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Do discourse global coherence and cumulated information impact on sentence syntactic processing? An event-related brain potentials study

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ABSTRACT

The present study aimed at exploring how two main primarily semantic factors of discourse comprehension, namely global coherence and amount of information cumulated across a passage, may impact on the sentential syntactic processing. This was measured in two event-related brain potentials (ERP) to grammatical (morphosyntactic) violations: anterior negativities (LAN) and posterior positivities (P600). Global coherence did not yield any significant effects on either ERP component, although it appeared advantageous to the detection of morphosyntactic errors. Anterior negativities were also unaffected by the amount of cumulated information. Accordingly, it seems that first-pass syntactic processes are unaffected by these discourse variables. In contrast, the first portion of the P600 was significantly modulated (increased) by the latter factor. This probably reflects bigger efforts to combine sentential information during situations highly demanding for working memory. Our results would suggest that processes involved in global discourse coherence appear relatively independent of the on-line syntactic and combinatorial mechanisms reflected in the LAN and the P600 components of the ERPs.

1. Introduction

Reading a sentence is a complex process in which several types of information concur and have to be analyzed in very short time. One of the open debates in psycholinguistics concerns how conceptual/semantic and syntactic information exactly interplay during these processes. In this regard, several models have been proposed on the nature and functional characterization of syntax and semantics. On the one hand, strongly modular models assume that informationally encapsulated, and at least partly sequential processes, construct distinct syntactic and semantic representations of the

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sentence (e.g., Ferreira and Clifton Jr., 1986). On the other hand, fully interactive models suggest that syntactic and semantic constraints interact directly and simultaneously with each other in this process (e.g., McClelland et al., 1989). In between, intermediate perspectives also exist, differing in the degree of independence and prevalence attributed to the semantic and the syntactic domains (e.g., Kim and Osterhout, 2005).

The high temporal resolution of event-related potentials – ERP – and their suitability to approach linguistic processes as they unfold over time, make them ideally suited for studying sentence processing. Indeed, distinct ERP components have been described that substantiate the distinction between syntactic and semantic processing. In the syntactic domain, the main ERP effects are anterior negativities and posterior positivities. The former, typically labeled as LAN – left anterior negativity – after their leftmost usual distribution, peak roughly between 250 and 550 ms, although the so-called ELAN – early LAN – may appear as early as 100–200 ms. Word category violations are the variations most frequently associated with ELAN (e.g., Friederici and Mecklinger, 1996), whereas other grammatical anomalies, including morphosyntactic violations (e.g., Coulson et al., 1998), usually elicit a LAN. Anterior negativities may reflect highly automatic first-pass parsing processes, the detection of a morphosyntactic mismatch, higher syntax working memory load, and/or the inability to assign the incoming word to the current phrase structure (Friederici, 2002; Gunter et al., 1997; Kluender and Kutas, 1993). Regarding the posterior positivities, a late positive component peaking at parietal sites and labeled P600 has classically been considered as a syntax-related ERP fluctuation, since it is typically elicited by syntactic violations and structurally ambiguous but correct sentences (Frisch et al., 2002; Osterhout and Holcomb, 1992). Accordingly, the P600 would indicate increased syntactic processing costs due to revisions and reanalyses of sentential structural mismatches, possibly also reflecting subsequent repair processes (Münte et al., 1998). The occasional P600 deflections to semantic violations (e.g., Kuperberg et al., 2003; Kolk et al., 2003; Hoeks et al., 2004; Kim and Osterhout, 2005) have also motivated an alternative interpretation of the P600, such as the reflection of the activity of a combinatorial system that integrates both semantic and syntactic information (Kuperberg, 2007), or a domain-general monitoring mechanism (Kolk and Chwilla, 2007).

Concerning the semantic domain, a systematic finding is the so-called N400 component (Kutas and Hillyard, 1980), a negative fluctuation resembling the LAN in latency and usually peaking at central and posterior sites (Kutas and Besson, 1999). Some authors have proposed that the N400 reflects post-lexical integration processes (Chwilla et al., 1995). An alternative perspective, however, characterizes the N400 as indexing the efforts of accessing long-term multimodal lexico-semantic memory (Kutas and Federmeier, 2011).

The distinction between syntax- and semantics-related ERP, however, has not been demonstrated to be unequivocal. As mentioned, particular semantic manipulations have been able to yield modulations in components typically considered as syntax-related. Similarly, syntactic manipulations in certain experiments have been able to modify the typical semantic N400 component (e.g. Bornkessel et al., 2004; Choudhary et al., 2009; Haupt et al., 2008). Despite these exceptions, nevertheless, the overall distinction and assumptions for these components still hold and are highly valuable in the study of language comprehension.

