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Brain response to Information Structure misalignments in linguistic contexts

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ABSTRACT

The paper inquires, through the analysis of electroencephalographic (EEG) recordings, the processing costs associated to misalignments between the information status (Given/New) of discourse contents and their linguistic packaging as Topic or Focus in discourse. The way information is packaged within utterances, that is, their Information Structure, guides language comprehension. Sentences are typically organized into Topic and Focus units, commonly conveying Given (already active in working memory) and New (not active) information, respectively. Nonetheless, for precise purposes, novel information can be presented in Topic, and known information in Focus. The paper accounts for the efficiency of brain processing in response to such "violations" of Information Structure, through both EEG spectral analysis and whole-brain functional connectivity patterns. The main contribution of the present work is the analysis of brain responses in natural contexts, i.e. when processing whole texts of more sentences, instead of isolated (couples of) utterances as is the case of a number of experimental paradigms pursued in the psycholinguistic domain. EEG signals recorded from a population of 54 subjects highlight the presence of rhythmic changes in different frequency bands, depending on aligned and misaligned Information Structures.

1. Introduction

The role and relevance of linguistic context in brain processing for both sentence understanding and knowledge updating have been investigated in some recent neurolinguistic studies [1]. Specifically, it is widely agreed that interlocutors continuously make predictions about the contents a speaker is about to convey next, on the basis of information already available in the foregoing discourse [2]. Moreover, participants build expectations that forthcoming contents are presented in ways coherent with their having been already introduced or not, and with their relevance to the communicative task at hand [3]. Anticipation is in fact one of the key strategies used by the brain to ease automation in language understanding: knowing in advance when and how a specific piece of information will be provided may allow to process it with less waste of cognitive resources, thus avoiding working memory overload [4].

On the other hand, it is commonly assumed that a greater effort is required to the brain when contextually unexpected contents are encountered, due to a mismatch between the input and the performed predictions. Several syntactic, morphological and semantic linguistic phenomena have been analyzed with the aim of unveiling the neural underpinnings of such states of affairs [5–9].

The aim of the present paper is to investigate, by means of the analysis of electroencephalographic (EEG) recordings, the brain processing cost associated to misalignments with respect to the way information is expected to be organized within utterances, that is, their *Information Structure* [10,11]. Any information provided in a sentence can be distinguished as being *Given* or *New*, referring to its activation state within the current discourse and in the conscious attention of its recipient [12,13]. Given, in this sense, is information recently introduced in discourse and therefore active in the addressee's short-term memory: something participants are currently thinking of. New designates information with no recent introduction in prior discourse or situation, and

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therefore inactive in the addressee's short-term memory. Language is sensitive to whether information is in one or the other of these conditions. After saying:

(1) Jane showed up at my home yesterday
it is possible to continue by saying:
(2) She has found a new job
The reason why the addressee will understand that Jane is the person referred to by “she” is that the idea of Jane is presently active in his working memory. But (2) cannot be uttered out of the blue, because in this case the addressee would find no referent for the pronominal subject, no suitable entity being currently “lit up” in his attention. If Jane is not Given in the utterance context, (3) must be uttered instead of (2):
(3) Jane has found a new job
At the same time, discourse actually develops through *Topic* and *Focus* (or *Topic* and *Comment*) units, which differently contribute to the illocutionary level of utterances, that is, the level in which cues to the interpretation of the intended communicative purpose are provided [13–15]. In oral communication, their detection is mainly triggered by prosody. The Focus of a sentence conveys information proposed by the speaker as his main contribution to the ongoing interaction, thus expressing the illocutionary force of the utterance [16]. The Topic instead provides the semantic background that makes the Focus understandable, and links focal information to the foregoing discourse. Consequently, only what is presented as Focus remains activated for anaphoric reference in the subsequent discourse:
(4) [She drinks]$_{\mathcal{T},(1)}$ [in front of the children]$_{\mathcal{F},(2)}$, and this$_{(2)}$ is bad.
(5) [In front of the children$_{\mathcal{T},(1)}$ [she drinks]$_{\mathcal{F},(2)}$, and this$_{(2)}$ is bad.
(6) [She DRINKS]$_{\mathcal{F},(1)}$ [in front of the children]$_{\mathcal{T},(2)}$, and this$_{(1)}$ is bad.[1]
(7) [In front of the CHILDREN]$_{\mathcal{F},(1)}$ [she drinks]$_{\mathcal{T},(2)}$, and this$_{(1)}$ is bad.
New information is typically presented as the Focus of a sentence, because introducing New contents is typically the speaker's communicative goal, while Given contents are typically encoded as topical, i.e. as background information whose re-sharing is not the purpose of the utterance, though resuming them may be useful to understand the New Focus. For this reason, the Given/New and Topic/Focus pairs have often been treated as coterminous, with Topic referring to Given content, and Focus to New information. Nonetheless, “the distinction between topic and comment is autonomous, in the sense that it cannot be derived from the distinction between ‘Given’ (i.e. the known from the preceding context or situation, contained among the presuppositions) and ‘New’ (not given)” [17]. Indeed, in ordinary communication, novel information may be presented in a Topic unit, while known information can be focalized, as in the following examples:
(8) A: What are John and Mary going to do over the week end?
B: [Mary]$_{\mathcal{T}/\mathcal{G}}$ [is going to play tennis]$_{\mathcal{F}/\mathcal{N}}$.[2]
(9) A: What are your friends going to do over the week end?
B: [Mary]$_{\mathcal{T}/\mathcal{N}}$ [is going to play tennis]$_{\mathcal{F}/\mathcal{N}}$.
(10) A: Are John and Mary going to play tennis?
B: Only [MARY]$_{\mathcal{F}/\mathcal{G}}$[1] [is going to play tennis]$_{\mathcal{T}/\mathcal{G}}$.

Example (8) contains the default alignment between activation states and linguistic packaging, while (9) and (10) contain misaligned configurations, where the expected patterns are reversed, with New and Given contents respectively encoded in the sentence Topic and Focus. In particular, in (10) the focalizing adverb *only* supports prosodic emphasis in producing a *contrastive Focus*, where already active, Given information is encoded in a way which is different from the most probable expectation of the addressee.

The effects on brain processing of encoding Given/New contents in aligned and misaligned configurations with respect to topical vs. focal packaging are therefore evaluated in this work. Specifically, the literature regarding the analysis of brain reactions to violations of Information Structure is reported in Section 2, together with a description of the limits characterizing the investigations so far carried out on this matter. Section 3 describes the fundamentals of the methodology we propose for inquiring the effects of misaligned Information Structures on brain processing, while Section 4 details the instruments exploited for carrying out the performed analysis. The obtained experimental results are presented and discussed in Section 5, while some relevant conclusions are drawn in Section 6.

2. The experimental literature so far: towards an expectation-based processing model

Earlier psycholinguistic investigations approached the processing of Information Structure units manipulating the syntactic structure of isolated sentences. Indeed, the effects of focality and topicality were measured contrasting sentences like *Jane went to the train station* to cleft versions like *It's Jane who went to the train station*. This paradigm has been used in a number of studies, from Erickson & Mattson's MOSES ILLUSION TEST [18] to later works [19–21] in which the shift from a syntactically unmarked to a syntactically marked sentence was resorted to as the only strategy to encourage the reading of one or the other Information Structure. A methodological implication resulting from this experimental setting was that the critical sentences ended up carrying all New information, since no prior context could allow the treatment of some content as Given or New: “without any preceding information, the listeners [or readers] analyze each sentence as completely new and no information has to be embedded in an already given context” [9]. This obviously led to probe Information Structure processing in conditions far from how human communication really takes place.

