Chapter

NEUROIMAGING AND APHASIOLOGY IN THE XXI CENTURY: EEG AND MEG STUDIES ON LANGUAGE PROCESSING IN APHASIA SINCE THE YEAR 2000

Marie Pourquié[1,·] and Phaedra Royle[2,†]

[1]Basque Center on Cognition, Brain and Language;
Université de Montréal, École d'Orthophonie et d'Audiologie;
Centre for Research on Brain, Language and Music
[2]Université de Montréal, École d'Orthophonie et d'Audiologie;
Centre for Research on Brain, Language and Music

ABSTRACT

This paper provides an update on a decade of neuroimaging studies (using electroencephalography, EEG, and magnetoencephalography, MEG) that have focused on linguistic processing in patients with aphasia. The goal of this paper is to shed light on the challenges and usefulness in using such techniques for the study of aphasia. We review study objectives, techniques and results, and highlight the linguistic structures that have been studied. The first part defines the challenges and

· E-mail: marie.pourquie@umontreal.ca.
† E-mail:phaedra.royle@umontreal.ca.

usefulness of EEG and MEG techniques for aphasiology; the second reports the procedures, targets and main results of reviewed studies; the last section addresses the following issues: What does neuroimagery add to classical behavioral studies on aphasia? Are they both necessary and why?

INTRODUCTION

The term "aphasia" stands for language impairments that arise following a brain lesion. Aphasiology can be defined as a science that infers neurocognitive organization of the human faculty of language from the study of deficits observed in aphasic patients. It also aims at developing therapeutic treatments for language recovery.

Although the first generation of neuropsychologists (e.g. Bouillaud, Broca, Wernicke) succeeded in identifying important brain areas involved in language processing from an empirico-inductive perspective, this classical approach has since been declared insufficient for the purpose of inferring precise language organization in the brain (Démonet & Thierry, 2001). Differences in lesion site and extent, and the particular background characteristics of individual subjects (e.g. age, gender, bilingualism, treatment, etc.) give rise to high levels of heterogeneity in aphasic manifestations. This makes it difficult to correlate a given specific cognitive function with any specific brain area, based only upon the study of aphasic symptoms. However, advances in the development of neuroimaging tools have allowed researchers to assess healthy individuals in order to explore the neural underpinnings of language. They have shown that the language network in the brain is much more extended that was thought before: it involves both hemispheres and the coordinated activity of multiple structures (Hagoort & Poeppel, 2013). Thus, neuroimaging techniques should be considered as complementary tools to traditional approaches in aphasiology for the study of neurocognitive underpinnings of human language. The present chapter is concerned with neuroimaging studies that assess language processing in aphasia. We present their goals, challenges and perspectives in the context of aphasiological research. We specifically focus on studies developed over the last decade using Electroencephalography (EEG) or Magnetoencephalography (MEG) [1].

[1] For a review of fMRI research on language processing in aphasia, see Crosson, McGregor, Gopinath, Conway, Benjamin, Chang, Bacon Moore, Raymer, Briggs, Sherod, Wierenga & White, 2007.

1. CHALLENGES AND USEFULNESS OF ELECTROENCEPHALOGRAPHY AND MAGNETOENCEPHALOGRAPHY TECHNIQUES FOR THE STUDY OF APHASIA

In the arena of clinical aphasiology, functional Magnetic Resonance Imaging (*f*MRI) studies are ubiquitous. Despite the growing number of Electroencephalography (EEG) and Magnetoencephalography (MEG) studies on normal language processing that have the potential to provide useful data for the further study of aphasia, only a few studies using such techniques to assess language processing in aphasia have so far been run. Before discussing the reasons why the use of these techniques appears to still be rare in aphasiological research, we define some basic concepts in neuroimaging research.

1.1. Neuroimaging Techniques

*f*MRI, EEG and MEG are non-invasive imaging techniques that aim to characterize different aspects of neuronal activity in the brain, both in time and in space. Whereas EEG and MEG track underlying electrical activity of the brain, *f*MRI maps local changes in brain blood flow. EEG and MEG each provide data with high temporal resolution (measured in milliseconds). While data from EEG are limited in spatial resolution information, both MEG and *f*MRI allow for high-level anatomical detail. Localized neural activity from MEG data is called electromagnetic source imaging (EMSI). In turn, *f*MRI detects local increases in relative blood oxygenation and provides good spatial but relatively poor temporal resolution (Halchenko, Hanson & Pearlmutter, 2005).

Traditionally, much of the research on brain imaging in patients had used magnetic resonance imaging (MRI, i.e. brain images based on magnetic resonance fields) combined with *f*MRI methods to study language processing in aphasia. MRI is used to visualize the brain structures and any architectural pathology which may be present, but not the cognitive functions of the brain. During *functional* magnetic resonance imaging (*f*MRI), participants perform a particular task during the imaging process, causing increased metabolic activity in the area of the brain believed to be linked to cognitive processing demands caused by the task. In this case, changes in blood flow are measured and superposed on the MRI. The usefulness of *f*MRI is clearly linked to this method's high imaging resolution for brain structures and lesions, which have obvious advantages when studying patient populations. However, this approach has a major disadvantage in the time domain, as recording time resolution is quite low (in the order of seconds, as it takes between 1 and 2 seconds for *Blood-oxygen-level dependent* (BOLD) levels, which are what are measured using *f*MRI, to change following a stimulus). As we know that language processing operates within hundreds of milliseconds after stimulus presentation, and unfolds rapidly and quite automatically over time during the processing of a stimulus or a sentence, much information on the time-course of language processing is not available to us using this method.

More recently, the use of event-related potentials (ERPs), which are electrical waves extracted from the EEG signal, have allowed for more fine-grained interpretations of ongoing cognitive processes during language processing, and have become an important source of evidence on the functional organization and temporal dynamics of language processing. ERPs are characteristic patterns of voltage change extracted from scalp-recorded electrical brain activity, time-locked to the presentation of critical linguistic (or other) stimuli (Luck, 2005). They can provide information at the level of millisecond-by-millisecond changes in brain activity. Systematic differences between ERP waves (or "components") in different experimental conditions can be used to study and understand neurocognitive processes involved in different aspects of language processing. ERP components differ in terms of polarity (whether deflections are negative or positive going), onset latency (when the curves depart from each other), duration (how long deflections last), topography (what their distribution is on the scalp), latency shifts (differences in onset or offset latency depending on experimental conditions or populations), and amplitude (the size of the difference between ERPs in two or more conditions).

EEG measures coordinated electrical brain activity. To record an EEG, electrodes are placed over multiple areas of the scalp to detect patterns of electrical activity. Scalp-recorded activity generated by the co-activation of tens of thousands of neurons in a region of the neocortex engaged in cognitive operations results in the ERP components observed. A number of ERP components linked to linguistic sub-domains such as phoneme discrimination, word segmentation, prosodic and intonational phrasing, morphology, conceptual semantics, syntax, discourse processing, and more have been identified in the last forty years (Hagoort & Poeppel, 2013). It should be noted that there is no one-to-one mapping between specific linguistic sub-domains and ERP components. That is, multiple domains of language processing can elicit similar ERP components, while processes involving what are considered to be unitary processes in linguistics (e.g., agreement checking) can elicit multiple components in the ERP wave. However, the waves found in specific linguistic contexts (e.g., morphosyntax, syntax, and word processing) are quite stable across experiments and languages, and therefore allow us to study the neurocognitive underpinnings of normal and impaired processing of language. For example, the N400, a negative-going wave peaking around 400 ms after stimulus presentation has been used since Kutas and Hillyard (1980) in tracking lexical access and semantic integration.

Magnetic resonance imaging (MEG), which measures magnetic fields linked to electrical activity in the brain, allows for similar fine-grained analyses of ongoing neurocognitive processes. In addition, this technique can provide better spatial resolution than ERPs because of the nature of the recording (see Rodden & Stemmer, 2008). The MEG equivalent of ERP is the event related field (ERF). ERFs measure changes in magnetic fields, again linked to the processing of a critical stimulus. ERFs show similar timing and amplitude changes as those found in ERPs but are always positive going, never negative. As with ERPs, reliable ERF components are observed in language-based experiments (see, e.g., Salmelin, 2007). However, they are not as widely used as ERPs for the study of language processing, in part due to higher operational costs for MEG.

