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*On the nature of biphasic ERP response to
syntactic violations: the case of subject-verb
agreement in Italian.*

Relatore
Prof. Francesco Vespignani

Laureando
Arianna Cascone
n° matr.1243705 / LMLIN

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Introduction

Language has always been matter of interest in psycholinguistics and neurolinguistics since it represents a complex system of communication exclusively belonging to the human brain. It has been explored in all of its facets and even currently there are no certainties about how it is mapped into the brain. Linguistic, psycholinguistic and neurolinguistic researchers never cease to search some clues which could resolve the mystery of this incredible ability. The real issue is that language has a very complex structure, divided into levels of analysis which do not facilitate the inquiry. Up to now, several advances has been made in the three domains and their collaboration is necessary to face the new challenges in this research field.

This concept represents the basis of this thesis. Even if this study is centered on the psycholinguistic point of view, I highlight the relevance of a collaboration between the fields which work with the linguistic matter because they are all involved in the language processing. In particular, I put the focus on the syntactic level of analysis, investigating subject-verb agreement violation processing which has been largely debated in literature. I will describe the psychophysiological correlates (ERPs) which emerge at this level in Italian studies as well as the different models that have interpreted their variability.

The first chapter will represent an introduction to the psycholinguistic world, offering all the relevant tools of the research field. I will provide a general overview on Electroencephalography (EEG) and Event Related Potentials (ERPs), then I will describe the most known ERPs components involved in language processing. I will explain why it is important to study linguistic violations and how they can be related to specific cognitive processes. Finally, I will put the focus on the nature of agreement from both the linguistic and psycholinguistic points of view.

The second chapter will show all the major psycholinguistic models, from the syntax-first model to the most recent works. I will evidence their strengths and weaknesses, their evolution and all the motivations which have led researchers to deepen the study on agreement, in particular the instability of some components such as the LAN and P600 which are considered the most related components to agreement violation processing.

The third chapter will be completely centered on the Italian case because it represents the domain in which electrophysiological components' instability is remarkably evident, especially in the agreement condition.

Finally, the fourth chapter will be the fulcrum of my thesis: I will propose a new perspective which could clarify some of the doubts emerged so far. I will describe the three bigger approaches to language processing: from the neurolinguistic to the emergentist theories. In conclusion, I will explain why it is important to consider the psychological component to interpret language processing responses and how it could be implemented in a new multilevel approach.

Chapter 1

In this chapter we will give a panoramic view about the psycholinguistic objects in the matter of syntax and we will introduce the tools which allow researchers to investigate the mysteries of language processing.

1.1 Electroencephalography (EEG) and Event Related Potentials (ERPs)

Nowadays it seems trivial and obvious speaking of electrophysiological methods to study language processing. Therefore, it has to be emphasized the fundamental role that these techniques have played firstly in the history of clinical research, and secondly, in language studies.

Electroencephalography has been discovered in 1875 but applied on the human scalp for the first time in 1924 by Hans Berger. If 140 years ago it was composed of a rudimental radio equipment, now it consists of a series of electrodes (sometimes collected on a cap) which are applied on the head. These electrodes are connected each to an amplifier which allows researchers to see the output of the electrical activity of the brain directly on the computer. What it is recorded is the activation of a population of neurons (called pyramid cells) at the same time. The output results in the electrical activity graphed as waves which vary in frequency, amplitude and shape. Even if the EEG is a non-invasive great technique to measure brain activity, it presents also some limitations: it can record only a part of the electrical activity, it does not give a specific topographical distribution and it is very sensitive to noises. As regards language elaboration, even if it has a great temporal resolution, it results difficult to find a correlation between specific neural activity and a cognitive process throughout a continuous recording.

Event related potentials can be defined as the resolution to this last limitation of the EEG. It is described as “[...] a major workhorse across both clinical and research applications of EEG” (Biasiucci et al., 2019). It is a secondary measure extracted from the EEG signal, a reduction of the electroencephalogram’s signal to a more specific index

related to specific cognitive events. More simply, it represents a part of the EEG recording which is systematically associated to a specific modulation of the electrical activity due to a specific stimulus in a precise moment in time. It is not just extracted by the continuous recording of the EEG but it is obtained by a procedure of average of several segments related to specific events. These elements make clear that ERPs is a useful technique to capture brain responses to specific aspects of the language processing, focusing on comprehension rather than production, analyzing neuronal reactions to specific aspects of phonetics, morphology, syntax, semantics or pragmatics. Being a derivation of the EEG, ERP is a measure with great temporal resolution, “a millisecond-by-millisecond record of neural information processing” (Sur S., Sinha V.K., 2009). The electric activity is graphed in waves which show positive or negative peaks. These are interpreted as the components. Each component is defined by three elements:

- Latency (what time the component appears from the presentation of the stimulus)
- Polarity (positive or negative)
- Topographical distribution (what is/are the electrode/s on the scalp where the deflection is maximal)

For example, N100 stands for a negative deflection emerging around 100 ms on the frontal sites (see Figure 1). In this work, we will focus on the main components which are related to language processing: ELAN, N400, LAN and P600 (see section 1.3). Clearly, despite the ms time resolution of the technique itself, the resolution, with respect to the variability of each components and respective cognitive processes, makes it between some tens to hundreds of ms, depending on the component under scrutiny.

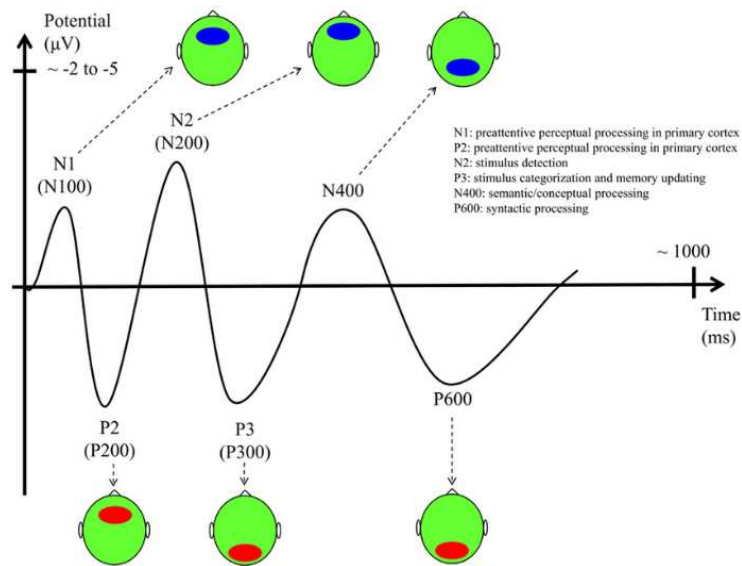


Figure 1. Modified by Daltrozzi and Conway., 2014. Example of some of the main ERP components which could emerge from a reading task.

Figure 1 shows the electrical activity which can be elicited through a linguistic stimulus. A large number of experiments in this domain have contributed to build an interpretative key of these peaks and their related cognitive processes. Therefore, correlates are collected in two macro-categories:

- Exogenous components : N1, N2, P1, P2. They depend on external factors such as stimulus presentation modality (auditory vs visual) or physical characteristics of the stimulus (e.g. a positive correlation between screen brightness and P1 amplitude have been recorded in Mangun et al., 1993) but they are not constrained by the task. These components are always found because they are necessary physiological responses which have short latency since they vanish in 100-200 ms (see figure 1).
- Endogenous components : N400, LAN, P300, P600. Contrary to the previous category, they are completely independent from presentation modality or physical characteristics of the stimulus but they are strongly dependent on the cognitive task. They are visible from 200 ms and their amplitude, latency and distribution can give an idea of the underlying cognitive processes (see section 1.3).

This categorization has to be read as an indicative subdivision because it seems that completely task independent components do not exist (Beres, 2017). Undoubtedly, there are components which depend more on cognitive and less on physical factors or vice

versa, but there could not be neat distinction. However, it is true that during the initial phases of the processing, more attention is given to presentation modality and external factors and then to cognitive aspects (De Vincenzi, Di Matteo, 2015).

1.2 Semantic and Syntactic violations

A fundamental discovery in linguistic processing studies with event-related potentials was the qualitative and quantitative variation in amplitude, latency and topography of the ERP correlates (endogenous components in particular) whenever the sentence contained anomalies. Kutas and Hillyard (1980) found the first component related to semantic access and integration, the N400, which emerged every time the critical word¹ was semantically incongruous with the context (for insights, see section 1.3.1). Since then, it was highly shared that online techniques like ERPs could account to psychological processes underlying language comprehension, those processes which involve all the levels of analysis, such as phonetics, morphology, syntax, semantics, pragmatics. They also exploit rapidly all the cognitive functions: attention, perception, working memory, long term memory, reasoning (De Vincenzi, 2004; Vespignani, 2013). Thereafter, a series of studies on electrophysiological responses to syntactic anomalies (e.g. Neville et al., 1991; Osterhout and Holcomb, 1992) found not only a different component, but also a biphasic pattern associated with it. Generally, syntactic violations seemed to elicit the so-called ELAN (*early left anterior negativity*) and/or LAN (*left anterior negativity*) on the basis of the time window in which they occurred: the former arises at about 150 ms (100-300 ms) whereas the latter appears later, between 300-500 ms. Subsequently, these components are accompanied by a second peak, the P600, a positive-going wave, with broad or/and posterior topographical distribution (see section 1.3). This difference between syntactic and semantic responses lead researchers to explore deeply the nature of the neural and cognitive processes underlying the two levels of analysis, proving that they are distinct and independent. Even so, the debate around ERP components and their

¹ In the experimental condition, the word which is supposed to elicit a specific response on the basis of the level of analysis to study is called critical word; more specifically it is the word which contains the anomaly. (De Vincenzi, Di Matteo, 2015).

direct link to cognitive processes is still open because there is not a single shared idea, the results are controversial (see chapter 3).

As regards the syntactic level, the literature shows that different domains elicit different responses. Up to now, there are four fields investigated:

- **Syntagmatic structure violation:** it refers to structural incongruity of a word, the category of which is incompatible with the previously processed words according to the rules of the language. For example, a sentence like “*The scientist criticized Max’s of proof the theorem” (compared to “The scientist criticized Max’s proof of the theorem” by Neville et al., 1991) is agrammatical because the position of the preposition should be occupied by a noun, thus, the structure have been violated. The point, here, is that not only the specific word “of” cannot appear after the given prefix “The scientist criticized Max’s”, but also any other word of the same category (prepositions in this case) would lead to an ungrammatical continuation. Since the insertion of the word in the structure built so far represents one of the first steps of the processing (needed in order to proceed with checking of semantic fit or agreement of specific features), one could expect that an anomaly of that kind should elicit an early response, the ELAN. Even if different works have reported this effect (Neville et al., 1991; Hahne and Friederici, 1999, 2002), we will see that this correlate has recently lost credibility (see section 2.1.4). The other correlates which seem to be sensitive to this phenomenon are the LAN and the P600.
- **Subcategorization violation:** related to the verb argument structure, that is lexical properties of the verb which require a specific syntagmatic structure. It is well known that a transitive verb differs from the intransitive one because the former calls for the direct object; if this structure is not respected, the parser has to revise the lexical information carried by the verb, thus spending more resources during the processing (as in “*Der Lehrer wurde gefallen – The professor has been fallen”, by Rösler et al., 1993 where ‘wurde’ requires a passive construction but it has been merged with an intransitive verb which is not used in the passive voice). This situation is reflected in the elicitation of a left anterior negativity, in the 300-500 ms time window, and a P600, between 700-1200 ms after the critical word’s onset (Rösler et al., 1993; Coulson et al. 1998).

- **Morphosyntactic/Agreement violation** : this domain has been largely investigated because there are many application scenarios (number and gender agreement and their sub-types, tense agreement auxiliary-verb and so on). This kind of morphosyntactic violation appears to be directly correlated with the two components because they have been reported both in the visual and in the auditory domain. Thus it has been proposed that the classical biphasic pattern LAN+P600 seems to reflect this situation (we will deepen this domain in the 1.4 paragraph).
- **Long distance dependencies**: this does not come under the category of violations but it is part of the ERP studies in the syntactic area. Long distance dependencies are particular syntactic structures where an element (called filler) is displaced in the left periphery of the clause but it keeps a dependency relation with the vacant position it has left (gap). Since the filler cannot be identified as such until the gap is met, the working memory has to take place in order to associate the two elements involved in the parsing. The most representative example is the wh-question in English. This condition has been conceived as a breeding ground for the elicitation of the LAN effect, thought to be directly associated with the working memory capacity (Kluender and Kutas, 1993).

1.3 Principal ERP components involved in language comprehension

1.3.1 The N400

In the previous paragraph we referred to the N400 as the first component discovered through the analysis of linguistic stimuli. It represents one of the most known component in the study of cognitive endogenous potentials. That's a negative deflection peaking around 400 ms after the critical word's onset in cases of semantically or categorically unrelatedness in lexical priming paradigms (Beres, 2017). As regards its distribution, it can be found mostly on the centro-posterior sites and it can be bilateral or slightly right lateralized. Besides the evident link between the N400 and the semantic violation, it has been discovered that the same component could be modulated also in other contexts,

namely cloze-probability conditions² (see figure 2), priming effects, also in non-linguistic domains like drawings and sounds (Vespignani, 2003), or even in changes of writing (using capital letters for the target word in a context of lower-cases letters; Beres, 2017). Moreover it has been demonstrated that the component is modality independent since it was likely to be found both in visual and auditory modality. Hence, it is widely shared that it is a particularly stable correlate of semantic access and integration.

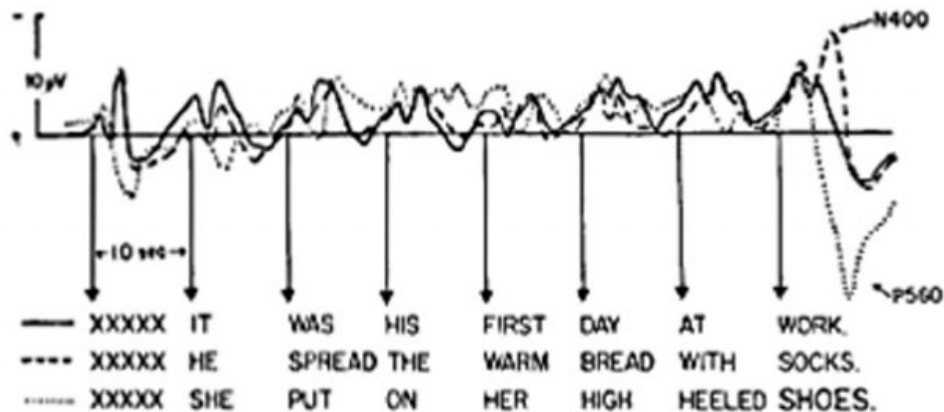


Figure 2. Modified by Kutas & Hillyard (1980). Grand average ERP recording in a sentence with semantically incongruous/congruous word and a sentence with capital letters. The negative deflection is evident for the semantic anomaly whereas the word in capital letters seemed to elicit also a positive deflection.

1.3.2 (Early) left anterior negativity - (E)LAN

The left anterior negativity is a negative-going wave which peaks around 300-500 ms, thus it has the same polarity and the latency as the N400 effect but the two correlates differ topographically because the LAN has a left-frontal distribution. Nevertheless, the latency can vary because it has been reported a LAN with a peak around 400 ms and other contexts in which the same component has been recorded around 150 ms. This early LAN has been largely debated over the years because, initially, it was assumed to be a distinct component, the so-called eLAN, in favor of the syntax-first models (Friederici, 2002, see section 2.1.1); it seemed to reflect an automatic processing coming from phrase structure and word category violations (Beres, 2017). Then, strong critics have been

² Cloze-probability represents the probability of a semantically correct word to be used in a specific context. For example, a sentence like "They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of palmes/pines/tulips" (by Kutas and Federmeier, 2000): it has been recorded a wider N400 for 'tulips' rather than 'pines' and an almost absent N400 for 'palmes' which was the most probable word.

addressed to the methodology which has led to this finding, first among them the non-replicability of the results (Steinhauer and Drury, 2012; see section 2.1.4). In sum, all the doubts that have arisen from the nature of this component have revealed a great instability and consequently its unreliability.

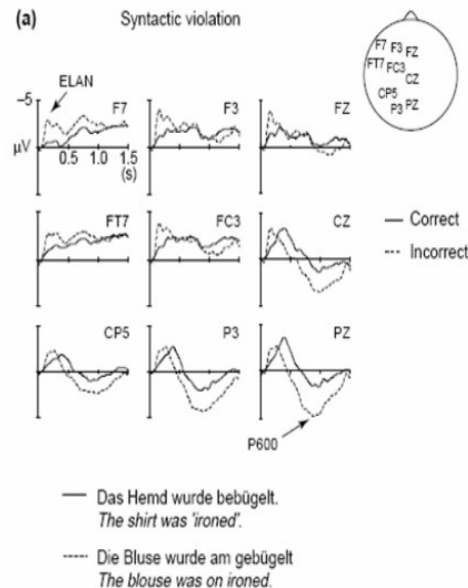


Figure 3. Modified by Hahne & Friederici (2003)

On the contrary, the LAN effect seems to be more consistent across the studies even if its nature is still debated, in particular its variability (see chapter 3). Generally, this effect is associated with agreement violations (especially in determiner-noun mismatches, but also in subject-verb disagreement), in particular whenever the agreement features (like number or gender) are explicitly expressed morphologically (Vespignani, 2013). Other studies have reported this finding also when there was clearly a working memory effort (Kluender and Kutas, 1993). We will deepen all the theories linked to the LAN effect in the next chapters.

1.3.3 The P600

The P600 has the same relevance as the N400 in the study of language processing. Being totally different from the N400, the P600 (called also Syntactic Positive Shift, SPS or Late Positive Component, LPC) has positive polarity and it is broadly distributed over the scalp even if its peak is generally recorded on the parietal sites (Pz) around 500 ms from critical word's onset and could last until 1200 ms. Generally, its functional interpretation

in relation to syntactic violation or complex sentences interpretation is to be an index of reanalysis and repair processes. Although, its nature does not seem to belong only to the linguistic sphere, other works reported this positive shift also in experimental conditions with music (Patel et al., 1998), mathematics (Lelekov et al., 2000) and sequencing (Lelekov et al. 2000; NúñezPena and Honrubia-Serrano 2004). More recent studies have focused on the association of the P600 with the LAN effect in a biphasic pattern, especially in cases of agreement anomalies (Angrilli et al., 2002; De Vincenzi et al., 2003; Hagoort & Brown, 2000; Molinaro et al., 2015; Molinaro et al., 2008; Molinaro et al., 2013; Molinaro et al. 2011a; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995; for insights see chapter 3). Further interpretations have evidenced two stages in this component (see section 3.1.6): in the earlier stage, the P600 seems to have a more frontal distribution and a latency between 500-750 ms, it should reflect problems of syntactic integration within a sentence (Kaan et al., 2000). Moreover, findings belonging to more recent works (Artesini, 2019; Molinaro et al., 2011a; Mancini, 2018) suggest that the anterior stage of the P600 reflects not only formal but also interpretative aspects (for insights, see chapter 3). As regards the later stage of the P600, it emerges in the time window between 750-1000 ms on parietal sites and seems to reflect the effective repair and reanalysis processes (Fromont et al., 2020; Artesini, 2020; Zandomenighi, 2012).