In a different tack, later neurolinguistic studies [1,9,10,22–24] have highlighted the role of context-driven strategies in Information Structure processing. More particularly, it has been observed that the costs required to process contents are not only contingent on the topical or focal nature of each content *per se*, but rather on the interplay between packaging strategies and activation degrees of the contents conveyed. Put another way, processing effort depends on precise expectations that prior discourse allows to formulate either on the Given/New status of some information or on the particular packaging it receives in the utterance, based on the goals attained by the speaker in the ongoing interaction. On a general basis, it has been demonstrated that when New information conflates with Focus and Given information with Topic, processing effort appears smaller than it is when Topic-New and Focus-Given combinations are encountered. In these studies, the effects on brain processing of Information Structure misalignments in a specific context have been investigated by typically resorting to texts comprising question–answer and context–target pairs. Such approaches have allowed to precisely locate the temporal reference of utterances eliciting Event-Related Potentials (ERPs), that is, brain responses measured as the direct result of specific cognitive events. Specifically, increases or decreases of processing demands in response to aligned and misaligned informational matchings have been revealed by variations in N400 signatures, with higher deflections elicited by misaligned packagings. The involvement of N400 modulations in such discourse phenomena

[1] Capital letters indicate prosodic emphasis marking the Focus when located to the left.
[2] $\mathcal{T}/\mathcal{G}$=Topic/Given; $\mathcal{F}/\mathcal{N}$=Focus/New; $\mathcal{T}/\mathcal{N}$=Topic/New; $\mathcal{F}/\mathcal{G}$=Focus/Given.

has been delved into on both phonological and syntactic bases. In more detail, an ERP study on Information Structure processing in Japanese [1] shed light on the role of syntax in graduating decoding efforts imposed by New information. Particularly, it has been observed that if in Japanese subject-object-verb (SOV) declarative sentences New information is placed in the syntactic position of Focus, its processing is generally faster and less effortful than it is if it were placed in sentence-initial position, where Topics are more typically realized. This effect is particularly salient if the preceding discourse context licenses expectations on the syntactic positioning of New information. From a phonological perspective [10], the effects of aligned vs. misaligned information packaging have been measured modifying intonation contours on Given and New contents. Specifically, when Given contents received superfluous accent and were therefore interpreted as Focus, their processing elicited higher N400 peaks. Analogous neural patterns were observed for missing accents on New contents, fostering their interpretation as Topic. Other ERP studies on Information Structure in German [9,22] pointed towards similar findings in this respect.

Such results possibly hinge on the fact that presentation of New information with Topic-like prosody at first induces the receiver to treat that content as Given, and search for it among the things recently mentioned in prior discourse, until he must realize that actually no such thing has been introduced. On the other hand, Given information, if accented Focus-like, is treated as having not been introduced yet in the foregoing discourse, thus requiring to be established from scratch in the addressee's Short-Term Memory, until the addressee realizes he actually has that content already active, without the need to fully process it anew.

Investigations on the role of context-driven expectations in sentence processing have also been pursued on the presupposition-assertion dichotomy, in which it has been observed that presupposed content that is contrary to the receiver's mental representation of the discourse model induces additional processing effort, as in the magnetoencephalography study [23] by Hertrich et al. Within the domain of Topic-Focus structure, interesting findings are also those discussed in [24], in which a strong association between more or less expected distributions of Topic and Focus units (in German) and P600 variations have been detected. Upon the assumption that topicalized objects (e.g. [*Theowl*]$_{\mathcal{T},\mathrm{Obj}}$, the hedgehog paints in the park) are harder to process than topicalized subjects (e.g. [*The hedgehog*]$_{\mathcal{T},\mathrm{Subj}}$ paints the owl in the park), the authors wanted to assess whether contextually activating the information carried by the object (e.g. CONTEXT: What about the owl? TARGET SENTENCE: [*The owl*]$_{\mathcal{G}}$, the hedgehog paints in the park) might reduce the costs related to the processing of objects appearing in a less typical position. Indeed, this proved to be so with significant peaking reduction in the P600 signature: if the referent designated by a syntactic object is made active in prior discourse, its extra-position and topicalization is likely to cost less.

The latter neurological studies inquired Information Structure processing in conditions that can be regarded as more natural and life-like than the paradigms based on isolated sentences. This is an important perspective, which deserves to be developed: (a) by further enhancing the naturalness of the linguistic/textual conditions in which target utterances are presented to experimental subjects and (b) by extending measurement techniques from ERPs to other parameters of brain activity, which may add further confirmation or partial correction to the existing findings.

Pursuant to the above-mentioned studies, the present investigation aims to further assess the expectation-based dynamics of language processing, and it attempts to do so by opting for an experimental setup involving extensive texts, where Topic/Focus and Given/New dichotomies are instantiated within a specified context, differently from [18–20] and [21], and through entire clauses instead of isolated utterances like in [1,9,10,22–24]. This setup allows to assess sentence processing in its natural and actual happening, which is not exactly the case for experiments based on single isolated clauses or couples of clauses. Only the preceding context of an utterance can establish its contents as Given or New.

It is generally well accepted that ERPs are more easily measured in response to word-length stimuli, that is, isolating single words within delimited portions of an utterance, and correlating their occurrence with a specific physiological response. However, the same procedure would be much less straightforward to follow if used to measure neural responses to longer strings of words—up to entire sentences—due to the overlapping of the effects for contiguous units. For this reason, as described in Section 3, in order to properly investigate the effects of Information Structure misalignments during sentence comprehension, we decided to resort to an alternative approach carrying out an analysis of the recorded EEG signals in the frequency domain.

3. Proposed methodology

The ERPs detected in EEG recordings mostly account for time- and phase-locked brain activity, while non-phase-locked activity is largely removed due to the sample averaging procedure [25]. Conversely, event-related changes in power and coherence of neuronal oscillations most notably represent non-phase-locked activity. Since the “natural” scenario we are interested in may involve Focus/Topic units and New/Given contents expressed by entire clauses, possibly made up of long strings of words, an analysis of the brain responses in the frequency domain seems to be more suitable. Furthermore, recent studies have investigated the relationship between ERPs and oscillatory activity in language processing [26,27]. For instance, oscillatory dynamics have been also considered for evaluating the cost of semantic violation. Quantifying the EEG rhythmic activity in different frequency bands may therefore allow gaining better insights into the processing of entire information units, without the need for considering stringent length constraints.

4. Experimental setup

The experimental tests performed for assessing the effects of misalignments between content information status and packaging formats are here described. As already remarked, the proposed experimental paradigm complements those commonly followed in the experimental literature on Information Structure violation: it lines up with models considering the impact of context on sentence comprehension, while propounding to extend the detection of the physiological correlates of Topic and Focus beyond the scope of single words. Section 4.2 presents the material used to design the protocol, that is, the specifications of the texts employed to elicit the desired responses, together with the characteristics of the population considered for the tests. The system adopted for acquiring EEG signals is described in Section 4.1. The preprocessing performed on the recorded data is presented in Section 4.4, while the spectral features employed to infer about oscillatory correlates of Information Structure processing are outlined in Section 4.5.

4.1. Data recording

The experimental analysis reported in the present work is carried out on scalp EEG signals acquired using a 19-channels system (GALILEO Be Light amplifier), with an original sampling rate of 256 Hz. The database consists of EEG recordings collected from $N=54$ healthy subjects, whose ages range from 20 to 35 years. During each EEG acquisition, subjects are comfortably seated on a chair in a dimly lit room. For the signal detection, the 19 electrodes are placed on the scalp according to the standard 10–20 montage, and the electrical impedance of each electrode is kept under 10 kΩ using conductive gel at the beginning of each acquisition. The EEG measures are referenced to the AFz position, and represented as potentials $v_j[t]$ between the j-th electrode and the reference electrode, with $j=1,\dots,M_{ch}$ and $M_{ch}=19$. EEG signals are recorded during the listening of a text suitably provided to emphasize different activation states and packaging conditions of information, as described in the following section. EEG recordings have been time-locked to the listened utterances by means of a synchronization signal which marks each occurrence of a relevant sentence on the raw traces. Ongoing EEG activity lasting four minutes has also been recorded for each subject before the performance of the linguistic task.