1.2. Challenges in Neuroimaging Research on Aphasia

Research into the neural basis of language processing is complicated by many factors linked to the specificities of aphasic populations (Démonet & Thierry, 2001). The considerable variability of lesion size, shape, and location and individual backgrounds may give rise to different spatial and temporal brain activity patterns. In some cases, it might be more suitable to analyze results at the individual subject level, rather than at group levels, in order to draw conclusions on the neurofunctional organization of impaired language processing.

On the other hand, the use of neuroimaging techniques also faces methodological challenges when used to assess impaired linguistic systems after brain damage. EEG and ERFs are characterized by their great temporal resolution. This means that they are highly sensitive in detecting ongoing cognitive events being processed in the brain, which are expressed through voltage or magnetic changes. But being sensitive to the most discrete implies being affected by the less discrete, which can be a disadvantage for data analysis and interpretation. Indeed, strong artifact signals generated by eye, mouth and tongue movements can mask cortical activity measurements related to cognitive processing.

Even though progress has been made to remove disruptive field patterns from the MEG data (Salmelin, 2007), imaging language production in aphasia remains challenging. For instance, in neurotypical participants, trial onset timing is defined according to the tight temporal relationship between stimulus presentation and response. However, patients' average response latencies are much longer and variable, making it tedious and less useful to set up an experiment that integrates measures of speech output speed and accuracy (Crosson et al., 2007). Moreover, ERP and MEG experiments need to present numerous stimuli in order to overcome high signal-to-noise ratios. This, coupled with the inherent inter-subject variability, creates larger signal to noise ratios in patients than with neurotypical participants. This might explain why, despite their apparent usefulness for the study of neurocognitive processing, we find very few ERP and MEG studies that have been carried out on aphasia and language production.

Rare neuroimaging studies have dealt with language production in aphasia (Sörös, Cornelissen, Laine, and Salmelin, 2003). To our knowledge, no study has yet assessed either phrase or sentence production in aphasics. The assessment of overt speech in patients with aphasia is useful, as it allows investigators to track response accuracy with the goal of determining if specific brain areas are necessary for the production of correct linguistic outputs. However, language production studies are constrained by the necessity to remain still during data collection and recording, and are additionally problematic with ERP as muscle movements create artifacts in the EEG wave.

This is probably the main reason why most neuroimaging studies of aphasia assess language comprehension. However, problems can emerge while assessing comprehension in patients with aphasia, as it can also be delayed and variable. Moreover, covert tasks prevent investigators from checking whether participants apply instructions accurately or have understood the stimuli. Finally, since aphasic participants may have difficulties either in retrieving words, or in producing responses once words are retrieved, it remains unclear whether observed activation patterns reflect word retrieval or post-retrieval response production difficulties.

In addition, some studies reviewed here (e.g. Angrilli, Elbert, Cusumano, Stegagno & Rockstroh, 2003) mainly focus on brain lateralization patterns rather than the time course of cognitive processes, which is unusual in ERP studies where timing effects are more relevant than their distribution over the scalp, due to the inverse problem[2]. Because of poor spatial resolution in ERPs, this methodological approach is usually not appropriate for research questions bearing on localization. The technical challenges related to the use of neuroimaging in aphasia (experiment modality, setting up time) in addition to problems linked to behavioral approaches (high variability of lesion sites and extent, distinct background, variable syndromes, different reorganization etc.) raise the issue about the point of doing research on aphasia using such techniques. The following section presents some benefits of neuroimaging studies for aphasiological research.

1.3. Usefulness of Neuroimaging Techniques for the Study of Language Processing in Aphasia

Currently, one of the main issues addressed by neuroimaging (especially *f*MRI) studies of aphasia is the role of the non-dominant, usually right hemisphere, versus perilesional cortex in language recovery. Meltzer, Wagage, Ryder, Solomon, and Braun (2013) argue that the use of neuroimaging helps to determine whether increased hemisphere activity during language tasks performed by individuals with aphasia represents takeover of function by regions homologous to the left-hemisphere language networks, maladaptive interference, or adaptation of alternate compensatory strategies. In addition, recent findings highlight the usefulness of temporally sensitive measures when studying aphasia by demonstrating that the latency of electrophysiological markers is of interest in patient populations (Zipse, Kearns, Nicholas & Marantz, 2011).

Both EEG and MEG approaches have obvious advantages in the study of language impaired populations, as they can be used with auditory stimuli, avoiding reading processes that might be impaired in patients, in addition to providing fine-grained information on the time-course of linguistic-cognitive processing. The information that they provide is thus complimentary to

[2] The fact that the neural correlates of the recorded activity on the scalp cannot be inferred from the electrode(s) where the activity was recorded, due to distortion from brain and scalp tissue. This is one reason why some researchers prefer MEG or *f*MRI to ERPs, as they do not suffer from this problem.

traditional approaches for the assessment of language difficulties in special populations, in particular because of their added value of measuring ongoing processes in language comprehension and production, rather than providing end-state data (reaction time and judgment values) or average brain activations patterns over rather long time periods, as is found in *f*MRI.

Finally, most studies of aphasia have reported dissociations that emerge behaviorally but not at the level of the brain. These indicate the possibility of compensatory strategies in patients' behavior. For instance, Meltzer et al. (2013) observed that right hemisphere activation can be observed with both accurate and inaccurate comprehension performance, which they interpreted as strategic recruitment of alternative networks rather than homologous takeover. Zipse et al. (2011) report that whereas participants with aphasia did not show semantic priming of the M350 (an electrophysiological marker of lexical processing in MEG, roughly equivalent to the N400 in ERPs), they did exhibit significant behavioral semantic priming. Semantic priming studies with neurotypical subjects can also show dissociations between behavioral and ERP data, especially with semantic priming (see Royle, Drury, Bourguignon & Steinhauer, 2012 for a review). Sörös et al. (2003) note a dissociation between noun and verb retrieval that only emerges after the disruption of the normal language network, and which is not visible with electrophysiological tools. Wassenaar and Hagoort (2007) also report that while control individuals show on-line sensitivity to thematic role assignment[3] between pictures and the sentences, aphasic participants did not display typical on-line ERP patterns, but showed off-line sensitivity to the sentence-picture mismatches.

Such data are of particular interest for aphasiological research as they seem to indicate that aphasic performance is the result of specific deficits bypassed by cognitive strategies. Thus, neuroimaging techniques offer the opportunity to illustrate and measure an assumption that has already been suggested in the literature on aphasia based on behavioral studies, namely that aphasia is not the pure manifestation of underlying linguistic deficits, but the sum of linguistic deficits compensated by cognitive strategies (Kolk & Van Grunsven, 1985; Kolk, 1995; Nespoulous, 1996; Sahraoui & Nespoulous, 2012). It appears fruitful to pursue both on-line and off-line approaches in order to obtain complimentary perspectives in our understanding of language processing in aphasia.

[3] That is, knowing which noun is the subject (agent) or the object (patient) of the verb, as in *the girl is pushed by the boy*, where the first noun in the patient of the verb and the second one the agent.

2. EEG AND MEG STUDIES ON LINGUISTIC PROCESSING IN APHASIA: PROCEDURES, RESULTS AND ANALYSES

A general impression that we can take from ERP and MEG studies on language processing is that only a few have used this approach to assess language processing in aphasia. Moreover, most concern language comprehension, and if they deal with language production then it usually is by way of picture naming tasks, that is the production of isolated words. Finally, they generally aim to determine which brain areas or hemispheres are activated – either the non-dominant hemisphere or perilesional areas – in individuals with aphasia performing specific linguistic tasks, in order to identify brain areas involved in language recovery. The present section is divided into three subsections: the first two present recent studies on lexical-semantic and syntactic processing run with aphasic patients; the third contains some remarks regarding our general assessment of these studies.

2.1. Lexical Processing

An ERP study by ter Keurs, Brown and Hagoort in 2002, investigated written word recognition in Dutch-speaking patients with Broca's aphasia (BA), and patients with right hemisphere damage without aphasia (RH), and controls. They asked participants to categorize items according to their word category (open and closed-class words). Of primary interest were ERP negativities linked to early word detection (the early anterior N210-325) and later lexical-semantic integration (the N400, for a review of studies on lexical semantic-processing involving this component, see e.g., Holcomb & Grainger, 2006 and Kutas & Federmeier, 2011). Controls and RH patients showed typical early and late negativities, in addition to a third later anterior negativity, to closed-class words, while patients with BA did not show either anterior component, in addition to presenting a delayed N400 that was longer lasting that those found in the other two groups. It should be noted that the items in this task were not controlled for frequency or length. Thus the closed-class items should have been perceptually salient, as they are typically shorter and more frequent than open-class words[4]. These data seem to signal

[4] Additional analyses integrating these factors did not show specific effects of frequency of word length on the data, however.

difficulties in early word class detection in patients with BA and may account for observed syntactic difficulties in these patients.