A large body of evidence from the ERP seems to support a "syntactocentric" view, in which syntactic information would be highly encapsulated, prevailing over and affecting semantic processing with no influence in the opposite direction (e.g., Friederici, 2002, 2004). This view is largely supported by studies using double violations – containing both syntactic and semantic anomalies simultaneously – usually yield an ELAN or a LAN and a P600. In these manipulations the N400 is either absent (e.g., Friederici et al., 1999) or significantly modulated – for example, boosted (Hagoort, 2003). However, several studies have also reported no effects of syntactic manipulations on semantic processing (e.g., van den Brink and Hagoort, 2004), or even a "semantocentric" direction of the effects (e.g., Gunter and Friederici, 1999; Martín-Loeches et al., 2006, 2012), demonstrating that semantic information may actually prevail or at least modulate syntactic processing under certain circumstances. A relevant line of research studying the syntax–semantics interplay has used pseudowords or "jabberwocky" sentences (Carroll, 1883) to create contexts devoid of semantic content. Results suggest that in jabberwocky sentences, as in normal sentences, it is possible to perform an early syntactic processing – reflected in the presence of anterior negativities – followed by a blocking of subsequent semantic integration processes in case of syntactic anomaly, this presumably supporting the syntactocentric view (Hahne and Jescheniak, 2001). Even though, the neural substrates of the syntactic processing in jabberwocky sentences might not be exactly the same as in regular ones because of a different distribution of the effects (Canseco-Gonzaléz, 2000; Yamada and Neville, 2007). Further, amplitude reductions of the P600 for jabberwocky in comparison to regular sentences (Canseco-González, 2000; Münte, 1997; Yamada and Neville, 2007) have led some authors to suggest that the P600 may be reflecting processes of reanalysis in which both syntactic and semantic domains interplay; the absence of semantic information would prevent the linguistic system from performing these reanalyses.

The debate on the interplay between syntax and semantics reviewed above might turn out yet more complicated when dealing with discourse comprehension. This approach actually enables a more ecologically valid and natural situation than the typical use of single, unconnected sentences. Discourse processing involves a number of active processes normally absent or much reduced during single, isolated sentence processing. In this regard, both information provided by the text – or utterance – and from long-term memory are brought by the reader – or listener – to interplay during discourse comprehension, yielding a mental representation of the described situation, i.e., a "mental model" or "situation model" (Johnson-Laird, 1983; van Dijk and Kintsch, 1983). At this level, readers or listeners activate knowledge that goes beyond the text, filling-in gaps and running mental models by means of inferences (Kim et al., 2012). Discourse coherence is built as based on the semantic connections between its elements – propositions and inferences (Wolfe, 2005).

In addition to inferential processes and coherence building, both tapping on cognitive system's resources, discourse comprehension would also increase working memory demands by gathering a progressively increasing amount of information as the narrative unfolds. Working memory is actually needed to establish links between temporarily distant parts of the sentence and, thus, for appropriate syntactic processing. In this regard, several studies have proved the influence of working memory load and individual working memory capacity on syntactic processing (e.g., King and Kutas, 1995; Martín-Loeches et al., 2005). Classical models of language working memory pondered whether there is a common pool of working memory resources for both linguistic operations – including syntax – and the maintenance of extracted information (Just and Carpenter, 1992) or whether separate stores exist for these processes (Waters and Caplan, 1996). More recent proposals (e.g., Lewis et al., 2006) posit that language working memory exhibits common features with other working memory domains, such as interference by stored information and time-dependent decay, and suggest that linguistic combinatorial processes, including syntax, might be affected by other not strictly linguistic processes. Very recent contributions have reported that morphosyntactic features are importantly affected by information stored in memory during cumulative retrieval-encoding cycles (Service and Maury, 2015). Overall, it seems that the amount of cumulating information across a narrative might openly affect syntactic processes.

Interestingly, coherence seems to strongly interact with the amount of information that can be remembered from a narrative. Bransford and Johnson (1972) and Dooling and Lachman (1971) found that paragraphs devoid of global coherence – series of disconnected propositions – are difficult to remember. Indeed, global coherence effectively doubles the number of words and propositions that readers can recall from them, a result that has been frequently replicated (e.g., Martín-Loeches et al., 2008; St. George et al., 1999). In line with this, narrative shifts during story comprehension the appearance of new characters, locations, actions, or time importantly involve extra processing efforts (Whitney et al., 2009). Accordingly, it seems that coherence reduces the processing demands for the encoding, storage and/or retrieval of information cumulated during discourse comprehension.

All of these processes – inferences, coherence building, and cumulating information – primarily pertain to the semantic domain (Frank et al., 2007; Kim et al., 2012; Kintsch, 1988; Kintsch et al., 1990). Indeed, a number of studies have reported a significant impact of discourse features on local – sentence-related – semantic processing as reflected by modulations in the N400 component, evidencing the immediate availability and relevance of this information during sentence comprehension (e.g., Van Berkum et al., 2005; Yang et al., 2013). It is not well understood however whether and how these semantic discourse features might impact syntactic processing. As outlined earlier, under certain circumstances semantics may importantly modulate and even prevail over syntactic processes and, hence, the impact of discourse features on syntax processing is an open and tenable possibility. The goal of this study is to survey on this matter.

In the present study, we manipulated two main discourse features, coherence and amount of cumulated information, in order to explore their impact on sentence syntax processing as reflected in the LAN and P600 components of the ERP. To this aim, we embedded morphosyntactic violations – gender or number disagreements – into two kinds of passages consisting of either whole coherent stories or incoherent sets of randomly scrambled sentences. Participants were requested to memorize as much as possible of each passage to reproduce it verbally afterwards. This way, cumulated information would mainly vary as a function of whether the morphosyntactic disagreement appeared in either the first or the second half of a passage.