4.2. Material

In order to carry out a systematic comparison between information items in different contextual activation states and linguistic packaging conditions, four couples of texts have been sorted out. Each couple is made of two texts (A and B) having the same notional content, but different as concerns the way it is informationally packaged. In other words, the same piece of information (whether contextually Given or New) is Topic in one text (from List A) and Focus in the other (from List B), or vice versa. Keeping the same content in both conditions is necessary to avoid biases possibly due to the processing of different ideas or states of affairs.

Below, an example of the used patterns is shown. The critical sentences are given in brackets and in italics:

ListA[3]:

Context Da adulti, siamo generalmente inclini a temere le emozioni negative. In questo senso, [*che si sviluppino dipendenze legate ai bisogni non soddisfatti*]$_{\mathcal{T}/\mathcal{N}}$ é molto frequente. Le nostre debolezze ci vengono rivelate [*dal verificarsi di questo tipo di dipendenze*]$_{\mathcal{F}/\mathcal{G}}$. In questi casi, molti si rifugiano nel bere un po' di vino con un amico. [*Dopo aver sorseggiato qualche bicchiere di vino*]$_{\mathcal{T}/\mathcal{G}}$, [*per un po'il dolore svanisce*]$_{\mathcal{F}/\mathcal{N}}$.

LIST B:

Context

Data la nostra inclinazione a temere le emozioni negative, spesso [*sviluppiamo dipendenze legate ai bisogni non soddisfatti*]$_{\mathcal{F}/\mathcal{N}}$. [*Quando si verifica questo tipo di dipendenze*]$_{\mathcal{T}/\mathcal{G}}$, scopriamo le nostre debolezze. In questi casi, molti si rifugiano nel bere un po' di vino con un amico. E [*il dolore per un po'svanisce*]$_{\mathcal{T}/\mathcal{N}}$ [*sorseggiando qualche bicchiere di vino con qualcuno*]$_{\mathcal{F}/\mathcal{G}}$.

Stimuli have been presented auditorily, with intonation clearly signaling topical and focal status of information units. Each considered subject has listened to all the four texts of a list, with $N_A=N_B=27$ users listening to either list A or B. All the scripts have been prepared as short narratives of about 100 words. An overall number of 38 relevant clauses, representing the interested information packagings, being them either Topic/Given ($\mathcal{T}/\mathcal{G}$), Topic/New ($\mathcal{T}/\mathcal{N}$), Focus/New ($\mathcal{F}/\mathcal{N}$), or Focus/Given ($\mathcal{F}/\mathcal{G}$), have been identified from the whole set of texts belonging to either list A or B. Specifically, considering the sentences conveying different alignment conditions in the two lists, yet within the same contexts, 27 occurrences of information presented either as $\mathcal{F}/\mathcal{N}$ or as $\mathcal{T}/\mathcal{N}$ in the two lists have been selected, while 11 instances of information proposed as either $\mathcal{F}/\mathcal{G}$ or $\mathcal{T}/\mathcal{G}$ have been picked out.

It must be stressed that, to our knowledge, such an experimental setup represents a progress in comparison with all preceding experiments accounted for in the literature, where only the processing of isolated sentences or couples of sentences was tested. In fact, real linguistic exchanges are almost never limited to context-independent utterances, which means that only testing utterances in context can be considered as the testing of something comparable to real linguistic behavior. All the rest, though more easily testable, risks to be something different, where the categories of Information Structure are not what they are in actual language use.

4.3. Prediction

Studies on the activity of frequency bands in sentence processing seem to converge quite consistently on the fact that oscillation amplitudes of δ (EEG subband comprising frequencies in the range [0.5–4] Hz) and θ ([4–8] Hz) bands are directly related to processing demands, in that amplitude increases (synchronization) correlate with working memory load [28]. On the contrary, α ([8–14] Hz) and β ([14–30] Hz) bands show an activity that is inversely related to processing demands, with amplitude decreases (desynchronization) indicating increased involvement of neural resources for sentence processing [28,29]. We have assumed that the efficiency and costs of integrating information in the mental discourse model does not hinge on its activation status *per se*, but on its packaging being expected or unexpected relative to prior discourse. On this account, if rhythmic changes are related to cerebral treatment of Information Structure, misalignments should reveal more costly processing than alignments, with significant variations expected in δ,θ,α or β band oscillations. More particularly, amplitude decreases in α or β bands and increases in δ or θ band should be observed in misaligned conditions, that is, when Given information is expressed as a Focus ($\mathcal{F}/\mathcal{G}$) and New information as a Topic ($\mathcal{T}/\mathcal{N}$).

4.4. Data preprocessing

The EEG signals acquired through the employed recording system are first downsampled to 128 Hz, after applying a proper anti-aliasing low-pass filter. A pass-band filter is then applied to retain spectral components in the range [0.5,40] Hz, containing the main EEG rhythms of interest for the present study. Subsequently, EEG signals are segmented into epochs time-locked to the onset of each utterance under analysis. Epochs containing artifact occurrences that definitely corrupted the signal are removed from the dataset by visual inspection. As mentioned in Section 4.2, 38 epochs have been obtained for each subject, related to the

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[3] **ListA.Context**

As adults, we are generally bound to fear negative feelings. In this sense, [*that unsatisfied needs generate dependences*]$_{\mathcal{T}/\mathcal{N}}$ is very frequent. Our weaknesses are revealed [*by the manifestation of these dependences*]$_{\mathcal{F}/\mathcal{G}}$. In these cases, many feel comfortable drinking some wine with a friend. [*After sipping some wine*]$_{\mathcal{T}/\mathcal{G}}$ [*the pain disappears for a while*]$_{\mathcal{F}/\mathcal{N}}$.

ListB.Context

Given our tendency to fear negative feelings, [*we often develop dependences related to unsatisfied needs*]$_{\mathcal{F}/\mathcal{N}}$. [*When these dependences come about*]$_{\mathcal{T}/\mathcal{G}}$ we discover our weaknesses. In these cases, many feel comfortable drinking some wine with a friend. And [*pain disappears for a while*]$_{\mathcal{T}/\mathcal{N}}$ [*sipping some wine with somebody*]$_{\mathcal{F}/\mathcal{G}}$.

utterances of interest contained in the four listened texts of either list A or B. The dataset exploited for evaluating the results presented in Section 5 therefore contains 27(=couple of subjects) × 27 (=contrast occurrences) instances (couple of epochs) for the contrast $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$, and 27 × 11 instances for the contrast $\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$. Combining both aforementioned datasets also allows us to perform a statistical analysis on the differences of brain responses to aligned or misaligned information structures on the basis of 27 × 38 comparisons.

In order to generate features which can be used to analyze the effects of Information Structure violations on language processing, the selected EEG epochs are further processed accordingly to the methods described in the following section.