Another ERP study on lexical access using semantic and associative priming again investigated the N400, here modulating it with prime presentation using associative relations (i.e., a word preceded by a semantically related word, e.g., salt-pepper)[5]. In their Japanese auditory study of lexical access in 10 participants with aphasia with auditory processing impairments, and 10 controls, Kojima and Kaga (2003) presented related and unrelated word pairs to participants. They observed longer onset and offset latencies, as well and smaller amplitudes for the N400 to unrelated pairs in patients. A correlation between the size of the N400 and an auditory comprehension score that was gathered before the experiment was also found. Behaviorally, the patients' recognition scores for the experimental items were normal but their reaction times were slower that controls. Unfortunately, the groups' ERPs and response patterns were not directly compared in the global ANOVAs, but only in post-hoc t-tests. According to the authors, the correlation between the offline measures and the N400 points to the usefulness of the N400 in establishing or confirming a diagnosis of lexical access impairment.

An ERP study led by Angrilli, Elbert, Cusumano, Stegagno and Rockstroh (2003) presents data on rhyming and semantic judgment with word pairs in 10 Italian participants with non fluent aphasia and 10 controls. Using primed rhyming pairs (i.e., a word preceded by another with which it rimed, e.g. *cat-hat*) or semantically related pairs (e.g., *wood-tree*) and fillers, they asked patients to make rhyming and semantic judgments on the stimuli. Data show different lateralization patterns in controls and patients, as well as longer reaction times and higher error rates in patients. Unfortunately, data were not analyzed on the target but rather the prime. Although stimuli were presented in different blocks, where participants were specifically asked to perform a phonological (rhyming) or a semantic task, thus promoting phonological versus semantic strategies to word recognition, the fact that analyses were made on the first rather than the second word makes it difficult to interpret this data in terms of lexical access, and makes the interpretation more about cognitive strategies used tasks rather than lexical access itself. We have no way of telling whether rhyming or semantic priming had any effect on lexical access and retrieval. In addition, the authors present no functional interpretation of the ERP patterns.

[5] Priming typically reduces the N400 amplitude.

Another lexical-decision task using ERPs was developed by Justus, Larsen, Yang, de Mornay Davies, Dronkers and Swick (2011). They studied a group of patients with aphasia resulting from damage to the pars opercularis (BA44) and the pars triangularis (BA45), i.e. roughly Broca's area, and a group of controls. The authors adopted lesion-based rather than symptom-based inclusion criteria, because they wanted to test the hypothesis that damage to frontal areas -- including Broca's area -- results in a behavioral dissociation between regular verb and irregular normal verb processing, linked respectively to procedural and declarative memory systems (Ullman 1997, 2005). Several studies in healthy people have reported priming stronger effects (reductions of the N400) for regular versus irregular verb forms using ERPs (Münte, Say, Clahsen, Schiltz & Kutas, 1999)[6] or behavioral methods (see Forster, 1999, for a review). In previous studies, Justus and colleagues (Justus, Larsen, de Mornay Davies & Swick, 2008; Justus, Yang, Larsen, de Mornay Davies & Swick, 2009) observed that in neurologically healthy individuals, hearing the past tense form of both regular and irregular verbs facilitates an auditory lexical decision to the corresponding present-tense target (e.g., *looked–look*, *spoke–speak*) and is accompanied by a reduction in the N400 component to the target word. On the other hand, other studies reported behavioral dissociations between regular and irregular morphological priming in a group with aphasia (Marslen-Wilson & Tyler, 1997; Münte et al, 1999; Tyler et al, 2002). Therefore, in their study, Justus et al (2011) aimed to test whether this dissociation extend to ERPs in a group with Broca's aphasia. Again, their study highlights a dissociation between behavioral and ERP data: whereas behavioral data show that irregular forms prime more than regular ones, ERP data show similar priming effects for both regular and irregular forms, in patients as well as controls. According to Justus et al. (2011), the ERP data demonstrate preserved lexical integration of all verb types. Thus the absence of behavioral regular-verb priming may not be attributable to pre-lexical or lexical access deficits. The authors reason that the absence of significant regular-verb priming in the response time data rather resulted from post-lexical events (covert articulation, segmentation strategies, and/or cognitive control)[7].

---

[6] Although, see Stockall and Marantz (2006) and Morris and Stockall (2012) for data on *equivalent* MRF and ERP priming for regular and irregular verbs, but not for semantically and orthographically related words (e.g., *boil-broil*).

[7] Note that the ERP data cannot be interpreted as reflecting *only* pre-lexical or lemma level access to the lexicon since the primes are not masked. Post-lexical effects can be found in ERP priming studies (see Kiefer & Brendel 2006; Kiefer, 2006; and Royle et al., 2012 for a discussion of issues related to task designs and semantic priming effects).

This study addressed current topics in the domain of neurolinguistics and psycholinguistics, which are still being debated, such as the existence of a dual division of English verb forms (regular/irregular) that links up to distinct neurocognitive processes (procedural/declarative systems) in the brain; whether English verb forms are better classified in a categorical (regular/ irregular) or rather a continuous way depending on morphophonological properties of verb forms (Justus and colleagues defend the view of a gradual, continuous, classification of verbs, distinguishing “weak” and “strong” irregulars, e.g. *send/sent*, and *drive/drove*, as being more and less "regular" respectively); and whether regular/irregular dissociations extend to ERPs. However, we note that the discussion is developed around the relationship between past tense and corresponding present tense forms, but the items used in the present tense in English are morphophonologically identical to infinitive verbs (e.g. *speak*). This may impact on the conclusions drawn by Justus et al. "that the lexical entries for the present-tense targets were successfully pre-activated by the past-tense primes" (p. 13). Indeed, the "cognitive path" (i.e. computational operations) between past tense forms and corresponding present-tense verb forms might not be the same as the one between past-tense forms and infinitives.[8] In order to test present tense forms in English that cannot be confused with infinitives, 3rd singular forms (e.g. *speaks*) would be more suitable.

Zipse et al. (2011) assessed lexical access in patients with aphasia, age-matched and younger controls, all native speakers of English, using MEG. Their goal was to explore whether individuals with aphasia exhibit differences in the M350, an ERF linked to lexical access and integration (roughly the equivalent of the ERP N400), compared with healthy controls. They also attempted to explore whether M350 differences were associated with either phonological or semantic processing deficits. They used a primed lexical decision task including two stimulus types: identity primed (i.e., a word preceded by itself, e.g., *cake-cake*) and semantically primed (e.g., *bread-cake*), along with control pairs, with targets corresponding to the identity and semantically related pairs but with different primes (e.g., *leg-cake*). Participants were instructed to decide as quickly and as accurately as possible whether the second word in each stimulus pair (i.e., the target) was a real or a nonsense word. The MEG data were analyzed to examine M350 latency amplitude in terms of (a) overall between-groups differences, (b) semantic

[8] In addition to the fact that infinitives (citation forms) are typically the most frequent forms in English.

priming within each group, and (c) identity priming within each group. Consistent with the age-matched control group, the group with aphasia showed both identity and semantic priming behaviorally. In contrast to the control group, the patient group did not show either semantic or identity priming of the M350 response. They also demonstrated longer M350 latencies than either control group. Furthermore, within this group, M350 latencies were positively correlated with a measure of semantic impairment. According to Zipse et al. (2011), increased M350 latency appears to be indicative of a semantic processing impairment[9]. Moreover, they suggest that the dissociation between the electrophysiological and the behavioral results observed in the group of patients — i.e. no semantic priming of the M350 but behavioral semantic priming — is likely due to the fact that whereas the M350 directly tracks pre-lexical and lemma level activation, reaction times reflect the sum of many cognitive processes, including post-lexical checking (Lorch, Balota, & Stamm, 1986). Therefore, they assume that some patients with aphasia might have a lexical activation deficit at the semantic level, coupled with preserved abilities to use strategic post-hoc lexical processes for word recognition. However, since the groups were not directly compared on priming effects, these data are not supported by appropriate statistical methods.