Specific predictions would largely depend on the assumptions undertaken for the several factors involved in language processing, as outlined above. In this regard, a syntactocentric view of the syntax–semantic interplay during sentence comprehension would certainly dismiss the possibility that discourse – mainly semantic – features could affect the highly encapsulated syntactic processes. This would be reflected in no modulation at all of either the LAN or the P600 components subsequent to morphosyntactic violations. The contrary would be the case, however, under a more interactive – or less syntactocentric – view, according to which the LAN, the P600, or both, might be modulated by discourse coherence and/or amount of cumulated information. As can be appreciated, the results of the present study should have implications for a number of controversial issues concerning language processing, while additionally making use of a procedure of greater ecological validity than traditional approaches based on the processing of single, unrelated sentences.

2. Results

2.1. Performance

2.1.1. Accuracy

The overall mean percentage of correct grammatical judgments was 87.4%. An ANOVA revealed neither significant effects of Grammaticality (88.43% for correct vs. 86.55% for incorrect; $F(1, 23)=0.71$, $p>0.1$), nor of Position (89.26% for the first half vs. 85.75% for the second; $F(1, 23)=2.62$, $p>0.1$). In turn, there were significant effects of Coherence on the accuracy measures ($F(1, 23)=8.43$, $p<0.01$) with a higher percentage of correct judgments in coherent paragraphs (89%) compared to the incoherent ones (85.9%). Accuracy measures did not yield significant interactions.

2.1.2. Reaction times (RTs)

RTs were affected by Grammaticality ($F(1, 32)=32.8$, $p<0.001$), meaning that faster responses were obtained in the incorrect sentences (mean: 508.45 ms) relative to correct ones (556.30 ms). No main effects on RTs were found for Position ($F(1, 23)=0.085$, $p>1$), nor for Coherence ($F(1, 23)=0.984$, $p>1$), and no interaction resulted significant.

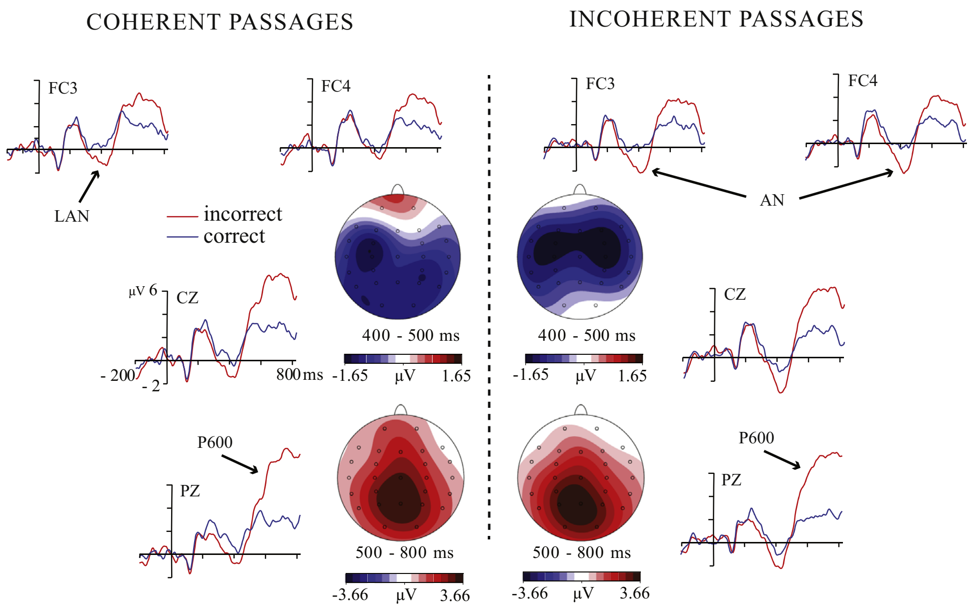

Fig. 1 – ERP to morphosyntactically correct and incorrect words as a function of the presence (left) or absence (right) of global coherence in a passage. ERP waveforms are represented at selected electrodes; difference maps (incorrect minus correct) correspond to the anterior negativities and the P600 effects.

Table 1 – Main ANOVA of ERP results.

	d.f.	Window (ms)				
		300–400	400–500	500–600	600–700	700–800
Coherence	1, 23	–	11.7**	8.9**	–	–
Coherence × Region	6, 138	–	4.6**	3.3*	–	4.8**
Position	1, 23	–	–	–	–	–
Position × Region	6, 138	–	–	3.3*	3.1*	–
Grammaticality	1, 23	10.5**	17.4***	–	42.6***	44.1***
Grammaticality × Region	6, 138	–	–	4*	12.7*	20.4***
Coherence × Position	1, 23	–	–	–	–	–
Coherence × Position × Region	6, 138	–	–	–	–	–
Coherence × Grammaticality	1, 23	–	–	–	–	–
Coherence × Grammaticality × Region	6, 138	–	–	–	–	–
Position × Grammaticality	1, 23	–	–	4.3*	9.3**	–
Position × Grammaticality × Region	6, 138	–	–	–	–	–
Coherence × Position × Grammaticality	1, 23	–	–	–	–	–
Coherence × Position × Grammaticality × Region	6, 138	–	–	–	–	–

F-values with *p* (*=.05, **=.01, ***=.001). Only significant results are reported.