4.5. Spectral characterizations of brain activity

The markers exploited in Section 5 to quantitatively evaluate oscillatory brain activity during the occurrence of aligned or misaligned utterances are introduced in this section. Specifically, two different spectral characterizations of brain signals are here considered: the first one is based on estimates of the signals' power spectral density (PSD), and it is presented in Section 4.5.1. The other one considers the coherence (COH) between simultaneously recorded EEG channels, as described in Section 4.5.2. In more detail, for both the performed analyses we define two different sets of features, based either on individual channels for PSD and individual channel pairs for COH, or on the overall behavior of the considered characteristics over different regions of interest (ROIs) defined on the scalp. Four distinct representations, exploiting different spectral characteristics of recorded brain signals, are therefore employed to investigate the effects of misalignment conditions on language processing.

4.5.1. Power spectrum density (PSD) characterization

Each relevant EEG epoch, with length depending on the specific utterance under consideration, is analyzed through the classical Welch's periodogram method for deriving the PSD associated to each channel. This latter is exploited to account for the contribution of distinct EEG rhythms to the differences observed in the considered contrasts.

Specifically, having indicated with $s_i[t]$ the EEG signal recorded by the i-th channel during the epoch under analysis, its PSD representation $S_i[f]$, with $f = 0, \ldots, 40$ indicating the investigated frequencies, selected with a resolution of 1 Hz from 0 up to 40 Hz, is estimated using a sliding Hanning window of 0.5 s with an overlap of 0.25 s, in order to improve the estimations' quality. A logarithmic transformation is then applied to the obtained PSD values, thus producing spectral features characterized by a Gaussian distribution, as required by the statistical analysis described in Section 5. Moreover, in order to refer the considered measurements to a common baseline condition, making it possible to compare recordings taken from different subjects, a further transformation is applied to each PSD estimate, thus obtaining the M_{ch} vectors $\overline{S}_i[f] = (S_i[f] - \mu_i^{(r)}[f])/\sigma_i^{(r)}[f]$, $i = 1, \ldots, M_{ch}$, where $\mu_i^{(r)}[f]$ and $\sigma_i^{(r)}[f]$ represent the mean and the standard deviation of the PSD estimate obtained, for each subject, from the i-th channel of the EEG signal recorded during the resting state phase performed before the linguistic task, as described in Section 4.1. This transformation in fact reduces inter-subject variability due to scale factors.

A restricted range of frequencies, namely [1–30] Hz, is then considered in the present study. The highest EEG frequencies (γ EEG subband, [30–40] Hz) are in fact not taken into account, since they have been typically found to be less relevant for the processing of unexpected events in language comprehension [26,30,31]. For each of the four remaining EEG subbands (δ, θ, α and β), the first marker of language processing efficiency is then obtained by computing, for each channel, the averages of the normalized PSD values $\overline{S}_i[f]$ over the interested frequency range.

In addition to this first representation, an analysis considering PSD distributions over different regions of interest (ROIs) is also carried out to find significant differences between alignment and misalignment conditions. Specifically, in Appendix A, Table A1, we report the list of the 27 PSD features exploited in the analysis of ROIs as described in Section 5 for each considered frequency band. As can be seen, the adopted values represent EEG power averaged across different regions of the head: both bilateral regions, such as frontal (F), centro-temporal (C) and parieto-occipital (P), as well as hemispheric regions, located in the sole right (r) or left (l) hemisphere, are taken into account. Moreover, also EEG power gradients between antero-posterion, contralateral, and cross-hemispheric regions are tested as discriminative characteristics.

Both the aforementioned spectral representations are exploited in Section 5 to infer about oscillatory correlates of Information Structure processing.

4.5.2. Spectral coherence (COH) characterization

Over the past decades, different methods have enabled the study of whole-brain functional connectivity patterns, and advances in neuroimaging have provided new insights into plasticity changes associated with language comprehension [32]. In the present study, the linear relationships between simultaneously recorded EEG signals (channels) is measured employing coherence analysis, a bivariate method frequently used due to its practical and intuitive interpretation. Coherence gives insights into the way functional networks cooperate with each other during various cognitive processes, like language processing, and into the dynamics of the related “transient functional language networks” [32]. In fact, different language operations rely on distributed patterns of information transfer between the different brain regions involved in language processing. In this context, COH quantifies the level of synchrony between two signals at a specific frequency f. Considering two signals $s_i[t]$ and $s_j[t]$, respectively, obtained from channels i and j of the same EEG epoch under analysis, the spectral coherence $N_{i,j}[f]$ for a particular frequency f is computed as

$$N_{i,j}[f] = \frac{|S_{i,j}[f]|^2}{S_i[f] \cdot S_j[f]} \tag{1}$$

where $S_{i,j}[f]$ is the cross-spectrum of signals $s_i[t]$ and $s_j[t]$, while $S_i[f]$ and $S_j[f]$ are their respective spectra. By definition $N_{i,j}[f]$ ranges between 0, corresponding to no synchrony at the frequency f, and 1, corresponding to maximum synchrony at the frequency f.

The spectra $S_{i,j}[f]$, $S_i[f]$ and $S_j[f]$ are computed by means of the Welch's averaged modified periodogram, with the same parameters used for estimating the PSDs. Similarly to the processing of PSD values, a Fisher's Z transformation is applied to the computed coherence values, in order to produce coefficients characterized by a Gaussian distribution. As for PSD features, a further normalization, with respect to the ongoing EEG activity, is also performed for generating the representation $\overline{N}_{i,j}[f]$, thus reducing the effects of inter-subject scale factors. Eventually, the considered COH features are obtained by taking, for each pair of channels and considered EEG subband, the averages of the normalized COH values $\overline{N}_{i,j}[f]$ over the interested frequency range.

Moreover, as performed for the PSD characterization in Section 4.5.1, an additional representation is also defined by computing mean coherence values for each ROI. In Appendix A, Table A2, we report the list of the 46 so-obtained features. In detail, we consider:

- 9 within-region coherence levels,
- 3 between-region coherence levels,
- 15 antero-posterior coherence gradients,
- 3 contralateral coherence asymmetries,
- 12 cross-hemispheric and ipsilateral antero-posterior long- and mid-range coherence levels,
- 4 contralateral coherence levels.

5. Results and discussion

The results of the performed analysis are reported in this section, together with a discussion on the observed brain rhythmic changes related to different activation states and packagings of information items. As already remarked, our purpose is to verify whether Information Structure violations induce a less efficient language processing, with respect to sentence packagings coherent with the presented informational states. To this aim, a *paired-sample t-test* methodology, based on the four proposed representations of brain oscillatory activity described in Sections 4.5.1 and 4.5.2, is employed in a statistical hypothesis testing framework.

In more detail, the considered EEG representations are first evaluated for all the utterances under analysis. Then, the features measured for corresponding notional contents presented through different packaging strategies, in the text of List A and B, are compared in order to find markers of significant differences between alignment and misalignment conditions.

The *null hypothesis* we would like to reject therefore assumes that conveying information under expected or unexpected packaging relative to prior discourse does not result in significant differences between the respective brain responses. The false discovery rate (FDR) method is employed to provide *p-values* corrected for multiple comparisons, expressing the consistency of such hypothesis, together with the corresponding confidence intervals for the exploited features of brain oscillatory activity. The FDR procedure is here adopted since it provides a less stringent control over false discovery compared to familywise error rate (FWER) procedures (such as the Bonferroni correction). The FDR in fact results more suitable for our study, where the great number of variables (frequency bands, channels, channel pairs) would lead the computed significance levels to zero (impossible to reject the *null hypothesis*). The normalization procedures described in Sections 4.5.1 and 4.5.2 for the considered spectral and coherence markers are needed to handle values characterized by Gaussian distributions, as required by the employed statistical analysis.