Sörös et al. (2003) present one of the few studies on language production using MEG. However, production was limited to object and action naming from picture stimuli, that is the production of isolated words (nouns and verbs respectively). The purpose of their study was to assess whether the dissociation largely described in the aphasic literature between noun and verb processing can be observed at the neurophysiological level. The study included 10 healthy Finnish speaking university students and one patient with anomia (JP). The drawings illustrated a simple scene including an object and an action. The same stimuli were used for action and object naming. JP showed superior naming of verbs compared to nouns, due to a left posterior parietal lesion. We note that the nature of the verb form elicited in action naming task is not clear. Sörös et al. (2003) only mention that "[b]oth words [objects and actions] used for the instructions are familiar Finnish expressions and have an identical word length." (p. 1789). However, the prompt "tekee" used to elicit a verb is either translated 'does' or 'is doing'. From a theoretical perspective, it seems relevant to describe the linguistic nature of the stimuli, because priming the production of, and producing, either infinitive,

[9] However, note that they do not directly test phonological priming, as their "phonological" pairs involved repetition priming.

progressive, or inflected 3rd singular present tense verbs may have different implications for neurocognitive models of language processing, and might also simply promote different responses in different patients.

No evident differences were observed in brain activation related to noun and verb retrieval in any participant, despite the fact that a clear behavioral dissociation between noun and verb retrieval was observed in JP, who showed more difficulties in naming nouns than verbs. MEG measurements revealed a specific activation pattern for JP's object naming in the left inferior frontal cortex, roughly Boca's area, that was distinct from his action naming as well as from the naming-related responses in controls. Broca's area seemed to be involved both in action and in object naming, but was activated significantly earlier and more strongly when naming objects. On the other hand, since JP showed increased naming latencies for nouns compared with verbs, the authors argue that this result suggests a temporally deviant and impaired activation of Broca's area in JP, and conclude that differences in brain activation related to noun and verb retrieval are not evident in healthy individuals but only emerge after the disruption of normal language networks. They also claim that this study is the first to demonstrate a neurofunctional basis for a dissociation of verb and noun production in an aphasic patient.

In sum, several studies used EEG or MEG to assess lexical access in aphasia. They concern various languages: English, Dutch, Italian, Japanese, and Finnish have been investigated. All but one used a priming task. The study by Söros and al. (2003) is the only one that used a language production task that involved picture naming. All mentioned studies assessed lexical access using isolated words; none used a sentential context. Lexical priming involved open and closed-class words, words of the same semantic fields, rhyming pairs, non words, regular and irregular verbs, past verb forms, and nouns and verbs. Generally, they tracked the N400 ERP component (or the M350 ERF one), to investigate lexical processing and deficits in this domain in participants with aphasia. Results from these studies show a varied picture of impairment, where ERP components in patients do not always reflect, or correlate with, behavioral data.

2.2. Syntactic Processing

Using ERPs to identify strengths and weaknesses in Dutch patients with Broca's aphasia, Wassenaar and colleagues developed three auditory experiments involving sentence comprehension (Wassenaar, Brown & Hagoort, 2004; Wassenaar & Hagoort, 2005, 2007).

Wassenaar and colleagues (2004) assessed morphosyntactic agreement processing in comprehension of simple and complex sentences that required Subject-Verb agreement within conjoined versus embedded clauses. They compared processing of sentences such as *De vrouwen betalen de bakker en nemen/*neemt het brood mee naar huis,* 'The women pay the baker and take/*takes the bread home' (conjoined sentences with less complex syntax) and *De vrouwen die de bakker betalen, nemen/*neemt het brood mee naar huis.* 'The women who pay the baker take/*takes the bread home' (embedded clauses with more complex syntax). The study included three groups of participants: patients with Broca's aphasia (BA), patients with a right hemisphere lesion without aphasia (RH) and controls. While controls showed a typical Syntactic Positive Shift (SPS, often also called the P600, a positive component emerging around 600 ms after critical stimulus) to agreement errors, this component was modulated by deficit severity in the BA group. That is, the stronger the deficit in the patient, the smaller the P600 was. The RH group evidenced normal ERP components and behavioral results. However, no between-group analyses were performed to support differences between patients and controls, which is less than ideal (Nieuwenhuis, Forstmann & Wagenmakers, 2011).

In a follow up study, Wassenaar and Hagoort (2005) compared processing of syntactic and semantic violations in order to track syntactic processing difficulties in a similar group of patients with Broca's aphasia, again in comparison to patients with right hemisphere lesions without aphasia and controls. In the syntactic violation condition, a word-category violation was created by adding a verbal suffix (e.g., -*t*) on a noun stem, in a position that was ungrammatical given the syntactic context (e.g., *De houthakker ontweek de ijdele schroef/*schroeft op dinsdag.* 'The lumberjack dodged the vain propeller/*propelled on Tuesday'. In the semantic violation, sentences ended with a word that violated sentential-semantic constraints (e.g. *De timmerman kreege en compliment van zijn baas/!bloem*. 'The carpenter got a compliment from his boss/!flower.' ERPs in the syntactic condition show similar results to the previous study, that is a SPS (or P600) for both the Control and RH groups, and a late and very reduced SPS for the BA group. In the semantic condition, results show expected N400 and SPS components for both the control and RH groups, and a reduced and more focal N400, as well as a reduced SPS, in the BA group. The BA group also shows reduced P300s in an oddball task used to track automatic detection of stimulus (tone) changes.

However, their results on the P300 did not correlate with the size of the P600, pointing to distinct cognitive mechanisms. Between-group analyses support differences on syntactic but not on semantic processing. The authors argue that ERPs can identify syntactic structure processing difficulties with BA, and that these processing difficulties can be independent of lexical access, which appears to be normal in the BA patients.

Finally, Wassenaar and Hagoort (2007) assessed thematic processing in similar groups (BA, RH and controls), by way of a picture-sentence matching task, contrasting semantically *irreversible active* sentences (e.g., *The young woman reads the exciting book*), semantically *reversible active* sentences (e.g., *The tall man pushes the young woman*), and semantically *reversible passive* sentences (e.g., *The woman is pushed by the tall man*). Previous studies on neurotypical German participants report a negativity followed by a positive shift (N400-P600) in argument structure violations where thematic roles (agents and patients) do not match up with the verb structure (Friederici & Frisch, 2000; Frisch, Hahne & Friederici, 2004). Results on irreversible active sentences with picture mismatches (i.e., the participants hear *The exciting book reads the young woman* and see [WOMAN READING BOOK]) show a typical biphasic N400-P600 in controls and RH groups, but only a late in P600 in the BA group. Processing reversible active sentences with incongruent images (i.e., the participants hear *The tall man pushes the young woman* and see [WOMAN PUSHING MAN]) induced a similar N400-P600 complex in controls and the RH groups (the P600 being non significant in controls), while no effect was observed in the BA group at the verb, and a slight negativity was observed sentence finally. Finally, reversible passive sentences in incongruous conditions (i.e., the participants hear *The woman is pushed by the tall man* and see [WOMAN PUSHING MAN]) elicited an N400-P600 in controls, a small P600 (with statistically marginal effects) in the RH group and no ERP components in the BA group. The ERPs of the BA group were clearly different from RH and control groups: whereas typical ERPs were observed in all sentence types in RH and control groups, the BA group showed a positive shift time-locked to the onset of the verb only for semantically irreversible sentences. Interestingly, in this study, the authors highlight a dissociation between BA participants' online electrophysiological and offline behavioral measures, suggesting that strategies might be used to compensate their on-line syntactic processing difficulties. Results demonstrate that BA participants seem to have strong difficulties matching up thematic roles in sentences and images even though off-line behavioral sensitivity to the sentence–picture mismatches were observed.