2.1.3. *Recall task*

The results in the recall task showed strong main effects of the factor Coherence ($F(1, 23)=246.33$, $p<0.001$), revealing that participants found it much easier to recall the ideas belonging to the coherent passages (mean: 65.04 idea units, SD: 14.8) than those embedded in the incoherent ones (mean: 34.55 idea units, SD: 13.3). The factor Position (first vs. second half) of the idea unit was not significant alone ($F(1, 23)=0.10$, $p>1$), neither in interaction with Coherence ($F(1, 23)=0.31$, $p>1$). For the recall task, we were only interested on the effects of Position and Coherence over the amount of idea units remembered, independently of their grammatical correctness. Therefore, we did not introduce Grammaticality as a factor in the statistical analyses.

2.2. *Electrophysiological results*

Visual inspection of the ERP revealed that the main effects of Grammaticality in the coherent condition – Fig. 1, left – consisted in a negativity maximal at left fronto-central leads and peaking around 430 ms. This might be interpreted as a left anterior negativity – LAN – although its distribution extended somehow posteriorly, which is within the normal range of LAN topographies (e.g., Kaan, 2007; Kutas et al., 2006). A posterior positivity – P600 – followed around 720 ms. In the incoherent condition – Fig. 1, right –, the anterior negativity appeared rather larger and bilateral. On the contrary, the coherent condition yielded a bigger P600. Statistical analyses – Table 1 – confirmed a significant effect of Grammaticality in two intervals: 300–500 ms and 600–800; and

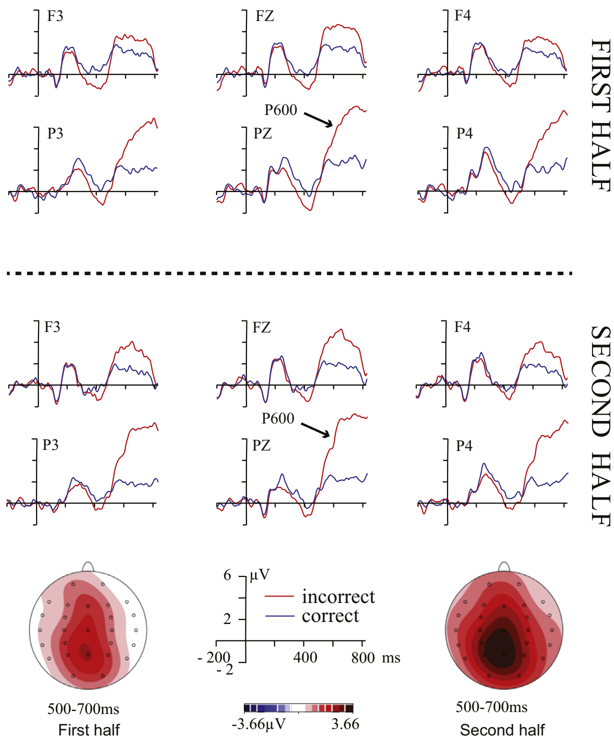

Fig. 2 – ERP to morphosyntactically correct and incorrect words as a function of their position within a passage. ERP waveforms are represented at selected electrodes; difference maps (incorrect minus correct) correspond to the initial period of the P600 effects.

of Grammaticality × Region from 500 to 800 ms. Grammaticality, however, did not significantly interact with coherence at any window. Accordingly, even if a trend for significance was found in the corresponding window (400–500 ms) for the interaction between Coherence, Grammaticality and Region factors ($F(6, 138)=2.3$; $p=0.08$), the apparent differences between coherent and incoherent passages in the distribution and amplitude of the anterior negativity would not be supported statistically.

The interaction Position × Grammaticality was significant in 500–600 and 600–700 ms consecutive windows. As can be seen in Fig. 2, this corresponds to larger P600 amplitudes for morphosyntactic violations in the second halves of the passages. A conspicuous result was the presence of main Coherence effects in the time windows from 400 to 600 ms, as well as of Coherence × Region interaction from 400 to 600 ms and 700 to 800 ms. In addition, a trend for significance was found in the window from 600 to 700 ms ($F(6, 138)=2.8$; $p=0.06$). These results would substantiate a long-lasting centro-parietal negativity, visually apparent from about 300 ms until the end of the epoch for words embedded in incoherent passages regardless of their grammaticality or position (Fig. 3). Based upon its timing and distribution, the result might be interpreted as an N400 effect extended over time. Finally, significant effects of the Position × Region interaction were found in the period 500–700 ms. This result – Fig. 4 – corresponds to the simultaneous appearance of a frontal positivity and a posterior negativity for the words in the second half of a passage irrespective of their grammaticality value or coherence of the passage.

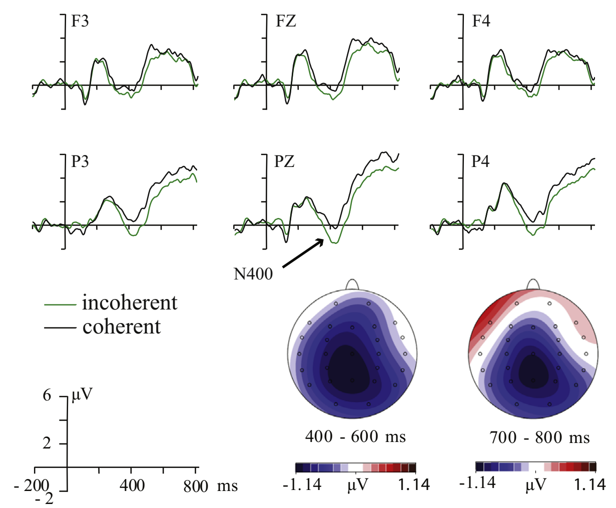

Fig. 3 – ERP to critical words in coherent and incoherent passages. A slow negative fluctuation, interpreted as a long-lasting N400 effect, appeared to words in incoherent passages. ERP waveforms are represented at selected electrodes; difference maps (incoherent minus coherent) correspond to statistically significant windows for this effect.