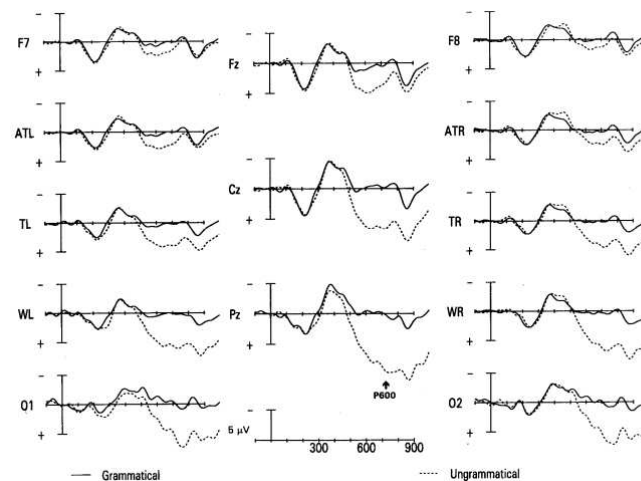


Figure 4. Modified by Osterhout & Nicol, 1999. Grand average waveforms showing an evident positive deflection on the parietal site elicited by an ungrammatical word (dashed line).

1.4 Agreement: definition and scope

Since this work is entirely based on the concept of agreement and all the implications linked to it in terms of cognitive processes, it is worthy to give a general description of this phenomenon. Agreement is a relation between two elements which shares grammatical features. Precisely, it represents the projection of a specific set of grammatical features from one element (the controller or trigger) to another (the target). That is a sort of dependency ruled by covariance, a statistical measure which assures a linear link between the two variables in the sense that as one element changes, the other have to change accordingly. Subject-verb agreement reflects perfectly this kind of relationship – but it could take the form of different configurations: noun-adjective, determiner-noun, auxiliary-lexical verb, pronoun and its antecedent (De Vincenzi, 2006). Person (1st, 2nd, 3rd) and Number (singular, plural) values are the major features involved and the most studied in literature³. Since they can be expressed in different ways cross-linguistically, they have been largely debated in the psycholinguistic domain: for example, in Italian, they are condensed in a single morpheme; as shown in (1), at the level of the verb, person (3rd person) and number (singular) features are easily identified in the suffix of the verb *-a*.

- (1) Mario_{3rd sing} gioca_{3rd sing} con la palla
Mario_{3rd sing} plays_{3rd sing} with the ball

Therefore, this situation has fueled the debate on the way these features are processed, specifically, if the parser interprets them as a bundle or individually (Mancini, 2012). Minimalist analyses treated Person, Number and Gender as a unit (the so called ϕ -features; Chomsky 2000, 2001) but other researchers have recognized their independence emphasizing that they have intrinsic interpretive differences (Bianchi, 2006; Sigurdsson, 2004; Mancini et al., 2014): Person represents the direct link between the argument role and the speech act participant (e.g. it defines whether the subject is the speaker or the addressee; Benveniste, 1966), whereas Number expresses the simple numerosity of the nominal argument. Hence, the deictic component present in the former feature makes

³ But agreement is also based on gender, case and definiteness (Haig and Forker, 2018). Gender is also involved in subject-verb agreement with past participle with an ergative verb (e.g. “è partito/a” – “He/She has left”) and with passive verbs. (De Vincenzi, 2006)

person value's processing more complex because it involves interpretative factors (for insights see *Person Asymmetry theory* in chapter 3). Instead, number feature represents "the mere numerosity of a nominal argument" (Mancini, 2012).

Besides that, there is the question of the directionality of agreement: what defines a controller and its target? Considering subject-verb configuration, the first theories (Chomsky 2000, 2001) gave the role of controller to the subject which has fixed features ; on the contrary, the verb has choice of feature value. Based on that, the subject is supposed to copy the set of features on the verb and not the other way around, thus, that's the latter which changes accordingly to the former. This theory has been questioned thanks to language specific phenomena, such as unagreement in Spanish (for insights, see section 3.1.6) in which the agreement operation comes firstly by the verb and then there is the checking of the features on the subject. In the next paragraphs we will describe how agreement operations have been analyzed in ERP literature, exploring methodologies, underlying theories and the variety of results.

Chapter 2

2.1 Neurocognitive models of parsing

The fundamental role of ERPs in language processing studies dates back to 1983, since the publication of Kutas & Hillard's paper. The immanence of the ERPs for more than thirty years (Molinaro et al. 2011) has demonstrated that they are the most suitable method in the language studies domain. The evidence emerged from electrophysiological data has allowed many researchers to hypothesize models of parsing which have been supported, questioned or elaborated differently over the years.

This chapter aims to show what are the major studies which have led to the current reflection about the correlation between ERP components and linguistic processes.

2.1.1 The syntax-first model

It is well known the importance of the first modular models which had the aim of finding the processes underlying language comprehension. The major debate which has been faced concerned the syntax-first models which, differently from interactive models⁴, assumed that syntax has a primary role and must precede the semantic processing; this means that in case of violations in terms of syntactic structure, the system is blocked and it cannot accede to the semantic information.

Friederici's neurocognitive model (2002) has been inspired by the garden path model by Frazier (1987) and Frazier & Rayner (1982) and it predicted three phases, defined by the specific ERPs correlates:

- I) The first phase (100-300 ms) corresponds to the insertion of the incoming word input into a hierarchical phrase structure. This procedure is based only on word category information. This phase is supposed to correspond to the ELAN if the system fails to create the syntactic structure.

⁴ The word interactive means that the functional components found during the processing of syntactic and semantic information do not act in independent, parallel ways but they, indeed, interact (De Vincenzi, Di Matteo, 2015).

- II) The second phase (300-500 ms) reflects the moment in which syntax and semantics work independently (De Vincenzi, Di Matteo, 2015) because morphosyntactic information and lexical/semantic information take place. Problems of integration at this level should elicit a LAN for morphosyntactic violations, or a N400 for anomalies concerning semantics. This phase cannot take place if the first step is not completed correctly.
- III) In the third phase (500-1000 ms), the two information cited in the second step work together, namely, they are integrated at this level. If this procedure is problematic, a reanalysis and repair processes intervene and this is reflected on the P600 component.

Despite the crucial role that this approach has had since the mid-1990s (Fromont et al., 2020), it has been demonstrated that it shows many weaknesses (see the section 2.2.1 For Steinhauer & Drury's report). The major doubt which has been called into question is the finding of an early negativity (eLAN) in case of violation in the syntagmatic structure because, if it seemed to be so stable in the acoustic modality, it wasn't the same for the reading domain. Furthermore, the clear evidence which emerged from this paper is the so called "semantic blocking" which means that the ELAN blocks the N400 and this was not entirely shared by the scientific community because it was not always found (Van den Brink, Hagoort, 2004; Luo et. al, 2010; Nickels, 2016, Fromont et al. 2020). In conclusion, it becomes clear that this model at best needed some revision.

The Figure below (Figure 5) schematize the description of the model.

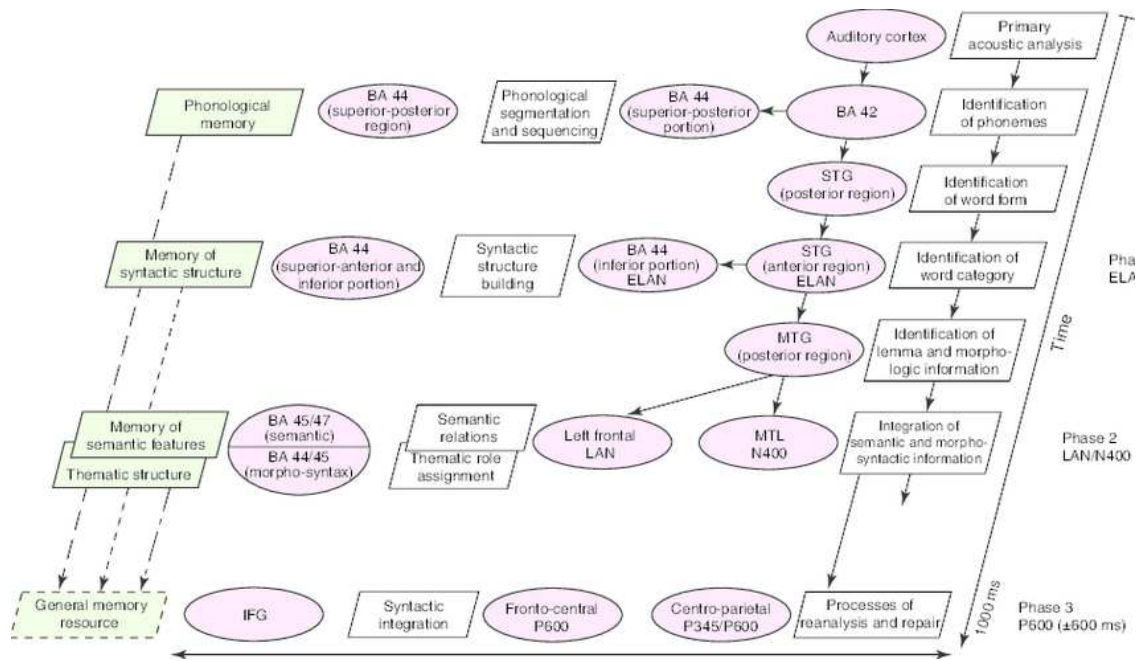


Figure 5. Modified by Friederici (2002)

2.1.2 The Memory, Unification, and Control (MUC) Model

If researchers like Friederici put the focus on automatic and syntactic aspects in order to support modular models, others have been inspired by parallel constraint based models in which most of the structure is lexicalized and retrieved from long term memory (Jackendoff, 1999) rather than built on line and the main parsing routines needs to consider semantic and pragmatic aspects to build a coherent interpretation from the onset of the processing of each single word. That's the case of Hagoort's neurocognitive model (2005, 2017). It differed radically from Friederici's perspective because the author assumed that the processing of a sentence does not occur through a strict hierarchy of phases; instead, different types of information (from prosodic factors to syntax and the content of the message) are processed and indistinctly applied as constraints as soon as they are available.

“There are good reasons to assume that in language comprehension syntactic, semantic and phonological unification processes operate concurrently and interact to some extent.” (Hagoort, 2005)

This framework is based on three components:

- **Memory:** which has the function of information retrieval because most of the syntactic structure is stored in the long-term memory and the specific chunk of structure is selected according to compatibility rules, there are no computational rules. Other types of information contribute to determine the strongest relation to build.
- **Unification:** with the aim of linking lexical frames through agreement features. The strongest link is found when a sort of equilibrium is reached, that is, through a work of selection and inhibition of alternatives. This strength is defined by phonological (prosody), syntactic (word order, agreement) and semantic information (world knowledge, plausibility). These types of information are organized in parallel.
- **Control** of communicative intentions and actions. That's a component which allows to pass from comprehension to production, to choose the correct language in case of bilingualism. This part of the model has been updated (taking into account also pragmatic aspects) over the years with revisions of the model.

These three components work at all the linguistic levels simultaneously, they have the same relevance. This was also supported by the description of the neurobiological functions of Broca's and the surrounding areas (for insights, see p.419-421 of the paper). Furthermore, fMRI analysis demonstrated the functional division of phonology, syntax and semantic which is an additional aspect against a modular vision (it is evident from Figure 6).

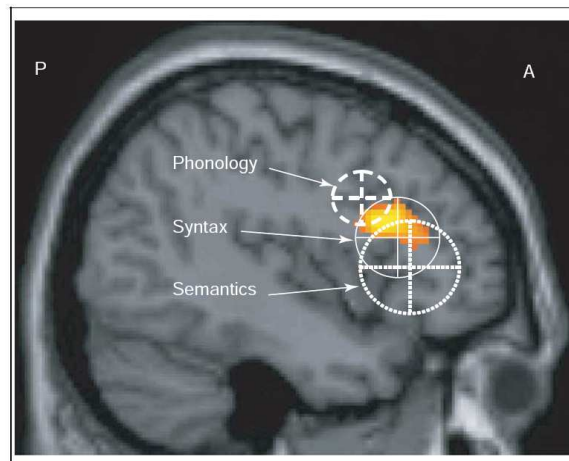


Figure 6. Modified by Hagoort (2005)

2.1.3 The two streams model

The majority of the first studies supported the idea that syntax has the control of the processing and guides other linguistic levels in order to complete the sentence comprehension processing. However, there are some researchers which have questioned this primacy of syntax, claiming the independence of semantics. Osterhout et al. (2012) tried to prove firstly that a modular account for language processing could not be representative of the underlying processes, and then that it was necessary to change perspective focusing on neurobiological basis because:

The complex behavior will become more understandable once the relevant neural circuits are known. [...] a theoretical perspective that imposes a priori assumptions concerning language and linguistic structure onto the brain, without due consideration of known neurobiological principles, might lead to a biased and ultimately inaccurate view of human language, language processing, and the evolutionary history of this important behavior. (Osterhout et al., 2012)

That's why the authors have hypothesized that language comprehension system works like the visual processing system, namely through streams of processing (for insights, see Ungerleider & Haxby, 1994). These have been described as independent, in the sense that each stream has to deal with different aspects of language, but also as cooperative between each other, in order to put together all those aspects through an integrative procedure.

This model went far beyond the simple individuation of these streams but it aimed to define the neural circuits underlying these processes in order to provide a neurobiological and psycholinguistic vision of the problem.

It is well known that the concept of distinct functions for language production and comprehension - and so, the existence of two processing streams - comes from the study on aphasic patients, in particular from Broca's and Wernike's deficits. Analysis based on fMRI methods has had an impact on this domain as it has given correspondence between the deficits manifested and the lesions on specific brain sites⁵ but it has been revealed that these results could not reflect the real situation because there is no direct link between specific brain areas and linguistic functions and this has been clarified in the ERP studies. Electrophysiological methods can investigate, as a matter of fact, the neural dynamics that come into play during the sentence comprehension processing and it's something that a static image such as that resulting from fMRI studies cannot capture (Osterhout et al., 2012).

ERP correlates elicited by syntactic and semantic violations are indeed different but exceptions proved that P600 is not always linked to syntax or to language functions in general - as it seemed that it was elicited by misspelled words and unexpected notes in famous musical compositions – and N400 could result from images, objects, stories or movie scenes presented in an anomalous context. However, it is sure that the two ERP correlates are evoked by something unexpected. These findings led the authors to see the problem from another perspective, if there was no direct correlation between ERPs and language functions, the concept of streams could disambiguate the situation:

- An anterior stream analyzes pattern of sequences – in this case syntax is one of the possible operations – and it can be operative if the anterior cortical-basal ganglia circuit is conserved.

⁵ It seems that damages to the basal ganglia could affect syntax; lesions at the perisylvian cortex, white matter and subcortical structures can produce problems in sentence comprehension; more in general, Broca's deficits are linked to anterior lesions (agrammatism in production) and Wernike's comprehension problems are due to posterior damages.

- A posterior stream has to deal with word combination from a conceptual point of view and it is linked to the posterior circuit which is involved in the conceptual knowledge.

The independence of the two streams has been verified testing neural responses to grammatical part of speech, in particular nouns and verbs, two grammatical classes which are characterized by lexical richness – and so both could activate the posterior stream – but they differ at the syntactic level because the logical structure of the verb (see section 2.1.4) requires a specific sequence of arguments; for this reason the verb activates the anterior processing stream more than the noun.

Their interaction, instead, has been tested by Kim and Osterhout (2005) introducing violations in passive sentences such as “the mysterious crime had been solving...”. Sentences like that evoked a P600 waveform and it has been explained in terms of “semantic attraction”: despite the fact that “crime” can be seen as an agent from a syntactic point of view, it plays a better role of theme from a semantic perspective, and the elicited P600 supported the idea that, in that case of syntactic complexity, semantics can take over and control the sentence comprehension processing. If not, a N400 component should have been elicited, due to a semantic violation perceived after accepting the syntactic construction. Instead, that’s the structure which is perceived as anomalous and the simple substitution of the inflection could resolve the violation (from “solv-ing” to “solv-ed”).

2.1.4 The Extended Argument Dependency Model (eADM)

Bornkessel and Schlesewsky’s model belongs to the group of the major frameworks conceived in the language processing studies. At a glance, it could appear as an evolution of the syntax-first model, in the sense that it was based on three hierarchical phases, but, we will list all the differences at the end of the paragraph. In this way, it will be clear that the eADM was not a simple reflection of Friederici’s model (2002) but it followed only part of its conceptions.

The authors defined it as “[...] a new cross-linguistically oriented, neurocognitive model of incremental language comprehension that is capable of deriving fine-grained

distinctions [...]” (Bornkessel, Schlesewsky, 2012). This description resumed perfectly functions and objectives of the eADM; we explain below what these words meant.

Before listing the three phases of language comprehension theorized by the authors, it is crucial to introduce the focus of this model, that is, the so-called ‘core relations’: the link established between the arguments and the verb and between the arguments themselves. This type of processing calls into question many factors that could be difficult to handle if one considers that all the languages have different structure building theories and different interpretations associated with selection and positioning of the arguments.

This model has been created to take into account all these aspects in a universal (cross-linguistic) perspective but without excluding elements which are more language-specific. Furthermore, it is based on simple sentences whose verbs require only one to three arguments.

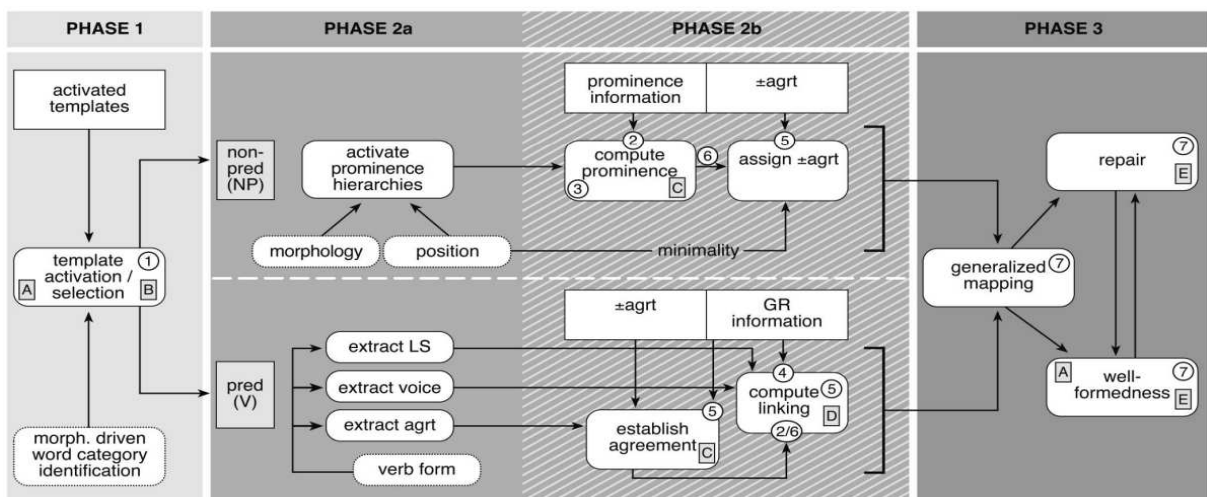


Figure 7. Modified by Bornkessel & Schlesewsky (2012)

According to the authors, language comprehension follows three phases:

- **Phase 1** consists of structure building and it has been interpreted in terms of precompiled syntactic templates, stored in the mental lexicon and selected only on the basis of categorial information, without considering relational aspects: it considers the number of arguments and their position established by the verb. In sum, the factors involved are word category, dominance and precedence. This is the phase which makes the model more similar to Frazier and Friederici’s models. From a ERPs perspective, this phase should be the domain in which the ELAN

emerges and, if Friederici (2002) interpreted this result as the correlation of word category violations, Bornkessel and Schlesewsky translated it into syntactic template failure, namely, when there is no template in the lexicon which could correspond to the input. The authors supported also Friederici's point of view about the interaction between the first phase and the others in the sense that the other phases have no influence on the ELAN but this latter can block the following stages (in line with Friederici's "semantic blocking").