The $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast, with New information presented either in aligned packagings as Focus, or in misaligned conditions as Topic, is analyzed in Section 5.1. The $\mathcal{F}/\mathcal{G}$ *vs* $\mathcal{T}/\mathcal{G}$ contrast, where Given content is presented in the expected way as a Topic or in an unexpected modality as Focus, is then evaluated in Section 5.2. Moreover, an overall comparison of recorded brain responses where whatever informational status (Given or New) is proposed either in aligned or misaligned conditions is reported in Section 5.3.

5.1. Alignment/misalignment with New information

The first analysis is conducted on PSD levels tested independently for each channel as features describing language processing efficiency. Fig. 1 reports the results obtained from the tests performed over the different occurrences of the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast, for distinct brain rhythms. Specifically, the topographic maps reported in the right-most column of Fig. 1 show the brain regions where significant differences (FDR corrected *p-values* < 0.05) are observed, meaning therefore that the null hypothesis can be rejected. Significant differences in the processing of $\mathcal{F}/\mathcal{N}$ and $\mathcal{T}/\mathcal{N}$ utterances are therefore observed for the α brain rhythm in the central, parietal and temporal regions, as well as for the β rhythm in the right centro-parietal region of the head. Further information is provided by the topographic maps reported in the left-most and central columns of Fig. 1, which respectively show the lower and upper values of the 95%-confidence interval on the difference of PSD population means between aligned and misaligned conditions. Specifically, from the reported confidence intervals it can be inferred that both α and β oscillations present larger oscillation amplitudes for the $\mathcal{F}/\mathcal{N}$ condition compared to the $\mathcal{T}/\mathcal{N}$ condition. The results in these two frequency bands suggest a larger event-related desynchronization (ERD) for the $\mathcal{T}/\mathcal{N}$ condition, which could indicate a less efficient processing due to the misalignments between packaging and informational status. The observed significant differences are supposed to be determined by an increasing difficulty in integrating information needed for language understanding in the misalignment condition, due to the search for a missing antecedent in prior discourse. Accordingly, power of α and β rhythms has been shown to be inversely related to task complexity, attentional and processing demand [33]. In particular, in language processing power reduction in the β frequency band due to phrase structure violation has been linked to an increased involvement of neural resources for sentence processing after mismatch [33]. The observations concerning the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast are in agreement with similar remarks reported in [30,26,34] with respect to the occurrence of semantic and prosodic mismatches, as already discussed in Section 3.

PSD features are then exploited to look for further significant differences in predefined ROIs regarding brain oscillatory activity in response to alignment and misalignment conditions between information status and packaging strategies. Fig. 2 reports the 95%-confidence intervals of the performed statistical analysis, when considering the 27 features listed in Appendix A, Table A1, as possible markers of language processing efficiency. Specifically, the features whose associated confidence intervals do not contain a null value for the expected difference are highlighted, since in these cases a statistically significant difference can be assumed between responses to $\mathcal{F}/\mathcal{N}$ and $\mathcal{T}/\mathcal{N}$ conditions. The obtained results support the findings related to the already discussed single-channel PSD representation: significant effects of unexpected packaging of New information are observed on the right central and right parieto-occipital power levels in the β frequency band, higher in the $\mathcal{F}/\mathcal{N}$ condition. A significant effect is also observed on the right centro-temporal power level in the α frequency band, again higher in $\mathcal{F}/\mathcal{N}$ conditions.

Similarly to the analysis performed for the power spectrum features, also the capability of coherence features as markers of language processing efficiency is tested. Specifically, Fig. 3 shows the result of the statistical analysis performed using the COH representation: the right-most column of Fig. 3 reports, for each EEG rhythm, the pairs of channels for which the difference of measured coherence in aligned and misaligned conditions is statistically significant (FDR corrected p-values ≤ 0.05). The colors of the depicted connections indicate whether the observed difference between $\mathcal{F}/\mathcal{N}$ and $\mathcal{T}/\mathcal{N}$ conditions is positive (in red) or negative (in blue).

The analysis of the connectivity maps reveals that, with respect to the $\mathcal{F}/\mathcal{N}$ condition, processing of $\mathcal{T}/\mathcal{N}$ utterances results

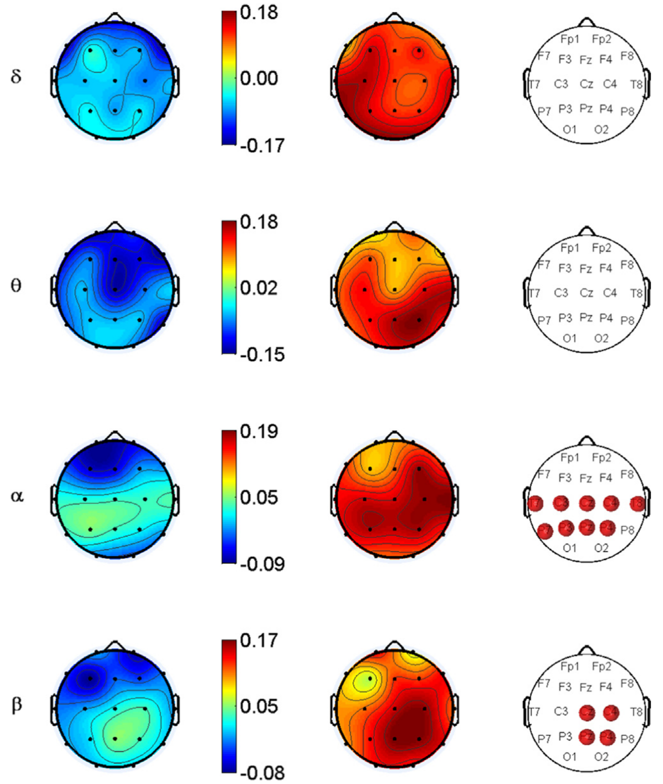

Fig. 1. Analysis of the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast through the PSD features of different subbands. Lower and upper limits of the 95%-confidence intervals for the considered differences are respectively shown in subplots (a) and (b). The map of the regions with significant differences (*p*-values ≤ 0.05) is shown in subplots (c).

in a greater frontal contralateral Fp_2-F_7 coherence level, and lower left-posterior (involving temporal region T_3) and centro-occipital (C_z-O_1 and C_z-O_2) coherence levels in the δ band. The α band shows a greater long-range cross-hemispheric coherence involving the frontal region Fp_2, and lower right posterior and fronto-occipital (C_z-P_z) levels in $\mathcal{T}/\mathcal{N}$ scenarios. These latter are also characterized by lower ipsilateral long-range (antero-posterior) connectivity and cross-hemispheric fronto-temporal (F_8-T_3) level in the β band.

Therefore, the obtained results suggest that aligned and misaligned Information Structure may evoke distinct coherence patterns in different frequency bands, possibly reflecting various aspects of sentence understanding, e.g. memory, semantic and syntactic integration, and parsing [32]. It should be noticed that previous literature has shown that COH increase in the “slow” frequency range (especially involving θ band) is correlated to an increased demand on working memory during sentence processing [35]. On the other hand, coherence increase in the higher frequency range (especially involving the β rhythm) seems to be related to efficient semantic integration and parsing processes (higher for congruous than for non-congruous sentences) [34].

Further evidence is obtained through the statistical analysis performed on the coherence characteristics evaluated within and between predetermined ROIs, listed in Appendix A, Table A2. The results in Fig. 4 show that language processing in $\mathcal{F}/\mathcal{N}$ condition induces a greater coherence in the left central (C_l) region, lower values in the frontal (F) region, together with a greater left centro-occipital (CO_l) coherence in the δ band. Additionally, a greater right centro-occipital (CO_r) coherence is present in the β band when considering $\mathcal{F}/\mathcal{N}$ conditions.

