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Review

Grammatical agreement processing in reading: ERP findings and future directions

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ABSTRACT

In the domain of written sentence comprehension, the computation of agreement dependencies is generally considered as a form-driven processing routine whose domain is syntactic in nature. In the present review we discuss the main findings emerging in the Event-Related Potential (ERP) literature on sentence comprehension, focusing on the different dimensions of agreement patterns (features, values, constituents involved and language): Agreement mismatches usually evoke a biphasic electrophysiological pattern (Left Anterior Negativity – LAN, 300–450 msec and P600 after 500 msec). This ERP pattern is assumed to reflect rule-based computations sensitive to formal (inflectional) covariations of related words (trigger–target). Here we claim that agreement processing is sensitive to both the type of feature involved and the constituents that express the agreement dependency. More specifically, LAN could reflect violation of *expectancy* (elicited by the trigger) for the target functional morphology; later, trigger and target are structurally integrated at the sentence level (earlyP600). However, morphosyntactic information could trigger the activation of higher-level representations that are not strictly syntactic in nature. The recruitment of this additional non-syntactic information (mirrored by N400-like effects) indicates that rule-based computations of agreement dependencies are not blind to non-syntactic information but are often recruited to establish sentence-level relations.

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1. Overview of the paper

Across the world, languages make extensive use of agreement to signal the structural relation between words in an utterance. In a first instance, agreement could be defined as the covariation of the inflectional (functional) morphology

between related words, a phenomenon observable in about 50% of languages (according to Bybee, 1985). For example, in English, a noun in subject position bearing the -s inflection is interpreted as plural and triggers agreement with the following verb. Thus, in (1) only when the forms of the subject and the verb co-vary is the sentence grammatical:

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- 1a. *The athlete is running.*
 1b. *The athletes are running.*
 1c. **The athlete are running.*
 1d. **The athletes is running.*

The extent to which world languages make use of agreement redundancy differs, so that while in an English sentence like (2a) Number feature is expressed only twice,

- 2a. *The white horses were happy in that cattle-farm.*

In Spanish (2b) and Italian (2c), the same feature is expressed on the first five sentence constituents.

- 2b. *Los caballos blancos estaban felices en ese rancho.*
 2c. *I cavalli bianchi erano felici in quell'allevamento.*

It is then evident that in some languages agreement is a very salient phenomenon for comprehension. For example, in languages with a relatively strict word order (such as English), comprehenders can often determine the subject by its linear position in a sentence, so they do not necessarily have to compute subject–verb agreement to recognize the noun referring to the subject; however, in other languages (such as Spanish or Italian) agreement can constrain the identification of the subject, that is licensed to move also into a post-verbal linear position (as considered by Bates et al., 1982; MacWhinney and Bates, 1989).

The saliency of agreement in morphologically rich languages underscores the need to understand what kind of neurocognitive mechanisms are involved in this computation. Neurocognitive models postulate the syntactically-driven nature of the processing mechanisms handling agreement and the features involved in it (Friederici, 2002; Grodzinsky and Friederici, 2006, based on Frazier and Clifton, 1996; Frazier and Fodor, 1978). Even with a different perspective, lexicalist neurocognitive approaches (Hagoort, 2005; Vosse and Kempen, 2000) consider agreement to be the consequence of a unification process which combines incoming words and constituents with an unfolding partial phrase marker based on formal features. In other words, the cognitive system would not focus on the lexical/semantic features of a word to evaluate its syntactic (agreement) dependencies, but only on its functional morphemes: morphological covariations are sufficient cues to process agreement. These cognitive approaches mirror the fact that standard analyses of agreement in formal linguistic models (Chomsky, 1981; Pollard and Sag, 1994) have underscored the syntactic nature of this dependency, describing it as an encapsulated formal process taking place in the syntactic build-up of the sentence, and fundamentally independent from the thematic roles, semantic and discourse functions of the elements involved.

In the present paper we will review the main findings that have emerged in the Event-Related Potential (ERP) literature addressing the main assumptions of current neurocognitive models on agreement processing during language comprehension. Almost thirty years of research on the electrophysiological correlates of agreement processing (since Kutas and Hillyard, 1983) have shown that ERPs are one of the most appropriate techniques to study language comprehension. ERPs represent the synchronized electrophysiological activity produced by large populations of cortical pyramid cells, time-

locked to an external or internal event. As compared, for example, with functional Magnetic Resonance Imaging (fMRI), ERPs have exquisite temporal resolution that makes it possible to disentangle processing routines that operate in a few hundreds of milliseconds. Also, this technique offers a window onto the time course of the neurocognitive processes elicited by an event: this is a considerable advantage compared to behavioral techniques such as eye-movements and reading times, which, in contrast, reflect the final (motor) product of those neurocognitive processes – that is, while an experimental manipulation could affect an early stage of processing or a later one, both could show the same behavioral effect. ERPs present the following modulations that have been proposed to reflect neurophysiological patterns of activation:

- Onset of wave differences and/or latency of peaks or other modulations in time could reflect the time course of distinct stages of analysis
- Amplitude differences could reflect the amount of resources invested in a computation
- Topographical differences could represent the recruitment of different neural populations

Unfortunately, determining the neural source of an ERP component is not straightforward, as stated by the *inverse problem*: given the distribution of an electric field on the surface of a sphere, the problem of determining its dipolar origin can have almost infinite solutions. Accuracy in ERP source reconstruction increases by using high-density electrode arrays (around 128 channels), even if the spatial resolution of the technique remains relatively low (on the order of few centimeters) compared to fMRI. Nonetheless, the topographies of ERPs nevertheless offer a multidimensional measure that could help in disentangling macro processing routines at a neurocognitive level.

In the present paper we review 29 published ERP studies (reported in Tables 1 and 2) that focused on the correlates of agreement violation comprehension. We will discuss these in the light of recent findings from our labs. First, we will describe the different dimensions in which agreement patterns vary. Second, we will describe the different ERP components that have been correlated with agreement processing. Third, we will present the critical findings across agreement dimensions. Fourth, we will sketch a functional interpretation of the stages through which agreement mismatches are processed. Finally, we will discuss the ERP findings on agreement and their consequences for mainstream neurocognitive approaches.

2. The dimensions of agreement

2.1. Features

Agreement patterns, defined as the “systematic covariance between a semantic or formal property of one element and a formal property of another” (Steele, 1978), involve the variation of three main features (or Φ -features), i.e., Number, Gender and Person (Wechsler, 2009).

Table 1 – Linguistic aspects of the studies that investigated agreement computation focusing on ERP methodology.

Authors	Lang	Feature	Structure	Example
Kutas and Hillyard, 1983	ENG	N	a. <i>Subject–Verb</i> b. <i>Quantifier–Noun</i>	a. As a turtle grows its shell <u>grow</u> too. b. All turtles have four <u>leg</u> and a tail.
Hagoort et al., 1993	DUT	N	<i>Subject–Verb</i> *grouped SVO and VSO structures	The spoiled child <u>throw</u> the...
Osterhout and Mobley, 1995	ENG	N	<i>Subject–Verb</i>	The elected officials <u>hopes</u> to succeed.
Osterhout et al., 1996	ENG	N	<i>Subject–Verb</i> *capital letter manipulation	The doctors <u>believes</u> ...
Munte et al., 1997b	GER	N	<i>Pronoun–Verb</i>	...june bugs, which <u>hums</u> loudly when...
Coulson et al., 1998	ENG	N	<i>Pronoun–Verb</i>	Every Monday he <u>mow</u> the lawn.
Hagoort and Brown, 1999	DUT	G	<i>Determiner–Noun</i> *initial/final sentence position	The (+M) broken <u>umbrella</u> (+N)...
Gunter et al., 2000	GER	G*Cl_Pr	<i>Determiner–Noun</i>	She travels the (+M) <u>land</u> (+N).....
Hagoort and Brown, 2000a	DUT	N	<i>Subject–Verb</i>	The spoiled child <u>throw</u> ...
Kaan et al., 2000	ENG	N	<i>Subject–Verb</i>	Emily wonders whether the performers in the concert <u>imitates</u> a...
Deutsch and Bentin, 2001	HEB	G	<i>Subject–Predicate:</i>	The woman saw the boy had <u>fallen</u> ...
Kaan, 2002	DUT	N	<i>Subject–Verb</i> *focus on interference	Although according to the rumor the emperor the dissident <u>will</u> ban...
Angrilli et al., 2002	ITA	N	<i>Subject–Verb</i>	The old waiter <u>serve</u> ...
Hagoort, 2003	DUT	N, G	<i>Determiner–Noun</i> *initial/final sentence position and additive adjective–noun semantic violation	The (+S,+M) broken <u>umbrella</u> (+P,+M; +S,+N)...
De Vincenzi et al., 2003	ITA	N	<i>Subject–Verb</i>	The old waiter <u>serve</u> ...
Hinojosa et al., 2003	SPA	P	<i>Subject–Verb</i>	The proof (that was) hidden by the public prosecutor <u>appeared</u> (1sg).
Kaan and Swaab, 2003	ENG	N	<i>Relative–Verb</i>	I cut the cake beside the pizza that <u>were</u> brought by Jill.
Wicha et al., 2004	SPA	G	<i>Determiner–Noun</i>	...he would finally be able to wear the (+M) <u>crown</u> (+F) for the rest of his life.
Barber et al., 2004	SPA	G	<i>Noun–Adjective</i>	The lighthouse (+M)/grandfather (+M) was <u>tall</u> (+S)...
Barber and Carreiras, 2005	SPA	N, G	a. <i>Determiner–Noun</i> b. <i>Noun–Adjective</i>	a. The (+S,+F) <u>piano</u> (+P,+F; +S,+M)...
Palolahti et al., 2005	FIN	N	<i>Subject–Verb</i>	b. The lighthouse (+S,+F) was <u>high</u> (+P,+F; +S,+M)...
Roehm et al., 2005	GER	N	<i>Subject–Verb</i>	A big bumblebee <u>buzz</u> among the flowers.
Martin-Loeches et al., 2006	SPA	N, G	<i>Noun–Adjective</i>	The order <u>executed</u> they not
Silva-Pereyra and Carreiras, 2007	SPA	N, P	<i>Pronoun–Verb</i>	The feeling (+S,+F) <u>deep</u> (+P,+F; +S,+M) moves.
Nevens et al., 2007	HIN	N, G, P	<i>Subject–Verb</i> *violations of Gender, Number, Number+Gender, Person + Gender	We (1pl) <u>understand</u> (1sg; 2pl; 2sg) the idea.
Molinaro et al. 2008a	ITA	G, Phtc	<i>Determiner–Noun</i> *compared to phonotactic violation	Although the crazy musician <u>will sing</u> a song, the... The olives stuffed with the (+F) <u>pepper</u> (+M) are very good.
Leinonen et al., 2008	FIN	N	<i>Auxiliary–Noun</i> *derivational violation root + suffix combination	*compared to phonotactic violation The man, who possesses a house, is <u>house-owning</u> man. *derivational violation root + suffix combination
Frenck-Mestre et al., 2008	FRE	P	<i>Pronoun–Verb</i> *manipulated phonological realization	In the morning I <u>eat</u> very little. *manipulated phonological realization
Molinaro et al., 2008b	ENG	N	<i>Subject–Verb Anaphora</i>	The famous dancer <u>were</u> nervously preparing <u>themselves</u> to face the crowd.
Vespignani et al., in preparation	ITA	N	<i>Determiner–Noun</i>	The (+S) <u>cars</u> (+P) in the...