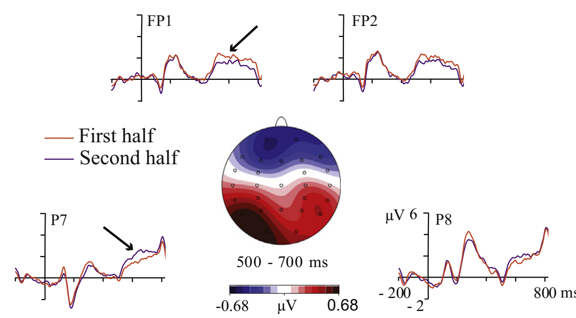

Fig. 4 – ERP to critical words as a function of their position within a passage. Overlapped, ERP waveforms for the first and second halves of the passages are represented at selected electrodes; difference maps (second vs. first half) correspond to the statistically significant windows for this effect.

3. Discussion

We conducted an experiment in order to investigate whether two primarily semantic factors prominent during discourse processing, namely global coherence and amount of cumulated information, are able to impact sentential syntactic processes, as reflected in anterior negativities and posterior positivities typically obtained to morphosyntactic violations. The manipulations were partially successful, yielding observable and differential effects on the ERPs for one of the factors – cumulating information – on morphosyntactic processing, but not for the other – global coherence. Even though, global coherence seemed to affect performance facilitating the detection of morphosyntactic errors.

The presumable incremental demands on working memory across a passage seem to increasingly complicate sentence linguistic processing. In our study, this was reflected in the significant amplitude increase of the initial portion of the P600 to ungrammaticalities occurring in the second half of a passage, as compared to those in the first half. Consequently, our results suggest that the extra processing effort ensuing from increasing working memory demands, regardless of coherence, is able to modulate the structural operations reflected in posterior positivities triggered by morphosyntactic violations.

A contradiction may appear here, however, if one considers that the number of remembered idea units for coherent passages doubled those for incoherent texts; that is, it might appear that more information is cumulated in coherent paragraphs and, therefore, that the latter convey higher levels of working memory load. Nevertheless, in order to explain the absence of interaction between the amount of cumulated information and coherence on the P600 component we assume that working memory demands during the second part of a paragraph might be comparably high – as compared to the first part – in both coherent and incoherent texts. This is explained in the following.

It is not actually well established in the literature what favors better recall in coherent narratives. St. George et al. (1994) explained this effect in terms of memory facilitation by means of the text's macrostructure – absent in the incoherent conditions. The integration of sentences into a superior schema would generate coherence that facilitates subsequent recall. Indeed, the content organization has been considered critical when discussing the limit of working memory. Miller (1956), in his seminal paper already stated that the limit of immediate recall did not relate to the amount of information remembered but to the amount of the meaningful items. On the other hand, differences in working memory performance can be explained by effects occurring either at the encoding, the storage, or the retrieval phases of the task (e.g., Kane and Engle, 2000; Unsworth and Spillers, 2010). It remains unclear however at which of these stages coherence effects on memory are taking place. The proposal by St. George et al. (1994) above seems to point to recall stages, but further research is needed here. Accordingly, in our view there are at least two alternative possibilities underlying our results. One is that coherence effects occur during the recall stage; hence the P600 would not differ as a function of coherence because of a similar amount of idea units stored regardless of coherence. The other possibility is that working memory capacity might be similarly demanded in both conditions notwithstanding differences in the absolute amount of cumulated information. In incoherent paragraphs, even with a lower absolute number of stored ideas, working memory demands would also be high because other processes or elements other than the corresponding working memory store – e.g., the phonological loop, the episodic buffer, or the central executive in Baddeley's (2000) model – could be importantly engaged as well, due to extra efforts necessary to keep information in the absence of a superior schema. That higher cognitive demands arise in incoherent paragraphs has already been suggested (St. George et al., 1994).

It is worthy of mention that we found differential effects of cumulated information on the P600 across time. That is, the effect was visible only in the first portion of the waveform (500–700 ms), while the last one (700–800 ms) resulted unaffected. This type of results supports suggestions that a first stage of the P600 reflects structural reanalysis, while a subsequent stage would relate to structural repair processes (Münte et al., 1998; Hinojosa et al., 2003). Therefore, our results would indicate that reading the last part of a paragraph conveys some difficulties in structural sentence analyses, a consequence of the increased working memory demands.