Similarly, Kielar, Meltzer-Asscher and Thompson (2012) used ERPs to investigate verb argument structure processing in agrammatic aphasia. A grammatical judgment task was assigned to English-speaking participants with agrammatic aphasia, as well as healthy young and older adults. Two conditions were tested: argument structure violations and semantic violations. The latter was included to determine whether participants evidenced the classical N400 effect to semantic anomalies and to investigate possible differences in sensitivity to argument structure and semantic information during sentence processing. In the argument structure condition, a transitive verb was replaced by an intransitive verb, creating an abnormal syntactic context frame (e.g., **Anne sneezed the doctor and the nurse*), since an intransitive verb does not select direct objects. In the semantic violation condition the final word of each sentence was semantically inappropriate (e.g., *Anne visited the doctor and the !socks*). Participants were instructed to press a green or red button based on their correctness judgment of each sentence. While controls showed a negativity followed by a positive shift (N400-P600), agrammatic individuals only showed a late positivity in response to argument structure mismatches. Additionally, participants with agrammatism showed a relatively preserved but reduced N400 response to semantic violations. According to the authors, these data show that individuals with agrammatism do not demonstrate normal real-time sensitivity to verb argument structure during sentence processing. They conclude that individuals with agrammatic aphasia are impaired in the on-line use of verb information during the integration of individual arguments into an overall sentence context.

More recently and using MEG, Meltzer et al. (2013) assessed sentence comprehension in aphasia by manipulating syntactic complexity in English sentences. Their study included 25 participants with aphasia of various types (e.g. mild-moderate anomic aphasia; mild nonfluent¸ mild to moderate fluent aphasia; mild anomic aphasia; mild conduction aphasia; moderate Broca's aphasia; very mild anomic aphasia) who retained sufficient language comprehension abilities to participate in the task. Their results were compared to data previously collected from young healthy controls assessed using the same paradigm (Meltzer & Braun, 2011), in addition to controls that were matched in age with the patients. A sentence-picture matching task was used to assess the comprehension of clauses with different levels of syntactic complexity (simple active, subject-embedded, and object embedded), which were either semantically irreversible (simple active: e.g. *The man is washing the glass in the kitchen sink*; subject embedded: e.g. *The man who is washing the car is doing a sloppy job;* object-embedded: e.g. *The glass that the man is* *washing has a small chip in it*) or reversible (simple active: e.g. *The man is teaching the woman about a hard math problem*; subject-embedded: e.g. *The man who is teaching the woman is discussing a hard problem*; object-embedded: e.g. *The man who the woman is teaching is discussing a hard problem*).

The main goal of this study was to compare behavioral and imaging measures within the group of aphasic patients. Moreover, this study aimed to determine whether increased right hemisphere activity during language tasks reflects functional takeover by regions homologous to the left-hemisphere language networks, maladaptive interference, or adaptation of alternate compensatory strategies. According to Meltzer et al. (2013), their data provide a measure of neural activity related to sentence comprehension, and of sentence content maintenance in short-term memory, which in turn allows them to deal with the controversy opposing two points of view on the nature of syntactic comprehension deficits in patients with aphasia (and object-embedded relative clauses, in particular): Whereas some investigators assume a loss of specialized syntactic processing mechanisms (e.g. Caramazza, Capitani, Rey, & Berndt, 2001; Drai & Grodzinsky, 1999), others suggest a depletion of more general-purpose cognitive resources that are required to handle processing demands of such sentences in working memory (Caplan, Waters, Dede, Michaud & Reddy, 2007). As expected by the investigators, results showed that patients performed well above chance on irreversible sentences, and at chance on reversible sentences of high complexity on off-line tasks. Moreover, they did not observe more activation of the right temporal lobe in aphasics relative to controls, nor that activation correlated with performance. But accurate comprehension was correlated with neural activity in the more dorsal fronto-parietal lobes of the right-hemisphere, particularly during the memory delay period. Since these areas have been assumed to be involved in working memory (see e.g., Postle, 2006, and Wager & Smith, 2003) and other tasks involving high demands on general cognitive resources such as attention and executive function, Meltzer and colleagues (2013) suggest that patients who successfully compensate for left temporal lobe damage seem to recruit more general cognitive resources during the effortful process of determining sentence meaning. The authors interpret successful sentence comprehension in aphasia as being supported by reanalysis of sentences in verbal short-term memory, which may draw more heavily on right hemispheric networks in aphasic patients than in controls.

The patient group heterogeneity is a useful addition to the discussion about the nature of syntactic comprehension deficits, as argued by the authors:

indeed, the fact that every single one of their patients exhibited comprehension failures on the same clause type (i.e. object-relative clause), regardless of the size, location, and extent of their lesion, supports a resource depletion account rather than the loss of specific comprehension mechanisms that would be "located" in one specific part of the brain.

However, in our opinion, in relation to the experimental protocol used in this study, some parameters should be more carefully taken into account in assessing patients with aphasia using neuroimaging techniques. In particular, the total time of the experiment, which was "approximately one and a half hours, including preparation" (Meltzer et al. 2013, p. 1251), seems too long and might induce fatigue, especially given the nature of the task (syntactically complex sentence comprehension) and environment (staying in a machine). After such a long session in such conditions, and because the task consisted in pressing the left or right button on a fiber optic response box to indicate which picture correctly depicted the action described in the sentence, the interpretation of randomness in response patterns is questionable.

In sum, ERP and MEG studies on aphasic morphosyntactic comprehension mentioned in this chapter concern languages less diverse than in studies that deal with lexical processing (see previous section): English, Dutch and German, that is only Indo-European (Germanic) languages. They study subject-verb agreement processing in sentences with different degrees of syntactic complexity (conjoined/embedded, active/passive and irreversible/reversible), verb argument structure (transitive/intransitive) and thematic roles (agent/patient), as well as semantic processing within sentences. Generally, they track both negative (LAN/N400) and positive (SPS/P600) neural signatures linked to lexical and syntactic processing in aphasic individuals, in comparison with neurologically impaired participants without aphasia or controls. Most evidence seems to point to difficult online processing of grammatical errors and complex syntactic structures in patients, as compared to semantic processing.

2.3. Remarks on Linguistic Manipulations in Experimental Tasks

A common approach to semantic and word finding deficits in aphasic patients is to study naming and other lexically-based processing, which is clearly not optimal when we want to assess language processing in its full complexity. The use of sentence structures to study semantics can give us a clearer view of semantic processing *in-context*, and would also allow for a better understanding of the facilitating and hindering factors in semantic processing within sentences in aphasics. As we saw, patients' results on semantically oriented questions in the sentence processing tasks were occasionally similar to controls. Semantic processing within sentences, a common technique in ERPs (Kutas & Hillyard, 1980; Kutas & Federmeier, 2000), should be developed to better understand what aspects of sentence processing are impaired, or processed differently, in patients with aphasia, especially those with semantic deficits.

In addition, we note that no study compared different groups of aphasic speakers. Some, such as Wassenaar and colleagues compare neurologically impaired patients with and without aphasia, but not between different aphasic subgroups. Since similar symptoms can arise from different lesions -- for example, word retrieval deficits technically called anomia, are found in many aphasia subtypes -- it might be useful to assess neural activity of a group of individuals with anomia in order to identify different deficits and strategies used during lexical access, even though off-line data show the similar superficial behavior across patients. Studies on single word lexical processing in patients with word-finding problems could also be refined in multiple ways using priming with phonological, orthographic, morphological or semantic priming pairs in order to better understand the naming deficits observed (Royle et al., 2012; Royle & Courteau, this book).

In 2008, Laganaro, Morand, Schwitter, Zimmermann and Schnider published an ERP study on naming in four anomic patients and controls, using delayed picture naming. Patients were tested pre and post therapy, in order to check whether specific deficit patterns and subsequent recovery could be mirrored by ERP patterns and changes in these over time. The delayed naming paradigm they used avoided movement artifacts in the ERP, while allowing for the evaluation of lexical activation in preparation for production. They asked French-speaking participants to name a series of line drawings. Behaviorally, patients showed improvement and maintained improved naming after treatment. They showed intermediate results on their ERP patterns, with normalization in the ERP signatures for the three patients with lexical-phonological difficulties but persistent deviance patterns in the patent with a lexical-semantic impairment. Further testing after six months showed additional pattern normalization in two patients with lexical-phonological difficulties in early time windows (100-300 ms after stimulus presentation) but more deviant patterns in later times windows (300-600 ms). Hemispherization changes were also observed in the patients, which might indicate the use of compensatory strategies in lexical access. This study seems to show that early automatic word (or image) detection can normalize over time but later (lexical-phonological or lexical-semantic) processes do not, despite better behavioral responses. It also appears that specific response error types (or strategies) can be reflected in the ERP profile. Unfortunately, little information is presented on the interventions that were used for the patient's lexical access difficulties.

