order to determine whether the WM resources required for comprehension of sentences that pose high WM demands are domain- (i.e. language-) specific. They used tasks matched for WM processing demands in language, mathematic and visuo-spatial WM contexts. Details aside, the mathematic and visuo-spatial tasks were intended to 'mimic' processing demands of subject and object relative clauses (e.g. the brackets in a math task function as embedding within a sentence). They found that the 'similarity of the sequence of demands' to the sentence processing task, and not the similarity of the cognitive domain, triggered similar WM demands and thus similar patterns of activation. Thus, maybe a more plausible approach to the role of Broca's area in syntactic processing is one that applies the concept of syntax not exclusively to language, but rather assumes that syntax is a formal property of any activity based on computation.

As an example, several fMRI studies have shown that increased sentential complexity correlates with an increase in activation of Broca's area (Just, Carpenter, Keller, Eddy & Thulborn 1996, Embick et al. 2000, Keller et al. 2001). If a general increase in complexity (and thus computation), rather than a specific syntactic process, is a reason for increase in activation in Broca's area, then this is further evidence that something other than syntax per se may be compromised in Broca's aphasic patients.

These insights indicate that the localization question has not been solved; it has just acquired a new dimension, weakening the modularity hypothesis and providing space in which to search for potential arguments supporting more interactivity within cognition.

3. Cognitive interfaces and multiple relative specializations

Language processing requires both intra- and inter-modular connectedness. The former is captured by models of grammar in which there is a level of phonological, syntactic, semantic (and conceptual), and discourse representation. The latter can be exemplified by the role of the memory subsystem employed in syntactic computation, which has been termed *syntactic working memory* (SWM) (Lewis 1999, Fiebach et al. 2001, Fiebach et al. 2002). It is possible that SWM, in although not quite in Fiebach et al.'s (2001) sense, is an interface module consisting of processes of storage and manipulation (recall and retrieval) of intermediate syntactic representations that emerge in the course of building full representations. Namely, Fiebach et al. (2001, 2002) are building a specific theory of sentence processing based on the concept of SWM, suggesting that it is grounded in neuroanatomy. Fiebach et al. (2001) argue that

> […] there exists a separate cognitive or neural resource that supports syntactic working memory processes necessary for the temporary maintenance of syntactic information for the parser. In the context of wh-movement, such a memory component is necessary for establishing filler-gap dependencies. … (p. 321)

and that

> ‘syntactic working memory, rather than syntactic processing per se, is supported by Broca’s area’ (p. 321).

The concept of SWM has the potential to link different cognitive domains. If indeed housed by Broca’s area, this presumably interface module would have multiple relative specializations. It is perhaps not too early to claim that a specific part of Broca’s area subserves syntactic transformations that are computationally more demanding, such as those involved in long-distance object dependencies. However, the claim that it subserves *only* syntactic computations in sentence processing that result in long-distance dependencies probably is, because more research on other cognitive domains, such as the one conducted by Keneddy & Small (2002), is needed for such a conclusion. It is plausible to assume that the area that presumably subserves only computations required for comprehension of long-distance sentential dependencies has a more general purpose, and is implicated in the sequential processing of structurally dependent, hierarchically organized elements. In that case, the concept of SWM would extend from syntax of language to syntactic computations in other cognitive domains.

If that is the case, then the concept of SWM can indeed be a cognitive interface module, which interfaces not only language, but other cognitive modules as well. In other words, it is not domain specific (Fodor 1983), or a bi-domain module (Jackendoff 2000, 2002), but applicable to more domains. It is possible that such a module operates on sequences of hierarchically dependent elements, such as those found in language, arithmetic, and music. In language, SWM would operate not only in syntax, but in morphology as well, given that words are sequences of morphemes, which are units with internal hierarchy. For example, SWM ensures that the parser obtains all information when needed (e.g. inflectional endings to determine grammatical functions and assign temporary thematic roles) so that it can construct partial (preliminary) syntactic structures as sentence unfolds in time. Similarly, SWM perhaps operates on sequences of numbers, sounds, or any other sequence with a hierarchical internal structure. (Sequences without internal dependency relations, such as random strings of numbers or letters, are probably handled by the short-term memory, i.e. a system which stores information for a short period of time and can manipulate them only linearly).