Our results relative to global coherence of a passage might support some influence on morphosyntactic processing, albeit we cannot be conclusive in this respect. The LAN and the P600 related to the processing of gender and number mismatches occurring within incoherent passages showed no significant differences relative to the coherent ones. This result might be in accordance with Hahne and Jescheniak (2001), who reported no differences in the anterior negativities between regular sentences and jabberwocky sentences, However, other authors have reported that the anterior negativities in jabberwocky sentences may exhibit a different topography (Canseco-González, 2000; Yamada and Neville, 2007). In this vein, our data also showed different topographies, though only supported by a trend for significance. The fact that participants detected more morphosyntactic errors in coherent than in incoherent passages can also add evidence for plausible coherence–syntax interactions. Nonetheless, the problem with this performance measure is that it occurred subsequent to sentence completeness. Consequently, it might be later on and unrelated to the on-line processing of our critical words, this being a reason why no significant effects emerged in either the LAN or the P600 components. Global coherence might therefore improve performance by affecting the processes occurring later during the task, and even these might not be necessarily linguistic – such as processes related to correct/incorrect button press decisions. In our view, further research is needed to better determine in which process – or processes – is text coherence impacting morphosyntactic processing. At present, our data support no noticeable effects of global coherence over on-line syntactic processing.

While contributing to define how discourse-level semantic factors might actually interplay with syntax sentential processing, our findings also entail a number of theoretical implications. As outlined in Section 1, the anterior negativities are primarily obtained to grammatical anomalies or manipulations (Gunter et al., 1997; Barber and Carreiras, 2005), while the P600 can be elicited by both grammatical and semantic anomalies (Osterhout and Holcomb, 1992; Martín-Loeches et al., 2006). First, the fact that incremental working memory demands affect the P600 but not the LAN could indicate that this semantic factor has no influence on the first-pass parsing processes. Second, the greater effect on the P600 for the second half of the passages – highly working memory demanding – harmonizes well with interpretations of this component as reflecting the activity of a combinatorial system integrating semantic and syntactic information in a sentence (Kuperberg, 2007), or a domain-general monitoring mechanism (Kolk and Chwilla, 2007). Therefore, the growing difficulties related with the active maintenance of an increasing amount of semantic information, seem to directly affect the combinatorial processes called by morphosyntactic violations. This is in consonance with Just and Carpenter (1992), who found that keeping the last word of a series of unconnected sentences into working memory significantly affects the processing of subsequent sentences. Our results would be locating these effects on the integrative combinatorial operations reflected in the P600.

It is noteworthy the observation, however, that no effects of coherence were found at all on these combinatorial processes reflected by the P600. This, together with our null results of coherence effects for the LAN component, leads us to suggest that the neural networks underlying global discourse coherence and those beneath the combinatorial processes reflected in the LAN and P600 ERP components during sentence comprehension are far apart and relatively independent of each other. Neuroimaging studies support this claim. While a comparison between incorrect syntactic sentences and correct sentences typically yields main activations in BA 44/45 of the left dorsolateral prefrontal cortex (Hagoort and Indefrey, 2014), the cortical areas most consistently related to discourse comprehension seem restrained to the medial prefrontal and parietal cortices, among others (e.g., Ferstl and von Cramon, 2001, Mar, 2011; Martín-Loeches et al., 2008; Mason and Just, 2009). Our results indicate that both types of neural networks do not seem to interact with each other, nor tap on the same processing resources, at least during on-line sentence processing.

The procedure we employed in this experiment clearly improved ecological validity in comparison to the typical use of isolated-unconnected sentences, although the inclusion of probe questions at the end of every sentence in a passage may be viewed as a shortcoming of our study. Two data strongly support nevertheless the effectiveness of our procedures in creating an experimental situation equivalent to more natural arrangements of discourse processing, in spite of the insertion of probe questions. One is the sound differences in the amount of retrieved idea units as a function of coherence in a passage, results almost doubling for coherent vs. incoherent texts. This is clearly in consonance with previous studies using narratives without intertwined probe questions (e.g., Bransford and Johnson, 1972; Dooling and Lachman, 1971; Martín-Loeches et al., 2008; St. George et al., 1999). The other is our finding of a negative long-lasting centro-parietal fluctuation for words in incoherent passages, interpreted as an N400 and previously reported in experiments with more natural discourse presentations in ERP contexts (e.g., St. George et al., 1994). This fluctuation would in turn suggest that the semantic processing of words – lexical access or post-lexical integration – is facilitated by coherence in a discourse (in line with St. George et al. (1994)), and would provide evidence that discourse factors convey important semantic modulations at the sentence and word levels (e.g., Yang et al., 2013).

It is also worth mentioning that coherence and cumulated information did not interact, even if in a first sight it might appear that both factors could at least be partially related. The data showed nevertheless that this is not actually the case, that both factors can be manipulated independently. Indeed, coherence is a factor that may or may not be present since the very beginning of a coherent paragraph, particularly considering that our data analyses always started with the second sentence of a paragraph. Coherence is a property of the paragraph that continues along the whole passage without necessarily increasing – or decreasing – in quantitative terms, at variance with cumulated information. Indeed, coherence would already occur between the second – our first analyzed sentence – and the first sentence in a coherent paragraph, keeping this condition unaltered along the continuing of the narrative. That coherence is a factor independent of the length of a passage is also supported by the fact that several studies have approached coherence using only pairs of sentences (e.g., Ferstl and von Cramon, 2001). By looking at our examples in Supplementary Appendix 1, it can be verified that the second sentence in a paragraph is already coherent in the coherent paragraph, while the opposite is true in the incoherent passage. Coherence is kept in an all-or-none fashion throughout the remaining of the paragraph. Cumulated information, in turn, increases along the passage by necessity.