Column headings indicate the following: *Authors* (and year of publication); *Lang*: language in which the study was run; *Feature*: type of feature manipulated (N: number; G: gender; P: person; Phtc: phonotactics); *Structure*: syntactic relation focus of the study; *Example*: English translated example of the stimuli as reported in the paper.

Table 2 – Methodological details and results of the studies that investigated agreement computation focusing on ERPs.

Authors	Lang	Feature	N	Items	SOA	Ref	Task	LAN/N400	E-P600	L-P600
Kutas and Hillyard, 1983	ENG	N	17	64	640/760	Linked mastoids	C	Verb: LAN (200–400) Noun: AN (200–500)		Verb: possible P600 Noun: possible P600
Hagoort et al., 1993	DUT	N	34	90	300 + 300	Left mastoid	P		Verb: P600 (500–700)	
Osterhout and Mobley, 1995	ENG	N	16 + 16 + 16	60	350 + 300	Left mastoid	P, A	Verb: Left-Frontal Neg (300–500)	Verb: P600 (500–800) amplitude task dependent	
Osterhout et al., 1996	ENG	N	24	50	350 + 350	Left mastoid	A, P		Verb: P600 (500–800) additive with P300 for case manipulation	
Munte et al., 1997b	GER	N	12	80	300 + 400	Average mastoids	P			Verb: P600 (800–1200) Terminal > Embedded > Declarative
Coulson et al., 1998	ENG	N	16	20–80 80–20	200 + 300	Left mastoid	C	Verb: Negativity (300–500)	Verb: small P600 (500–800)	
Hagoort and Brown, 1999	DUT	G	24	40	300 + 300	(Left mastoid?)	A	Noun: Negativity in final position (300–500)		Noun: P600
Gunter et al., 2000	GER	G*Cl_Pr	32	40	300 + 200	Right mastoid	Word probe	Noun: Gender violation: LAN (350–450); Cloze-probability: N400 (350–450)		Noun: high cloze-probability P600 (550–950)
Hagoort and Brown, 2000a	DUT	N	32 + 30	30	129 + 129	Left mastoid	C		Verb: overall distributed P600 (500–750)	Verb: Posterior P600 (750–1000)
Kaan et al., 2000	ENG	N	36	28	300 + 200	Left mastoid	C		Verb: P600 with a central maximum (500–700)	Verb: P600 with a posterior maximum (700–900)
Deutsch and Bentin, 2001	HEB	G	24	50	600 + 300	Tip of the nose	Recogn	Predicate: eLAN (80–250); N400 (250–550) only for animate	Predicate: P600 (500–750) only for marked and inanimate	
Kaan, 2002	DUT	N	16	40	315 + 215	Right mastoid	A	Verb: AN (300–500)	Verb: P600 (500–700)	Verb: P600 (700–900)
Angrilli et al., 2002	ITA	N	25	60	300 + 300	Linked mastoids	C	Verb: LAN (350–450)	Verb: P600 (500–700)	
Hagoort, 2003	DUT	N, G	24	40	300 + 300	Left mastoid	A	Noun: increased N400 for combined violations (300–500)	Noun: P600 (500–700) not sensitive to semantics	
De Vincenzi et al., 2003	ITA	N	25	60	300 + 300	Linked mastoids	C	Verb: LAN (350–450)	Verb: P600 (500–700)	
Hinojosa et al., 2003	SPA	P	30	40	300 + 200	Right mastoid	G	Verb: AN (250–400)	Verb: P600 (500–600–700) centro-parietal	
Kaan and Swaab, 2003	ENG	N	26	40	300 + 200	Left mastoid	A		Verb: P600 (500–700) sensitive to complexity	Verb: P600 (700–900) larger for ungrammatical
Wicha et al., 2004	SPA	G	28	44	300 + 200	Average mastoids	P			Noun: P600 (500–900)

(continued on next page)

Table 2 – (continued)

Authors	Lang	Feature	N	Items	SOA	Ref	Task	LAN/N400	E-P600	L-P600
Barber et al., 2004	SPA	G	24	40	300 + 300	Average mastoids	G	Adjective: LAN (350–450)	Adjective: P600 (500–700) larger for Grammatical gender	Adjective: P600 (700–900)
Barber and Carreiras, 2005	SPA	N, G	24	40	300 + 300	Average mastoids	G	LAN (300–450)	P600 (500–700)	LateP600 (700–900) larger for gender violation
Palolahti et al., 2005	FIN	N	10	80	400 + 400	Average mastoids	G	Verb: LAN (330–440) affected by further semantic violation	Verb: P600 (450–800)	
Roehm et al., 2005	GER	N	19	80	450 + 150	Average mastoids	G	Verb: LAN (250–500)	Verb: P600 (550–700)	
Martin-Loeches et al., 2006	SPA	N, G	34	40	300 + 200	Average mastoids	G	Adjective: LAN (420–520)	Adjective: P600 (700–900) unaffected by semantics	
Silva-Pereyra and Carreiras, 2007	SPA	N, P	24	40	300 + 300	Average mastoids	G	Verb: LAN (300–450) for both violations	Verb: P600 (500–700) larger for combined violations	Verb: P600 (700–900)
Nevins et al., 2007	HIN	N, G, P	23	30	400 + 200	Linked mastoids	A		Verb: P600 (600–800) larger for Person + Gender	Verb: P600 (800–1000)
Molinaro et al. 2008a	ITA	G, Phtc	21	30	300 + 300	Average mastoids	C	Noun: LAN (350–450) with more central distribution compared to Phtc	Noun: P600 (500–700)	Noun: P600 (700–900) larger for phonotactic
Leinonen et al., 2008	FIN	N	15	80	800 + 800	Tip of the nose	A	Noun: AN (450–550)	Noun: P600 (600–800) enhanced by a further derivational violation	Noun: P600 (700–800)
Frenck-Mestre et al., 2008	FRE	P	15	30	450 + 150	Left mastoid	A		Verb: P600 (600–800) larger for phonologically realized errors	
Molinaro et al., 2008b	ENG	N	26	30	400 + 200	Left mastoid	A	Verb: LAN (300–450)	Verb: P600 (500–700) Anaphora: P600 (500–700) sensitive to the number of the verb	
Vespignani et al., in preparation	ITA	N	24	40	300 + 300	Average mastoids	C	Noun: LAN (350–450)		Noun: P600 (500–1000)

Column headings: *Authors*: name of the authors and year of publication; *N*: number of participants in the study; *Lang*: language in which the study was run; *Feature*: type of feature manipulated; *Items*: number of items per condition; *SOA*: stimulus onset asynchrony between subsequent words in milliseconds, numbers separated by “/” implicate variability in the rate of presentation, numbers separated by “+” indicate the time of presentation of each word plus the following blank; *Ref*: reference used for the analysis, “Average mastoids” means that ERPs recorded on-line using the left mastoid have been re-referred off-line to the average activity of the two mastoids, *Task*: task required to the participants, C: comprehension questions, P: passive reading, A: acceptability judgment, G: grammaticality judgment, Word probe: decide whether or not a probe word appeared in the last presented sentence, Recogn: recognition test at the end of the experiment; LAN/N400: main result in the time window around 400 msec; E-P600: main result in the earlyP600 time window around 600 msec; L-P600: main result in the late-P600 time window around 900 msec.

Number pertains to the numerosity of the discourse referents expressed by either nominal or pronominal constituents: for this reason Number is semantically interpretable on the nouns, defined as Number agreement triggers. Its values usually vary between an unmarked form (assumed to be singular) and a plural marked one: English implements plural marking for ‘more than one’ through *-s* inflection, but languages with richer morphological systems can have a *dual* form for two entities, some have a *trial* form for three, and yet others have a *paucal* form, indicating a small number of entities (Corbett, 2000). This feature is mapped onto the verb inflection in most languages, but also, for example, onto determiners and adjectives in Romance and Slavic languages.

The second main agreement category is *Gender*. This feature presents a very complex pattern across languages. For example, in Spanish and Italian, nouns can be either masculine or feminine, in German nouns can be also neuter, while in Dutch nouns can bear either common or neuter Gender. Gender values reflect semantically interpretable differences when they refer to humans and many other animate entities (in Spanish *abuel-o*, grandfather; *abuel-a*, grandmother), but Gender becomes a purely arbitrary formal feature with no possible semantic interpretation when referring to inanimate referents (in Spanish *far-o*, lighthouse; *mes-a*, table). In these later cases Gender agreement is considered a pure grammatical phenomenon.

Neither Number nor Gender is completely transparent, i.e., there is no complete, unambiguous mapping between the inflectional morphology of a noun and the feature copied onto relative agreeing constituents. Generally speaking, while there are few exceptions for Number (such as the English word *thesis*, that ends with an *-s* but is singular), nouns with irregular Gender are numerous: a distinction could be made between irregular nouns (such as the Italian and Spanish *man-o*, hand, a feminine noun in the two languages whose inflectional pattern is the masculine one) and opaque nouns (as in the Italian *pesc-e*, or the Spanish *pez*, both meaning ‘fish’, nouns with an inflectional pattern that can be masculine or feminine). Interestingly, while Number inflection is variable, since it independently combines with the lexical stems of nouns, grammatical Gender tends to be a fixed property of the stem, since only one value is usually attributed to each noun (Ritter, 1988).

The third agreement category is *Person*. This feature relates to the role of a participant in the speech act: first Person expresses identity with (or inclusion of) the speaker, second Person expresses identity with (or inclusion of) the addressee, third Person exclusion of both speaker and addressee (third Person is also considered as a non-person, Benveniste, 1966). The interpretation of Person therefore involves a link between clause-internal positions and the participants in the speech act. Person values are inherently expressed by (pro)nominal elements that trigger agreement on the verb.

Some authors have suggested that the different features are hierarchically organized. According to the *Feature Hierarchy* hypothesis (Greenberg, 1963) Person is more important than Number and Gender in the hierarchy because it can occur across languages independently of the other two. Next in ‘importance’ comes Number and last Gender given its lexical status (e.g., Person > Number > Gender; Greenberg, 1963; Harley and Ritter, 2002; Shlonsky, 1989; Silverstein,

1985). According to some authors (Carminati, 2005; De Vincenzi, 1999), this hierarchy would reflect in a graded pattern the ‘cognitive salience’ of the different features for the languages that overtly mark the three. Thus, processing differences should be expected when different features (Person, Number, or Gender) are involved in agreement. Until now few behavioral studies have supported this hypothesis: Carminati (2005) showed that combined Person–Number features were more effective in the *immediate* (early processing stages) on-line establishment of sentence-internal dependencies in Italian sentences compared to Number alone and followed by Gender. Critically, also De Vincenzi (1999) reported an earlier analysis of Number features that had an on-line impact on reading times, compared to Gender that showed its effect at the end of the sentence.

However, Faussart et al. (1999) claimed that only *late* reanalysis/repair processes are costlier after detection of Gender violations because of the lexical nature of Gender features, but at the same time suggest that there are no *early* differences between Gender and Number processing. Thus, while both Carminati (2005) and Faussart et al. (1999) support the proposal that there is a dissociation in the processing of the different features, the two studies propose a qualitatively distinct approach in terms of processing: Carminati suggests that *initial* stages of processing are sensitive to Feature Hierarchy, while Faussart et al. propose that only *late* stages of processing could bring evidence of a feature dissociation. Faussart et al. suggest that reanalysis/repair processes consist of a series of backward steps toward earlier stages to detect the source of the incongruence. Thus, assuming this hypothesis, costlier reanalyses would imply the access to lexical information (Gender) compared to reanalysis processes focusing on functional morphology (Number). One of the aims of the present paper is to compare the results of studies investigating the processing of different features and evaluate the fitting of the results with the Feature Hierarchy hypothesis.