- **Phase 2** represents the moment in which some relational aspects come to light. This stage is divided into two further steps in which (2a) the arguments are classified in a hierarchy through an encoding of features, defined "prominence information" (Bornkessel, Schlesewsky, 2012) and through what the authors call "language-specific weightings"; the following step (2b) reveals how these features can be linked together. For a more detailed view: phase 2a consists of assigning the so-called Generalized Semantic Roles (GRs) to the arguments, which are divided into Actor (the most prominent argument) and Undergoer (the less prominent argument) on the basis of dependencies required by the context; this type of assignment can vary cross-linguistically, that's why the authors assumed that the universal component of the hierarchy based system is paired with the definition of individual hierarchies determined by information types (which are language specific⁶); in this way the **compute prominence step** could be accomplished, and it is important to build interpretive relations between the arguments. Processing conflicts at this point should give rise to a N400 since there is an interpretive conflict, but it has been demonstrated that there are cases in which appears a fronto-central negativity different from the normal electrophysiological correlates (N400, LAN), the authors called that "scrambling negativity"⁷. As regards verbs, their interpretation goes under the **compute**

⁶ The prominence scales - listed in Bornkessel & Schlesewsky's work "Processing Syntax and Morphology: A neurocognitive Perspective" (2009) – are :

- Morphological case marking (nominative>accusative/ergative>nominative)
- Argument order (argument1>argument2)
- Animacy (+animate>-animate)
- Definiteness/specificity (+definite/specific>-definite/specific)
- Person (1st/2nd person > 3rd person)

⁷ This ERP correlate is thought to be found in languages which do not allow for argument drop such as Russian, thus it would be not elicited by languages like Japanese and Turkish.

linking step which has the function of associating the logical structure⁸ of the verb to the arguments already computed. This phase corresponds to the elicitation of early parietal positivities in languages with true object-experiencer verbs like Icelandic⁹. These two important steps cannot be considered completed without another fundamental phase which is the assignment of agreement for arguments (assign \pm agrt) and the establishment of agreement for verbs and arguments (establish agreement). Assignment of agreement is determined by the prominence and if there is no prominence computed, it is assigned through minimality (namely, the first argument receive the feature +agrt)¹⁰. Establish agreement is a step in which the system has to assure a matching between the structure required by the verb and the features of arguments computed; in case of a mismatch, the system cannot accede to the compute linking step¹¹. The ERP component found at this level has been defined as “agreement LAN” in order to distinguish it from the “linking LAN” which reflect problems due to mismatches between the LS of the verb and the effective argument hierarchy of the phrase. This latter correlate is more rare in the sense that it has been found only in German whereas the agreement LAN is more frequent.

- **Phase 3** is supposed to be the last step of the processing in which the interpretation can be considered completed but the system has to pass through two specific moments of the processing. The first is the General Mapping in which all the information computed up to this point are integrated with extralinguistic aspects such as prosody, plausibility, world knowledge, frequency and so on. The second is the Well-Formedness step, which is relevant to evaluate the acceptability of the structure on the basis of the discourse context. On the latter step depends whether the system has to face a repair operation or not. As regards the ERP correlates of these two final stages, the authors reported two types of late positivities different

⁸ The logical structure (LS) of the verb includes the argument representation that the verb requires.

⁹ In these languages the dative object is expected to be found in the first position compared to the nominative one. If the parsing compute an unexpected nominative argument preceded by the object-experiencer verb, the problem will be reflected in the early positivity.

¹⁰ The example provided by the authors is the German sentence in which the first argument agrees with the verb but it does not recover the actor role.

¹¹ Chinese is used as a support of this theory because it has no agreement and the system stops exactly at the establish agreement step.

in topography and amplitude and the classical P600 in line with the syntax first model.

A further point in favor of this model is the precise description of the neuroanatomical correlates for each phase of the processing but we don't discuss it here.

Now that all these aspects of the model are clarified, it becomes intuitive that this perspective differs crucially from Friederici's framework. Although the base of this idea has been inspired by the syntax first model in the sense that the processing in comprehension is divided into three hierarchical phases and the first step is basically subject to word category information, the structure and conception of the two other phases is completely different. First of all, Phase 1 in the eADM is based on templates, retrieved from long term memory (similarly to Hagoort), whereas it is built on syntactic rules in the syntax-first model. Secondly, the general lexical-semantic process in the phase 2 of Friederici's idea is divided into four other subphases (agreement relations, assignment of prominence information, Generalized Semantic Roles, linking) in Bornkessel & Schleewsky's conception. This phase 2 contains also part of what is present in phase 3 of the syntax first model, that is, the grammatical function reanalysis whereas. The last phase of the eADM, instead, is focused on "general aspects of higher cognition" (Bornkessel, Schleewsky, 2012), again possibly linked to the "control" component of Hagoort MUC model. Finally, it is important to highlight that the eADM tends to separate universal aspects from language specific processing operations in a crosslinguistic view which is completely absent in Friederici's framework.

2.2 Actual development of empirical researches and the (re)vision of the electrophysiological correlates

2.2.1 A break with the past: critics to the first neurocognitive models

It is highly shared the idea that Friederici's model (Friederici, 1995, 2002, 2011) has had a crucial role in the history of language processing studies. She has built a big, solid and apparently solid castle, defined "the most influential ERP-based neurocognitive model of language processing to date" (Fromont et al., 2020). Steinhauer and Drury (2012) have

revealed big cracks in that important building which have brought down not only the syntax-first model but all the theories supporting the existence of ELAN. They considered some previous studies, analyzed in detail the results and in particular the methodology, identifying flaws which have led to a wrong interpretation of the effects. This review is a milestone which warns of both inferential and methodological errors and it leads the way to new ERP studies. The first issue the authors have faced is the modality in which this hypothetical ELAN was found: Friederici (2002) affirmed that she found ELAN effect presenting the stimuli in acoustic modality but, according to her, it is likely to be found also in reading tasks (Friederici et al. 1999); Steinhauer and Drury (2012) demonstrated that the component is not modality independent because it is not so stable in the visual modality and most of the studies they cited – even Friederici’s own works – confirm this assumption¹². It is well known the importance of finding a component effect in both the modalities in psycholinguistics and this is the first demonstration that the ELAN could have been misinterpreted. Another problem the authors have introduced is the specificity of the component for what they call “outright violations” regarding the syntactic structure: Friederici (2002) justified the fact that the ELAN was not found in some previous studies because the sentences proposed had possible continuations and the component can be found only when there is no other possibility to continue the sentence. Steinhauer and Drury (2012) pointed out that it is a contradiction because Friederici’s own sentences had, although complex, grammatical continuations. Furthermore, they explained that, even the simple addition of a suffix (-en) to the verb in a sentence used by Friederici could resolve the violation¹³, a morphologic variation of the same word category (for insights read section 2.1.2. of the article). This procedure rises doubts also about the specificity of the

¹² “[...] most reading studies investigating word category violations failed to observe ELANs [...] and either found only later anterior negativities ([L]ANs) after 300 ms (Friederici, Hahne, & Mecklinger, 1996; Friederici & Meyer, 2004; Hagoort, 2003; Hinojosa, Martin-Loeches, Casado, Munoz, & Rubia, 2003; Martin-Loeches, Munoz, Casado, Melcon, & Frenandez-Frias, 2005; Newman, Ullman, Pancheva, Waligura, & Neville, 2007; Roehm & Haider, 2009, Experiment 2), N400s (Federmeier, Segal, Lombrozo, & Kutas, 2000; Gunter & Friederici, 1999), or even relative positivities between 300 and 500 ms (Frisch, Hahne, & Friederici, 2004) compared to control conditions.” From “*On the early left-anterior negativity (ELAN) in syntax studies*” by K. Steinhauer and J. E. Drury, 2012, *Brain & Language*, 120, p. 137.

¹³ *Die Bluse wurde am gebügelten Jackett mit Nadeln befestigt (The blouse was to-the ironed jacket with needles pinned)*. The example the authors provide is a sentence used by Friederici in her experiment. In this way, their theory is much more believable because they bring to light the contradiction between the operational definition given by Friederici and what she effectively found in the experiment.

ELAN for phrase structure violations: it is more likely to think of a morphosyntactic violation if the simple addition of a suffix can make the sentence grammatical.

Another point to consider is the hypothetical independence of external influences. Contrary to what had been claimed by Hahne and Friederici (1999), the ELAN effect is not independent of strategic factors because the rest of the sentence could be predictable when the prefixes *ge-/be-* were index of only verbs (even if they can design also a series of nouns but they were not exploited in the experiment). In that way, the subject's parser could anticipate the violation and it was compatible with the timing in which the ELAN has been found. In addition, the component has been found 200 ms before the verb when it is well known that the category information can be accessible only at the end of the word, where the inflection appears. This raises doubts about the association between the word category identification and the ELAN (Section 2.1.3. of the article gives a more specific vision of the issue).

The substantial part of the paper concerns what the authors classified as methodological problems. They assumed that most of the studies, with the aim of finding the component, were based on a "limited range of paradigms". The strongest criticism they provided is the highly diffused context manipulation (keeping the same target word), the effects of which could led to a misunderstanding about the results. It is important to consider the influence of the context which can intervene at all the linguistic levels, in particular at the phonological one because prosody, stress and duration are relevant aspects of the case, especially in the acoustic domain. The situation becomes more complicate because it has been demonstrated that most of the designs of these studies were asymmetric and this created lexical and contextual differences.

According to Steinhauer and Drury (2012), the two major consequences of the context manipulation are:

- (I) The spillover: a fictitious short-term effect which is part of an event related to the previous word or an effect which appears late in onset but it is always linked to what precedes the target word.
- (II) DC Offset which turns out in a shift of the effect (in a positive or negative range) due to a correction of the baseline.

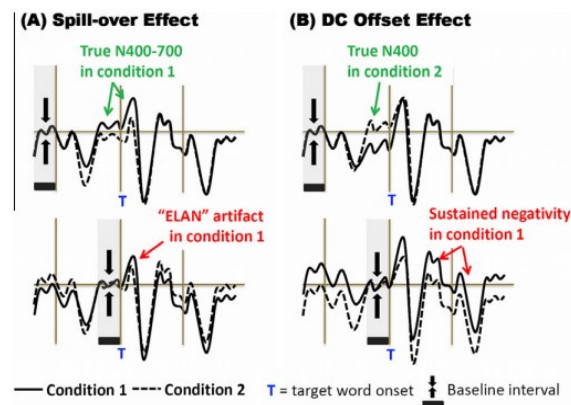


Figure 8. Modified by Steinhauer & Drury (p.142)

Therefore, they explained the difficulties which emerge when manipulating the context in the control condition. In general, it is important to consider these two situations because the effects change even if the preceding term is a function or content word and it was evident in Friederici's sentences in which the prior word could be a preposition, a verb, a noun or an adverb (section 2.1. of the paper). The authors claimed that this was the reason why the interpretation of ELAN was very weak because it seemed to be only an artifact due to contextual factors (see the examples in sections 2.2.3.- 2.2.5). Instead, if we take into account the target manipulation paradigm, it becomes easier to avoid these problems but it is less likely to find the component.

From this perspective emerged also the question of how to distinguish local ELAN from sustained negativities. It became difficult to justify the existence of these two early effects. Local ELAN seemed to appear together with a P600 and it has been claimed to be the result of the superposition of sustained negativity and the onset of the positive component. The sustained negativity seemed to emerge when there was no P600 effect. Then, the real issue concerned the correlation between PS violations and local ELAN because the effect seemed to be only an artifact due to the propagation to the frontal electrodes of the P600. Since most of the studies based on PS violation showed a biphasic pattern, it is less likely to think of a local ELAN. The interesting point of this claim is that Steinhauer and Drury (2012) did admit that it is possible to have an early syntactic effect but it is not necessarily elicited by (morpho)syntactic violation, it could also be an offset artifact.

The final discussion that called into question the syntax-first model is the fact that PS violations can block the semantic integration (Friederici et al., 1999). This blocking effect is not always present. Actually, they emphasized again that this effect has been found only in experiments in which the context was manipulated, repeating that the influence of the latter could be the real reason of this situation and not the PS violation. Clearly the fact that ELAN findings are challenged posits a strong doubt on the existence of a purely syntactic stage 1 of processing and this criticism applies to both Friederici and eADM model, independently from the fact this stage is based only on word category on or more complex templates. As Steinhauer and Drury (2012) admits, the concerns about ELAN does not imply that this stage 1 of processing cannot be conceived but just that there are no positive evidences about the existence of this stage which can be (weakly) postulated even in absence of positive ERPs evidence about it.

2.2.2 Individual differences and the nature of the biphasic pattern

It is clear that ERP response interpretations have been largely debated in the history of language processing studies: from a general point of view, the N400 was thought to be elicited by semantic violations, the LAN was associated with syntactic structure anomalies and the P600 appeared with this latter correlate and represented the syntactic repair process. Independent and interactive ERP components which have always, however, showed some exceptions and there was no clear picture of the processes underlying language comprehension processing.

Tanner and Van Hell (2014) tried to untie the knot by assuming that all the previous researches had taken into account only grand mean results when interesting effects could be observed by analyzing individual responses. The classic biphasic pattern LAN-P600 elicited by morphosyntactic anomalies in other studies had been questioned since it could represent a simple artifact due to grand average manipulations. This issue has been introduced by Osterhout (1997), see also Osterhout et al. (2004), who has found monophasic responses in his participants, a N400 and P600 respectively, but also a biphasic pattern when averaging response has been done. In line with Osterhout's results, Tanner and Van Hell described inter-individual differences in their work since they found

that some subjects responded to morphosyntactic violations with a negativity which could only be interpreted as the N400¹⁴; other subjects showed a P600 and only a little part of the participants manifested a biphasic pattern, one third precisely (Freunberger et al. 2021).

Their experiment was based on two types of conditions: subject-verb agreement and tense constraints, morphosyntactic manipulations which were expected to elicit the classic biphasic pattern described in the previous literature and a positive correlation between the negative and the positive ERP components. The reliability of the study lied on the statistical analysis centered on Anova and repeated measures about a large span of factors (grammaticality, condition, hemisphere and other external factors which could influence the results such as left-handers in parentage; for insights see section 3 in the paper). Focalizing on specific ROI¹⁵, they found a negative correlation between the two components because more positivity (in the right hemisphere) was associated with less negativity (in the left hemisphere) and vice versa; this result has disappointed their expectations. Furthermore, the calculation of a Response Dominance Index (RDI) has allowed them to measure the dominance which occurred in each participant and it is explained through the equation below (1):

$$RDI = \frac{(P600_{Ungram} - P600_{Gram}) - (N400_{Gram} - N400_{Ungram})}{\sqrt{2}} \quad (1)$$

The results supported the idea of dominance and clarified the real nature of the biphasic response. This latter has been described as an artifact due to spatio-temporal overlap between the N400 and P600 in the sense that in averaging operations the widespread P600 in the right hemisphere came by to erase part of the bilateral N400 effect, leaving a residual left negativity. This would explain the fact that the LAN effect is not so stable in other studies. The figure below (Figure 9) shows clearly this situation:

¹⁴ It is well known that the N400 and the LAN have the same latency (both appearing in the 300-500 ms time window) but they differ crucially in topography since the first has a centro-parietal distribution and the latter is more anterior on the scalp distribution. However there are authors (Molinaro et al. 2015) who describe the topographical distribution of the two components as a continuum, they are not so categorically different.

¹⁵ Regions of interest, centro-parietal electrodes (C3, Cz, C3, CP1, CP2, P3, Pz, P4).

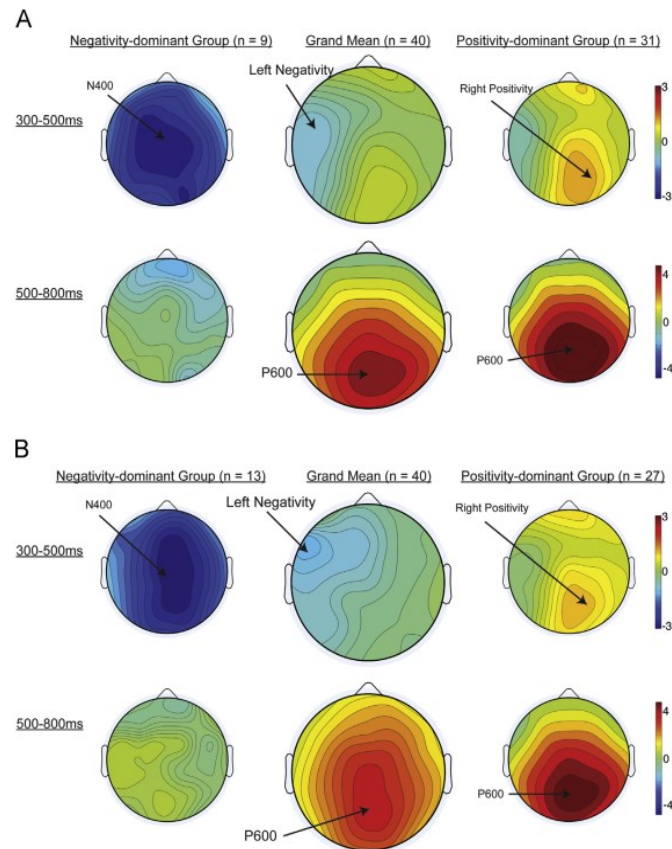


Figure 9. Modified by Tanner & Van Hell (p.297)

The relevance of this paper lies in the conception of the biphasic pattern: according to the authors, this result indicates that LAN-P600 effect has not to be seen as the manifestation of two stages of the same processing but it reflects a differential strategical reaction to morphosyntactic violations. This study is one of our reference points since it considered the agreement condition and the issue of the biphasic pattern, in particular we will refer to its statistical analysis in order to provide a further vision of the (morpho)syntactic processing.

2.2.3 The LAN effect really exists

Initially it seemed that Tanner and Van Hell (2014) had hit the mark but there were still some aspects to consider (Molinaro et al. 2015; see section 2.3 for insights). Caffarra et al. (2019) tried to deepen the real nature of the LAN effect by analyzing local agreement

violation responses - specifically determiner-noun gender constraints – in Spanish. The choice of a morphologically rich language was not random since previous studies (Friederici and Weissenborn, 2007) have put forward the idea that languages like English, based on word order mechanisms, do not need to elicit the LAN because there is not a complex morphosyntactic structure based on inflectional paradigms which may require an automatic and early effect (Tanner and Van Hell, 2014). If the object was to find this ERP component, it was necessary to study a language which had more probability to show the effect. This also applies to the choice of local agreement manipulations instead of testing subject-verb agreement violations: it would be more likely to find a LAN in a stronger relation such as that present in the same phrase.

The importance of this study is reinforced by the statistical analysis which appeared stronger than Tanner and Van Hell's in terms of numerosity of data. Caffarra et al. investigated ERP effects in the correct and violated condition by analyzing not only the level of subjects but also items and trials' levels in order to get a clearer picture of the problem.

The first step of the work was centered on the topographical individuation of the LAN and, contrary to the cited works, it has been successful in finding it in 55% of the participants, 46% of the items, and 49% of the set of trials, to be exact (Caffarra et al. 2019). This early anterior effect not only exists at all the levels analyzed but it is far more evident than the others (N400 and P600). This was the first proof that the LAN effect could not be simply an artifact due to averaging operations. However, it is important to consider that, also in this case, the effect was not completely stable.

The second obstacle was the strong correlation between positivity and negativity found in Tanner and Van Hell's report (see section 2.2.2). Caffarra et al. (2019) measured LAN-P600 effects and N400-P600 effects through the Pearson correlation coefficient. Indeed, 66% of the participants showed a biphasic response and, even if the two effects did not seem to be correlated at that level, they showed a little correlation when items had been analyzed (it was stronger when the effects were detected at the same electrode). This result called into question the assumption of positive and negative responders, in particular the conception of dominance.