Finally, it remains to be commented the interaction of Position by Region between 500 and 700 ms. This corresponded to small fluctuations of negative polarity at anterior leads and positive at posterior ones, for words of the second half of a paragraph, as compared to the first – Fig. 4. This effect was independent of Coherence and Grammaticality, and is probably mainly reflecting absolute increases in memory load as a function of cumulating larger amounts of information across a passage. This in turn is in consonance with previous reports for memory load effects for different types of information (e.g., Mecklinger and Pfeifer, 1996; Ruchkin et al., 1990).

We have been able to find neurophysiological modulations of discourse-related cumulating information in on-line sentential syntactic processes, but not of global coherence. On the one hand, larger the amount of information cumulated along a discourse, larger the amplitude of the initial portion of the P600. This modulation could indicate bigger efforts to combine sentence information subsequent to incremental working memory demands unfolding throughout a passage. On the other hand, the semantic coherence of a passage does not seem to have an influence on on-line morphosyntactic processing, which might be suggesting that the processes involved in global coherence appear relatively independent of the syntactic and combinatorial mechanisms supporting on-line sentence comprehension depicted by the LAN and the P600 ERP components. Both machineries probably relate to discretely separate neural systems.

4. Experimental procedures

4.1. Participants

Twenty-four native Spanish participants (11 women, mean age 24.7 years, range 18–52) took part in the experiment. All had normal or corrected-to-normal vision, and were right-handed, with average handedness scores (Oldfield, 1971) of +83 (range +42 to +100). Prior to the experiment, the participants gave their informed consent and declared neither neurological nor psychiatric complaints. The participants were reimbursed for taking part in the experiment. The study was performed in accordance with the Declaration of Helsinki and approved by the ethics committee of the Center for Human Evolution and Behavior, UCM-ISCIII, Madrid, Spain.

4.2. *Materials*

The initial material consisted of 20 concise, whole and coherent stories, selected from different literary sources, namely brief narratives and short tales by distinguished contemporary writers in Spanish – e.g., J.L. Borges, A.M. Matute, I. Calvino, A. Monterrosso, as well as some Aesop's fables. The texts were adjusted and adapted into passages of comparable size, arranged each to contain 9 sentences of variable length (between 4 and 26 words).

For each of these 20 passages, two different versions were composed as a result of inserting four morphosyntactic violations – gender or number, this counterbalanced – into each one. In either version, the first sentence never contained a violation. The remaining 8 sentences were divided into two halves of 4 sentences each in order to arrange the possible allocation of the morphosyntactic violations, so that two violations would appear within sentences 2–5, and the other two in sentences 6–9. In one version, the position of the two ungrammatical sentences within each half was assigned randomly. The ungrammatical sentences in this version were grammatical in the other version, and vice versa. The place of the morphosyntactic violation within a corresponding sentence was also assigned randomly – the first and last positions were always excluded, and could apply to either a noun or an adjective. This rendered two versions of the initial 20 passages, each with 5 grammatical and 4 ungrammatical sentences, the location of the latter being interchangeable across versions. Then, each passage consisted in a whole coherent story containing 4 morphosyntactic violations.

Next, we built the incoherent passages. To do this, the two versions of the 20 passages obtained above were the treated separately. As a rule, the first sentence of each passage remained always the same. In one version, the remaining sentences of all the passages were pseudo-randomly scrambled and interchanged between passages, resulting in a group of 20 incoherent passages. The same procedure was applied to the other version. Thereafter, the manipulation resulted in two incoherent groups of 20 passages each, identical but differing in the location of the morphosyntactic violations.

The experimental material was then organized in four different stimulation sets of 20 passages each. Every set contained all the sentences, but varying relative to their grammaticality condition as well as to their location into a coherent or an incoherent passage. Within each set the presence of coherent and incoherent passages was equiprobable, and their order of appearance randomized. With all these procedures, we finally accomplished that every particular sentence could appear in four different forms, every four participants: correct in a coherent story; correct in an incoherent story; incorrect in a coherent story; and incorrect in an incoherent story. Examples of a coherent and an incoherent paragraph are provided in Supplementary Appendix 1.

The stories were presented word-by-word in the center of a computer screen. All the stimuli appeared white on black, and were controlled by Presentation® software. Participants' eyes were about 65 cm from the screen, yielding viewing angles of the words between 0.78° and 1.38° in height and between 1.18° and 6.8° in width.

4.3. *Procedure*

Participants were assigned randomly to one of the four stimulation sets and the presentation of the sets was counterbalanced. Prior to the presentation of the experimental session, participants were trained with two different passages than those appearing during the recordings. Participants were told that they would read passages that make sense – coherent – and others that do not – incoherent, and to perform a grammaticality judgment task at the end of each sentence by pressing one of two buttons. The response hand for these correctness judgments was counterbalanced across participants. To ensure that the sentences were read as part of a broader passage, we asked participants to memorize the passage as faithfully as possible. After the presentation of each passage, participants performed a recall task, having to tell aloud as much as they could remember from the just-read passage. The duration of the whole experimental session – excluding electrodes preparation – was about 30 min.