In a follow-up study in 2009, Laganaro, Morand and Schnider tested 16 patients with anomia, half with lexical-semantic deficits and the other half with lexical-phonological ones, and controls, again using delayed picture naming. Here a more detailed analysis of differences between the two groups of patients gives added depth to their data, namely showing that the N400 component linked to lexical access and integration was reduced in lexical-semantic patients, while present in lexical-phonological ones. A later positive-going deflection was observed in lexical-phonological patients only. This later component is believed by the authors to reflect difficulties in word-form encoding. This study shows that it is possible to identify different anomic impairment types and response strategies in patients. However, one must note that in this study, the patients were quite variable in their post onset times (1 month to 6 years). Because normalization in patients can take 6 months to one year, and, as the previous study shows, patients pre- and post-treatment can exhibit changing ERP patterns, the data cannot be used to conclusively support neurocognitive distinctions between subtypes of anomia patients.

As we have seen throughout this chapter, many neuroimaging studies use comprehension tasks. They have the added advantage of not eliciting verbal responses in patients while targeting aspects of language that are difficult to probe in elicitation or spontaneous speech paradigms. Future studies should put more emphasis on morphosyntactic comprehension in aphasics and take advantage of cross-linguistic richness in multiple languages in order to create experiments that can assess morphosyntactic comprehension, a known domain of difficulty in patients. For example, Pourquié (2013) demonstrates that pro-drop languages are perfectly suitable for the assessment of verb inflection comprehension in aphasia. Since the pronoun or noun phrase subject is optionally phonologically realized in pro-drop languages, speakers are often forced to extract grammatical information about subjects through verb inflection *only* (e.g. the Spanish verb form: [PRO3**s**] *com**e***/ [PRO3**p**] *com**en***, eat.3s/p `s/he eats/they eat'). In comparable English contexts, the grammatical properties of the language, i.e. obligatory overt subjects, make it unclear whether speakers distinguish singular and plural agreement through verb inflection (-*s/Ø*) or pronouns (*he/they*), and where patient's difficulties may lie. Hence, pro-drop languages are prefect candidates to assess morphosyntactic comprehension, as they allow the creation of tasks focused on verb inflection comprehension. Conversely, since many published studies of aphasia concern English, tasks assessing verb inflection usually investigate past tense processing because its marking is morphologically overt: e.g. *They play* vs. *They play**ed*** (e.g., Holland, Brindley, Shtyrov, Pulvermüller, Patterson, 2012). There is extensive literature on tense deficits in aphasia – and past tense processing in particular, (e.g., Bastiaanse, 2013) – reporting that individuals with agrammatic aphasia have problems producing inflected verb forms. In addition to assessing past tense processing using neuroimagery, it would also be relevant to test verb comprehension in the present tense in order to identify possible deficits not involving PAST. This would allow investigators to examine whether or not aphasic individuals show difficulties comprehending verb inflection, even in simple structures (e.g. active sentence in the present tense).

Therefore, the present chapter reiterates the need for more cross-linguistic studies and studies of multilingual speakers that would provide further insight on the neurocognitive underpinnings of impaired linguistic systems after brain damage, and rehabilitation. Indeed, as mentioned above, studies that assessed morphosyntactic comprehension in patients with aphasia concern languages that are structurally close. Given the varieties of syntactic structure configurations found across languages (Cinque & Rizzi, 2008), more cross-linguistic comparisons would be useful to further examine these innovative but preliminary findings.

Hence, a general remark we want to express through this chapter is that neuroimaging studies of aphasia should not only be neuroanatomically motivated but also linguistically and psycholinguistically driven. We have noted that neuroimaging studies on aphasia are far more concerned with neuroanatomic aspects of language recovery, i.e. neural plasticity, than by cognitive flexibility. Crosson et al. (2007) note that “clearly more attention should be focused on what are the structures that can contribute, the circumstances under which they can contribute, how to engage those structures in the service of language rehabilitation, and how to suppress activity in structures that might interfere with optimizing language performance.” (p. 160). Here the word "structure" refers to anatomical structure.

From a more cognitive and linguistically driven approach, and in the interests of both theoretical and therapeutic perspectives, it would be of particular relevance to determine for example, which *linguistic* structures (e.g.

active, passive, declarative, negative, question, embedded or not) or domains of language (e.g. lexical, morphological, syntactic, phonological, prosodic) are recoverable and which ones are not; how peripheral and core cognitive functions linked to language are impaired; whether the same type of linguistic structure is equally impaired in one language or another in multilingual patients or across languages (Menn & Obler, 1990; Gitterman, Goral & Obler, 2012); whether or not a significant relationship is identifiable between the functional nature of recovery and neuroanatomical reorganization of the brain. This opens a large program of research, which should not forget that aphasia is, in its essence, a "linguistic problem" (Jakobson, 1963) and that today, aphasiology is an interdisciplinary research field that benefits not only from cutting-edge technologies but from the combined expertise of linguists, psycholinguists and neuroscientists (Nespoulous, 1994). Finally, although most studies suggest the deployment of cognitive strategies in aphasia, there has been little characterization of these strategies in terms of linguistic and cognitive processes.

3. What Does Neuroimagery Add to Classical Behavioral Studies on Language Processing in Aphasia?

Functional neuroimaging techniques, *f*MRI in particular, have been primarily used in the context of aphasiology research to study reorganization of brain-based language substrates in aphasia. More recently studies using EEG and MEG techniques attempt to measure brain activation involved in different linguistic tasks in aphasic individuals. In addition to studying language processing in patients with aphasia and to comparing it to neurotypical language processing, neuroimaging studies can be useful in determining training benefits and their impact on neural reorganization, in the context of aphasiology. For instance, Cornelissen, Laine, Tarkiainen, Järvensivu, Martin and Salmelin (2003) show that behavioral improvements were accompanied by changes in cortical dynamics in language training (re-learning) in chronic anomic patients.

Other studies have developed linguistically driven treatments. The Treatment of Underlying Forms (TUF) (Thompson & Shapiro, 2005) considers both the lexical and syntactic properties of the sentences used during treatment as well as those selected for generalization testing. An important observation emerging from their study is that training on more complex but related structures yields more wide-ranging treatment improvement than using simpler structures as a starting point. Such results have important implication for intervention. Using MEG, Faroqi-sha (2008) reports results from a study of treatment effects on recovery in 6 individuals with chronic agrammatic aphasia. The task focused on morphosyntactic comprehension. Sentences were correct (e.g., *Yesterday the teacher graded the exams*), semantically anomalous (e.g. *Yesterday the !honeybee graded the exams*) or morphologically anomalous (e.g. *Tomorrow the teacher *graded the exams*). Semantically anomalous sentences were included as a control condition since individuals with agrammatic aphasia are known to process these sentences with high accuracy (Hagoort, Wassenaar & Brown, 2003). All participants demonstrated quantitative and qualitative changes in neural activity following therapy, and the final spatiotemporal patterns were similar to those found in neurotypical participants. According to Faroqi-sha (2008), these results demonstrate that neurophysiological changes following language therapy were specific to the linguistic process that was targeted, and not the result of general cognitive or compensatory mechanisms.

Thus, in the context of therapeutic research, the use of neuroimaging can help to measure the effect of treatment patient populations, as well as on specific language processes. Another avenue of neuroimaging research would be to study the effects of specific types of treatment on recovery (or changing) behavioral patterns in patients, and their link to normalization or maintenance of deviant ERP components. ERP studies on bilingualism have recently shown convergence on first language learner profiles by second language learner's ERPs (White, Genesee & Steinhauer, 2012), in addition to the effects of language training approaches on this process (Morgan-Short, Steinhauer, Sanz & Ullman, 2012). A research program of this type integrating therapeutic approaches should be a fruitful avenue of investigation.