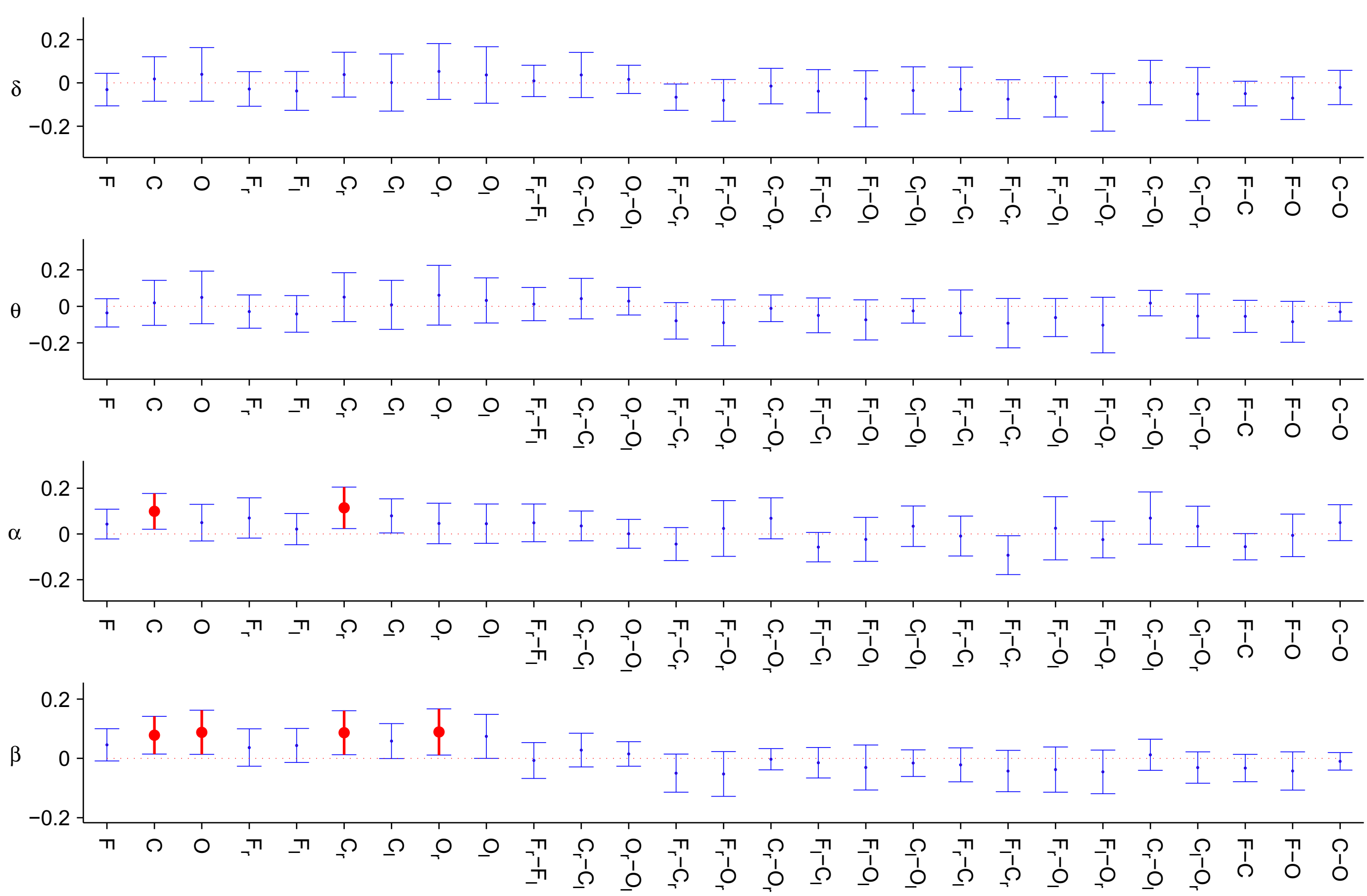

Fig. 2. Analysis of the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast through the PSD features in Table A1, evaluated on different ROIs. The 95%-confidence intervals for the considered differences are shown by vertical bars. Red spots highlight PSD ROIs with significant differences (*p*-values ≤ 0.05). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

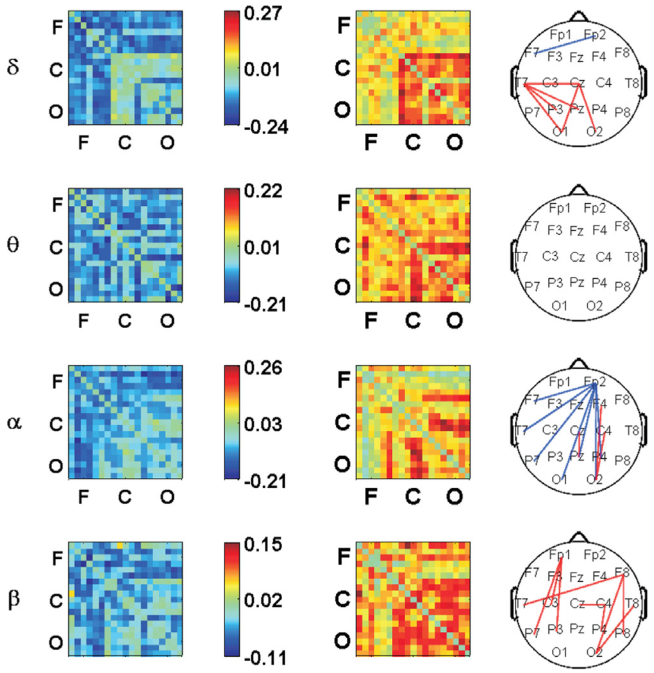

Fig. 3. Analysis of the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast through the COH features of different subbands. Reported links indicate the presence of significant differences (p-values ≤ 0.05) in coherence. Greater coherence in $\mathcal{F}/\mathcal{N}$ is shown in red, while greater coherence in $\mathcal{T}/\mathcal{N}$ is shown in blue. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

5.2. Alignment/misalignment with Given information

The same analysis performed for the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast is also performed in case of aligned and misaligned utterances conveying Given information. Specifically, Fig. 5 illustrates the results of the statistical analysis performed for PSD features. As can be seen, significant differences between $\mathcal{F}/\mathcal{G}$ and $\mathcal{T}/\mathcal{G}$ conditions can be found in the θ band, with a greater left temporal power expected under $\mathcal{F}/\mathcal{G}$ scenarios. This suggests a major event-related synchronization (ERS) that could be due to an unmet expectation on the organization of information in the sentence. As outlined in Section 3, θ synchronization has been in general linked to increased working memory load [28]. The $\mathcal{F}/\mathcal{G}$ misalignment is therefore supposed to perturb an efficient information processing involving short-term memory.

As shown in Fig. 6, the analysis performed on the PSD ROI features listed in Appendix A, Table A1, outlines significant differences for the right centro-frontal power gradient within the θ rhythm, higher in the $\mathcal{F}/\mathcal{G}$ condition. Significant differences between $\mathcal{F}/\mathcal{G}$ and $\mathcal{T}/\mathcal{G}$ cases are also noted in the centro-frontal power gradient within the β band, lower in the $\mathcal{F}/\mathcal{G}$ condition. These observations are in line with the evidence that θ and β rhythms are known to be involved in language processing (including encoding New information [36,28]), and to show inverted behavior with respect to processing load [37].