Each passage started with a fixation cross appearing in the center of the screen during 500 ms, followed by a blank screen of 500 ms. Thereafter, the words appeared consecutively in the center of screen for 300 ms each, and with an SOA – stimulus onset asynchrony – of 600 ms. A question mark appeared 1200 ms after the offset of the last word of each sentence, indicating the time (1500 ms) for the grammatical judgment. The first word in each sentence had its first letter in capitals, whereas the last word included an end-point. After the presentation of the whole passage and 1 s after the offset of the last question mark, the word "RECUERDO" – "recall" – appeared in the center of the screen prompting participants to tell as much as they could remember from it. During this recall period, the verbal responses were recorded for further, off-line analyses. In this regard, all possible responses for each passage were previously organized into "idea units", in reference to possible individual sentences, basic semantic propositions, or phrases, in line with Bransford and Johnson (1972). Our passages varied in the number of these idea units from 10 to 18 (mean 14.5). A schematic representation of the experimental procedures can be seen in Fig. 5.

4.4. *ERP recordings*

The electroencephalogram – EEG – was recorded from 28 tin electrodes embedded in an electrode cap – EasyCap®. Electrode locations were Fp1, Fp2, F7, F3, Fz, F4, F8, FC3, FC4, FT7, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CP4, TP8, P7, P3, Pz, P4, P8, O1

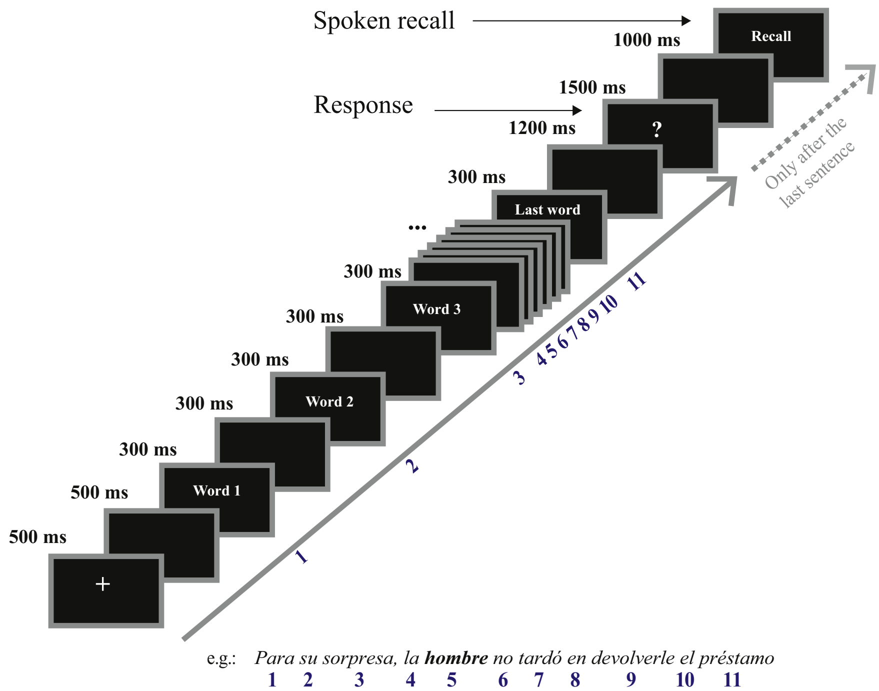

Fig. 5 – Stimulation procedures. Participants were presented the passages word by word. At the end of each sentence, a judgment of grammaticality was requested. At the very end of each passage, participants had to recall verbally as much as they could from the whole passage. Translation into English of the example provided: ***To his surprise, the$_{FSG}$ man$_{MSG}$ did not take a long time to give the loan back.***

and O2, plus right mastoid – M2, according to the extended 10/20 International System (American Electroencephalographic Society, 1991). All electrodes were referenced online to the left mastoid – M1, and re-referenced off-line to the average of the left and right mastoids. Bipolar horizontal and vertical electro-oculograms – EOG – were recorded for artifact monitoring. Electrode impedances were always kept below 3 kΩ. The signals were recorded continuously with a bandpass from 0.01 to 40 Hz and a sampling rate of 250 Hz.

4.5. *Data analysis*

The continuous EEG was divided into 1000-ms epochs, establishing a baseline of 200 ms before the onset of each critical word. Artifact rejection was performed semi-automatically. First, epochs exceeding a range of $\pm$100 μV were eliminated. Second, off-line ocular artifact correction was performed using the method described by Gratton et al. (1983). Third, the epochs still presenting artifacts were removed by visual inspection. Overall, the mean rate of rejected epochs by artifacts was 13.12%. Epochs with incorrect responses were also removed (mean rate=11.92%).

In order to have an overall estimation of main modulations and their time courses, the statistical analyses were calculated for eight consecutive time windows of 100 ms each, starting at stimulus onset and lasting until the end of the epoch (800 ms). These windows appropriately fit the main findings, according to visual inspection of the data, while permitting us exploring the whole epoch statistically. Mean amplitudes were calculated at each of these windows, thereafter analyzed with repeated-measures analyses of variance – ANOVA – in which electrodes were grouped in the following regions of interest, based upon visual inspection of the distributions of our main effects: left frontotemporal (F7, FT7, T7), left frontocentral (F3, FC3, C3), right frontotemporal (F8, FC8, C8), right frontocentral (F4, FC4, C4), parietal (Cz, P3, Pz, P4), left posterior (TP7, P7, O1), right posterior (TP8, P8, O2). The factors included in the ANOVA were Grammaticality – two levels: correct and incorrect, Coherence – two levels: coherent and incoherent, Position – two levels: first half and second half, and Region – seven levels. The Greenhouse–Geisser correction (Greenhouse and Geisser, 1959) was always applied when appropriate.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.brainres.2015.11.008.

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