Finally, the authors have faced the problem of subject variability in terms of rigid statistical analysis. They used mixed-linear models to test whether the LAN would be reduced by the introduction of subject variability to the model. The figure below (Figure 10) summarize the results and these plots seem very suggestive in the sense that they show data distributions and not simply the means.

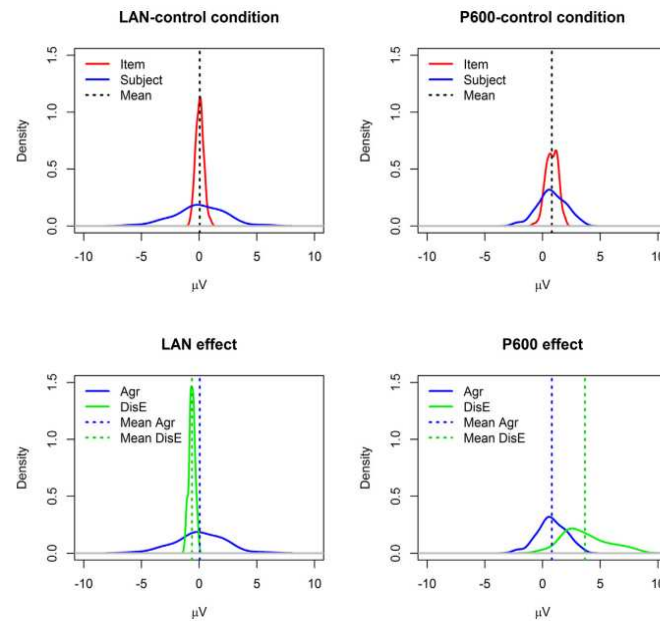


Figure 10. Modified by Caffarra et al. (2019)

Firstly, in the control condition, we can appreciate more variability at the level of subject and less variability for items; the same situation can be observed for the P600 effect. As regards the violation condition, the LAN and the P600 effects differs drastically: in the first case, the EEG activity seems to vary a lot in the correct condition whereas it becomes more stable in the disagreement condition. The distributions of the second ERP correlate seem to follow the opposite way: the violation condition shows more variability than the agreement condition.

All in all, it becomes difficult to accept the description of the LAN effect as an artifact due to averaging procedures (namely a leftover of a N400), the statistical results are too strong to be rejected. However, it will be worthy to analyze the subject-verb agreement counterpart in a morphologically rich language in order to extend the theory of the existence of the LAN effect also in non-local morphosyntactic relations.

2.3 What are the real electrophysiological correlates of syntactic violations?

All this discussion is functional to give a general overview of the theories on the cognitive processes underlying language comprehension. So far, it is clear that there is not yet a definitive vision of the problem and that may be so for a long time still. The actual picture could appear very confusing if we take into account all the previous studies: the first doubts about the existence of the LAN effect date back to the 90s, when Osterhout (1997) found a sort of instability when syntactic violations had to be computed, the P600 appeared much consistent. This debate lasted approximately thirty years and, for the moment, Caffarra's theory (2019) on the biphasic pattern seems to be the most reliable. The LAN exists. At least in local agreement violations such as determiner-noun violations in Spanish.

As regards syntax-first models, up to now, it has been demonstrated that they could not represent the mirror of the sentence processing mechanisms, even showing an elegant proposition (Hagoort, 2005; Steinhauer, Drury, 2012; Tanner, Van Hell, 2014; Caffarra et al., 2019; Fromont et al. 2020a, 2020b). The major criticisms have been addressed to the early detection of syntactic violations (before the 300 ms time window) because, after Friederici's proposition, different studies tried to find an ELAN and failed (Hagoort et al. 2003; Frisch et al. 2004; Steinhauer and Drury, 2012; Zandomenighi, 2012). In addition it has been demonstrated that methodological basis of those experiments showed several weaknesses (see section 2.2.1). The actual debate, indeed, is centered on the LAN and the N400.

Even counting only the effects elicited from 300 ms onwards, the question is much more difficult because the differences between the two components at issue are not easily discernable (Molinaro et al. 2015). The question is: what study we can rely on? This is not simple, considering that there is not a single shared result. What we have collected in literature is that some experiments on morphosyntactic violations led to a biphasic pattern which not always involved a LAN effect (e.g. N400-P600: Zhang et al. 2011; Tanner, Van Hell, 2014; Fromont et al., 2020; Idrissi et al., 2021), others have found the classical LAN-P600 pattern described for syntactic violation (Osterhout, Holcomb, 1992; Osterhout, Mobley, 1995; De Vincenzi et al. 2003; Martin-Loeches et al., 2005; Molinaro

et al. 2011; Zandomenighil, 2012; Caffarra et al. 2019); the rest of the works have found monophasic responses of N400 (Hahne, Friederici, 2002; Kolk et al., 2003; Kim, Osterhout, 2005), or P600 (Osterhout, Nicol, 1999; Hagoort 2003; Kuperberg, 2007; Kim, Osterhout, 2005).

Putting a magnifying glass on these studies, it has to be highlighted that most of them were based on local agreement violations such as determiner-noun or noun-adjective violations and only part of them investigated subject-verb agreement violations (Osterhout, Moebly, 1995; De Vincenzi et al. 2003; Tanner, Van Hell, 2014; Bornkessel, Schlesewsky, 2012; Steinhauer, Drury, 2012). This could represent a problem because, if it is true that nouns have argumental structure, it is also true that they select a single article. The question of the verb is much more complicated and the structure of the phrase – and then its interpretation - is dependent on the arguments the verb selects and other syntactic aspects (see footnote 3). So, studying only local relationships which are surely much stronger than a between-phrase relationship is important but it could not give a fulfilling picture of the morphosyntactic computation. In sum, more details must be defined in this linguistic domain.

There is also the problem of the crosslinguistic variation. In the eADM, Bornkessel and Schelewnsky (2012) have introduced this issue. Investigating subject-verb agreement violations could emphasize some relevant aspects which could be important to support a theory that aims to be generalizable. If the LAN would come by to be described as the stable correlate of problems occurring at subject-verb agreement level, it is important to put the light on some language specific aspects: for instance, languages which allow post-verbal subjects, such as Italian, could not elicit a LAN in sentences like “I topi mangia...” (“Mice eats...”), because the first element could be interpreted as the topicalized pre-verbal object “I TOPI mangia il gatto” (“MICE eats the cat”¹⁶).

In conclusion, we cannot give an exhaustive answer to the question on the electrophysiological correlates elicited by syntactic violations because there are still many aspects to implement in the psycholinguistic research. Our work aims to give some clues which, one day, could led other researchers to find a fulfilling solution.

¹⁶ Clearly this is a structure which is ungrammatical in word order based languages such as English.

Chapter 3

3.1 Subject-verb violation: an overview on Italian studies

3.1.1 Biphasic pattern with an exception

Some of the first Italian studies based on number or gender agreement processing had the main aim of understanding if the syntactic processing was distinct from the semantic one. This probably came from the publication of the first modular models and the intention to prove them cross-linguistically; in fact, the works we describe in this paragraph are chronologically and thematically close to Friederici's model (2002). However, despite they are a little outdated, it has to be highlighted that these studies have allowed following researches to deepen and focus the problem mainly on syntactic or semantic processing, considering aspects which have never been investigated before (see Section 3.1.2 and following).

The importance of these studies lies on the results of their experiments because two out of three have reported a *weak* LAN effect on the syntactic violation and the subsequent P600 (Angrilli et al., 2002; De Vincenzi et al., 2003). These findings were supported by a questionable statistical analysis (which we discuss below, see section 3.1.1.1).

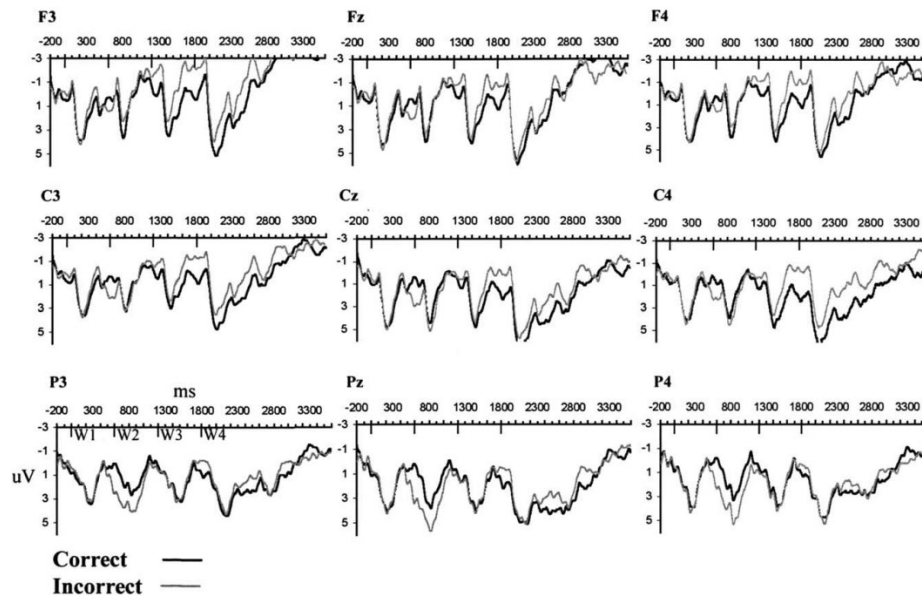


Figure 11. Modified by De Vincenzi et al., 2003. The picture shows averaged ERP recording during the syntactic violation. The first evidence is that on the fronto-central electrodes, in particular F3 and C3 (around 400 ms) emerges a negative peak (hypothetical LAN).

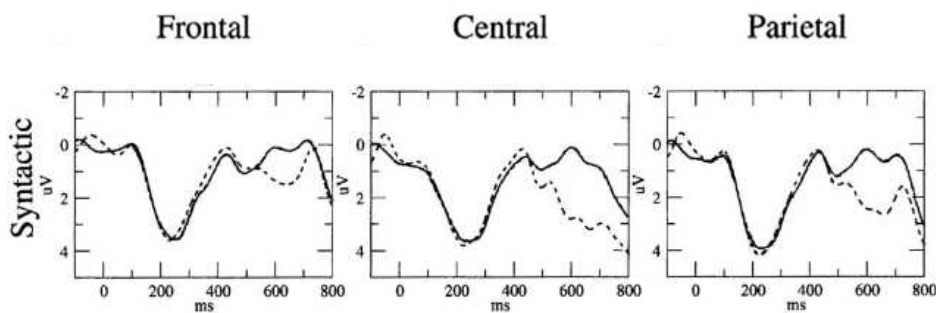


Figure 12. Modified by Angrilli et al., 2002. The panel shows grandaverage waveforms of participants who were faced with a syntactic violation. What is evident is the positive-going wave, the P600, in the 500-700 ms time window, more accentuated over the central and parietal sites.

Studying responses to agreement violations in a language like Italian is a matter of interest in psycholinguistic because that's a free-word-order language which allows for postverbal subjects. If an ERPs correlate as the left anterior negativity reflects the early detection of a syntactic error, it may be less stable if the mismatch encountered turns out to be just a specific syntactic structure called 'focus' (see section 2.3 and 3.1.5). The articles we will refer to in this chapter have the aim of finding an answer to this phenomenon.

Experiments by Angrilli et al. (2002) and De Vincenzi et al. (2003) were based on the same phrase structure and the violation was associated to the lexical verb, as in (1).

- (1) Il cameriere anziano serve/*servono con espressione distratta (The old waiter serves/*serve with a vacant look).

We will compare the two results with another work which did not find exactly the same response by its participants.

In the first article, twenty five Italian native participants (18-29 years old) were asked to read the sentences presented on the screen word-by-word and their brain activity was recorded through nineteen electrodes placed on the scalp and eye tracking monitoring (Angrilli et al. 2002). Statistical analysis has been carried out in order to support the electrophysiological findings: the authors used a group of electrodes based on their localization on the scalp (frontal, central, posterior) as one variable and the condition of the sentence as another one (control, violated). The analysis has been centered on the specific time windows in which the ERP correlates were likely to be found (400-500 ms for the LAN/N400, 500-700 ms for the P600). We will not discuss in detail the responses to semantic violation in order to focus on the syntactic parsing.

As one could expect, the P600 elicited by the target word (the verb) in the violation condition was evident widely but more over the central and posterior areas. The statistics confirmed that the incorrect sentences caused the emergence of a positivity, bigger in amplitude rather than the control condition (see Figure 9). That's not a surprising finding since it is clear that the posterior positive correlate for the syntactic processing is a very stable reference to repair and reanalysis processes in cases of syntactic anomalies, also cross-linguistically (for example Hagoort, Brown & Groothusen, 1993; Osterhout & Mobley, 1995; Friederici et al., 1996). However, the nature of this positivity has to be deepened since other following studies have reported that such a ERP correlate could be not confined to the linguistic field (see Patel, Gibson, Ratner, Besson, & Holcomb, 1998; Patel, 2003) and others have proposed that it is not a monolithic component since it could be show two distinct phases (see Molinaro et al. 2011a; Kasparian et al. 2017; see section 3.1.6).

What deserves attention is the significant effect linked to the LAN. The authors have examined the four left anterior electrodes (T3, C3, F3, F7), during the 350-450 ms time window, conducting a one-tailed t-test. It seemed that the statistical data showed that the

LAN was effectively found, supported by the findings in other languages (see Friederici et al., 1996 and Neville et al., 1991).

Similar results have been shown in the latter work, De Vincenzi et al. (2003), but only because it represents an extension of analysis of the same data described above. The authors tried to provide an in-depth study looking for significant results to confirm that the syntactic processing comes prior to any other levels of processing, and so the semantic one. That's why they carried out two experiments, one based on the difference in reading time, the other focused on the ERP responses evoked by the comprehension of sentences. The first task has involved thirty Italian native students (18-25 years old) who had to read 180 sentences, 60 of which were filler sentences¹⁷. What they found was a confirmation of the classical modular assumption: not only the identification of the syntactic violation preceded the semantic one but it would be also rapidly repaired. The statistics¹⁸ confirmed that the incorrect condition required more time to be read (thus processed) and this effect lasted until the word following the target (the verb), the significant effect stopped there¹⁹. The second experiment was centered on the ERPs' recording during the whole sentence and not only at the level of the target word or the final one. Twenty five Italian native students participated (18-29 years old). Presenting the same sentences and the same procedure of the first experiment, the authors analyzed statistically the results: they exploited a 3-way ANOVA in order to take into account all the possible important levels, adding the word position to the two already analyzed by Angrilli et al. (2002) (sentence condition and the same electrode groups). Again, the possible emergency of the LAN has been examined through a one-tailed t-test. Furthermore, in the 300-500 ms time window, the analysis has been performed by dividing the time frame in 10 ms intervals and each of them was tested through a one-tailed t-test considering two specific electrodes for both the semantic and syntactic ERP correlates (C3-T3 for the LAN, Pz-P4 for the N400). This was necessary to identify the exact moment of the anomaly detection.

¹⁷ 30 sentences included the syntactic violation (subject-verb agreement mismatch), 30 had a semantic anomaly and 120 represented the control condition, so they were all correct.

¹⁸ Separate ANOVAs. Items and subjects as dependent variables (for insights see section 2.4 of the article).

¹⁹ That was the semantic anomaly which showed a long-lasting effect, persisting until the end of the sentence. This lead to the interpretation that the difficulty in reading the agreement mismatch could be easily resolved because it involved only the choice of the wrong item, so the number value marking the verb or the subject. The semantic anomaly required the comprehension of the whole sentence to understand the problem.

Since the statistics and the sentences manipulated were the same as the previous article (Angrilli et al. 2002) it is reasonable to appreciate the same results, thus a biphasic pattern for the syntactic anomalies (LAN and the subsequent P600). What emerged was also a sustained negativity from 400 ms (at W3, the element before the verb) to 700 ms, after W3 and W4. Therefore, the peak reached at the level of the target word for number-agreement violation returned to baseline while the final words were characterized by a negative wave. This was another point to show distinction for the two kinds of language processing because the negative wave associated to the semantic anomaly did not show the same alternations, it was maintained for the entire sentence. Finally, the earlier detection of the LAN (which became significant at 340 ms) rather than the N400 (significant at 430 ms) was a further evidence for the difference between the semantic and the syntactic violation processing (precisely a difference of 90 ms). Again, shorter reading times to read a sentence including a subject-verb mismatch compared to longer reading times for semantic problems confirmed that there was also a difference at the level of the influence that these violations had on the entire sentence because only the semantic incongruity required an entire vision of the context, the syntactic anomaly could be resolved immediately.

To conclude the picture of the first studies involving number/gender agreement processing, it could be useful to add into this overview another work (Balconi and Pozzoli., 2004), the results of which differ significantly from the two described above. Even if the authors had the same object of Angrilli et al. (2002) and De Vincenzi et al. (2003), they tried to confirm the difference between the two levels of processing from another perspective: they analyzed responses both to visual and auditory stimuli. The research was divided into two experiments in which the first was centered on a reading task (without specific instructions, the participants were not told what to do), the latter consisted of a comparison between the reading and listening tasks (the participants were aware of the task). Twenty-one Italian students (mean age 22.7) participated and they were shown ninety sentences with semantic or syntactic incongruity. The structure of the sentences was organized in such a way that the syntactic problem was at the level of the finite verb, like in (2):

(2) La porta dell'ufficio è/*sono aperta/aperte (The door of the office is/*are open).

A repeated measure ANOVA has been carried out²⁰ and it has shown that there were no differences caused by the manipulation of the task, which means that there have been found similar responses for both visual and auditory stimuli: N400 for semantic violations and P600 for syntactic anomalies. While the negativity was more noticeable at the posterior sites, the P600 showed a wider distribution, making difficult an attempt to give it a specific localization²¹. Finally, the expected differences due to the implicitness of the first task compared to the second have not been fulfilled because there were no variations in amplitude nor in latency of the components already identified.

3.1.1.1 Discussion

The mentioned works provided important points of reflection, the most relevant is the reason why the LAN was found in two out of three similar works. This kind of finding has to be deeply analyzed since other following studies, based on the same violations, on the same language and on almost similar statistical analysis found difficulties to detect a left anterior negativity (see the sections below). We will bring out the possible aspects which led Angrilli et al. (2002) and De Vincenzi et al (2003) to find the LAN and what has inhibited its clear elicitation in Balconi et al (2004).

First of all, it would be necessary to see the structure of the sentences and the target word at issue because if the first two studies used a lexical verb, the latter studied physiological responses on auxiliaries. This opens the question of the material exploited but, since it is not available, we could not deepen this aspect.

Secondly, it is necessary to deepen the question of the statistics. We have described the LAN detected in the first studies as a weak finding. Actually, the application of a one-tail t-test could result in a questionable statistical operation: it is widely known that this kind of t-test is limiting and restricting. It is widely known that data acquired through this directional hypothesis cannot be determined as ambiguous; this is already a point against the LAN issue: even nowadays researchers try to understand the conditions which lead to

²⁰ Amplitude and Latency were the dependent variables. Independent variables were: within subject factors (for site and for condition) and between subject factors (for the type of task).

²¹ “The lateralization and localization effects were tested in a successive ANOVA for repeated measures (lateralization × condition × localization). For the amplitude variable, no factors, nor their interactions were statistically significant. [...] In the meantime, the ANOVA applied to the latency variable did not reveal any significant effect of the three factors lateralization, condition and localization” (for insights, see the statistical data tables in Balconi et al., 2005).

the elicitation of this component and it has not been found yet a fulfilling answer. It makes clear that a one-tail t-test could not be the solution. Moreover, it has been applied to a single electrode while other studies have analyzed groups of electrodes and this could be another point of reflection. So, using a one-tail t-test means that there is a strong hypothesis that there is no possibility for any positivity in that condition.