In sum, studies on intervention and neuroimaging in aphasia language processing support the following claims. 1. Neuroimaging research on sentence and word processing in healthy speakers can be used as a complimentary approach to behavioral studies of aphasia, in particular for the development on neurocognitive models of language processing following brain lesions. 2. Neuroimaging studies of aphasia can help distinguish deficits and strategies, and specify the role of right hemisphere and perilesional areas (as long as MEG or *f*MRI are used for localization) in recovery, as well as measure treatment effects on brain activation during language processing. 3. Neuroimaging and behavioral approaches are both necessary and provide complimentary data on language deficits and processes, as they focus on different aspects of language production and comprehension: neuroimaging is not always suitable for the assessment of language production, and it cannot clearly assess the qualitative strategic aspects of recovery, while off-line language comprehension tasks can result in ambiguous results in terms of their interpretation. In fact, brain activation should not be the only matter of interest, as structures produced by patients in off-line responses to specific targets can provide us with rich information about processes and strategies used to provide linguistic outputs. Thus, an integrated approach to language processing deficits in aphasia should be pursued, not only using on-line and off-line methods for evaluation, but also with the combined knowledge of linguistics, clinical professionals such as speech language pathologists, and neuroscientists.

CONCLUSION

The classical syndrome approach of aphasia is considered to be unstable for the identification of neurocognitive underpinnings of normal language processing. Correlations between lesion areas and language impairments can be unreliable due to systematic post-lesional reorganization of the brain and high inter-individual differences in aphasic populations. However, neuroimaging allows us to examine patients as individuals or groups, and can be regarded as a complementary tool to the behavioral approach, in the context of aphasiology, especially in view of the information they can provide regarding the time~~s~~ course of underlying cognitive processes. On the other hand, many challenges exist within different neuroimaging techniques for the study of normal language processing, and even more exist in aphasiology. Despite the complexities of neuroimaging experimental design, some studies are being carried out on aphasia and open a promising research pathway. Aphasiological research enriched by the development of neuroimaging addresses issues such as the differentiation between language deficits and cognitive strategies used to overcome these. Brain activation and areas involved in language recovery, and treatment effects on cognitive flexibility and brain plasticity are some of the domains that can be directly assessed using neuroimaging techniques. Since behavioral results show dissociations not observable in imaging, the classical syndrome approach should however not be abandoned or overlooked. In particular, this chapter outlines the necessity to qualify the linguistic nature of deficits and strategies in addition to illustrating them through brain imaging. As both approaches fulfill different functions and bring to the fore qualitatively different data, aphasiological research should be able to take advantage of their distinctive and complimentary benefits in further studies.

REFERENCES

Angrilli A, Elbert T, Cusumano S, Stegagno L. & Rockstroh B. (2003). Temporal dynamics of linguistic processes are reorganized in aphasics' cortex: an EEG mapping study. *Neuroimage,* 20(2):657-66.

Bastiaanse, R. (2013). Why reference to the past is difficult for agrammatic speakers. *Clinical Linguistics and Phonetics, 27*, 244-263.

Bouillaud, J.B., (1825). Recherches cliniques propres à démontrer que la perte de la parole correspond à la lésion des lobules antérieures du cerveau. *Archives generales de médecine*, Paris, 8: 25-45

Broca, P., (1861). Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphémie (perte de la parole), *Bulletin de la Société Anatomique*, 6: 330-357

Caplan, D., Waters, G., Dede, G., Michaud, J., & Reddy, A. (2007). A study of syntactic processing in aphasia: Behavioral (psycholinguistic) aspects. *Brain and Language, 101*, 103–150.

Caramazza, A., Capitani, E., Rey, A., & Berndt, R. S. (2001). Agrammatic Broca's aphasia is not associated with a single pattern of comprehension performance. *Brain and Language*, *76*, 158–184.

Cinque, G. & Rizzi, L. (2008). The cartography of syntactic structures V. Moscati, ed. *CISCL Working Papers on Language and Cognition*, *2*, 43-59.

Cornelissen, K., Laine, M., Tarkiainen, A., Jarvensivu, T., Martin, N., & Salmelin, R. (2003). Adult brain plasticity elicited by anomia treatment. *Journal of Cognitive Neuroscience*, *15*, 444-464.

Crosson, B., McGregor, K., Gopinath, K., Conway, T.W., Benjamin, M., Chang, Y. L., Bacon Moore, A., Raymer, A., Briggs R. W., Sherod M., Wierenga, C. E., & Keith, D. (2007). Functional MRI of Language in Aphasia: A Review of the Literature and the Methodological Challenges. *Neuropsychology Revue*, *17*, 157–177.

Demonet, J.F. & Thierry, G. (2001). Language and Brain: What is up? What is coming? *Journal of Clinical and Experimental Neuropsychology. 23, (1)* 49-73.

Drai, D., & Grodzinsky, Y. (1999). Comprehension regularity in Broca's aphasia? There's more of it than you ever imagined. *Brain and language*, *70*, 139–143.

Faroqi-Shah, Y. (October 2008). *An MEG investigation of neurophysiological changes following therapy for agrammatic aphasia.* Talk presented at Academy of Aphasia, Turku, Finland. Available at http://aphasiology.pitt.edu/archive/00002152/01/viewpaper.pdf

Forster, K. I. (1999). The Microgenesis of Priming Effects in Lexical Access. *Brain and Language, 68*(1/2), 5-15.

Friederici, A. D., & Frisch, S. (2000). Verb argument structure processing: The role of verb specific and argument-specific information. *Journal of Memory andLanguage*, *43*, 476–507.

Frisch, S., Hahne, A., & Friederici, A. D. (2004). Word category and verb-argument structure information in the dynamics of parsing. *Cognition*, *91*, 191–219.

Gitterman, M., Goral, M., & Obler, L.K. (2012). *Aspects of multilingual aphasia*. Bristol: Multilingual Matters.

Hagoort, P., & Poeppel, D. (2013).The infrastructure of the language-ready brain. In M. A. Arbib (Ed.), *Language, music, and the brain: A mysterious relationship* (pp. 233-255). Cambridge, MA: MIT Press.

Hagoort, P., Wassenaar, M., & Brown, C. (2003). Real time semantic compensation in patients with agrammatic comprehension*. Proceedings of the National Academy of Sciences*, *100*, 4340-4345.

Halchenko, Y. O., Hanson S. J., & Pearlmutter, B. A. (2005). Multimodal Integration: fMRI, MRI, EEG, MEG. In L. Landini, V. Positano & M. Filomena Santarelli (Eds.) *Advanced Image Processing in Magnetic Resonance Imaging*, Dekker, 223-265.

Hari, R., & Salmelin, R. (2012). Magnetoencephalography: From SQUIDs to neuroscience, *Neuroimage*, *61(2):*386-96.

Holcomb, P. J., & Grainger, J. (2006). On the Time Course of Visual Word Recognition: An Event-related Potential Investigation Using Masked Priming. *Journal of Cognitive Neuroscience, 18*(10), 1631-1643.

Holland, R., Brindley, L., Shtyrov, Y., Pulvermüller, F., & Patterson, K. (2012). They played with the trade: MEG investigation of the processing of past tense verbs and their phonological twins. *Neuropsychologia*, *50*(14) 3713-3720.

Jakobson, R. (1963). *Essai de linguistique générale.* [Essay in general linguistics]. Tome I. Editions de Minuit, Paris.

Justus, T., Larsen, J., Yang, J., de Mornay Davies, P., Dronkers, N., & Swick, D. (2011). The role of Broca's area in regular past-tense morphology: An event-related potential study, *Neuropsychologia, 49*, 1-18.

Justus, T., Larsen, J., de Mornay Davies, P., & Swick, D. (2008). Interpreting dissociations between regular and irregular past-tense morphology: Evidence from event-related potentials. *Cognitive, Affective, & Behavioral Neuroscience, 8*, 178–194.

Justus, T., Yang, J., Larsen, J., de Mornay Davies, P., & Swick, D. (2009). An event-related potential study of cross-modal morphological and phonological priming. *Journal of Neurolinguistics, 22*, 584–604.

Kiefer, M. (2007). Top-down modulation of unconscious 'automatic' processes: A gating framework. *Advances in Cognitive Psychology, 3*(1-2), 289-306.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious 'automatic' processes: Evidence from event-related potentials in a masked priming paradigm. *Journal of Cognitive Neuroscience, 18*, 184-198.

Kielar, A., Meltzer-Asscher A., & Thompson, C. K. (2012), Electrophysiological responses to argument structure violations in healthy adults and individuals with agrammatic aphasia. *Neuropsychologia, 50*, 3320–3337.