At this point, the distinction between the questions of whether Broca's area is indeed the locus of certain types of syntactic operations, such as those related to syntactic displacement, or a specific aspect of WM employed for the purposes of these syntactic operations, starts losing its sharp edges. Nevertheless, the search will continue to find a functional definition of Broca's area. In that sense, evidence from aphasia is indispensable. However, in order to make useful contribution to this research, linguistic theories on aphasia need to broaden their scope of interest from theoretical constructs to clinical reality, viewing aphasia as real neurological deficit whose one aspect is represented by language disturbance. From this point of view, focus is shifting from the question whether Broca's area subserves syntax in general, or only syntactic operations involved in syntactic displacement, or SWM, to the question of what other parts of the brain are implicated in syntactic processing, and to processing itself.

In contrast, the distinction between *where* exactly in the brain and *when* in the course of processing the breakdown in syntactic comprehension in

Broca's patients occurs is sharper then ever. Computation of dependency relations in syntax requires language external resources (e.g. WM) that enable manipulations on intermediate representations to happen in time – Broca's aphasics experience breakdown in these processes somewhere before the final result is reached. Observing *when* exactly the processing crashes provides an excellent opportunity to study how comprehension processes unfold in time.

Choosing between the two perspectives – *where in the brain* vs. *when* processing crashes - has theoretical and methodological consequences. Theoretically, the former intends to solve the localization question for syntax (*Where in the brain do syntactic processes occur?*), while the latter focuses on timing (*How do these processes unfold in time*?). Given the different perspectives and complexity of both questions, research on comprehension deficits needs to include on-line investigation of the processes involved, employing techniques such as fMRI and ERP. The former is necessary because of its high spatial resolution, while the high temporal resolution of the latter enables observation of processing in real time.

In summary, research on aphasia thus far has mostly been based on *behavioral* off-line (sentence-picture matching task, act-out task, grammaticality judgment task) and sometimes on-line (real time) experiments (e.g. cross-modal lexical priming). Sentence-picture matching, act-out tasks, and grammaticality-judgment tasks are all off-line behavioral methods in the sense that they are not concerned with subjects' real-time responses as they perform a certain task. While off-line paradigms are acceptable for testing general comprehension of sentences, research on the processing of traces of dislocated syntactic elements needs application of on-line methods (Zurif, Swinney, Prather, Solomon & Bushell 1993, Thompson et al. 1999). Behavioral methods provide important insights into the processes involved in sentence comprehension, but they cannot help us determine which neural structures these processes are based on (Müller, King & Kutas 1997). For example, although behavioral cross-modal priming experiments show that the antecedent of the trace is reactivated as soon as the parser reaches the trace, they cannot show 'how the structural configurations internal to the sentence elicit WM costs' (Fiebach et al. 2002, p. 251). The methods based on reaction-time cannot be considered the most accurate indicator of on-line sentence processing if used with patients who cannot generate fast and accurate movements (e.g. pressing a button), because these movements actually are measurements of on-line processing (Müller, King & Kutas 1997).

A technique that overcomes these limitations by enabling measurement of the brain's activity throughout the processing is the ERP technique. Although ERP studies of aphasic language processing are still rare, this method has the potential to untangle many problems that are open at the moment. For example, the impact of inflectional morphology on syntactic comprehension could be explored by conducting an ERP experiment of grammaticality judgments, given that syntactic violations elicit the P600 effect. Recent advances in imaging techniques are also slowly penetrating neurolinguistic research. Since methodology often shapes theory, with the methodological limits stretching upon the theory itself, an ideal approach would combine behavioral off- and on-line methods with neural on-line methods (ERP, fMRI). Research on comprehension deficits in Broca's aphasic patients could benefit from methods such as ERP or fMRI –both on-line neural methods – because they provide an insight in *what* happens *where* in the brain as language unfolds.

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