In conclusion, we will take into account these studies but we are aware that the LAN found in those conditions is a marginal case.

3.1.2 Wide variability of the LAN effect: the case of inflectional or conjoined lexical subject

The cases presented in the previous paragraph are not sufficient to describe the instability of the LAN effect but there are more recent studies which have explored complex syntactic structures in order to provide a more complete picture of the phenomenon. The work of Molinaro et al. (2011a) is an exhaustive example of complex manipulation of the stimuli.

(3) The boy and the girl

(4) The siblings

Taken isolated, (3) and (4) appear simple to process since they convey semantically the same concept. The problem arises when the manipulation of the sentence with these elements creates a mismatch not only locally with the following verb (in the spec-head relation) but also in a distant constituent:

(5) *I fratelli giunse a casa stanchi della giornata (The siblings arrived [+S] at home tired [+P] by the day)

(6) *I fratelli giunse a casa stanco della giornata (The siblings arrived [+S] at home tired [+S] by the day)

(7) *Il fratello e la sorella giunse a casa stanchi della giornata (The brother and the sister arrived [+S] at home tired [+P] by the day)

(8) *Il fratello e la sorella giunse a casa stanco della giornata. (The brother and the sister arrived [+S] at home tired [+S] by the day)

In sentences like (5), (6), (7) and (8) the parser is forced to make a choice in order to manage the two distinct mismatches. Previous experiments tried to explain this phenomenon through the Repair or Recency hypotheses²² but the authors found that these theories could not be always generalized. They tried to prove this assumption by using two experiments, one with conjoined noun phrases (the boy and the girl) and the other with nouns characterized by internal inflectional information (the boys). If the latter is easier to turn to singular by simply “ignoring” the final /s/, the first is composed of independent elements and it is impossible to find a rapid shortcut to adapt it to singular.

The structures analyzed were: (a) PSP (sentences like (5) where the mismatch is only between the subject and the verb) (b) PSS (like (6) where the mismatch is both between subject-verb and subject-modifier but there is agreement between verb-modifier) for the inflectional plural subject; (c) CSP (like (7): subject-verb mismatch) and (d) CSS (like (8): subject-verb and subject-modifier mismatches; agreement between verb-modifier) for the conjoined plural subject.

The first experiment (on inflectional plural, (a) and (b) structures) involved 24 mother-tongue Italian speakers (24.77 mean age) and they were subjected to 360 sentences : the first constituent contained the verb, the second was a prepositional phrase and the third included a modifier. Separating the first and the third constituents served as temporal lag to better individuate the differences between the two. The authors avoided further artifacts by studying structures which couldn't be ambiguous in terms of influences of thematic roles (the first NP was always the subject), interferences between the genre of the noun in the PP and the following modifier (feminine for the PP and masculine for the third constituent) and the position of the adjective (never in final position). Group of electrodes were included in the statistical analysis both for the LAN (quadrant analysis) and the P600 (longitude analysis) taking Condition (PPP vs PSP; PPP vs PSS; PSP vs PSS) and Clusters as factors. What emerged from that kind of analysis was that the LAN could be found

²² The repair hypothesis provides for the resolution of the problem through the intervention of working memory: a sentence like “The famous dancers was nervously preparing themselves/herself” can be managed by turning the subject to singular (so the verb drives the sense of the sentence) and by keeping the switch in mind up to the end of the sentence. The final singular reflexive pronoun does not cause problems anymore because the initial constituent has been already *repaired*.

In the recency hypothesis, the parser is expected to give priority to local mismatches and so the ungrammaticality within the VP: verb-pronoun disagreement. The initial violation is temporarily ignored because different alternatives of representation are stored in mind and it cannot influence the rest of the sentence.

only under specific conditions: indeed, at the verb position it has been found a biphasic result, a slightly posterior LAN (called ‘focal LAN’) and a long lasting P600, split into two phases (an early phase individuated at the anterior and parietal electrodes and a delayed more posterior phase). At the modifier position the situation changed in function of the condition, the PSP structure elicited a P600 and the PSS did not. The fact that the modifier was not in a local spec-head relation (like the subject-verb relation) could be the reason why the LAN was absent in both the conditions. This result was in line with the repair and recency hypotheses in the sense that the parser takes one number value and modifies it to make the first part of the sentence grammatical but this action creates incongruence with the modifier.

The second experiment (with conjoined subject, (c) and (d) structures) proved that this reasoning could be adapted only for inflectional plural. Other 22 Italian subjects took part at the experiment. They had a reading task with the same 360 sentences of the first experiment but the first constituent differed for a conjoined subject. Conducting the same analysis it emerged that the LAN was absent both at the verb and at the modifier position. As for the P600, it was found only in his early phase and broadly distributed on the scalp (in case of disagreement) for the verb and only in the CSS condition for the modifier. This evidence made clear that the recency hypothesis was not suitable for this context because it was the conjoined subject’s value that drove the interpretation of the sentence and the P600 clearly reflected the individuation of the mismatch between the verb and the modifier, caused by the switch of the verb value (CSS > CPS). According to the recency hypothesis, the parser should have given priority to the constituents belonging to the VP, temporarily “ignoring” the conjoined subject. The repair hypothesis could be more reliable: since the parser could not turn the subject to singular, plural number value had to drive the parsing and if the verb changed in number, becoming plural, it would not match anymore with the modifier, then eliciting a P600. Furthermore, the interpretation for the shorter P600 was linked to the absence of the working memory role because resolving the disagreement adapting the verb value does not require the same resources as changing the subject and keeping it in mind until the end of the sentence.

The results between the first and the second experiment have been statistically compared in order to test the consistency of the findings. It has been shown that the statistical

interaction of condition, cluster and experiment factors at the verb position could suggest that the LAN effect was real and not simply an artifact.

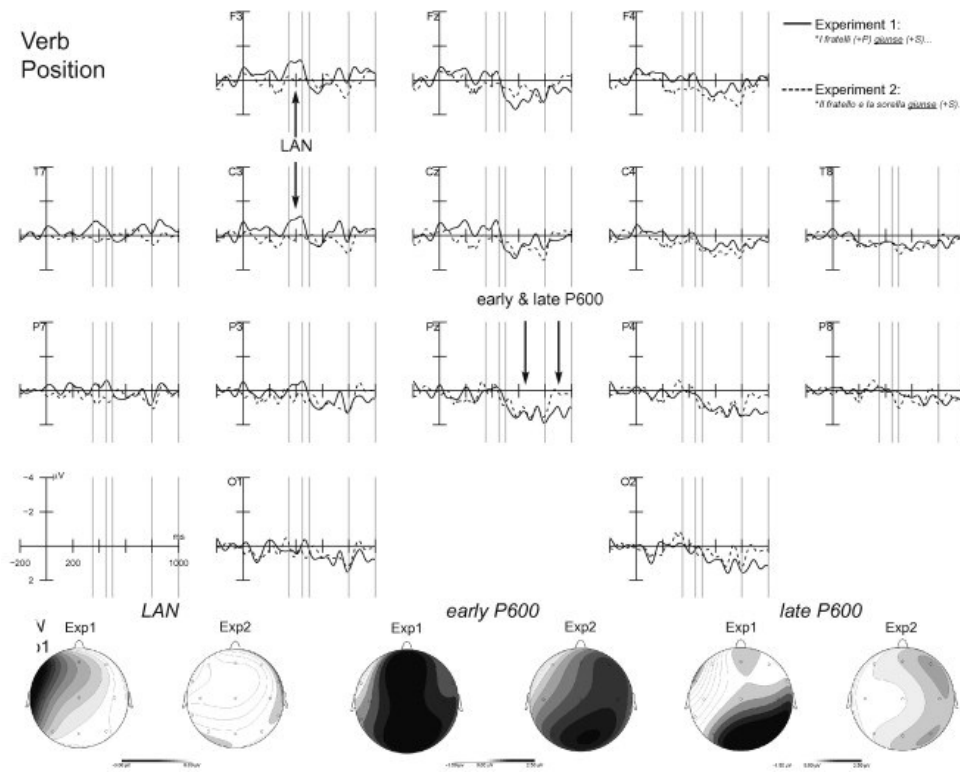


Figure 13. Modified by Molinaro et al. (2011a). Average waveforms at the level of the verb in experiment 1 (inflectional plural subject) and experiment 2 (conjoined plural subject). The LAN effect is appreciable at the 350-450 ms time window while the early and late P600 have been recorded respectively at the 500-800 ms and 800-1000 ms time windows.

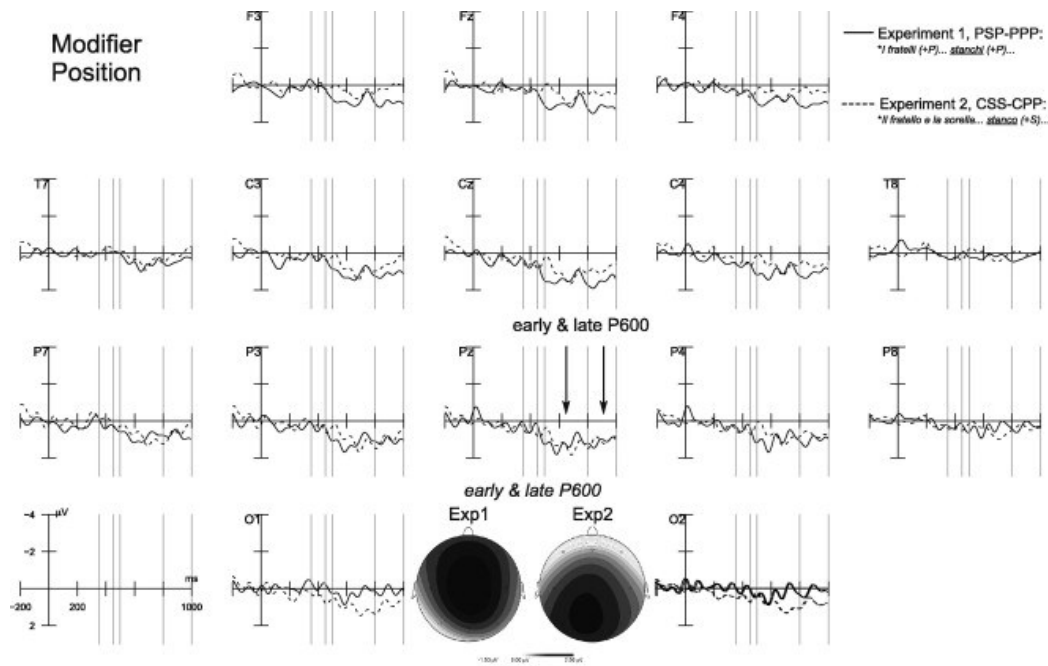


Figure 14. Modified by Molinaro et al. (2011a). Grand average waveforms at the level of modifier in experiment 1 and experiment 2. The time window analyzed to compare the results was between 500-1000 ms.

Finally, the authors tried to provide a further statistical support by adding another experiment based on the offline interpretation of the sentences. The task was based on a judgment of the sentences' grammaticality, repetition and correction of them. It emerged a difference in RTs because the conjoined subject required more time to be processed. Furthermore, the repetition of the sentences revealed that those which contained the inflected subject and the correct ones were repeated almost correctly, the problem arose with those including the conjoined subject because it seemed that the repair process carried out online had an impact on the offline interpretation. In sum the solution found online, during the reading task, seemed to reflect the offline repetition. This could be read as a support for the repair hypothesis but it goes against theories like Friederici's (2002) and Bornkessel and Schleewsky's (2012) where repair operations are expected as later stages.

As regards the LAN effect issue, the authors advanced the hypothesis that the detection of the mismatch when the number agreement is morphologically expressed in the subject is much more rapid compared to a condition in which the plural form is syntactically driven (Arcara et al., 2019), especially because the morphological marker of the inflected

subject is plural (ragazz-i) while the final marker for the conjoined subject is singular (il fratell-o e la sorell-a). Another element which could have had an influence on the results is the position of the verb which appeared earlier with the inflected subject (3rd position) rather than with the conjoined one (6th position). Since the LAN is generally linked to early detection of syntactic violations, this reasoning seems to acquire sense. We will deepen these oscillating results regarding the early negativity in the following sections.

3.1.3 The person asymmetry hypothesis

Subject-verb violations clearly show a wide variability between subjects as well as the interpretations linked to them. Another study about the Italian case, Mancini et al. 2014, concentrated the vision on the agreement features, particularly on person and number values in order to compare the impact they had on the sentences' processing. In particular, even if agreement calls into question syntactic properties, it is possible that the processing managing person and number features implies the contribution of more complex semantic and pragmatic factors, and so interpretative aspects. We will see below that person anomalies can cause more marked problems of processing than number anomalies because person seems to involve also the speech act representation, thus, more resources are necessary to repair the violation. That's why, in a sentence like (9):

(9) Io hai letto un libro (I_{1st sing} have_{2nd sing} read a book)

Without a context, it is difficult to detect the reference, it could equally be a first person or a second, namely the "speaker" (1st person) or the "addressee" (2nd person).

The authors divided the study in two experiments in order to find an evidence of values' influence on pronominal (experiment 1) and lexical subject (experiment 2). Similarly to Molinaro et al. 2011a, the authors used two types of subjects, observing their interactions with the verb.

In the first experiment, the participants involved were around 18-36 years old. The stimuli included anomalies at the level of person and number features and the subject was pronominal. The mistake was always localized on the auxiliary. The aim of the experiment was to analyze variation in reading times. Linear-mixed models were at the basis of the statistical analysis. Specifically, the authors created a model which included

random effects, in fact they compared the by subject and by item random intercepts to the by subject slope (for insights about the setting of the intercepts see section 2.1.4 in Mancini et al. 2014). What emerged was a strong statistical effect between person and number values, but the ambiguity raised when no significant difference has been identified between the incorrect forms.

This result has been linked to ambiguity of the stimuli presented, in the sense that it has not been taken into account the *Person Asymmetry Theory* advanced by Mancini (2018). In this study the author exposed an explanation to the qualitative differences which emerged in the processing of 1st and 2nd person, on one side, and the 3rd, on the other. The shared idea, in line with Bianchi (2006) sees the first and the second person being the direct reference to the speaker and addressee, the two main speech-act roles; the third, on the contrary, is an external entity involved in the discourse. Consequently, this assumption changed the way to look to the plural forms: 1st and 2nd person plural cannot be seen as simple multiplication of individuals because the discourse level require only one speaker and addressee, they are “unique entities”. Their plural forms have been described as conveying an associative meaning because a plural like *we* (1st_{plur}) implicates the presence of the speaker and the addressee or the speaker and other associates. The same reasoning can be carried out for the 2nd person plural, *you_{plur}*, because it indicates the addressee and its associates. In sum, the parser, which has to process these kinds of plural forms, has to integrate two types of information: the type of participants (the “different statuses”) and the number. Instead, 3rd person plural is seen as the true pluralization because the only thing that changes in the passage from singular to plural is the number, it represents a group of individuals involved in the discourse (it has been defined *augmentative* form). Here, the parser will not “dwell” on the semantic-pragmatic doubt about the presence or the absence of the addressee or other associates, *they* simply includes more than one external entity. Clearly, all of this has specific consequences on the electroencephalographic response: Mancini defined “online analysis of an agreement relation” as “[...] not a monolithic process. It is a composite procedure sensitive to feature manipulation and to the interaction between the same features” (Mancini, 2018). What emerged was that mismatches which included 3rd person_{sing} and 3rd person_{plur} (such as “Lui scrivono una lettera a casa ogni sera” “He write_{3rd plur} a letter at home every evening”) elicited the typical biphasic pattern LAN + posterior P600. On the contrary, it became

more complicated when the mismatch involved 1st person_{sing} and 1st person_{plur} (like “Io scriviamo una lettera a casa ogni sera” “I write_{1st plur} a letter...”)) and this problem of integration at the level of the discourse analysis was reflected in a wider P600 characterized by an early anterior phase. There is a sort of “sensitivity to the different anchoring relations established between morphosyntactic and discourse layer of sentence structure” (Mancini, 2018), thus, it means that during the parsing of person and number features in subject-verb agreement violation, interpretative factors come into play. This kind of reasoning could be supported by previous findings about the conjoined subject (see section 3.1.2), “Mario and Luigi” is different from “I cani corre” because the first is plural not only from the formal point of view but also conceptually, the parser could not resolve the mismatch by switching the subject to singular, while it is possible in the latter case. It would be interesting to deepen this aspect in order to find other supports to the hypothesis that the early anterior P600 reflects interpretative processes which go beyond the semantics and the pragmatics of the number.

The second experiment tried to untie the knot of the ambiguity of the stimuli, by using lexical subjects (avoiding, in this way, all the variables which could come into play with pronominal subjects). So, the structure of the sentences involved always a 3rd person (lexical subject) but the mismatch with the verb could have been created by person violation (3rd sing + 2nd sing), number violation (3rd sing + 3rd plur), or person-number violation (3rd sing + 2nd plur). What the authors found was that person anomalies differed from number anomalies, emphasizing that person processing requires more resources and this results in longer reading times compared to number processing. It’s clear that when there is a mismatch involving person value, the processing could be not so fast because there is no direct association with the reference entity:

(10) Il giornalista_{3rd sing} hai_{2nd sing} scritto un libro (the journalist_{3rd sing} have_{2nd sing} written a book)

(11) Il giornalista_{3rd sing} hanno_{3rd plur} scritto un libro (the journalist_{3rd sing} have_{3rd plur} written a book)

In a sentence like (10), the parser had to deeply analyze the sentence in order to decide if the subject is really a 3rd person or an addressee. On the contrary, (11) could be easily resolved since it is clear that the reference entity is a 3rd person and the only aspect to deal

with is the number²³. Now it becomes obvious that the parser would take longer times analyzing (10) rather than (11).

3.1.4. A study on Attriters

It's widely known that even nowadays it's not clear what underlies the processing of number and person agreement. However, it's interesting to see what are the implications of these two types of values when the parser faces a violation because they can vary across the studies.

For what concerns number agreement processing of the Italian language, the work of Kasparian et al. (2017) represents a fundamental key for researches on linguistic processing of subject-verb agreement violations. The authors analyzed responses' variability to local and non-local mismatches (that is, number agreement processing in three separate constituents). The particularity of this paper lies on the choice of special subjects called "attriters": that's a group of Italians who moved to Canada, where the usage and the exclusive exposure to the English language (L2) has provoked an increase in their L2 proficiency at the expense of native language performance, which decreases or is directly interrupted (Italian) (Gallo et al., 2021). Given the huge differences between the two languages in question, and the particular situation of this population sample, it would be great to know to what extent the L2 could interfere in number agreement violation processing and the differences which would emerge between native speakers and attriters. It has been proved that cases of number agreement violations did not elicit LAN effects, only bilateral anterior negativity or broad N400-like effect, the only situation in which it has been reported was the study based on very strict statistical analysis, a t-test on a small group of electrodes. One of the possible explanations concerning this particular phenomenon was the possibility of postverbal subject in Italian and this kind of research focuses on this linguistic aspect.

²³ Results for number ambiguities are in line with De Vincenzi et al. (2003) (see section 3.1.1).