A further involvement of specific working memory processes in the $\mathcal{T}/\mathcal{G}$ vs $\mathcal{F}/\mathcal{G}$ differences is therefore suggested by the related results in the θ band. This is in accordance with the evidence that

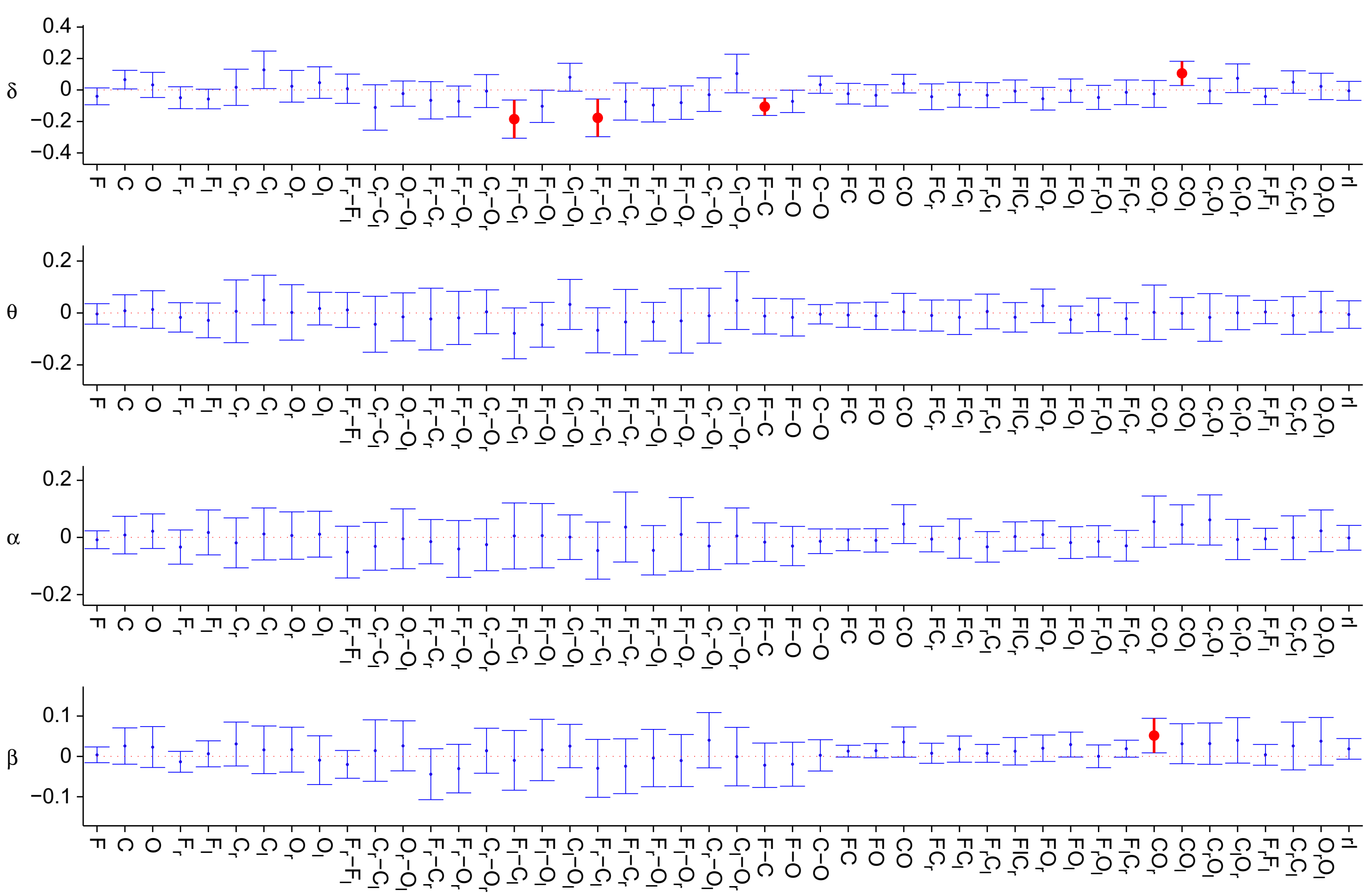

Fig. 4. Analysis of the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ contrast through the COH features in Table A2, evaluated on different ROIs. The 95%-confidence intervals for the considered differences are shown by vertical bars. Red spots highlight COH ROIs with significant differences (p-values ≤ 0.05). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

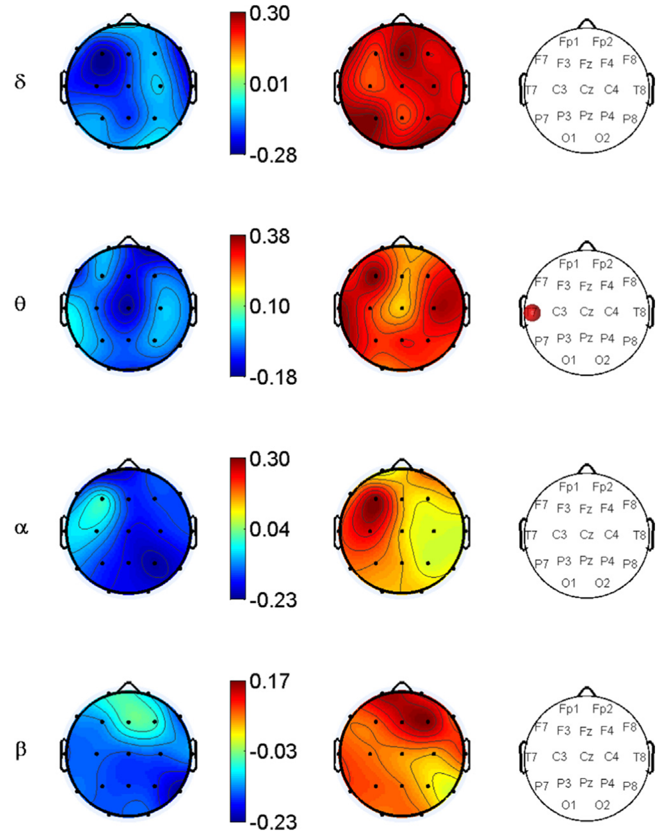

Fig. 5. Analysis of the $\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$ contrast through the PSD features of different subbands. Lower and upper limits of the 95%-confidence intervals for the considered differences are respectively shown in subplots (a) and (b). The map of the regions with significant differences (p-values ≤ 0.05) are shown in subplots (c).

Given information requires retrieval processes involving working memory.

The tests performed analyzing the coherence values between pairs of EEG channels reveal that the $\mathcal{T}/\mathcal{G}$ condition shows lower left ipsilateral short-range coherence involving region C_3, and right short-range fronto-temporal $(F_8 - T_4)$ coherence in the θ band, as shown in Fig. 7. In the α and β bands the $\mathcal{T}/\mathcal{G}$ condition shows a significant greater posterior connectivity involving the right temporal region T_4. In the β band we also observe a greater central and centro-posterior coherence for the $\mathcal{T}/\mathcal{G}$, and a greater cross-hemispheric fronto-parietal $(Fp_2 - P_3)$ coherence for the $\mathcal{F}/\mathcal{G}$ condition.

Furthermore, Fig. 8 reports the results of the analysis performed by considering coherence values over the ROIs listed in Appendix A, Table A2. We can observe a greater coherence in C_l, O_l and CO_l, and a lower value in O_r in the θ band for $\mathcal{F}/\mathcal{G}$ scenarios, together with lower gradients $C_r - C_l$ and $O_r - C_l$. Also in the α band we find a lower $C_r - C_l$ gradient for $\mathcal{F}/\mathcal{G}$. Moreover, the β rhythm shows lower F, inter-hemispheric C_rC_l, right and cross-hemispheric CO mean coherence for the $\mathcal{F}/\mathcal{G}$ condition.