2.2. Constituents involved

Agreement relations across the sentence vary also on the dimension of the type of constituents involved. An agreement relation always involves an *asymmetric* relation between two sentence constituents. For example, in the subject–verb Number agreement relation the subject is considered the *trigger* element, while the verb is considered the *target* element. This trigger–target relation clearly assigns a different weight to the agreeing elements: it is in fact assumed that the value of Number is semantically interpreted on the subject position and then this feature is copied to target elements such as verbs (see *feature-copying framework*, Chomsky, 1981, 1995). Similarly, Gender values are interpreted based on the trigger noun value, which tends to be a fixed property of that noun (Ritter, 1988): the morphological properties of the agreeing elements (determiners and adjectives) change according to the value of the trigger noun. It is then evident that some constituents could be more relevant than others in agreement computation.

Phrasal-internal agreement dependencies (e.g., determiner–noun) may be computed differently from those involving *across-phrase* relations (e.g., subject–predicate). Agreement

relations within a noun phrase may be more crucial for structure-building than across-phrase relations. On the other hand, across-phrase agreement cues could be more crucial for establishing clause-level relations. These types of dependencies also interact with the type of *feature* involved: Person is realized only as an across-phrase relation (e.g., subject–verb), while Number (subject–verb, subject–predicate vs determiner–noun, noun–adjective) and Gender (subject–predicate vs determiner–noun, noun–adjective) can be expressed both within and across phrases.

The complexity of the phenomenon increases if the cross-linguistic variability in *word order freedom* is included in the equation. While English presents a relatively fixed word order for simple declarative clauses out of context, Romance languages (such as Spanish and Italian) allow the subject to be in a post-verbal position: this means that a subject–verb mismatch could be interpreted as grammatical in the verb position just because the post-verbal construction is syntactically licit in those languages. In this dimension, subject–verb agreement relations differ from determiner–noun relations, in which a determiner cannot be in a position following the noun within the phrase. From a cognitive perspective this could have important processing consequences: in fact, when required to understand sentences that are presented serially word-by-word, comprehenders could build up expectancies of the inflectional properties of the following constituent for certain constructions but not for others. In other words, an Italian or a Spanish speaker could actively predict the morphosyntactic properties of the noun when presented with a determiner; on the other hand, since these languages do not have a rigid word order (both null-subject and post-verbal constructions are in fact possible), this expectation could be weaker when processing a verb after a noun (that is not necessarily its subject) in initial sentence position.

In the present paper we will critically consider the different ERP results mainly based on the type of structural relation (based on type of feature and constituents involved) under investigation.

3. The methodological approach to agreement processing and ERPs

Agreement processing has been mainly studied focusing on the processing of feature mismatches. In the present review we focus on studies that used visual presentation of sentences. Typically, a sentence including a constituent with mismatching features is serially presented word-by-word, as text. ERPs are then calculated based on the onset of the mismatching word presentation. Participants are required either to comprehend or to evaluate the acceptability of the sentence. This type of paradigm has been implemented in more than 30 studies. Although participants are presented with “unnatural” linguistic materials containing ambiguity, grammatical errors or other mismatches, such errors – while temporarily disrupting sentence comprehension – do not necessarily affect the ability to extract a coherent interpretation of the sentence meaning. Comprehenders are in fact able to understand nearly every utterance, not only ambiguous sentences, but also truly ungrammatical ones. Native speakers can easily handle environmental noise, ambiguities,

speech errors, hesitation and repetitions, which are typical of everyday language. This flexibility in dealing with syntactic incongruities and recovering from erroneous analyses is an essential skill of the parser that is useful not only for communicating with non-proficient speakers (e.g., children and second language speakers), but also for language learning (Osterhout et al., 2006).

Understanding the processing mechanisms involved in the computation of mismatches could also have a heuristic value: different responses to different types of errors can in fact open a window onto the different levels of representations of language. For example, the finding of different patterns of activation to semantic (Kutas and Hillyard, 1984) and syntactic (Osterhout and Holcomb, 1992) violations strongly supports the view that the brain handles differently these two aspects of language.

3.1. Language-related ERP components

Since the seminal study of Osterhout and Mobley (1995) two main effects, Left Anterior Negativity (LAN) and P600, have attracted interest in the agreement literature. These effects are most often observed in EEG sentence processing studies when control conditions are subtracted from violation conditions.¹ The earlier is a left-frontal negativity (LAN) evident after the N1-P2 ERP complex. This ERP effect has been mainly reported in the 300–450 msec interval,² i.e., the same interval as another classical ERP component, the N400 (Kutas and Hillyard, 1984; Kutas and Federmeier, 2009). While the P600 has a later onset, the LAN/N400 dissociation can be identified in the topographical properties of these two effects: differently from the LAN, the N400 shows its maximum effect in the central–parietal areas of the scalp, slightly right-lateralized for visually presented words (Fig. 1).³

¹ A critical distinction should be made between the notions of component and effect in the ERP domain. While the former reflects a deflection in the ERP waveforms typically elicited by a specific category of stimuli, the latter indicates a difference between the ERP waveforms elicited by two different experimental conditions. For example, all content words elicit the N400 component, that could modulate in amplitude depending on the lexical properties of the word, thus showing an N400 effect given a lexical manipulation.

² LANs could modulate in latency. According to Friederici (2002, 2004) it is possible to distinguish between an early component (early Left Anterior Negativity – eLAN, onset around 100 msec) and a later one (LAN, onset around 300 msec). The former component would be sensitive to phrase structure violations, while the latter would be more related to morphosyntactic processing. In the present paper we will mainly consider the LAN effect.

³ It should be noted that, especially for early components which are typically focal and short-lasting, variance on a range of physical and psycholinguistic stimulus features (i.e., length and standardized lexical frequency of words) may well explain the variance of neurophysiological responses (King and Kutas, 1998; Osterhout et al., 1997; Penolazzi et al., 2007). In the agreement violation literature however, the critical word tends to be always a content word (nouns, verbs or adjectives, see Table 1), i.e., a stimulus that is longer and less frequent than function words (Neville et al., 1992). Interestingly, so far no study has investigated ERPs elicited by agreement violations in which the target element is a function word. We are now planning in our lab a line of research on this topic, analyzing the processing of mismatching clitics in Spanish.

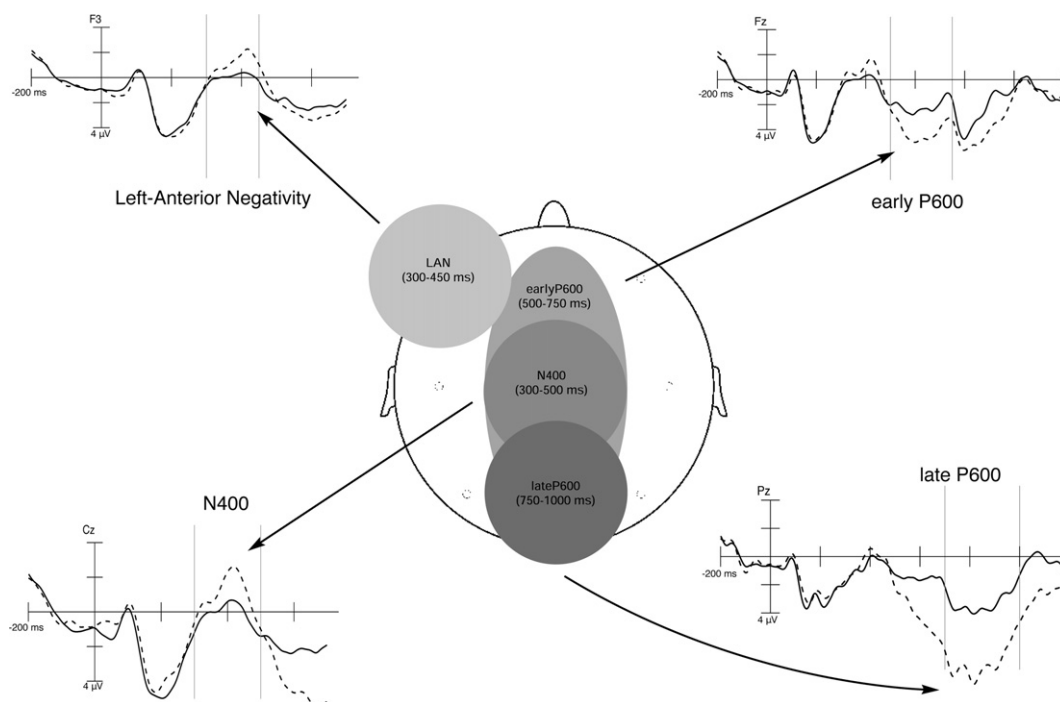


Fig. 1 – Main ERP components affected by agreement manipulations. Each ERP component could be identified by a scalp distribution (sketched in the scalp model), a timing and a polarity of the effect. In the following Figures, the relative dimension of each circle will correspond to the percentage of studies that reported that component across languages (corresponding to 100% in this image; in Figs. 2–4 we also report the relative data points, i.e., how many studies reported that component out of the total).

Also, compared to auditory presentation of the sentences, visual orthographic information plays a critical role in agreement computation of visually presented sentences. Compared to auditory presentation, in visual presentation semantic and morphosyntactic information is available to the processing system at the same time (since the word is visually presented as a whole). On the other hand, during auditory presentation semantic and syntactic information could be available at different times (given the temporal course of speech). This could be relevant for interpreting the onset of an electrophysiological effect. However, when the onset in time of the critical information is optimally defined, language-related ERP components tend to have the same morphological and temporal features for agreement processing (Demestre et al., 1999; Hagoort & Brown, 2000a; Wassenaar et al., 2004; for review see Friederici, 2002). For example, a Magneto-Encephalography (MEG) study by Marinkovic et al. (2003) detailed the spatiotemporal dynamics of modality-independent word processing: they showed that after 300 msec (i.e., after the LAN/N400 onset) electrophysiological brain activity is similar for both visual and auditory presentation.

The ERP components we discuss in the present review are typically correlated with the visual perception of a content word.

- i. The N400 is generally considered the correlate of increased semantic processing. However, the precise functional interpretation of this component has been

long debated. While some studies (Brown and Hagoort, 1993; Holcomb, 1993) have presented the N400 as reflecting the cost of integrating a word in a semantic context, a consistent line of research focusing both on single visual word presentation (for review see Barber and Kutas, 2007) and on sentence-level ‘expectancy’ processes (for reviews see Federmeier, 2007; Kutas et al., 2006; Lau et al., 2008) discuss the N400 component as reflecting the amount of cognitive resources invested in recognizing a word. The expectancy hypothesis explains the sentence-level findings through a predictive approach: the facilitation of processing words in a sentence would reflect the extent to which the context pre-activates specific word properties (see Dambacher et al., 2006; Lau et al., 2008; Molinaro et al., 2010; Van Petten and Kutas, 1990). Interestingly, contextual information would affect the word recognition process: not only strictly semantic associations, but also world knowledge, pragmatics and more general discourse-level information (for review Van Berkum, 2008).

- ii. The LAN is considered to reflect a stage of processing related to the early detection of a morphosyntactic violation (Bornkessel and Schlesewsky, 2006; Friederici, 2002; Munte et al., 1997a, 1997b): it has been reported both in languages with relatively free word order and rich morphological marking for agreement (Italian: Angrilli et al., 2002; Finnish: Leinonen et al., 2008; Spanish: Barber and Carreiras, 2005) as well as in

languages with residual agreement patterns (Dutch: Hagoort and Brown, 2000a; English: Osterhout and Mobley, 1995; German: Roehm et al., 2005). Some authors have also reported LAN effects during the reading of grammatical sentences that, to be comprehended, required working memory resources (Kluender and Kutas, 1993; Streb et al., 1999). An interesting distinction has been made between the ‘morpho-syntactic’ LAN and the ‘working memory’ LAN (Fiebach et al., 2002): the former has been termed *focal* LAN since its onset is around 300 msec and it returns to baseline around 450 msec; the latter is the *sustained* LAN, a topographically similar effect with the same latency that does not come back to the baseline. In the present review we focus on the focal LAN.