Sentences were created in such a way that the target words (verb and the modifier) were separated in two constituents; therefore, the three types of structures the subjects were faced with were:

- XYX: the problem lied on the verb (il lavoratore *tornano dalla fabbrica sporco di grasso - The worker (sg) *return (pl) from the factory dirty (sg) with grease)
- XYY: the problem was the subject (*il lavoratore tornano dalla fabbrica sporchi di grasso - *The worker (sg) return (pl) from the factory dirty (pl) with grease)
- XXY: the mismatch was created by the modifier (i lavoratori tornano dalla fabbrica *sporco di grasso - The workers (pl) return (pl) from the factory *dirty (sg) with grease)

In addition to the reading task, attriters and non-attriters have been subjected to different behavioral tasks in order to classify them in high or low proficiency and to exclude differences due to reading speed or working memory. The tasks were :

- Written self-report measure
- Written C-test
- Written error detection test
- Verbal semantic fluency task
- Reading fluency task
- Letter-number sequencing task

Every single ERP response has been analyzed at the level of the verb as well as the modifier and the time windows taken into account corresponded to small intervals: 300-500 ms, 550-650 ms, 650-1000 ms, 1000-1200 ms for the first and 300-500 ms, 500-600 ms, 600-900 ms, 1000-1300 ms for the latter. In this way it was possible to isolate the specific ERP responses as well as the specific instant in which the violation would be detected. Throughout repeated measures ANOVA the authors tried to find variability between and within the subjects.

What emerged from the reading time test was that attriters were slower than monolingual controls. Although, the most interesting result was the variability in the ERP components elicited by the two types of agreement violations because the behavioral tasks did not

show significant differences between the groups. At the level of the verb, what made the two groups distinct was in the first time window (300-500 ms): while the controls showed the so called LTN²⁴, attriters elicited a more distributed negativity which covered the scalp from midline to lateral sites (see Figure 15). This non-attested ERP component found in monolinguals has been justified as the result of the overlap of the subsequent positivity which cancelled the negativity at the other sites. However, even if this could be in line with Tanner and Van Hell Hypothesis (2014), it has been demonstrated that the frontal negativity was not the result of the overlapping positive wave²⁵. It is necessary to focus on the P600 which showed two distinct phases: the earliest was represented by an effect of proficiency because it was wider for L1 high proficiency group (as for the two groups, it has not been detected any difference). Remarkable was the latency of the later phase of the P600 in controls which resisted until 1200 ms while it was reduced in attriters (until 1000 ms), indeed there was no late P600 in attriters' response (see Figure 16). In sum, the most reliable hypothesis to these results was that, in attriters' condition, the L2 has really an influence on processing of Italian violations because, if controls have the possibility to expect the so called "focus" structure, with a post-verbal subject, attriters immediately process the violation caused by the very strict word-order of English, thus L2 has become so rooted that the only acceptable structure could be subject-verb.

At the level of the modifier, no significant differences have been detected since both the groups showed a biphasic pattern which involved a N400-like wave and a large P600 which was more distributed in attriters (found also in frontal sites). Also here, the longer lasting P600 has been found in controls but it has been demonstrated that this durability of the positive-going wave was correlated to the amount of L1 exposure because, within attriters, the more they have been in contact with the Italian language, the larger would have been their positive response, thus more native-like (Kasparian et al., 2017). As for the negativity, the motivation behind the absence of any difference between the groups could be the impossibility of alternatives, as it could be for the subject-verb condition, because the modifier was bound by the preceding noun.

²⁴ A weak negativity localized at the level of the left temporal sites (T3, T5) in the 300-500 ms time window.

²⁵ The authors tried to find a statistical HemisphereGroup interaction but no significant findings emerged. Moreover they analyzed 50 ms to 50 ms to refute the overlapping theory (for insights see Kasparian et al., 2017).

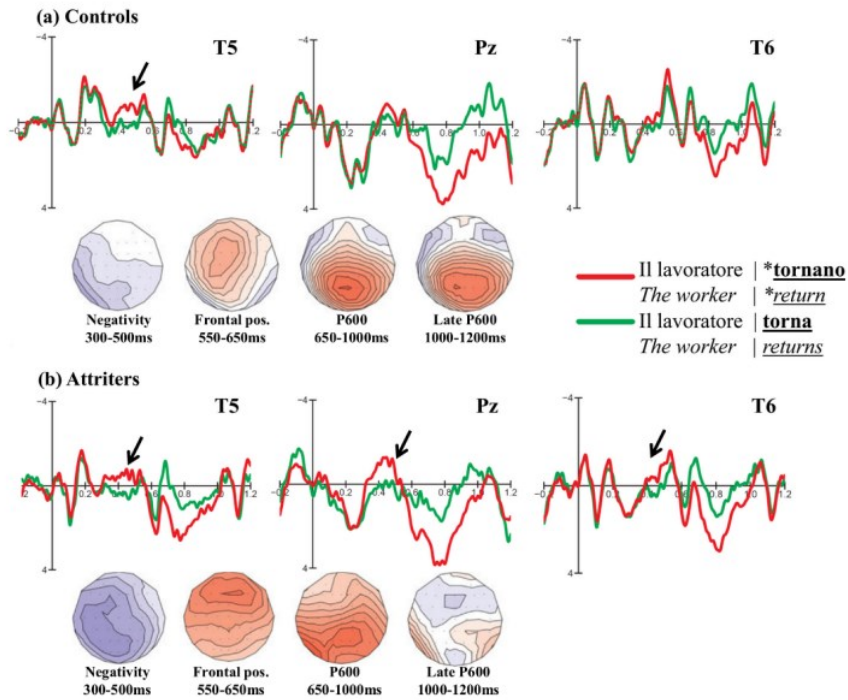


Figure 15. Modified by Kasparian et. al (2017). The picture compares negative effects in Controls (a) and Attriters (b). The electrodes considered were T5 (representative of left temporal site), Pz (as midline site) and T6 (as right site). It is evident that the Controls show a small negative-going wave at the left temporal site (LTN) while the negative effect in Attriters is broadly distributed.

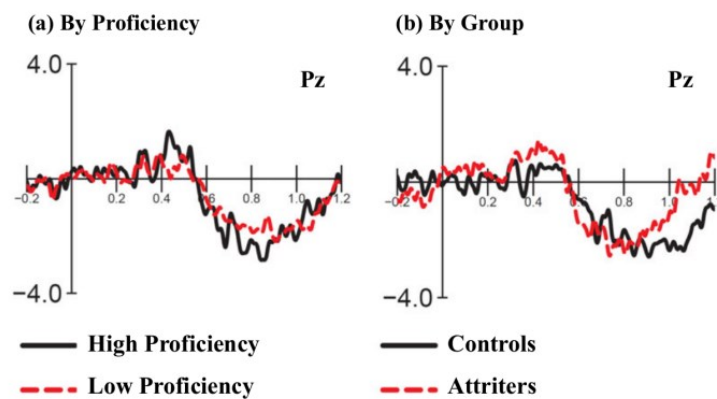


Figure 16. Modified by Kasparian et al. (2017). Differences between early and late P600 in high proficiency-low proficiency comparison (a) and controls-attriters comparison (b). It is appreciable the difference in early P600 for (a) compared to the late P600 deflections for (b).

In conclusion, it is clear that attriters and monolinguals do show qualitative and quantitative differences at the level of ERP responses during online processing of Italian subject-verb agreement mismatch. What it has to be explored is the case of the early frontal positivity found at the level of the subject-verb mismatch but not at the modifier. Generally, in the literature, it has been described as the P3a component, a positive-going wave which emerges when the individual is surprised by early morphosyntactic mismatches, those that cannot be predicted because there is not enough context; that's why it is elicited early in sentence (at the verb) but not later (at the modifier) where the mismatch could be much more predictable.

3.1.5 The post-verbal hypothesis

At this point it seems that the Italian case show many shades which cannot be neglected in the psycholinguistic study of underlying processing of subject-verb agreement. Number agreement violation in subject-verb relations is a condition which elicits different responses cross-linguistically. If other studies do have reported the LAN effect (see Molinaro et al. 2011b for insights about the debate), it gets a little complicated when it comes to the Italian language. The ambiguous results have been associated to specific linguistic aspects (such as free word order, possibility of post-verbal subjects, null subjects) that could influence processing and, consequently, electroencephalographic responses. This could be the reason why there are consistent differences between a Romance language like Italian and the Germanic opponents like English and German. Variability in ERP responses during the processing of an Italian agrammatic sentence is the only certainty we have up to now. What we have to deepen is the motivation which underlies this variability. The solution of the post-verbal subject has been deeply questioned: Bornkessel and Schelewnsky (2012) affirmed that the question of the post-verbal subject has to be seen from another point of view because generally it should elicit anything since the Italian structure allows for a DP preceding the verb; the real question is the nature of the verb and the thematic structure it conveys. For example, in the seminal study De Vincenzi et al. (2001), a sentence like “Il cameriere anziano serve” could be continued in a rather syntactically and semantically marked way as “Il cameriere anziano serve aiutarlo, poverino” or, better with different verbs as “Il cameriere anziano bisogna aiutarlo, poverino” or “Il cameriere anziano devi aiutarlo, poverino”. Within Friederici or

garden-path models these structures should become available only after repair/reanalysis since the simpler structure would be that the initial DP is the subject, however within eADM model both agreement checking (LAN) and argument-linking (N400) stages could be involved as a function of the specific type or verb and prominence of the subject, factors which have not been controlled on the studies reviewed so far.

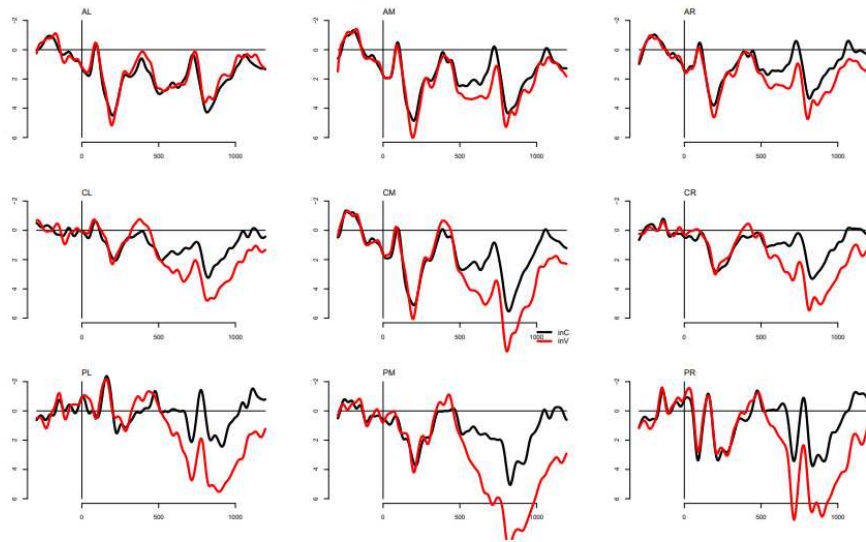
Actually, aside from marked idiomatic dislocations in which a DP can precede an intransitive verb such as in “I bambini vai a prenderli tu”, there is clearly a more viable possibility to have a DP preceding a verb without agreement for transitive verbs (also unergatives but with focal meaning), thus, if there is no rule providing for agreement between the object and the verb, the absence of LAN becomes possible assuming that the system automatically explores the null or post-verbal subject option before repair stage. The problem that may arise is whether the verb which follows the object is intransitive but this may elicit a N400, at least following eADM hypothesis. We have explored this problem also analyzing Kasparian et. al. (2017) study on attriters condition compared to monolinguals (see section 3.1.4): they found that the possibility of postverbal subject elicited a left temporal negativity (LTN) rather than a pure left anterior negativity.

A further study which directly faced the post-verbal solution as an influence for Italian sentence’s processing comes from the thesis of Recla (2017/2018). The author tried to clarify the confusing situation of the LAN by analyzing differences in amplitude and topography of this component during online processing of sentences with transitive and intransitive verbs. The study was divided into two experiments, the first characterized by only plural direct objects, the second had only singular direct objects.

The sentences were designed with the following structures:

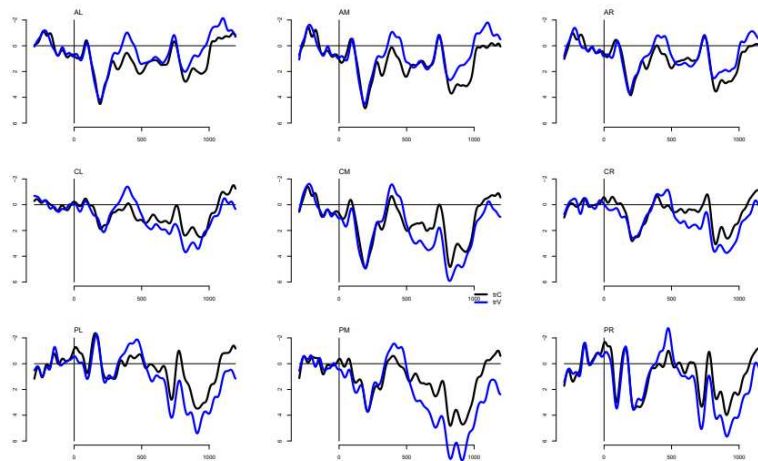
- (12) a. Il comico scherza spesso su questioni serie. (The comedian jokes often upon topics serious)
b. * Il comico scherzano spesso su questioni serie. (*The comedian joke often upon topics serious)
- (13) a. Il bambino rincorre i cani per tutto il giardino. (The child chases the dogs all over the garden)
b. * Il bambino rincorrono i cani per tutto il the giardino. (*The child chase the dogs all over the garden)

What emerged was that both the types of verbs elicited a LAN effect (even if with transitive verbs it was more distributed, being labeled as an N400-like effect) and no statistical differences came out. Then, the same study has been revised by Biondo, Bergamini, Vespignani (2018) and it emerged that transitive verbs elicited a broadly distributed LAN/N400 effect while the unergative ones showed a LTN (see figures 17 and 18).



* Il comico scherzano ...

Figure 17. No post-verbal subject, unergative verbs. The negativity elicited by unergative verbs does not show a wide amplitude but it is evident on the left posterior site (PL) around 300-500 ms: it could be interpreted as a LTN. Another appreciable result appears in the posterior sites, around 600-1000 ms, a wide positive wave-going, the P600.



* Il bambino rincorrono ...

Figure 18. Post-verbal solution, transitive verbs. In this picture the negativity seems to appear at the anterior and central sites, in the 300-500 ms time window. The P600 appears in the posterior sites, in particular in PM, its amplitude is a little smaller than the one associated with unergative verbs.

The hypothesis which came out from the difference between the two negativities was that LAN/N400 could represent the effort of gathering resources in order to evaluate the post-verbal solution. Furthermore, if the topography of the negativity was matter of debate, the positive wave-going was quite clear. The 600-1000 ms time window did show an evident P600 in both the conditions, what made them distinct was the amplitude (smaller for transitive verbs) but also the number agreement condition. For example:

(14) *I bambini rincorre i cani... (*The children chases the dogs...)

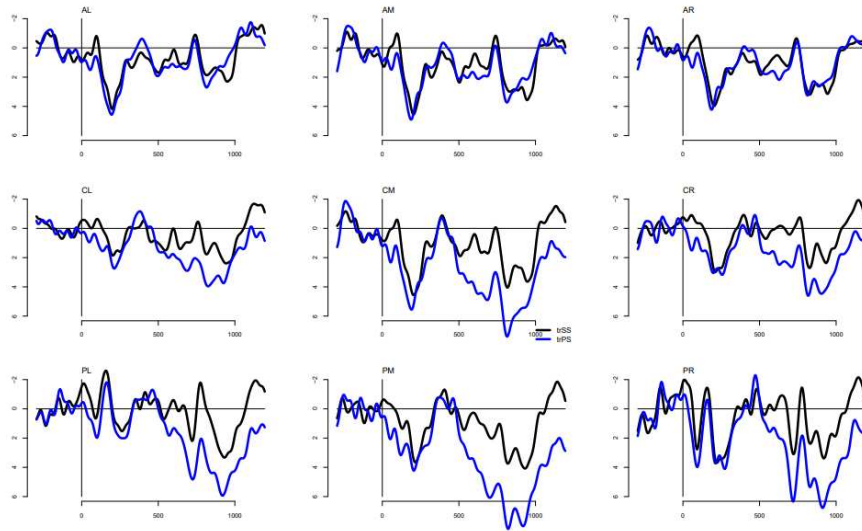
A sentence like (14) seemed to elicit a larger P600 compared to (13b) because the verb could not agree nor with the subject nor with the direct object and this should require more resources in terms of reanalysis and repair.

Since the direct object was always plural in the first experiment, the authors tried to obtain new findings by turning it to singular and comparing it with the plural form:

- (15) a. *I bambini rincorre il cane in giardino. [PS]
 b. *Il bambino rincorrono il cane in giardino. [SP]

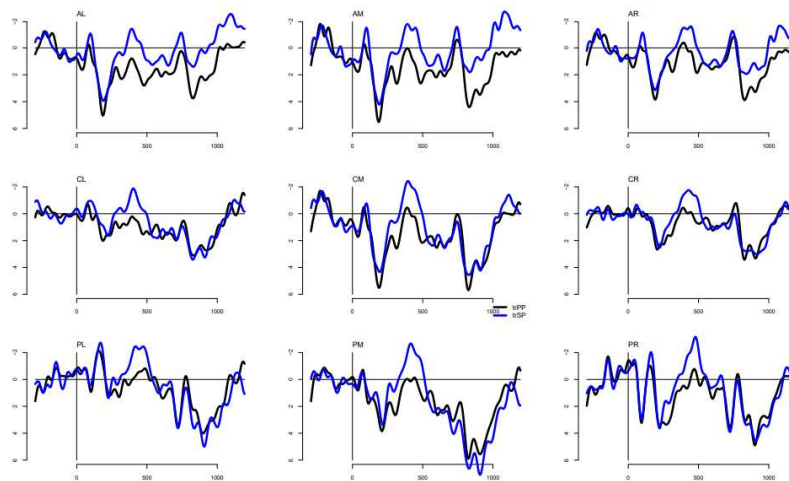
The first expectation was a difference in amplitude between the two elicited P600, for a wider positive wave associated to sentences like (15b). What emerged was that the effect

of broad LAN/N400 effect with the smaller P600 was driven by plural transitive forms only (see figure 20). Recla did not find statistical differences which could confirm the assumption proposed in the first experiment.



* [I bambini rincorre ...](#)

Figure 19. Modified by Biondo et al. (2018) Transitive verbs - Singular Target. Grand average waveforms elicited by trSS (black; transitive condition with singular subject and singular verb) and trPS (blue; transitive condition with plural subject and singular verb) conditions for anterior, central, posterior sites along left, central, right line. A wide P600 is evident on the posterior sites.



* [Il bambino rincorrono ...](#)

Figure 20. Modified by Biondo et al. (2018) Transitive verbs - Plural Target. Grand average waveforms elicited by trPP (black; transitive condition with plural subject and plural verb) and trSP (blue; transitive condition with singular subject and plural verb) conditions for anterior, central, posterior sites along left, central, right line. A wide P600 is evident on the posterior sites.

subject and plural verb) conditions for anterior, central, posterior sites along left, central, right line. A broadly distributed negativity is evident all over the sites and a small P600 is visible on PM.

In conclusion, there are conflicting opinions about the postverbal subject solution, on one hand the eADM model does not predict the LAN effect since the subject inversion or left dislocation of DO represents a linguistic property typical in Romance languages like Italian. On the other hand there are proof that not only the LAN/N400 has been effectively reported in this case but it seemed that another more posterior correlate, the LTN, was also found. Thus, it should be investigated the meaning of this alternation between left negativities with frontal and parietal topography and also the nature of this negative posterior correlate which has not a real description up to now.

3.1.6 Clinical and cross-linguistic studies

For what concerns the case of subject-verb agreement processing, there are two considerable issues we have to discuss: the variability of the early negativity and the nature of the P600. The data reviewed up to now do not help to model a definite picture of the LAN and its topographical variation. There is not yet a shared theory behind the processing of subject-verb agreement violations in a language like Italian. That's the reason why it could be useful to find cross-linguistic supports to the actual outcomes.