Kojima, T., & Kaga, K. (2003). Auditory lexical-semantic processing impairments in aphasic patients reflected in event-related potentials (N400). *Auris Nasus Larynx, 30(4):*369-78.

Kolk, H. H. J. (1995). A time-based approach to agrammatic production. *Brain and Language, 50*(3), 282–303.

Kolk, H. H. J., & Van Grunsven, M. J. F. (1985). Agrammatism as a variable phenomenon. *Cognitive Neuropsychology, 2*, 347–384.

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*, 463-470.

Kutas, M., & Federmeier, K. D. (2011). Thirty Years and Counting: Finding Meaning in the N400 Component of the Event-Related Brain Potential (ERP). *Annual Review of Psychology, 62*, 621-647.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science, 207*, 203-205.

Kutas, M., & Schmitt, B. M. (2003). Language in Microvolts. In M. T. Banich & M. Mack (Eds.), *Mind, Brain and Language: Multidisciplinary perspectives* (pp. 171-209). Mahwah, NJ: Lawrence Erlbaum Associates.

Laganaro, M., Morand, S. & Schnider, A. (2009). Time course of evoked-potential changes in different forms of anomia in aphasia. *Journal of Cognitive Neuroscience, 21(8),*1499-1510.

Laganaro, M., Morand, S., Schwitter, V., Zimmermann, C., & Schnider, A. (2008). Normalization and increase of abnormal ERP patterns accompany recovery from aphasia in the post-acute stage. *Neuropsychologia, 46(8),* 2265-2273.

Lorch, R. F., Balota, D. A., & Stamm, E. G. (1986). Locus of inhibition effects in the priming of lexical decisions: pre- or postlexical access? *Journal of Memory and Cognition, 14*, 95-103.

Luck, S. J. (2005). *An Introduction to the Event-Related Potential Technique.* Cambridge, MA: MIT Press.

Marslen-Wilson, W. D., & Tyler, L. K. (1997). Dissociating types of mental computation. *Nature, 387,* 592–594.

Menn, L. & Obler, L. K., (1990). *Agrammatic Aphasia, A cross-language narrative sourcebook*. Amsterdam: Benjamins.

Meltzer, J. A., & Braun, A. R. (2011). An EEG-MEG dissociation between online syntactic comprehension and posthoc reanalysis. *Frontiers in Human Neuroscience, 5*, 10.

Meltzer, J. A., Wagage, S., Ryder, J., Solomon, B & Braun, A. R. (2013) Adaptive significance of right hemisphere activation in aphasic language comprehension. *Neuropsychologia, 51(7):* 1248-1259.

Morgan-Short, K., Steinhauer, K., Sanz, C., & Ullman, M. T. (2012). Explicit and Implicit Second Language Training Differentially Affect the Achievement of Native-like Brain Activation Patterns. *Journal of Cognitive Neuroscience, 24*(4), 933-947.

Morris, J., & Stockall, L. 2012. Equivalent masked priming with irregularly and regularly inflected primes. *Brain and Language, 123*, 81-93.

Münte, T. F., Say, T., Clahsen, H., Schiltz, K., & Kutas, M. (1999). Decomposition of morphologically complex words in English: Evidence from event-related brain potentials. *Cognitive Brain Research, 7*, 241-253.

Nespoulous, J.-L. (1996). Les stratégies palliatives dans l'aphasie [Palliative strategies in aphasia]. *Rééducation Orthophonique*, *34*(188), 423–433.

Nespoulous, J.-L. (1994). Le langage : Introduction. Linguistique, Neurolinguistique et Neuropsycholinguistique. Un parcours en quatre étapes. [Language: Introduction. Linguistics, Neurolinguistics and neuropsycholinguistics. A route with four stages.] In M. Jeannerod & X. Seron (Eds.), *Neuropsychologie humaine*¸ Bruxelles: Mardaga, 10 : 317-9.

Nieuwenhuis, S., Forstmann, B. U., & Wagenmakers, E.-J. (2011). Erroneous analyses of interactions in neuroscience: a problem of significance. *Nature Neuroscience, 14*, 1105-1107.

Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience, 139*, 23–38.

Pourquié M., (2013). Verb processing in Basque and French agrammatic aphasia: A "post-lexical access" deficit. *Aphasiology*, DOI:10.1080/02687038.2013.808735

Rodden, F. A., & Stemmer, B. (2008). A Brief Introduction to Common Neuroimaging Techniques. In B. Stemmer & H. A. Whitaker (Eds.), *Handbook of the Cognitive Neuroscience of Language,* Oxford, UK, 57-67.

Royle, P., Drury, J. E., Bourguignon, N., & Steinhauer, K. (2012). The temporal dynamics of Inflected word recognition: A masked ERP priming study of French verbs. *Neuropsychologia, 50*(14), 3542-3553.

Sahraoui, H., & Nespoulous, J.L. (2012). Across-task variability in agrammatic performance, *Aphasiology*, *26*(6), 785-810.

Salmelin, R. (2007). Clinical neurophysiology of language: The MEG approach. *Clinical Neurophysiology, 118*, 237-254.

Sörös, P., Cornelissen, K., Laine, M., & Salmelin, R. (2003). Naming actions and objects: cortical dynamics in healthy adults and in an anomic patient with a dissociation in action/object naming. *Neuroimage, 19(4),* 1787-1801.

Stockall, L., & Marantz, A. (2006). A single route, full decomposition model of morphological complexity: MEG evidence. *The Mental Lexicon Journal, 1*(1), 85-123.

Swaab, T., Brown, C. M., & Hagoort, P. (2003). Understanding words in sentence contexts: The time course of ambiguity resolution. *Brain and Language*, *86*(2), 326-343.

ter Keurs M, Brown CM, & Hagoort P. (2002). Lexical processing of vocabulary class in patients with Broca's aphasia: An event-related brain potential study on agrammatic comprehension. *Neuropsychologia, 40(9):*1547-61.

Thompson, C. K. & den Ouden, D. B. (2008). Neuroimaging and Recovery of Language in Aphasia*, Current Neurology and Neuroscience Reports*, *8*, 475–483.

Thompson, C. K., & Shapiro, L. P. (2005). Treating agrammatic aphasia within a linguistic framework: Treatment of underlying forms. *Aphasiology*, *19*, 1021–1036.

Tyler, L. K., de Mornay Davies, P., Anokhina, R., Longworth, C., Randall, B., & Marslen-Wilson, W. D. (2002). Dissociations in processing past tense morphology: Neuropathology and behavioral studies. *Journal of Cognitive Neuroscience, 14,* 79–94.

Ullman, M. T., Corkin, S., Coppola, M., Hickok, G., Growdon, J. H., Koroshetz, W. J., & Pinker, S. (1997). A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience, 9,* 266–276.

Ullman, M. T, Pancheva, R., Love, T., Yee, E., Swinney, D., & Hickok, G. (2005). Neural correlates of lexicon and grammar: Evidence from the production, reading, and judgment of inflection in aphasia. *Brain and Language, 93,* 185–238.

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory: A meta-analysis. *Cognitive, Affective & Behavioral Neuroscience*, *3*, 255–274.

Wassenaar, M., Brown, C. M., & Hagoort, P. (2004). ERP-effects of subject-verb agreement violations in patients with Broca's aphasia. *Journal of Cognitive Neuroscience*, *16*(4), 553-576.

Wassenaar, M., & Hagoort, P. (2005). Word-category violations in patients with Broca's aphasia: An ERP study. *Brain and Language*, *92*, 117-137.

Wassenaar, M., & Hagoort, P. (2007). Thematic role assignment in patients with Broca's aphasia: Sentence-picture matching electrified. *Neuropsychologia*, *45*(4), 716-740.

Wernicke, C., (1874). Der aphasische Symptomenkomplex. Eine psychologische Studie auf anatomischer Basis. [The aphasic symptom complex: a psychological study from an anatomical basis.] Breslau: M. Cohn et Weigert

White, E.J., Genesee, F., & Steinhauer, K. (2012). Brain Responses Before and After Intensive Second Language Learning: Proficiency Based Changes and First Language Background Effects in Adult Learners. *PLoS ONE, 7(12),* e52318. [PONE-D-12-22453].

Zipse, L., Kearns, K., Nicholas, M., & Marantz, A. (2011). A MEG investigation of single-word auditory comprehension in aphasia. *Journal of Speech, Language and Hearing Research*, 1577-1596.

S. E.