Given its proposed independent status from the N400, it appears that the topographical properties of the LAN are critical for determining its identity: it should be noted that three studies (Hinojosa et al., 2003; Kaan, 2002; Leinonen et al., 2008; while Kutas and Hillyard, 1983, did not report ERPs for lateralized frontal electrodes) reported anterior bilateral effects for agreement mismatches without a clear left maximum. Hinojosa et al. (2003), however, presented the critical word in final sentence position, where the syntactic effect could overlap with discourse-level effects (see Osterhout and Holcomb, 1995); Kaan (2002) used fairly complex Dutch sentences with intervening material between the subject and the (mismatching) verb, that could trigger additional working memory processing difficulties; finally, the Finnish study by Leinonen et al. (2008) used novel words with which the participants were not familiar, thus contaminating the basic inflectional manipulation. For the sake of simplicity we will consider these effects as belonging to the family of anterior negativities different from N400 effects.

- iii. The P600 can be recognized as a positive shift starting around 500 msec after stimulus onset and returning to the baseline around 1 sec (Fig. 1). This component shows larger amplitudes over posterior electrodes, although a frontally distributed P600 has been reported in the literature (for example, Friederici et al., 2002; Kaan and Swaab, 2003). Given the extremely heterogeneous conditions that elicit P600, this component cannot be exclusively associated to agreement processing difficulties, but, more reliably, could be interpreted as a late stage of reanalysis that could operate on qualitatively different sources of information (for reviews see Bornkessel-Schlesewsky and Schlesewsky, 2008; Kuperberg, 2007). However, it should be noted that there is a strong correlation between the appearance of the P600 effect and a grammatical violation.

We, among others, have proposed that the P600 could reflect two functionally different processing stages (Barber and Carreiras, 2005; Carreiras et al., 2004; Hagoort and Brown, 2000a; Kaan and Swaab, 2003; Molinaro et al., 2008a). The early stage (about 500–750 msec) has a broad distribution over the scalp, and is also evident in the frontal portion of the scalp; the late stage (about 750–1000 msec) is confined to the

posterior areas of the scalp. Within the agreement processing literature, a functional dissociation between these two subcomponents has been hypothesized: the earlier stage would represent difficulties in integrating the processed constituent with the previous sentence fragment (Kaan et al., 2000), while the later stage would represent reanalysis/repair processes (Carreiras et al., 2004; Barber and Carreiras, 2005; Molinaro et al., 2008a). In the present review we will deal separately with the two subcomponents of the P600 (earlyP600, lateP600); it should be however noted that most of the studies have statistically evaluated the P600 in the earlier time window (about 500–800 msec).

Grammatical agreement could be relevant also in computing sentence-level relations in the case of temporary ambiguities. In these studies, alternative interpretations of the sentence are available to the comprehender and grammatical information could disentangle between the different options. Typically, in these studies (a few examples are Carreiras et al., 2004; Friederici et al., 2001; Kaan et al., 2000; Mecklinger et al., 1995; Penolazzi et al., 2005) no LAN effect is reported but only late positivities that could differ in their onset: the most consistent finding in this literature, the P600, is often dissociated from an earlier positivity with a maximum around 350 msec (Friederici et al., 2001; Mecklinger et al., 1995; Penolazzi et al., 2005). Reviewing in detail this literature is out of the scope of this paper, but two main points should be remarked: (i) the lack of the LAN in these studies suggest that this component is sensitive to agreement relations that are critical for structure-building; (ii) the finding of different positivities in different time intervals supports the hypothesis that different subcomponents could interact in determining the P600 amplitude.

3.2. Language-related ERP components and aphasia

Identifying the neural network reflected in an ERP component is not at all straightforward. However, some studies on aphasia and sentence comprehension have tried to shed light on this topic. The rationale behind these studies is the following: if a patient presenting a well-defined cerebral lesion does not show an ERP effect that normal controls usually show, this means that the lesioned area is involved in the neural network eliciting that ERP component. Most of these studies did not use visual presentation, but rather speech comprehension, given the difficulties of the patients in performing a reading task. Nonetheless, since most of the language-related ERP components have been reported also for speech comprehension (although with different latencies, Friederici, 2002; Hagoort and Brown, 2000a, 2000b), these findings could provide useful information for the present analysis.

Thus, Friederici et al. (1998) reported a double dissociation concerning the earlier negative components. When presented with both syntactic (word category) and semantic violations during speech comprehension, a patient with an extended lesion in the anterior part of the left hemisphere sparing the temporal lobe (Broca’s aphasia) did not show any eLAN (with onset around 100 msec) for the syntactic manipulation, but a normal N400 for the semantic one (but see Swaab et al., 1997a, 1997b, for delayed N400 effects in Broca’s aphasics).

In contrast, a patient with a left temporal-parietal lesion (Wernicke's aphasia) had the opposite pattern: he showed no N400 for the semantic violation, but a normal eLAN for the syntactic violation. These findings thus suggest that the anterior portion of the left hemisphere is supporting the neural network triggering the LAN effect, while the superior temporal lobe is involved in the processing routines related to the N400. A further study (Friederici et al., 1999) supported these observations, focusing on the role of the basal ganglia in the more procedural aspects of grammatical processing (Ullman et al., 1997). When presented with word category violations, a group of patients with focal lesions to the left basal ganglia showed an eLAN similar to normal controls, while the P600 effect was somewhat reduced.

While these studies did not show any modulation of the P600 in Broca's aphasics, a series of studies in Dutch did. Both Hagoort et al. (2003) and Wassenaar et al. (2004) focused on the processing of subject–verb Number agreement errors during speech processing. A group of Broca's aphasics were insensitive to agreement violations, as evident from the missing P600 effect compared to both normal controls and non-agrammatic aphasics (Hagoort et al., 2003). However, this sensitivity was modulated by the severity of the syntactic comprehension impairment: low comprehenders did not show an agreement effect at all, while the group of high-comprehenders showed a P600 effect, albeit reduced in comparison to normal controls (Wassenaar et al., 2004; see also Wassenaar and Hagoort, 2005, for word category violations). The lack of the LAN effect for number agreement violations in these latter studies is probably due to the complex sentence structures used in those experiments, i.e., conjoined (**The baker greets the customers and ask the boy not to make so much noise*) and embedded constructions (**The baker that greets the customers ask the boy not to make so much noise*, see discussion of examples 3a–3b, Molinaro et al., 2011). Consequently, it is not possible to evaluate the behavior of the morphosyntactic LAN effect in agrammatic patients, since simpler sentence constructions should have been used. Findings on word category violations (Friederici et al., 1998, 1999) seem to indicate that the frontal areas of the left hemisphere are involved in the network triggering the LAN, even if the effect reported in those studies (eLAN, onset around 100 msec) is earlier than the one usually reported for morphosyntactic agreement violations (LAN, onset around 300 msec), may be representing two functionally distinct components (Friederici, 2002). Furthermore, left-frontal cortical areas connect with subcortical regions (basal ganglia) to develop a network involved in processing the more procedural aspects of syntactic processing (Ullman et al., 1997): this network is possibly involved in eliciting the P600 (Friederici et al., 1999).

4. ERP findings on agreement processing

Previous studies that dealt with agreement manipulations in normal subjects are reported in Tables 1 and 2 in chronological order. For each study we provide in Table 1 the details of the linguistic materials used in the study. In Table 2 we report the methodological aspects of the different studies. The last

three columns in Table 2 sketch the main findings divided into the three main time windows of interest: the LAN/N400 negativities show effects in the 300–450 msec interval on average, while the P600 has been mainly evaluated statistically in its early interval (500–700 msec). It is worth keeping in mind that these published studies are not a real “sample” in any statistical sense, because null effects are less likely to be published.

We visually represent the main ERP results separately based on the dimensions of agreement (*feature by constituents*): in each figure we isolate the percentage of studies that reported each component for that type of dependency. The bigger the circle (or the oval for the earlyP600, see Fig. 1 for the maximum of each circle, corresponding to 100%) for each component, the larger the percentage of studies that found that component for that type of dependency. We thus visually represent the consistency of a component for a specific manipulation.

In Table 2 we outline the methodological aspects of the studies considered. Before discussing the results related to the different agreement patterns, it is relevant to mention the technical details that can have an influence on ERP data. The average number of participants in these studies on agreement is 23.3 (SD = 6.6), with only a few studies presenting less than 15 participants (Munte et al., 1997b; Palolahti et al., 2005). The number of items per condition is 48.8 (SD = 17.9), with only one study using less than 30 observations per condition (Kaan et al., 2000). It appears that a good compromise in running ERP experiments on agreement comprehension is to have at least 20 participants and around 40 items per condition (less than .5 SD from the mean). Rate of presentation is on average 611 msec (ITI: 279 msec on average) with one study using a rapid serial visual presentation (129 + 129: Hagoort and Brown, 2000a) and a few studies using a very long SOA (600 + 300: Deutsch and Bentin, 2001; 400 + 400: Palolahti et al., 2005; 800 + 800: Leinonen et al., 2008). The choice of reference is crucial: while most of the studies used the left mastoid (11) or off-line calculation of the average activity of the two mastoids (10), some reports used either on-line linked mastoids as reference (4, not recommended because the shunting of currents between electrode sites may distort the distribution of the scalp voltages, Miller et al., 1991), or the right mastoid (3), or an electrode put on the tip of the nose (2). Interestingly, while in the earlier studies the standard was to use the left mastoid as reference (9 studies before 2003 use this setting), more recent reports tend to make use of the off-line average reference (9 studies since 2004). When using the left mastoid as reference the authors usually report monitoring the right mastoid activity to determine if there is any effect of the experimental variables on the mastoid recordings. However, the reference choice seems crucial for studying hemispherically lateralized components, such as the LAN. Using as a reference an electrode that is on the same scalp side as an expected ERP effect could in fact reduce the amplitude of the effect itself, since all the activity detected by the reference (and the adjacent electrodes) is considered as zero activity. Critically, since most of the ERP effects have their neural sources in the left frontal–temporal brain areas (see Section 3.2), the left-mastoid reference does not appear to be an optimal choice. One

consequence of this is that while few studies that used the left mastoid as reference reported a (left-lateralized) negativity in the 300–500 time window (4 out of 11), most of the studies using average activity of the two mastoids as reference reported a left-lateralized negative effect (8 out of 10). Finally, the task performed by the participants in most cases is a direct task (Grammaticality or Acceptability judgment at each stimulus, 17), and in a minority of cases an indirect (more ecological) task (Passive reading or Comprehension questions, 12). Only two studies used uncommon tasks like the Word probe (whether or not a probe word appeared in the previous sentence, Gunter et al., 2000) and a Recognition task (at the end of a block recognizing if the sentence was presented or not, Deutsch and Bentin, 2001). While the effect in the 300–500 msec time window seems to be unaffected by the type of task (11 out of 17 studies using direct tasks and 7 out of 11 studies using indirect tasks reported early anterior negativities), the P600 amplitude is sensitive to the task properties: it is larger for direct tasks (acceptability or grammaticality judgments) compared to indirect tasks (passive reading or comprehension questions), as shown by Osterhout and Mobley (1995), Osterhout et al. (1996); and further discussed by Kuperberg (2007). The P600 is also sensitive to the proportion of violations in the whole experimental set: Coulson et al. (1998) showed that the lower the proportion of stimuli in the whole set the higher the P3b component, which showed the same latency and distribution as the P600 related to the grammaticality manipulation (but see Osterhout et al., 1996; Osterhout, 2000).