As regards more posterior negativities, there are two relevant studies based on Spanish (Mancini et al., 2011) and Basque (Mancini et al., 2019) which have reported correlates similar to LTN, N400-like pattern described above during online processing of agreement violations. Mancini et al. (2011) compared brain responses to different forms of (dis)agreement, one of which is typical in Spanish, the Unagreement condition²⁶. While the standard processing of agreement requires a linear check of the matching features from the subject to the verb, unagreement needs that the parser starts from the morphosyntactic information linked to the verb and then assures the matching with the subject features. This was supposed to reflect different brain responses compared to the classical formal violation. What emerged from the study was that this reverse processing

²⁶ Spanish differs from the other Romance languages because third-person plural DPs can be accepted either with a following first-person and second-person plural verb. As in the following examples: “Los cocineros cocinamos...” (The cooks_{3,pl} cooked_{1,pl}) and “Los cocineros cocináis...” (The cooks_{3,pl} cooked_{2,pl}). (Mancini et al. 2011)

elicited a *left posterior negativity* (sometimes labeled as an “N400-like”), clearly different from the correlates found in pure mismatches (singular subject-plural verb), that is a broadly distributed negativity at the fronto-central electrodes, the traditional N400. This particular response, the N400-like effect, has been associated with necessarily different neural networks compared to the LAN because there is not a real detection of morphosyntactic violation; on the contrary, those structures are grammatical in Spanish. However, that correlate needed to be justified and the authors proposed that there must have been a violation of expectation because there was a problem of speech-act participant representation (see section 3.1.3), in the sense that the first element, third-person plural subject, evoked a representation with non-participants, while the second, first or second-person plural verb, involved the speaker (or the addressee). Even if this semantic-pragmatic struggle alerted the parser, the situation could be immediately fixed thanks to the “reverse Agree operation” (Mancini et al. 2011). This procedure seemed to have an impact also in the following components: indeed, it has been reported the absence of P600, or rather, a sustained negativity (similar to the N400’s topography but in the 500-800 ms time window) which has erased part of the positive deflection (for insights, see Mancini et al., 2011). The other posterior negativity has been reported in a work centered on person agreement in Basque (Mancini et al. 2019). It’s a typologically different language (SOV) compared to Spanish and Italian (SVO) and it is characterized by agglutination and ergativity. Thus, in this language, determiners take the form of bound morphemes featuring number and case (absolutive, ergative). They are attached to the subject and the object (NPs)²⁷ and they agree with the verb which reflects that features (see the examples in Mancini et al., 2019, section 1.3). The authors studied augmentative and associative person agreement mismatches (easily explorable thanks to the rich morphology of the language, see Mancini et al., 2019 for insights; for associative and augmentative meanings, see section 3.1.3) in order to capture differences in brain responses. What emerged was that both the associative and augmentative mismatches elicited early negativities (300-500 ms interval), different in distribution and latency: the former’s negativity has been defined as N400-like (centro-parietal) with a shorter latency compared to the latter mismatch which has been marked by an apparent pure N400 with

²⁷ a. Gizon-a (Man-the sg.abs) b. gizon-ak (men-the pl.abs/man-the.sg.erg) c. gizon-ek (men-the pl.erg) (Mancini et al. 2019)

a longer latency. The other appreciable outcome is in the subsequent time window (500-900 ms) where a P600 followed the shorter negativity in associative mismatches but it was absent after the longer N400 in augmentative ones. This last monophasic pattern seemed to reflect the one found in the unagreement condition of Spanish. Though, formal differences between the two correlates (such as topography and latency) and individual variability in the acceptability test in Basque made researchers moving away from the idea of “a Basque manifestation of unagreement” (Mancini et al. 2019). In addition, it has been advanced again the hypothesis of violation of expectation in the associative mismatch: the system faced the clash of specific person values (1st or 2nd person) evoked by the subject and non-participant role (3rd person) specified by the verb. This resulted in a biphasic pattern. That’s something that did not occur in the augmentative mismatch. It is possible that when marked person values are carried by the verb, the violation is tolerable and prevents from the activation of repair processes, thus it seems that there are specific contexts in which the parser is more flexible than strict.

It remains the question of the P600 and its internal composition, specifically, if it is a monolithic component or split into subphases. On the one hand there are a lot of works in literature which refer to the correlate as a unique deflection reflecting repair and reanalysis processes (in linguistic and non-linguistic fields), on the other, some studies, some of which are more recent (Molinaro et al., 2011a; Mancini, 2018, see sections 3.1.2 and 3.1.3; Friederici, Hahne, & Saddy, 2002; Carreiras, Salillas, & Barber, 2004; Kaan & Swaab, 2003 for anterior P600; Friederici et al., 2002; Hagoort & Brown, 2000; Osterhout & Holcomb, 1992 for posterior P600) have evidenced two stages easily discernable in the electroencephalographic recording, since the first seems to be associated to the earlier time window (500-750 ms) with a more frontal distribution, the second is generally present around 750-1000 ms and has the typical centro-parietal distribution of the P600 (Artesini, 2019). In this respect, there is a work which has touched this point, Artesini (2019). The author analyzed brain responses to syntactic (subject-verb agreement anomalies) and semantic violations in deaf subjects with a cochlear implant. The aim was to observe to what extent deafness could affect language acquisition and processing and what was the impact of the cochlear implant. Thus, the participants involved were normal hearing, preverbal CI users (with early deafness) and postverbal CI users (with late deafness). Besides the clinical condition, the author provided a further

analysis based on changes in ERP responses to syntactic violations in function of the age. In comparing controls (normal hearing subjects) with preverbal CI users, no significant differences have been recorded, just a little deviation in the early time window of the P600 because CI users seemed to show a wider effect in the central and frontal sites (see Figure 21). Since the same analysis conducted on postverbal CI users did not show the same amplitude of the P600, it has been thought a possible correlation between the age of implantation and the amplitude of the early stage of the positive correlate. This suggested that subjects with early cochlear implantation are more likely to behavior like normal-hearing controls when it comes to syntactic violation processing.

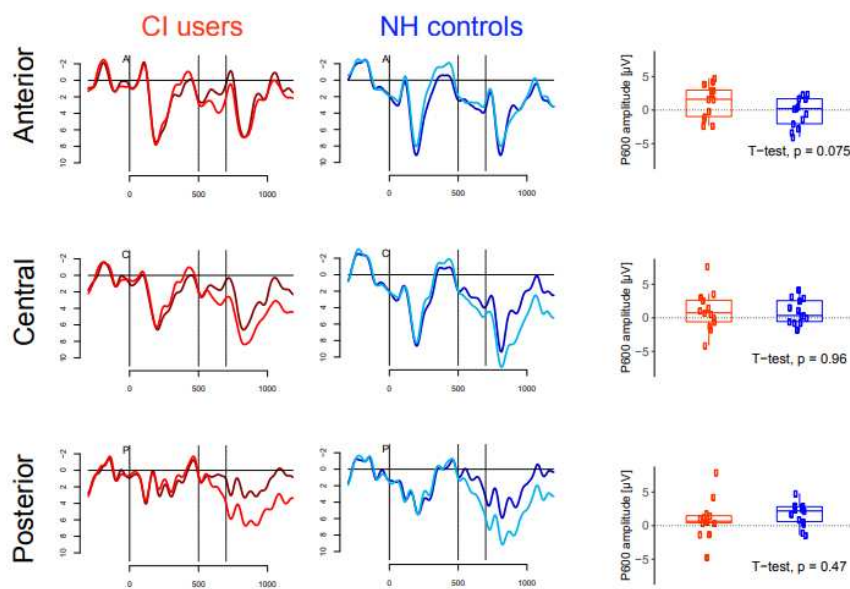


Figure 21. Modified by Artesini (2019). Grand average waveform recording of CI users compared (red) to normal-hearing controls (blue) for anterior, central, posterior clusters elicited during the processing of a syntactic violation. The two vertical lines capture the 500-700 ms time window.

Beyond the evidence of an anterior P600, this study provides fundamental data concerning the variability of the LAN effect in subjects without pathologies, exploring possible age effects. The author analyzed four groups of participants, distributed according to small ranges of age (12-17; 18-28; 29-44; 45-65). The electroencephalographic responses differed evidently between the groups: as it can be appreciated in Figure 22, in the youngest group the negativity showed its peak in the central and frontal sites suggesting that it has taken the form of the traditional N400. In the other group's recording (18-29 years old), represented in Figure 23, a prototypical left

anterior LAN seemed to take place. The third group responded differently from the others. Since on the fronto-lateral sites the negativity was almost absent and it seemed to emerge wider on the left and posterior clusters (see Figure 24) it could not be seen as a LAN, rather a LTN (left temporal negativity) seems to be more representative label of the effect. Finally, in the older group (45-70 years old), whose recording was represented in Figure 25, the negativity seemed to take again the form of a N400, mostly distributed on the central electrodes.

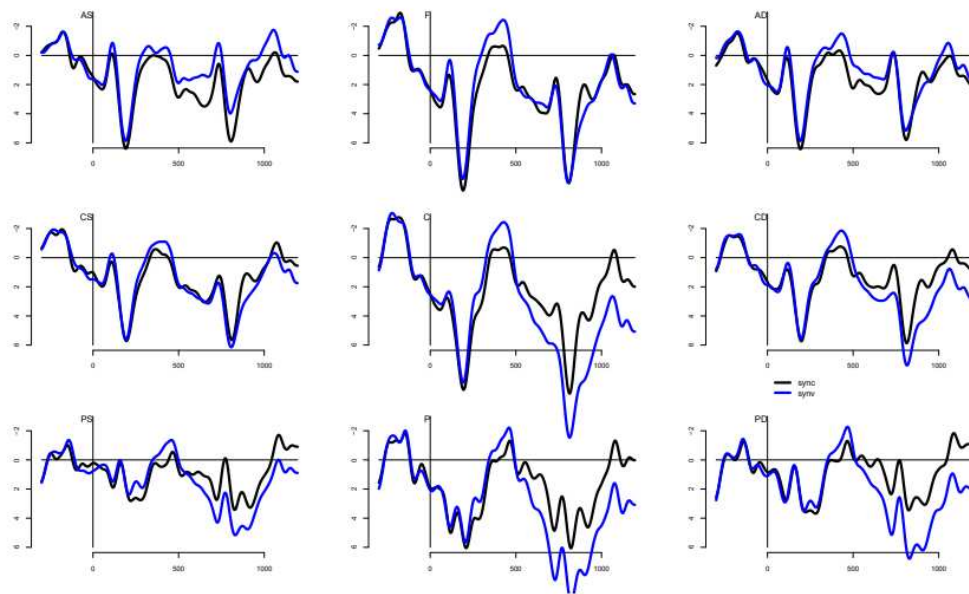


Figure 22. Age effect ($N=12$)- G1 (12-17). Modified by Biondo et al. (2018) Grandaverage waveforms showing a negative peak on the central and posterior sites.

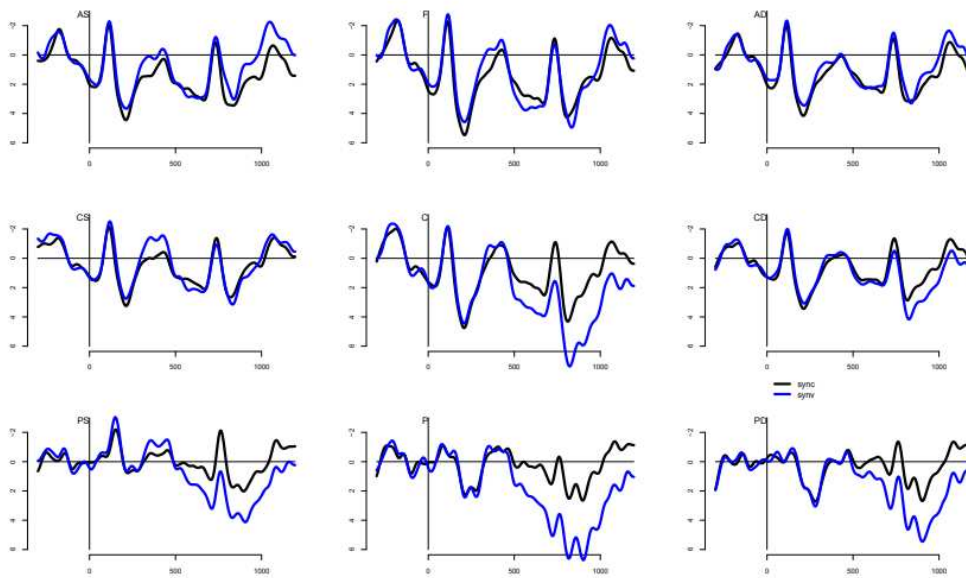


Figure 23. Age effect ($N=12$) - G2 18-28. Modified by Biondo et al. (2018) Grandaverage waveforms showing a negative shift on the left frontal sites.

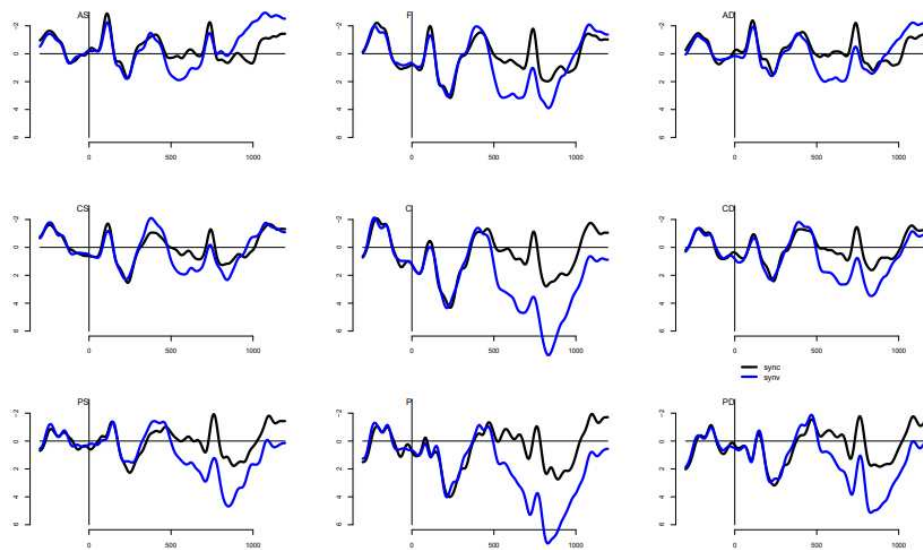


Figure 24. Age effect ($N=12$) - G3 29-44. Modified by Biondo et al. (2018) Grandaverage waveforms showing a negative-going wave similar to a LTN.

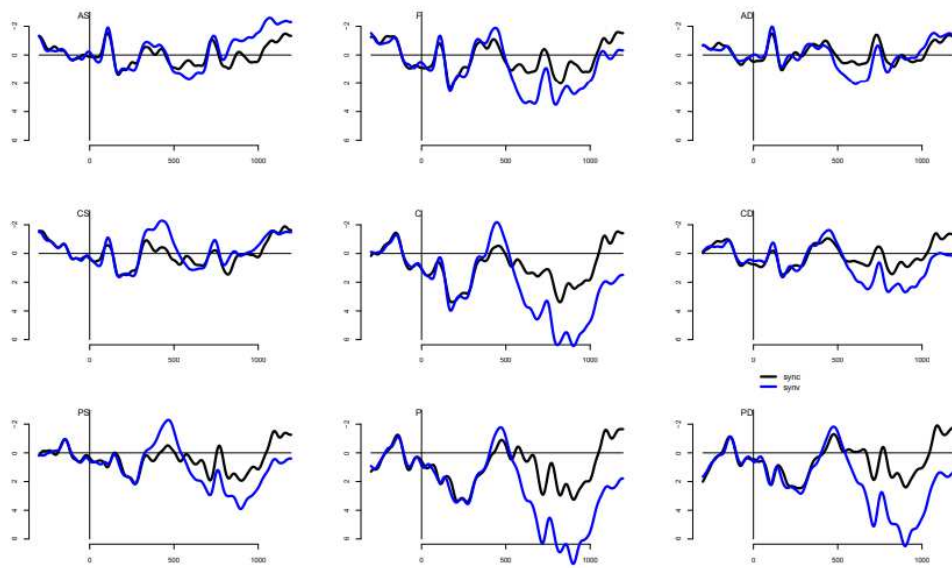


Figure 25. Age effect ($N=12$) G4 45-65. Modified by Biondo et al. (2018) Grandaverage waveforms showing a negative peak on the central and posterior sites.

In conclusion, what we concretely have in terms of responses to subject-verb agreement processing is not clear. We have analyzed studies based on the same language, similar materials and similar tasks and we faced always different responses. By now it is necessary to consider also inter-variability between individuals as suggested by the across age comparison by Artesini, 2019. We discuss this point in the conclusion section.

3.2 General Discussion

In the previous paragraphs, we have analyzed the conditions in which the early negativity manifested all its variability and, finally, there are three hypotheses turning around this mysterious component:

- (I) It could take the form of a N400 (which is predicted at least for some verbs by the eADM model);
- (II) It has been described as the classical LAN (by De Vincenzi et al., 2003);
- (III) It has been interpreted as a LTN (Biondo et al., 2018 and Kasparian et al., 2017).

We have observed that this variability is a constant across the studies and this does not help to find a single shared idea about the presence and topographical variability of the pre-P600 negativity which appears as soon as the agreement violation is detected at the level of the target word (generally is the verb). In addition, this “mutant” component seems to be subject to variability in different ranges of age, taking the form of LAN only in the 18-29 y.o. group (which is the usual age range of most experiments, typically collecting data from university students) . The cross-linguistic comparison did not help to confirm or reject the hypothesis about the existence/inexistence of the correlate, it has only expanded the field to other possibilities to be taken into account (the LTN or N400-like wave). Therefore, we have not enough data to give an answer to the problem: evidently, subject-verb agreement violation processing has yet to be explored in all of its facets, in particular through languages characterized by rich morphology and free word order where it is less likely to encounter a real morphosyntactic anomaly.

Up to now, the only conclusions which we can discuss on the early negativity is that there are interindividual and across-experiments large differences. It has to be deepened if this variability is due to age differences (which could be in line with Tanner and Van Hell theory, see section 2.2.2 for insights) or to other factors (individual and context). Future studies could be centered on this individual variability exploiting statistical analysis such as Linear Mixed Random Models in order to compare variability between subjects and items, collect larger datasets and further manipulate the likelihood of having a preverbal DP which is not the subject for different reasons (prominence of initial DP animate/inanimate, argument structure and lexical/semantic preferences of specific verb arguments).

Moreover, there is the question of the nature of the LAN compared to the LTN: it is still not clear what elicits these two correlates and what they really mean in terms of processing, the only certainty is that they are distinct components. This could pave the way to new researches.

As regards the P600 and its internal stages, the question seems to be more stable since there is a sort of generalization of the results in different conditions for the same language (such as Italian) and also cross-linguistically. Actually, it could be valid the idea that the P600 is not only the reflection of reanalysis and repair processes as the literature suggests.

Rather, it should be convincing that the early anterior stage of the positive shift is linked with more interpretative aspects whereas its late parietal stage corresponds to what has been described as repair and reanalysis processes.

Chapter 4

4.1 What are we left with?

The first chapters had the main purpose of giving an idea of the scientific background regarding theories and studies which have been developed around the concept of the neural underpinnings of sentence processing mechanisms which allow for language comprehension. Before entering into the specific matter of possible new approaches, we should take stock of the general situation. We have explored the existing psychophysiological models which have paved the way for new perspectives in language processing. We appreciated the evolution of these theories from Friederici's model to the eADM and we have seen convincing models being unhinged by new data (like Caffarra's, 2019 and Tanner & Van Hell's, 2014). Then, we put a magnifying glass on the agreement phenomenon in Italian studies (and a cross-linguistic comparison), showing that the issue is more likely complex than expected, thus the predicted biphasic pattern LAN+P600 casts serious doubts. Therefore, the final picture appears a little confusing because a precise theory to rely on does not exist and the data are not generalizable since we have different responses for the same cognitive operation (subject-verb agreement computation). If we take for granted that the same violation could be processed *differently* between individuals on the basis of the idea that different ERP responses correspond to different cognitive processes, one central question I aim to discuss in this chapter is if it is possible to relate all this to the generative tradition or to any theory of language which assumes that structural constraints on the way human languages are shaped is based upon strong universal cognitive constraints. Namely, what happens to the universality of language processing mechanisms if ERPs elicited by a same violation is processed differently across healthy L1 adult individual with similar competence?

Before trying answer this question we should briefly discuss three different approaches to the link between mind and neural signals and processes:

- The **psychophysiological**, classical cognitive approach
- The strict **neurolinguistic** approach

- The **emergentist**, linguistic agnostics approach

4.2 Three approaches to language processing in the brain

It is widely shared that psycholinguistic researches have made fundamental progresses in the language processing domain. It is also true that the principal aim of all the experiments was to demonstrate a sort of connection between cognitive operations, neural and behavioral responses, as if a particular electroencephalographic wave or a specific activation or damage in specific patches of the brain cortex could represent the way that cognitive operations were computed. For years – probably since the generativist vision of the genetic predisposition to language - researchers in the linguistic domain tried to demonstrate this connection, but the debate is still widely open. We, thus, displace the attention proposing another perspective: is it really profitable to think of a direct link between a specific area in the brain or a physiological response and a specific linguistic operation? And which is the better way to describe this relation?

Before describing three distinct visions in which can be found in the literature, some definitions are useful: with **cognitive operations** we refer to rather abstract implementations of cognitive functions such as the classical merge, agree, bind in Chomskyan literature; with **cognitive processes** we refer to specific processes linked to cognitive models of processing, like “attachment” and “repair” of garden-path model of sentence comprehension or “unification” and “control” in Hagoort MUC model; with **neural processes** we define the specific activity in time (polarization, depolarization) of groups of neurons in the brain which are partially measured by detecting different peaks or effects in the ERPs, intracranial recordings or indirectly recorded by changes in the metabolism of a brain area which can be measured with fMRI and other neuroimaging techniques. Epistemologically different approaches try to link these different functions in different ways:

- I. The classical approach of cognitive psychophysiology is more clearly followed by Friederici (2002) and its descendant model eADM (Bornkessler & Schelewensky, 2012) but also by the simpler and more lexicalist MUC model by

Hagoort (2005). These models leave the issue of the link with abstract cognitive operations to the reference parsing model: garden-path model for Friederici is inspired by generative approaches, while Vosse and Kempen (2000) model for Hagoort model is strictly connected with lexicalist views of grammar (Jackendoff, 2002). In doing this, the models do not directly discuss explicit abstract cognitive operations but try to link specific cognitive processes to neural processes by using the conceptualization of ERP components. This approach could be also defined as the “long pathway” in that the link between possibly innate universal operation and specific brain function is mediated by psychological models of parsing. Given that the link is indirect, this approach could hardly answer to questions of theoretical linguistics, at least in a direct way.

II. The strict neurolinguistic hypothesis, under the guidance of authors like Moro (Musso et al. 2003) and Friedmann & Grodzinsky (Friedmann & Grodzinsky, 1997), which are focused on the search for a direct correspondence between cognitive operations and specific brain areas or neural process, somewhat trying to bypass the idea of a need of an intermediate theoretical description in terms of psychological cognitive processes. The hope is to find specific signal or an activation of a determined cerebral area which systematically covariates with abstract universal cognitive operation (neural signature), assuming a same neural processes or area is the neural underpinning of a cognitive operation in comprehension, production, acquisition in a systematic way.

III. The emergentist vision represents an opposite radical position with is rather agnostic or explicitly deny the need of universal language-specific cognitive operations to describe how language works. At a theoretical level this approach is frequently rooted on Goldberg (1995) and Tomasello (1998) works, characterized by a strong anti-generativist vision of language processing. Within this approach, there are no language-specific mechanisms responsible for language processing since it is assumed that language develops by using domain-general cognitive functions such as imitation, intentionality and abstraction through statistical learning (from Saffran’s studies), chunking theory (Miller, 1956). Not all researchers taking this approach are explicitly inspired by constructional grammar theoretical linguistics. It is possible to study which aspects of neural correlates of

language processing can be explained in terms of general domain cognitive processes, leaving space to the fact that processes linked universal cognitive operations could emerge in a subtractive way, namely in terms of cognitive and neural processes which are not simply explained in terms of general non-specific processes. This latter approach can be dubbed as theoretically agnostic.

All these approaches seem to have an unshakable foundation since countless experiments have been carried out in order to prove the basic idea they intended to sustain. It would be quite impossible to choose a hypothesis and reject the others with the limited resources we had until a few years ago. New findings in psycholinguistics described in this thesis probably allow to see some light at the end of the tunnel or, at least, with those, we hope to provide some hints for new discoveries.

Neurolinguistic and parsing models have this common final scope of connecting in a direct way the cognitive operation to brain signals for the former and to cognitive processes for the latter. From the first studies on agrammatism (Friedmann, Grodzinsky's tree pruning hypothesis, 1997), neuroscience has definitely made progress because, initially it aimed to describe the the frontal and parietal areas in function of the cognitive operations they computed (merge, speech perception, semantic retrieval). More recently, it has exploited new methods to capture neural substrates. Actually, works on neurocomputational models, in particular those like Artoni et al. (2020), exploited intracranial stereo-electroencephalographic recording to study variations of high gamma event-related spectral perturbation at frequencies up to 300 Hz in epileptic patients to disentangle syntactic structures from sounds (thought to be strictly intertwined with the syntactic structure; Artoni et al., 2020). Despite the high modern technique, the major aim of these researchers was to find the same correlation we have described above (we do not provide an in-depth description of these models, for insights see Friederici et. al, 2017; Friedmann, Grodzinsky, 1997; Artoni et al., 2020). Instead, the other side of the coin is represented by the linguistic agnostics' approach which differs drastically from the other models and are too frequently linked to Goldberg (1995) or Tomasello (1998) theories of language which questioned the fact that language structure is biologically driven and they tried to find an alternative to the Chomskyan model by exploiting the construction grammar (Goldberg, 1995) on one hand, and by reclaiming the chunking theory (Christiansen, 2015). Seeing language as a product of experience and developing usage-

based theories has demonstrated that the basic assumption could not be generalized cross-linguistically, thus, revealing the weaknesses of these revolutionary points of view.

Considering all these implications, it is clear that the wide inter-individual variability found in ERP responses to subject-verb agreement (Artesini, 2019) could shake the neurolinguistic and the parsing models. In particular, if the basic idea was based on a 1:1 relationship (for insights, see section 4.4) - neural behavior-linguistic cognitive operation for the former and ERP components-cognitive processes for the latter - it becomes difficult to justify the motivation behind LAN effect found in a 20-years-old brain and N400 found in a 50-years-old brain for the same violation (Artesini, 2019). It should be deepened the question of signature noise and mood artifacts to exclude these approaches but, if we take for granted that this variability is the really reflection of different processing mechanisms for the same cognitive operation, the two hypotheses have to be deeply revised because their assumption is no more reliable. What does this mean? Should we count on the linguistic agnostics' theory? Should we really abandon the strong Chomskyan description of language, falsifying all the generativist theories which have accompanied researchers for years?

The issue with functional interpretations of ERP components has been indeed a strong motivation to move toward the two more extreme approaches (neurolinguistic and emergentists). In fact, many scholars strongly criticized the psychophysiological approach dubbing it ERPology (see Luck, 2014), suggesting that the overall scientific effort in attaching psychological labels to physiological processes is a meaningless enterprise prone to circularity or reasoning and with very few usefulness outside the field itself since it is not useful to inform neither psychological theories nor physiological ones. A strongly opinioned position on this point can be found in Buzsáki (2019), which assumes no meaning in trying to link psychological construct to the internal working routines of the brain since the latters have no explicit knowledge of the world and of the overall organism goals. These epistemological limitations and the relative failure of the research program itself (the functional interpretation of ERPs components are still rather generic after about 60 years of intensive research from the discovery of the N400 by Kutas and Hilliard) can suggest to move along with new approaches be it the neurolinguistic or the emergentist one and not keeping wasting time and efforts in endless circular reasoning. Aside from this strong epistemological observations, other more empirical

criticism could suggest to just abandon the psychophysiological approach. One explanation of the different outcomes for a same violation is the fact that ERPs data are noisy and so, variability of negativity topography can be just due to random noise and this going toward higher statistical power require too much effort (collecting hundreds of EEG recordings for each experiment). Another criticism is about the use of the violation paradigm since the physiological indexes elicited by the comparison between correct and violated sentences (which are typically needed to get strong and visible ERPs effects) cannot be directly linked to the natural process of computation of syntactic relations. This is because the cognitive process linked to coping with irregularities could differ across subjects and situations, while the process of computing agreement on correct sentences can be exactly the same. Despite both epistemological and empirical reason are strongly suggestive to discard the value of ERPs data and to move toward different approaches and measure, there is also a strong reason for keep to work on the puzzle: the motivation is that it is a pity to lose the rich information given by hundreds of ERPs papers on online sentence processing, being the larger body of research on neural correlates of language processing we have. This “economic” reason suggests, in line with the Kuhn (1962) idea of normal science, to do our best to figure out if the knowledge we acquired can be somewhat useful before abandoning it.

We will propose a new perspective trying to save both the rich empirical body of research on ERPs data on syntactic violations and the generativist vision, thus, giving up the hypothesis of the direct link - carried on by the first two approaches - and avoiding, at the same time, a strict conception like Goldberg’s or Mortensen’s or a strict neurolinguistic approach that bypasses a psychological level of description.

4.3 Independence of disciplines

The starting point for a new perspective has to take root in a different vision of the core foundations. Hence, we have to reclaim the independence of the disciplines which rule language processing mechanisms, that is linguistics, psychology and physiology emphasizing the different ways they can interact by means of inter-field theories (Darden and Maull, 1977). This discourse will help to clarify the multilevel approach we want to

propose. The concept of psychophysiology is important in psycholinguistics since physiological responses are the basis of the study on language processing, specifically, every psycholinguistic dissertation we have investigated is based on physiological responses like ERPs. Cacioppo et al., (2007) have described precisely the problem we are facing in this work, providing evidences that physiological responses cannot be easily and directly associated with psychological cognitive processes.

Because psychophysiology is intimately related to anatomy and physiology, knowledge of the physiological systems and responses under study contribute to both theoretical and methodological aspects of psychophysiological research. However, knowledge of the physiological systems is logically neither necessary nor sufficient to ascribe psychological meaning to physiological responses. [...] However, one cannot logically conclude that a processing stage or state has definitely been detected simply because a physiological response found previously to vary as a function of a psychological processing stage or state has been observed.

The authors described the two disciplines as complementary in the sense that both are necessary in the psychophysiological study but in most cases, it is impossible to make inferences directly from one to the other because from the psychological manipulation to the physiological response, other factors could contribute to that specific response. To better understand this theory, they provided a nomenclature of the possible relations in which the two levels can interact:

- One-to-one relation (1:1) (defined “psychophysiological marker” relation if it is context-dependent or “psychophysiological invariant” relation if it is context-independent): the most desirable condition but the most improbable to reach because it provides for one psychological element associated with a single physiological response.
- One-to-many relation (1:2) where one psychological element is associated with two or more physiological elements.
- Many-to-one relation (2:1) (“Psychophysiological outcome” if it is context-dependent; “psychophysiological concomitant” or correlate if it is context-independent) two or more psychological elements are related to one physiological response.

- Many-to-many relation (2:2) two or more psychological elements are associated with the same subset of elements in the physiological domain.

The point for our work is that it would be necessary to consider the disciplines ruling language processing as independent and, for this reason, a non-reductionist approach should be carried on. Thanks to the authors, we have appreciated the qualitative differences between psychology and physiology but also the importance of an appropriate interpretation of their interaction, since a superficial vision could lead to erroneous results. Although precise, the description of the four interaction conditions is already complicated; therefore, it becomes intuitive that the situation may get worse with the introduction of a third independent domain: the linguistic domain.

Moving the focus on our reasoning, it is clear that a 1:1 relation is the most preferable condition, Friederici and colleagues tried to demonstrate at any cost that physiological changes (ERP correlate) are directly connected to the cognitive operation (agree) and the cognitive process. It would be convenient that a component like N400 always varies in function of the manipulation of the lexical access and, vice versa, that measuring the N400 we always monitor the lexical access. But this result is far from being systematic since, for the same component, we can have a many-to-one relation, in the sense that both semantic anomaly and frequency have an influence on the N400 effect. Just as we have more than one component (early negativity followed by P600) whenever the parser faces a syntactic violation and more than one early negativity (LAN, LTN, N400). The problem is that, aspiring to 1:1 relationship in psycholinguistics, researchers could run into some problems. For example, in cases like inter-individual variability in agreement condition, it could be difficult to account for the three different electrophysiological responses (LAN, N400, LTN) elicited by the same cognitive operation. The only alternative is to generalize with an early negativity without considering all the possible nuances due to age effects. Whether, in view of the results, one could pose the question: why all these attempts (all the studies we have reported in the 2 and 3 chapters) to find a direct link between the electrophysiological responses and the underlying cognitive process? To answer this question we should contextualize the background of these researches because in most of the cases, the reference theory was Friederici's or the eADM models. Before discovering interindividual variability in agreement computation, it would have been acceptable a possible 1:1 relation. It is these recent findings which have brought down

certainties. So, for example, studies based on agreement features processing conducted by authors like Nevins et al. (2007) or Mancini (2012), see section 1.4, represent a striking example of this attempt to answer to theoretical linguistics questions through psychophysiology. Again, this empirical problem would acquire sense if the P600 represented a stable index of complexity or processing difficulties in computing the cognitive operation of agreement (one to one relation) but if the correlate changes in function of individual strategies to cope with the problem, it becomes impossible to answer to the abstract linguistic question.

Given the proof of inter-individual variability in agreement violation processing, and the necessity of deviating from the neurolinguistic and parsing points of view, we are left with two alternatives: (a) we could think that the cognitive operation of agreement is computed in three different ways and this variety is reflected in three different physiological responses or (b) we should doubt the existence of the abstract cognitive operation of agree (in line with the linguistic agnostic's approach) because there are many cognitive operations which rule e.g. subject-verb agreement. Results like Caffarra's (a more stable biphasic pattern for article-noun rather than subject-verb, 2019) suggest that abandoning the idea of agree – thus, choosing the (b) option – could not be the only solution. Probably agreement do exist but maybe it is not a single cognitive operation, we will discuss this point in the next paragraph.

4.4 Final considerations

The whole chapter has been built around one major question: how to save the generativist approach in the light of the new findings in psycholinguistics? Is it possible to create a connecting line between the generativist vision and the ERPs? As we have highlighted in the previous paragraphs, the loss of credibility of two of the big schools of thought (pure neurolinguistic approach and parsing models) leaves us with the most radical anti-generativist idea. It is clear that, if we take as model the linguistic agnostics' theory, the answer to our question would be generally negative. Thus also, in such a case, we should accept the idea that data collected from neuroscience cannot effectively falsify a linguistic theory and renounce to the foundational Chomskyan idea of language sciences as a unitary discipline. We are dealing with distinct disciplines and the only aspects we have

to deepen are compatibility and connection between them. Therefore, the inter-individual variability in function of age or variability in fine-grained properties of language (specific lexical aspects, transitive vs intransitive verbs etc.) related to different ERP components push for the hypothesis that the same cognitive operations can be managed by different cognitive processes. This means that we can still consider the existence of an abstract cognitive operation of agree but this can be concretely realized by exploiting resources of different executive functions (working memory, attentional control, inhibitory control etc.). Currently, there is no theoretical approach of this kind but it could account for similar responses in a 9-years-old child and a 70-years old adult for the same cognitive operation. It would be really interesting to invest further resources in this new approach because executive functions could reveal important aspects of language processing variability. The basic idea is to implement a theory which takes into account all the possible levels of analysis, i.e. a multilevel approach in which physiological, psychological and linguistic domains can interact without being bypassed or underestimated.

5. Conclusion

In this thesis, the major aim consisted in the proposition of a new perspective in psycholinguistic research. In particular, the theories which have been developed so far can hardly account for a connection between the psychophysiological and the linguistic domains. The recent findings - which have evidenced an inter-individual variability in subjects' electrophysiological responses during the processing of subject-verb agreement violations - turned out to be a real challenge for the previous hypotheses. In this contest, it is worthy displacing the point of view on other aspects, such as executive functions.

In the first chapter, we have described the tools exploited by psycholinguistic researchers, giving a brief overview on electroencephalography and event-related potentials in general. Then, we have described the most important ERP components associated with the language processing, explaining their importance as eventual "markers" of neural behavior linked to the linguistic levels of analysis. In particular, we put the focus on the motivation of studying linguistic violations, especially at the syntactic and semantic levels. After, we narrowed the field to the agreement operation which represents the fulcrum of our work, exploring its facets from the linguistic and psycholinguistic point of view.

In the second chapter, we focused the attention on the evolution of the major neurocognitive models of parsing, providing a critical analysis of their strengths and weaknesses. This phase represented the starting point to achieve our object: we have demonstrated that the agreement operation processing shows a huge variability as many factors are involved. This outcome paves the way to new hypotheses.

Consequently, in the third chapter, we analyzed studies based on Italian, which is characterized by a rich morphology and language-specific properties useful for the psycholinguistic inquiry. These factors play a fundamental role in the agreement condition: it is widely known that this cognitive operation occurs through the manipulation of features – Person, Number, Gender – and it is also really sensitive to language-specific aspects, such as post-verbal subjects. Therefore, Italian represents the perfect field of application for psycholinguistic research. However, all these implications turn out to be the sword of Damocles: the desired results for a linear and coherent theory

to rely on were anything but reliable. If the biphasic pattern LAN+P600 seemed to be the consistent correlate of agreement violation processing, in Italian it has been demonstrated that it was not generalizable to all ranges of age. Moreover, the ERP components did not always correspond cross-linguistically or across the different works on the same language. This issue did not find any solution in the set of theories proposed, from the syntax-first models to the most recent works.

Hence, we dedicated the fourth chapter to a general comparison between the three bigger approaches to language processing in the brain: the classical psychophysiological cognitive approach, the strict neurolinguistic point of view and the emergentist vision. Showing the big picture in matter of neuro-psycho-physiology, we considered an eventual application of that approaches in terms of linguistic operations, agreement in particular. We highlighted all the epistemological and empirical problems put in question in literature, especially the reliability of ERP in linguistics and the concept of violation in the psycholinguistic study. Then, we reclaimed a non-reductionist vision of the disciplines involved, showing the relevance of each of them individually.

All these considerations led us to propose a new approach which could take into account the cognitive processes activated to manage cognitive operations, an approach which considers the variability of responses as a product of different exploitation of executive functions. So, I propose a “multilevel approach”. However, it has to be highlighted that, even if this hypothesis could find response in the most recent data, it is probably necessary to partially rethink the approach with theoretical and empirical upgrades in order to give it concreteness. In the next future, it would be worthy applying this approach to new experiments with bigger samples, exploring all the possible aspects in the linguistic domain and developing specific hypothesis of possible alternative cognitive processes which may realize a same cognitive linguistic operation, in order to provide a better comprehension of the underlying cognitive and neural processes which rule language processing.

6. References

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