4.1. Number agreement ERP pattern

Most studies have focused on Number agreement mismatches (23). We consider three main types of Number agreement dependencies (Fig. 2): subject–verb (within-clause relation), determiner–noun and noun–adjective (either within phrase or when the adjective in predicate position refers to the subject noun). Findings are reported for languages with complex paradigms of agreement (Italian, Finnish, Spanish) and in languages with reduced agreement (Dutch, English, German). Only one study focused on the ERP correlates of Hindi, a non-alphabetic language. In the present analysis on subject–verb agreement, reported in Fig. 2, we excluded the studies that focused on subject–verb Number dependencies that are implemented across clause boundaries (3 studies, see Table 1).

Most of the studies on subject–verb agreement (74%) reported a LAN followed by a P600 for Number mismatches. Only a few early studies did not report the LAN effect (Hagoort et al., 1993 and Osterhout et al., 1996, both using the left-mastoid reference), while the recent Hindi paper by Nevins et al. (2007) focused on a non-alphabetic language, in which it is hard to evaluate the visual complexity of the visual stimuli. Considering all the studies, there seems to be no critical influence of the task used in the experiments, since both direct and indirect tasks elicited the LAN-P600 pattern; only the P600 amplitude showed to be task dependent (see above).

Determiner–noun and noun–adjective violations also elicit the LAN + P600 pattern: exceptions are the study by Hagoort

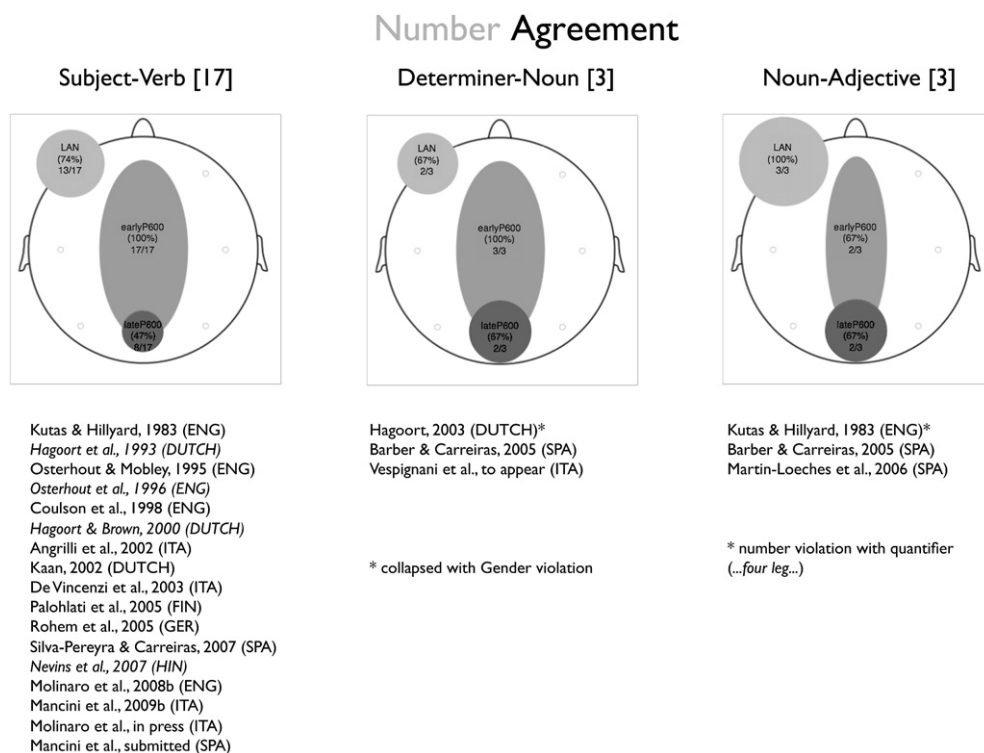


Fig. 2 – Pattern of ERP effects reported for Number agreement manipulations in three different sentence constructions: subject–verb (within clause), determiner–noun and noun (usually in subject position)–adjective (in predicate position). Between squared brackets we reported the number of studies considered in each construction. Below is the list of papers considered (in Italics the ones that did not report a LAN for subject–verb Number violations).

(2003) that did not report the LAN effect for determiner–noun number violations, but they were collapsed with Gender agreement violations (plus a left-mastoid reference was used) and the study by Kutas and Hillyard (1983) that did not consider the P600 component in their analysis for noun–adjective violations.

At first glance, it is evident that most of the studies on Number agreement have reported the LAN-P600 pattern. Also, when presented with an interfering Number-marked noun in the subject–verb relation, the same ERP pattern was recorded (Kaan, 2002). These findings have been taken as evidence that Number features represent reliable morphological cues to signal structural relations within a sentence (even for long-distance dependencies, within the same clause): in this sense, the LAN would correlate with the detection of morphosyntactic processing difficulties (as suggested by mainstream sentence processing proposals). This hypothesis has received recent support by the finding that, when presented with Number disagreements that involve a subject–verb inflection mismatch (as in 3a), Italian speakers showed a LAN effect at the mismatching verb that was not evident when morphosyntactic cues were underspecified in the trigger position (as in 3b, Molinaro et al., 2011). Interesting to note, the surface properties of the trigger seem to be critical for eliciting the LAN.

3a. **I ragazzi corre...*

The boys runs...

3b. **Il ragazzo e la ragazza corre...*

The boy and the girl runs...

While in 3a the plurality of the trigger could be directly extracted by the noun phrase morphology (*I ragazz-i*), in 3b the conjoined noun phrase does not have any plural marking: both noun phrases are singular and the conjunction (*e*, and) could not be considered a marker of plurality (it can be used for clause coordination, *I like the wine and she likes the beer*, and in conjoined noun phrases that require a singular verb, *Running and jumping is very funny*). Since we recorded the LAN on the verb only in 3a, we proposed that the LAN dissociation is related to the availability of relevant inflectional morphology in the triggering subject.

Another interesting aspect of Number dependencies resides in the fact that the LAN is not reported when the Number disagreement is presented across clauses (as in 4, Munte et al., 1997b; see also Kaan et al., 2000; Kaan and Swaab, 2003):

4. **Der Opa hat zwei Maikaefer gefunden, die beim Fliegen laut brummt.*

The grandfather has found two june bugs, which *hums loudly when flying.

These findings suggest that morphological Number cues are more ‘salient’ in the on-line processing of intra-clause dependencies. Overall, the findings on conjoined noun phrases (Molinaro et al., 2011) and on across-phrase violations suggest that within-clause Number agreement processing is sensitive to the morphosyntactic properties of the trigger elements, especially in the early stages of processing (LAN). In fact, when Number values are not morphologically expressed, or if they are expressed in another clause, the LAN is not triggered.

As suggested before, the level of expectations induced by the context could have an impact on the LAN. Indeed, two separate studies in Italian focused on the processing of Number agreement violations between determiner and noun (Vespignani et al., in preparation) and between subject and verb (De Vincenzi et al., 2003). In a language with relatively free word order such as Italian, the detection of a morpho-syntactic mismatch between a determiner and a noun could be unambiguously considered as an agreement violation; in contrast, a morphosyntactic mismatch between a noun in initial position and the following verb could be considered as grammatical if the subject was in a post-verbal position (it should be noted that there is initial-noun-as-subject preference also in Italian). These two examples thus differ in the level of expectations induced by the context, with a stronger expectation for the noun morphology in the former case compared to the expectation for the verb morphology in the latter. Interestingly, the LAN effect was statistically much more robust in the former study, compared to the latter: the LAN reported by De Vincenzi et al. (2003) did not elicit a statistically significant effect in the overall statistics, but only a marginally significant effect in a region-of-interest analysis confined to the left-frontal electrodes. Similarly, Balconi and Pozzoli (2005) did not find clear LAN effects for subject–verb Number agreement violations in Italian. In contrast, Vespignani et al. (in preparation) reported a statistically more robust effect for determiner–noun Number mismatches. These findings suggest that the type of structure under investigation is critical in determining morphosyntactic expectations for the following marked constituents: a more robust expectation for a supposed-to-agree constituent in fact triggers a more reliable LAN effect.

4.2. Gender agreement ERP pattern

Regarding Gender agreement, 9 studies focused on the ERP correlates of either determiner–noun or noun–adjective gender mismatches (Fig. 3). Gender agreement patterns are more complex than Number agreement patterns and, differently from Number, vary considerably across languages. Fig. 3 shows the main findings for Gender agreement patterns: as for Number, within-clause relations elicited the LAN-P600 pattern (see Barber and Carreiras, 2003, 2005, for differences in the constituent dimension). Thus, despite this heterogeneity of Gender patterns, there are no substantial differences across languages (Dutch, Spanish, German and Italian) and tasks: the majority of the studies in fact reported a LAN followed by a P600 (80%). For what concerns determiner–noun Gender agreement violations, only Hagoort (2003) and Wicha et al. (2004) did not report the LAN.

While Hagoort’s (2003) study in Dutch collapsed Number and Gender violations reporting underspecified anterior negativities, the lack of a LAN effect in the study of Wicha et al. (2004) is at odds with all the relevant literature in Romance languages. Barber and Carreiras (2005) presented a determiner–noun Gender violation where the value of the noun was transparent and Spanish speakers showed the same LAN effect at the mismatching noun as for the Number violation in the same position (6). This paper supported the

Gender Agreement

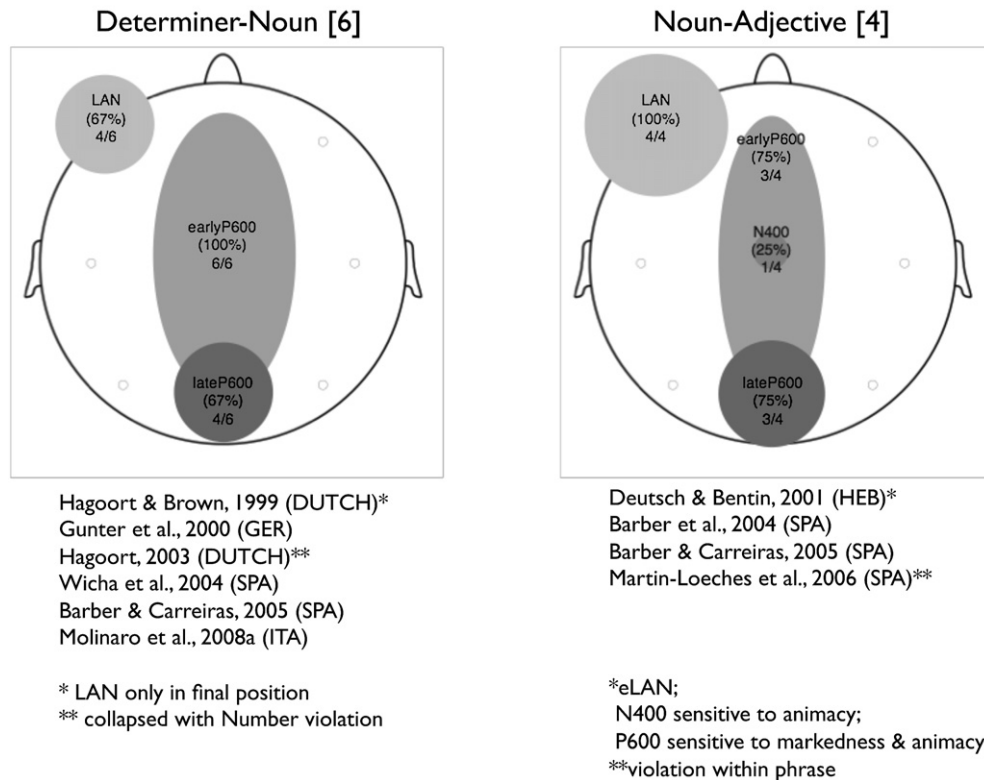


Fig. 3 – Pattern of ERP effects reported for Gender agreement manipulations in two different sentence constructions: determiner–noun and noun (usually in subject position)–adjective (in predicate position). Between squared brackets we reported the number of studies considered in each construction. Below is the list of papers considered.

idea that there is no differential computation of the two features at the morphosyntactic initial processing stage.

6. *El masc.sing/*La femm.sing/*Los masc.plur faro...*
The lighthouse...

Molinaro et al. (2008a) presented Italian speakers with determiner–noun Gender agreement violations; Italian has a very similar Gender pattern to Spanish. Compared to a phonotactic violation [in Italian the masculine determiner could either have the *lo* or the *il* form based on the initial phoneme of its noun, see (7)], these authors reported a LAN with a more central distribution (a negativity evident for example also on the electrode C4) for the Gender violation.

7. *Lo masc.lo/*Il masc.il/*La femm scialle...*
The shawl...

The difference between these two latter studies could be attributed to the properties of the target noun where the violation is detected. In fact while Barber and Carreiras used transparent nouns, Molinaro et al. used nouns with opaque Gender (the Italian word *scialle* ends with a phoneme that could be either masculine or feminine). This topographical difference across studies could be related to the fact that while agreement dependencies involving transparent Gender marking on the target position do not imply access to the

lexical properties of the noun to be recognized, this access (correlated with a more central effect) is needed to process the Gender mismatch on opaque nouns (and elicit a more N400-like response, Kutas and Federmeier, 2009; Lau et al., 2008).

When considering noun–adjective relations, only Deutsch and Bentin (2001) reported an eLAN (onset of the effect around 100 msec) followed by an N400 on a predicate that could agree or not with the previous noun in subject position: if the previous noun was animate (5a) the N400 effect was more prominent compared to the inanimate-noun condition (5b).

5a. **...keytzad hasaxkaniot* (article “ha” + subject fem. pl. “the actresses”) *maksimim* (predicate masc. pl. “enchancing”)...
...the actresses [were] enchancing...

5b. **...keytzad hatmunot* (article “ha” + subject fem. pl. “the pictures”) *maksimim* (predicate masc. pl. “enchancing”)...
...the pictures [were] enchancing...

It should be noted that this study used some uncommon technical procedures (long SOA, 600 + 300 msec, reference on the tip of the nose, recognition task). However, these findings have stimulated discussion about the role of Gender features in agreement computation, i.e., whether formal Gender and biological Gender subjects trigger agreement processes of the same nature (formal-syntactic) or different (formal-syntactic

and biological-semantic), as suggested by Ritter (1988), for a review see Barber et al., 2004.

Barber et al. (2004) focused on the same agreement dependency, but they did not report differences in the topographical distribution of the LAN for Gender mismatches depending on the animacy of the subject noun (8a–b).

8a. *El faro_{masc} es alta_{femm}...

The lighthouse is high...

8b. *El abuelo_{masc} es delgada_{femm}...

The grandfather is skinny...

These authors presented Spanish speakers with noun--predicate Gender mismatches, where the mismatch was realized on the predicate, i.e., a constituent whose Gender marking is variable depending on the value expressed on the triggering noun. Here, to process the agreement relation there is no need to access the lexical representation of the adjective, since the Gender features were very transparent (-o for masculine and -a for feminine) and therefore there was a very high correlation between the biological Gender and the inflectional patterns of nouns.

The two studies differ in the earlier effects (eLAN + N400 in Hebrew vs LAN in Spanish). While the eLAN effect could be due to the long SOA used by Deutsch and Bentin (2001), it is possible that the processing routines emerging between 300 and 500 msec are sensitive to the different properties of the two languages for what concerns noun marking: in Spanish, noun Gender is marked mainly on inflections, while Hebrew marking (as in most Semitic languages) is expressed on the noun stem (see also Leinonen et al., 2008, for similar findings in Finnish nouns). It is possible that the subject (also depending on its animacy) could trigger an expectation of the morphological properties of the following predicate. If this expectation concerns the adjective stem, as in the Hebrew study where Gender features are expressed on the stem, and it is disconfirmed, an N400 is triggered; on the other hand, if this expectation concerns the adjective inflection, as in Spanish where Gender is expressed by the inflection, the agreement violation triggers the LAN. This dissociation would derive from the fact that morphological decomposition is crucial in Spanish to process agreement: the cognitive system could rely only on the inflection (a functional morpheme) to identify the expected agreement feature. Morphological decomposition is not possible in Hebrew, thus compelling the system to deal with the whole stem for feature identification (similar to the case of opaque nouns, Molinaro et al., 2008a).

4.3. Person agreement ERP pattern

The feature of Person has received less attention in the ERP literature on agreement: only 5 studies in fact have discussed the ERP correlates of Person agreement mismatches between subject and verb (Fig. 4). Those studies reported very heterogeneous findings that could be attributed to large differences between studies. For example, some authors treated this feature as a general morphosyntactic mismatch (Hinojosa et al., 2003) presenting the error in sentence-final position

Person Agreement

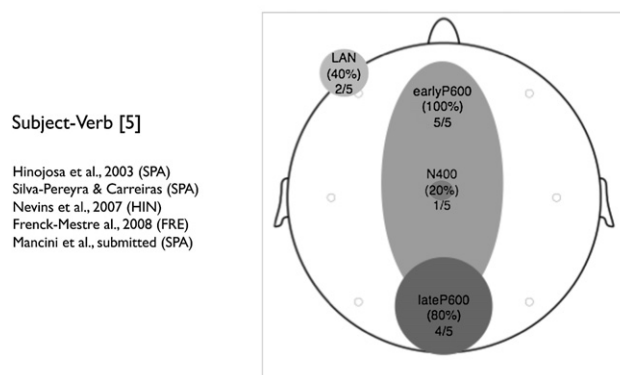


Fig. 4 – Pattern of ERP effects reported for Person agreement manipulations for the subject–verb relation. Between squared brackets we reported the number of studies considered. On the left the list of papers considered.

(not a felicitous choice given possible overlapping wrap-up effects, Osterhout and Holcomb, 1995), while others mainly focused on the morphophonological realization (Frenck-Mestre et al., 2008, that used a left-mastoid reference), or analyzed this feature in non-alphabetic languages in which the visual complexity of the stimuli could not be evaluated (Nevins et al., 2007).

Silva-Pereyra and Carreiras (2007) compared the processing of Person and Number disagreements that involved either the first or the second Person in Spanish (9). These authors reported a similar LAN + P600 pattern for Number and Person mismatches.

9. Yo abro_{1st.sing}/*abrimos_{1st.plur}/*abres_{2nd.sing} la puerta.
I open the door.

A distinction could be drawn, however, across Person values: first and second Person in fact express the role of an argument with respect to the participants in the speech act, while third Person refers to entities that do not actively contribute to the unfolding of the speech. Thus, there is qualitatively different metalinguistic knowledge expressed by first/second Person values compared to third Person values: in the former case the discourse-level representation directly involves speaker and comprehender, while in the latter case there is no direct link to the speech act. Interestingly, focusing on a third Person perspective compared to a first Person perspective activated different neural networks in a PET study (Ruby and Decety, 2001).

This distinction is also evident in the plural form: the plural of first and second Person cannot be considered a multiplication of the entities expressed by their singular counterpart: they make reference to heterogeneous groups respectively formed by a Speaker and its associate (we = I + yousg or he/she), and an addressee with its associate (youpl = yousg + he/she). A true pluralization is reliably produced only with third Person, which permits shifting from one individual to a group

of individuals equally deprived of speech roles. Based on this, first and second Person singular forms have been said to have a specification for the Person feature, but not for Number, whereas third Person is specified for Number, but not for Person (Benveniste, 1966; Harley and Ritter, 2002). As a consequence of this analysis, the lack of differences between Person and Number violation reported by Silva-Pereyra and Carreiras (2007) could be due to the fact that differences are real, but were obscured by just analyzing trials with first and second Person, without including, for example, a pattern of first/second Person on the trigger and third Person on the target.

The relevance of the Person value in agreement computation is supported by a recent study by Mancini et al. (2009): they reported different ERP effects for Number agreement violation involving first/second Person (10a) versus classic third Person violations (10b). In that study, the early phase of the P600 was frontally larger for Number agreement violations involving first/second Person compared to the Number violation using third Person.

10a. *Tu chiudi* _{2nd.sing}/**chiudete* _{2nd.plur} *il negozio*.

You close the shop.

10b. *Lui chiude* _{3rd.sing}/**chiudono* _{3rd.plu} *il negozio*.

He closes the shop.

These results support the idea that increased processing difficulties are triggered during the processing of Number involving first or second Person compared to third Person. It follows that a pure Number mismatch is reliably produced only with third Person pronominal and lexical subjects.

In a recent follow-up ERP experiment (Mancini et al., submitted for publication) we considered these aspects, recording differences for Number (11a) and Person violations (11b).

11a. **El periodista* _{3rd.sing} *trabajaron* _{3rd.plur} *mucho*.

11b. **El periodista* _{3rd.sing} *tabajaste* _{2nd.sing} *mucho*.

The journalist work hard.

While the Number violation elicited a LAN + P600 pattern, the Person violation elicited a N400-like component (with a left-posterior maximum extending also in frontal areas of the scalp, where it did not differ from the Number mismatch) followed by a P600 that was larger in both the early and late phase compared to Number. These findings thus suggest that the Person feature could elicit a qualitatively distinct ERP pattern compared to Number and Gender features (when optimally manipulated). The N400 effect could be explained by the fact that Person requires a direct link to discourse-level representations that could be linked to both the subject and the verb Person values (as suggested by Mancini et al., 2009): the shift from the third Person (an argument with no role in the speech act) expressed in the subject position to the first Person of the verb (expressing a speech participant, the speaker) activates a more complex discourse-level representation, triggering an increased N400 effect (as also showed by St. George et al., 1994; Van Berkum et al., 1999). In contrast, the shift between Person values that express speech participants (such as, for example, the subject has first Person and the verb second Person, as in Silva-Pereyra and Carreiras, 2007) does not elicit an additional N400: in that case, the first/second value on the subject already makes reference to a discourse-level representation in which the comprehender is involved (either as a speaker or as a comprehender); thus, when reading the verb, a more complex speech-act representation is already available and no additional N400 is triggered.

As suggested by Van Berkum (2008) discourse-level information expressed in a sentence context could create expectations for a specific lexical item (see also Federmeier, 2007; Lau et al., 2008), thus influencing the recognition of the

Table 3 – ERP studies that compared the effect of an agreement manipulation across features.

Study	Feature	300–500 msec	500–750 msec	750–1000 msec
Barber et al., 2004 (SPA)	GENDER (grammatical vs semantic) ^a	n.d.	Larger frontal P600 for GRAMMATICAL GENDER	n.d.
Barber and Carreiras, 2005 (SPA)	NUMBER GENDER	n.d.	n.d.	Larger P600 for GENDER
Molinaro et al., 2008a (ITA)	GENDER PHONOTACTICS ^b	TOPOGRAPHY more central LAN for GENDER	n.d.	Larger P600 for PHONOTACTICS
Silva-Pereyra and Carreiras, 2007 (SPA)	PERSON NUMBER	TOPOGRAPHY bilateral AN for PERSON?	n.d.	n.d.
Nevins et al., 2007 (HIN)	PERSON GENDER NUMBER ^c	n.d.	larger frontal P600 for combined PERSON±GENDER	n.d.
Leinonen et al., 2008 (FIN)	NUMBER DERIVATIONAL ^d	NUMBER: (L)AN DERIVATIONAL: N400	n.d.	n.d.
Mancini et al., submitted for publication (SPA)	PERSON NUMBER	NUMBER: LAN PERSON: N400-like	Larger frontal P600 for PERSON	Larger P600 for PERSON

a Semantic = biological gender.

b Phonotactically illegal determiner-noun combination (masculine determiner in Italian IL/LO).

c Violations of Gender, Number, Gender + Number, Person + Gender.

d Derivational violation is “verbal stem” combined with “nominal suffix”.

target word. Consequently, the N400 reported by Mancini et al. (submitted for publication) could reflect contextual expectations in which a qualitatively different discourse-level representation was activated (Table 3).

5. Agreement computation: hints from ERPs

5.1. The N400/LAN dissociation

Initially, we proposed that at least three consecutive time intervals could be differently sensitive to agreement processes, as evidenced by ERPs. The earlier (about 300–500 msec) is associated with the LAN/N400 negativities. In the literature on agreement, within-clause feature mismatches that are morphophonologically realized elicit an increased negativity in the majority of the studies: the LAN has been described as evidence of the early detection of a morphosyntactic mismatch. In this view, this component would dissociate from the N400 that would correlate with semantic processing.

Osterhout et al. (2004) questioned the reliability of the LAN effect as an index of syntactic processing (but see the reference choice argumentation in Section 4). Their argumentation focused on the fact that this component is not evident in the single-subject averages across conditions. Following Osterhout's (1997) arguments, syntactic manipulations could elicit different electrophysiological reactions across individuals: while some participants would show a P600 effect (discussed below), others would react to syntactic difficulties triggering N400. As a consequence, the LAN effect evident in the grand-average across subjects would be a byproduct of the averaging process. In our opinion, this argument concerns more generally the nature of research on human participants: every neuroimaging technique (including fMRI and MEG) has to deal with inter-subject variability, and the considerable differences that could be identified across subjects. In those cases, generalization of the results is only possible averaging across participants. Assuming this inter-subject variability in the normal population (and considering the published reports), the selection of independent groups from this population should have determined a higher heterogeneity of results, in the sense that some studies should have reported a N400, some studies a P600 and most of the studies some effects in-between. However, the present review on agreement processing did not report such variability, supporting the reliability of anterior negativities as correlates of morphosyntactic processing difficulties.

Critically, we have shown that the early negativities are sensitive to the type of reference used (see Section 4), with the average mastoid reference as the best choice to observe stronger LAN effects. This may not be the only important methodological factor that could have an effect on the LAN component: for example, Deutsch and Bentin's (2001) study used some uncommon methodological procedures (long SOA, reference on the tip of the nose, a Recognition task), reporting an eLAN effect. It could be that the effect is due to the properties of the language under consideration, but more studies should be planned to evaluate the influence of methodological details on the early negativities.

As a matter of fact, the distribution of the earlier negativity has shown to be sensitive to the experimental paradigm employed in the study. Barber and Carreiras (2003, 2005) showed that when Spanish speakers are presented with subject–adjective pairs, both Number and Gender mismatches elicit a N400 component; the same pairs presented in a sentence context elicited the LAN-P600 ERP pattern. These findings suggest that Φ -features are not processed as syntactic elements *per se*, but could be treated as critical cues for performing a task, either sentence-level computations (triggering LAN) or out-of-sentence metalinguistic judgments that could be accomplished comparing morpheme values at a lexical level (triggering N400). Interestingly, when presented with determiner–noun word pairs, which constitute a basic syntactic unit (a noun phrase), a negativity evident in both frontal and posterior areas of the scalp was reported. Also, Munte and Heinze (1994) presented pronoun–verb word pairs (that could be read as a sentence, *you-write*) reporting an anterior distributed effect for morphosyntactic violations in German. These findings support the idea that basic morphosyntactic analysis best correlates with anterior negativities around 350 msec.

At the sentence level, the early negativity has a frontal portion (that is usually left-lateralized in the scalp,⁴ indexing basic syntactic processes), which can extend to more central and posterior areas depending on the amount of non-syntactic information that is needed to process the mismatch: in fact, if agreement depends on features that cannot be extracted by the morphophonological properties of the target constituent but require lexical access (as in the case of Gender opaque nouns or adjectives in Hebrew: Molinaro et al., 2008a; Deutsch and Bentin, 2001), the negativity could extend also to more central areas of the scalp; also, agreement processing could trigger the activation of discourse-level representations that have not been instantiated at the clause level (as for the Person mismatch) and a more posterior negative effect could be recorded.

5.2. The P600s

Later (around 500–750 msec), the early P600 effect shows interesting modulations based both on the Gender properties of the noun triggering agreement (grammatical or biological Gender), and on the involvement of the Person properties (Number mismatches involving first/second vs third Person). This stage of processing has been suggested to represent integration efforts between the presently processed elements and the previous context, based on semantic and syntactic information (Kaan et al., 2000), diagnosis processes (Carreiras et al., 2004), or access to discourse-related information (Kaan and Swaab, 2003).

In a recent study, we presented Spanish speakers with morphophonological mismatches that are, however,

⁴ It is worth noticing that we are interpreting the ERP effects based on the scalp distribution. For example, the main spatial mode of the difference wave of the LAN is left anterior on the electrodes, but that does not mean that the differential activity comes from a left frontal source location. It could easily come from anterior temporal lobes, for example (Service et al., 2007).

syntactically acceptable (Mancini et al., in press). These structures are known as Unagreement patterns: in the example (12a) the sentence presents an apparent Person mismatch in the values expressed on the subject (third Person plural) and verb (first Person plural, but the verb is syntactically acceptable also with second Person).

12a. *Los periodistas* _{3rd.plu} *trabajamos* _{1st.plur} *mucho*.

12b. *Los periodistas* _{3rd.plu} *trabajaron* _{3rd.plur} *mucho*.

Journalists work hard.

These structures are licit in Spanish, and they are interpreted assigning the value of the verb to the lexical subject (in English it would be *We journalists work hard*). We found a reduction in the amplitude of the earlyP600 compared to a control syntactic condition that did not show any inflectional mismatch. Unagreement patterns (12a) require the interpretation of the Person value in the verb position *without* integrating it with the morphological properties expressed by the noun in subject position. Somehow, the system has to inhibit the integration of the verb feature with the ones expressed on the previous noun, while this integration process has to be pursued for the control condition (12b). This suggests that the earlyP600 interval represents integration processes at work also during normal full agreement computations.

More specifically, this earlyP600 interval would correlate with a stage of processing in which, after an initial identification of the structurally related constituent (sensitive to morphophonological cues, Wagers et al., 2009), the target element is integrated within a structurally organized sentence representation. This sentence-level representation would not only depend on syntactic information (such as the matching of Φ -features), but also on semantic and discourse-level information that has been shown to increase the earlier phase of the P600 (see Bornkessel-Schlesewsky and Schlesewsky, 2008; Kuperberg, 2007).

LateP600 modulations have been reported independently from the earlier ones. It has been suggested (Barber and Carreiras, 2005; Molinaro et al., 2008a) that the modulation of the amplitude of the lateP600 effect may evidence the ease with which the parser can go back to the previous processing stages in order to re-access the information necessary to fix the anomaly: a deeper reanalysis would imply the access to more and more superficial features such as the one required by Gender compared to Number features (Barber and Carreiras, 2005), for phonotactics compared to Gender in Molinaro et al. (2008a). Repair processes would be performed on-line in order to pursue a single coherent representation of the sentence structure (for a detailed description of repair mechanisms see Molinaro et al., 2008b, 2011; Vespignani et al., in preparation).

the Φ -feature (Number, Person, Gender) under investigation should be selected carefully: features vary on the dimension of the values expressed, and on the type of constituents where agreement is realized. For example, the selection of the value changes the type of computation induced by Person agreement mismatches, which may trigger the access to qualitatively different discourse-level representations such as the speech-act role of the participants (see Silva-Pereyra and Carreiras, 2007 compared to Mancini et al., submitted for publication). These results apparently agree with the predictions of the Feature Hierarchy hypothesis (Carminati, 2005; Silverstein, 1985) that assigns a different status to the different features, in the sense that each feature could trigger qualitatively different processing difficulties based on its intrinsic nature. In this critical review, however, it is important to consider the whole stream of processing, distinguishing between early (LAN/N400) and late (early and lateP600) ERP effects.

In fact, if we consider the early time window (LAN/N400), we cannot identify an idiosyncratic effect for each feature: the earlier effect can vary in topography within a feature if the values of that feature are experimentally manipulated. In addition, the early effect does not modulate in latency or polarity. The common denominator of the different feature violations is the LAN, a component that seems consistently correlated with the basic syntactic analysis of incoming constituents and the morphosyntactic information they express. In this view, inflectional information could be sufficient to determine the agreement process if there is a direct mapping between the inflectional morpheme and the value expressed in that target constituent. In these cases a mismatch usually triggers a LAN.

Otherwise, if access to lexical representations is required to resolve the agreement mismatch, an additional N400 is likely. This depends on the constituent where the agreement dependency has to be established: a LAN response extending also in areas more typical for a N400 was recorded in fact for Gender violations on nouns that could be also opaque or irregular. Similarly, if Gender values are marked in the constituent stem (as in Hebrew adjectives), they have to be extracted by the lexical stem. Also, Person mismatches could trigger difficulties in activating more complex metalinguistic knowledge at a discourse-level. However, if all these (discourse-level and lexical) factors are taken apart, there seems to be no difference (and consequently no hierarchy) in the cognitive computation of the different features, at least in the earlier stage of processing, which is not in line with what the Feature Hypothesis would predict.

On the other hand, interesting differences emerge in the P600 time windows. As suggested by Faussart et al. (1999), differences in the processing of features can be detected in the later stages of processing. Person violations elicit increased earlyP600 components (Mancini et al., submitted for publication; Nevins et al., 2007; Silva-Pereyra and Carreiras, 2007) compared to Number violations. It could be argued that this difference, and in particular the direction of this difference supports the higher cognitive relevance for the Person feature compared to Number. However, assuming this directionality, when comparing Number and Gender we should expect more processing difficulties for the former

6. Theoretical implications

6.1. Evaluation of the Feature Hierarchy hypothesis

In the present paper we analyzed the ERP findings on agreement processing. We showed that when studying agreement,

compared to the latter. In contrast, Barber and Carreiras (2005) reported the opposite pattern in the lateP600, with a larger effect for Gender compared to Number: apparently, Gender violations are more difficult to reanalyze compared to Number feature (in line with Faussart et al., 1999). These findings support the proposal that repair routines are differently recruited by the different features: however, if a feature hierarchy could be sketched at this point based on the amplitude of the P600 effects, Person and Gender violations are apparently more difficult to reanalyze than Number violations.

A possible solution was offered by assuming the backward step reanalysis model proposed by Faussart et al. (1999): the more the system has to regress to a previous stage of processing to perform reanalysis, the larger is the lateP600. In this frame, Gender processing would be performed at an earlier stage (lexical) compared to Number (a feature that independently combines with the lexical stem, see Ritter, 1988). However, also if we follow this argument, it is unclear why Person violations (activating discourse-level representations) would elicit larger lateP600 compared to Number (Mancini et al., submitted for publication; Silva-Pereyra and Carreiras, 2007).

Summarizing, while there seems to be dissociation among features based on the neurocognitive resources invested to reanalyze agreement mismatches, this dissociation is not in line with the Feature Hierarchy (Person > Number > Gender; Harley and Ritter, 2002; Silverstein, 1985). Alternatively, it could be the case that less processing difficulties (as mirrored by the lateP600) are elicited by Number violations just because the re-interpretation of a mismatch involves re-processing of the morphological inflection of the trigger, while Person and Gender (as Phonotactic) violations require the re-interpretations of representations that are not only confined to the inflectional morphology of the trigger.

Overall, ERP findings on agreement do not clearly support the saliency Feature Hierarchy proposed by Carminati (2005) and De Vincenzi (1999) at a cognitive level. Nonetheless, the nature and properties of each Φ -feature could trigger qualitatively distinct processing routines.

6.2. Processing agreement in sentences

In the present paper we report evidence confirming the generally accepted idea that the process underlying the LAN effect represents basic syntactic processes focused on morphophonological cues. An agreement relation depends on a trigger element (such as, for example, a subject noun phrase) and a following target element (such as the following verb): if the inflectional morphology of the target constituent does not match with the value expressed in the trigger constituent, a LAN is found (as already suggested by neurophysiologically-based approaches: Bornkessel and Schleewsky, 2006; Friederici, 2002; Hagoort, 2005; Ullman, 2001). However, there are some constraints that should be met.

- First, the value of the *target* element has to be transparent, otherwise the cognitive system has to recruit further lexical information to resolve the agreement dependency, as for Gender opaque nouns and adjectives in Hebrew. In those

cases, a N400-like response would index the recruitment of higher-level representations compared to the information expressed by the functional morphology of the target word.

- Second, the Φ -value should be superficially expressed on the initial *trigger*: it is not the same to consider the value of the noun in subject position and the value of the whole subject, since only the former could be inflectionally marked. It appears that a value inflectionally expressed on the trigger is critical for eliciting a LAN (as shown by the plural conjoined subject case in Italian). It would be interesting to evaluate LAN behavior when the trigger shows opaque Gender.
- Third, it appears that an 'anchoring' representation should be available in the *trigger–target* pattern. Formal linguistic theories (Chomsky, 1981, 1995; Pollard and Sag, 1994) assume that a feature has to be semantically interpreted, since it refers to an anchoring value. Gender and Number abstract feature representations can be interpreted from noun morphology. However, consider the case of Person disagreements in Spanish (Mancini et al., submitted for publication): if the verb makes reference to the speech act (either first or second Person) that was not referred to by the subject (a third Person subject), the processing system cannot anchor the Person feature expressed by the verb (speech participant) to the available representation activated by the subject (non-speech participant).

As a consequence of these constraints, it appears that syntactic analysis (correlating with the LAN modulation) is sensitive to cues that are expressed (marked) in the *functional morphology* of both agreeing constituents (see Wagers et al., 2009). Following some hypotheses about active predictions as the possible underlying processes of these early components, the identification of the morphologically expressed feature may well trigger an active expectation for a following constituent showing the same value. For instance, a determiner triggers an expectation for a noun, while a noun triggers an expectation for a verb. This expectation is syntactic in nature, to create syntactically well-structured sentence representations. Critically, the build-up of the syntactic tree depends also on the covariation of the trigger/target Φ -features. More specifically, a feature expressed by the functional morphology of a trigger would initiate a search for a target constituent with a matching feature. If the features are expressed formally, as functional morphemes attached to lexical stems, the cognitive system could rely just on those cues to satisfy the agreement expectation, and establish the syntactic relation (without accessing non-functional information). When the value expressed on the expected constituent does not match, a LAN is triggered.

The claim that the LAN is the correlate of active syntactic expectations for a morphosyntactically related constituent is just a hypothesis (for a cue-retrieval approach see Wagers et al., 2009). However, this component emerges in the same time interval as the N400, a component that is assumed by many researchers to represent lexical predictive processes triggered by semantic contextual information (Federmeier, 2007; Lau et al., 2008). This parallelism between the two early negativities is suggestive of similar predictive processing mechanisms, that are however sensitive to different linguistic

properties. Consistent with this argumentation, an MEG study in Finnish by Service et al. (2007) reported similar dipolar sources around 400 msec for morphosyntactic and semantic violations. The dissociation between morphosyntactic and semantic negativities elicited in the two conditions was due to a different contribution of the two hemispheres: while the N400 effect showed similar power in the two hemispheres, the LAN effect was predominant on the left side. However, on the left side dipole locations were similar for the two manipulations (but see data on aphasia in Section 3.2).

As discussed before, under some specific circumstances, ‘pure’ LAN effects are not found (Barber and Carreiras, 2003, 2005; Deutsch and Bentin, 2001; Mancini et al., submitted for publication; Molinaro et al., 2011). In the absence of decomposable functional morphemes recognizable in the target element or in the absence of the expected anchoring value for that feature, the system has to rely on additional non-syntactic resources to resolve the agreement relation. In those cases the LAN counterpart is still triggered (since agreement still concerns syntactic relations), but an additional central negativity can be found, indexing the recruitment of additional neural populations (that store lexical, semantic and discourse-level information).

This approach brings us to a novel point of view on the processing of agreement, which has been classically treated by cognitive models as an encapsulated phenomenon, purely syntactic in nature (Frazier and Clifton, 1996; Frazier and Fodor, 1978; Friederici, 2002; Grodzinsky and Friederici, 2006; Hagoort, 2005; Ullman, 2001; Vosse and Kempen, 2000). In this review we have stressed the fact that morphosyntactically-based agreement operations are *always* processed on a syntactic basis, but they could require access to qualitatively different types of representations (lexical or discourse-level) depending on the agreement pattern that has to be resolved.

Critically, we are not claiming that every type of representation (formal, semantic and discourse-level information) counts for agreement processing at the same level. Findings from Barber et al. (2004) are interesting in this regard. In that study, the authors manipulated the nature of the Gender feature expressed on the trigger noun in subject position, in that it could be either a pure grammatical feature (*far-o*, lighthouse) or more semantic, expressing the biological Gender of the referent (*abuel-o*, grandfather). Critically, in both cases, Gender features were transparent both on the target and the trigger. The authors reported a LAN time-locked to a following mismatching adjective in both cases, without reporting any interaction between the grammaticality and the animacy manipulation (either in the early or in the late stages of processing). This suggests that agreement dependencies are processed focusing primarily on the functional morphology of the trigger/target pair. Only in cases where this information is not completely transparent, could the cognitive routines involved in agreement processing recruit further non-syntactic information to deal with the structural relation.

7. Future directions

Agreement processing needs to be further explored: there are still many gaps to fill. For example, although a large number of

papers have been devoted to Number agreement, no study until now has focused on the qualitative distinction between the values that express Number. Some theoretical proposals (Eberhard et al., 2005) in fact have stressed the qualitative distinction between singular and plural, suggesting that the latter feature is a marked version of a (singular) default version of a noun as it is stored in the mental lexicon (morphophonologically marked, for example, in English and Spanish with the final -s, see also Bock and Eberhard, 1993; but see Sauerland, 2008). So far, most ERP studies have collapsed in the same condition singular and plural versions of a Number agreement mismatch. However, since plural is a more complex feature (it could be expressed as dual, trial or paucal across word languages) than singular (see also Kennison, 2005), we could expect different effects on agreement processing depending on the markedness of the triggering element.

In addition, the distinction between mass (*water*) and count (*chair/-s*) nouns could be relevant for agreement processing: recent ERP findings have shown that processing of these two categories of nouns could have early effects in the N150 (Mondini et al., 2008). The mass/count dimension thus showed earlier effects than the components related to agreement processing, and could have a measurable impact on these latter components.

Crucially, a within-subject evaluation of the processing of agreement with either transparent versus opaque grammatical Gender or grammatical versus biological Gender on nouns has not been published. Based on the data points that have been collected until now, the detection of a Gender violation on an opaque noun, compared to a transparent noun should elicit a more centrally distributed negativity as compared to the LAN. In addition, if Gender is extracted from the lexical properties (of opaque nouns) the effect should be sensitive to the lexical frequency of the target constituent. These few examples show that more has to be done to understand better the neural mechanisms involved in agreement processing and their relation with more general (non-syntactic) language comprehension routines.

One critical dimension where agreement studies need to extend to concerns generalization across languages. For example, there are few studies that organically disentangle feature processing across agreement patterns in case-marked languages. For example, Zawiszewski and Friederici (2009) presented interesting data from Basque, a particularly interesting case-marked language that presents object–verb agreement patterns. Interestingly, these authors reported a N400 followed by a P600 for object–verb agreement violations; however, in this study Number and Person features were not manipulated independently. Thus, it is still unknown how these two features could be represented at a neurocognitive level in Basque speakers. In addition to Basque, there should be more studies that examine historically-unrelated languages; almost all the studies listed in Table 1 are Germanic or Romance, except for single studies on Finnish, Hindi and Hebrew.

As noted above, the studies on agreement have mainly focused on the processing of agreement violations, discussing the comparison between violation and control. Although the emerging findings have a heuristic value, more focus should

be placed on new experimental paradigms to be able to better evaluate the findings discussed in the present review.

Finally, more studies have to be designed to understand the nature of the ERP components that are discussed in the present paper. For example, we have proposed that the LAN represents the correlate of an active predictive process based on relevant syntactic information (such as surface cues), but we cannot exclude that it represents the reactivation in working memory of a previous sentence constituent involved in the agreement dependency based on the surface cues (a relevant phenomenon in agreement, see Wagers et al., 2009). These two proposals have different cognitive implications, since the first one states that while comprehending, active expectations could already offer a structural frame to interpret incoming linguistic information, while the latter proposal offers the idea of a limited amount of (working memory) resources that could be recruited to disentangle sentence-level dependencies.

The two proposals are not completely at odds however, in the sense that language comprehension could rely on a dynamic interaction between information that is partially pre-activated and information stored in working memory. Interesting findings on the role of working memory for syntactic processing are reported by Vos et al. (Vos et al., 2001; Vos and Friederici, 2003). For example, Vos and Friederici (2003) presented complex object-first relative clauses and even more complex object-first complement clauses to readers with individual differences in working memory. While low-span readers did not show any structure effect, high-span readers revealed a main effect of structure (subject- vs object-first) in the early stage of the P600. Thus, while the LAN would better correlate with syntactic-based expectations, the early P600 would represent the reactivation of relevant contextual information to operate a structural integration of the processed constituent with the context. Future research should investigate the balance between these two types of information, and agreement patterns could represent a critical tested in this line of research.

8. Conclusions

Agreement features have been always considered in the psycholinguistics literature as purely formal cues; those cues would be computed by the neurocognitive system through processing routines that are syntactic in nature and are sensitive to values expressed by small linguistic units (functional morphemes) that only play a functional role. This perspective reflects the proposal of formal linguistic theories (Chomsky, 1981; Pollard and Sag, 1994) that have only focused on the syntactic role of agreement relations. Similarly, many models have proposed that agreement relations are analyzed by an encapsulated stream of processing that is exclusively syntactic in nature.

In this review we have dissociated the syntactic nature of agreement dependencies, e.g., their role in structuring the relations among words in a sentence, from the on-line processing of these dependencies. The product of agreement computation is the syntactic structure of the message, but this product could be achieved by also accessing non-syntactic

cognitive representations. Furthermore, agreement Φ -features do not trigger syntactic processing *per se*, since the information they refer to concerns the intended message, but are computed as functional cues when transparently expressed throughout a sentence.

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