5.3. Brain responses to alignment/misalignment

Besides the separated analysis on the $\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$ and the $\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$ contrasts, comprehensive evaluation comparing brain responses to generic alignment and misalignment conditions is also performed. As shown in Fig. 9, also in this case significant and extensive lower levels of the PSD are observed for the misalignment condition in the β frequency band. A narrow but equally significant difference observed in the α band involves the right temporal region, where the misalignment condition shows lower EEG power. These results suggest possible common patterns of

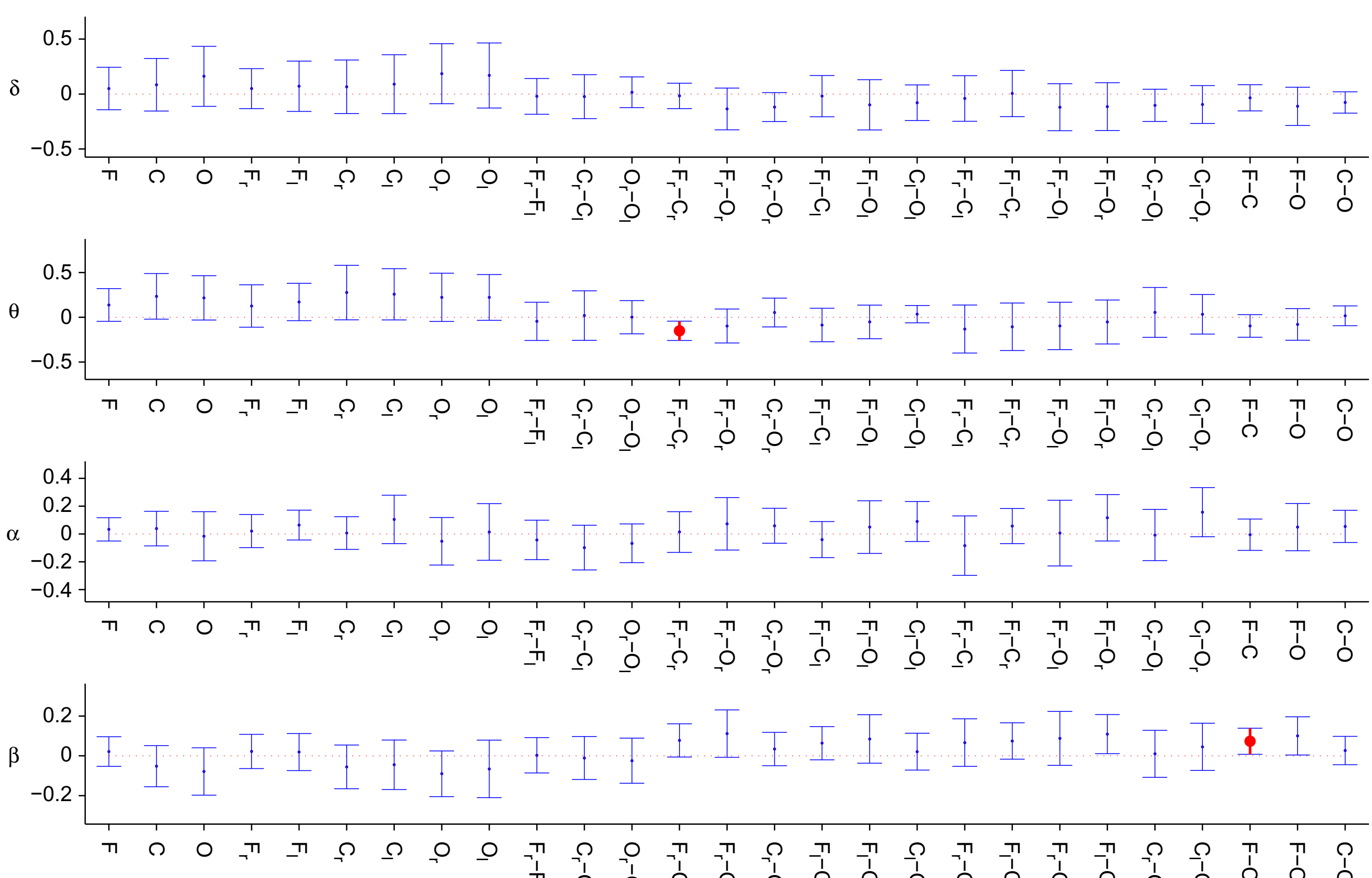

Fig. 6. Analysis of the $\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$ contrast through the PSD features in Table A1, evaluated on different ROIs. The 95%-confidence intervals for the considered differences are shown by vertical bars. Red spots highlight PSD ROIs with significant differences (p-values ≤ 0.05). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

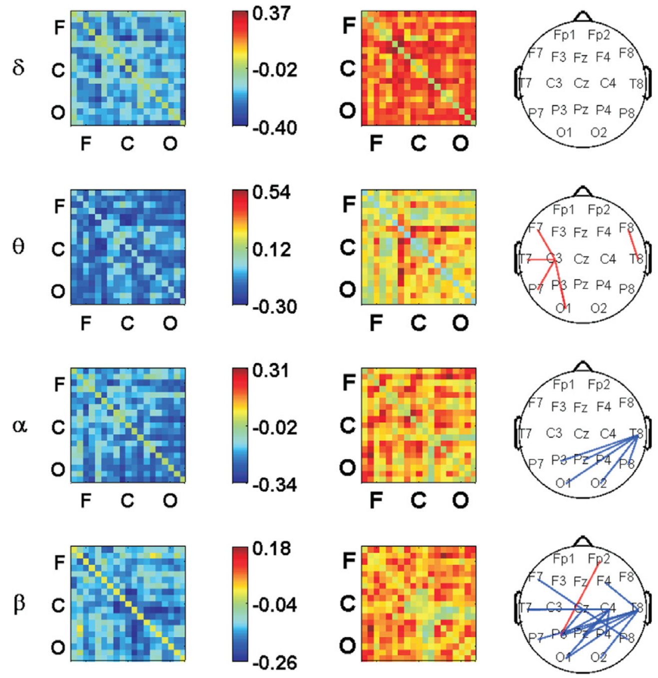

Fig. 7. Analysis of the $\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$ contrast through the COH features of different subbands. Reported links indicate the presence of significant differences (p-values ≤ 0.05) in coherence. Greater coherence in $\mathcal{F}/\mathcal{G}$ is shown in red, while greater coherence in $\mathcal{T}/\mathcal{G}$ is shown in blue. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

power changes in the α and β bands between alignment and misalignment conditions, whatever the informational status of the considered content.

The outcomes of the analysis of PSD correlates in different ROIs are shown in Fig. 10, where lower mean power of the β rhythm in the right hemispheric parieto-occipital region is reported for the misalignment condition. Within the same frequency band, also lower right and cross-hemispheric centro-frontal, and parieto-frontal power gradients, were detected for the misalignment condition.

As for the analysis of coherence correlates, significant lower values are observed in the posterior region for the misalignment condition in the β frequency band, mainly involving right centro-temporal and occipital regions C_4, T_4, T_6 and O_1, as shown in Fig. 11. A similar but less broad result is observed in the α band for the posterior connectivity levels involving the same regions. Fewer coherence patterns showing more strength for the alignment condition are observed in the α and β bands involving antero-posterior long-range cross-hemispheric connectivity. Slow waves (δ and θ frequency bands) show more strength of few short range intra-hemispheric COH patterns in misalignment conditions: T_4-P_4 for δ rhythm; frontal COH, C_3-O_1 and P_3-O_1 for θ rhythm. These findings support the discussion reported in Sections 5.1 and 5.2, and highlight common patterns of significant changes between alignment and misalignment conditions, beyond the differences observed in specific contrasts.

Eventually, Fig. 12 shows that coherence correlates of language processing under alignment and misalignment conditions can be

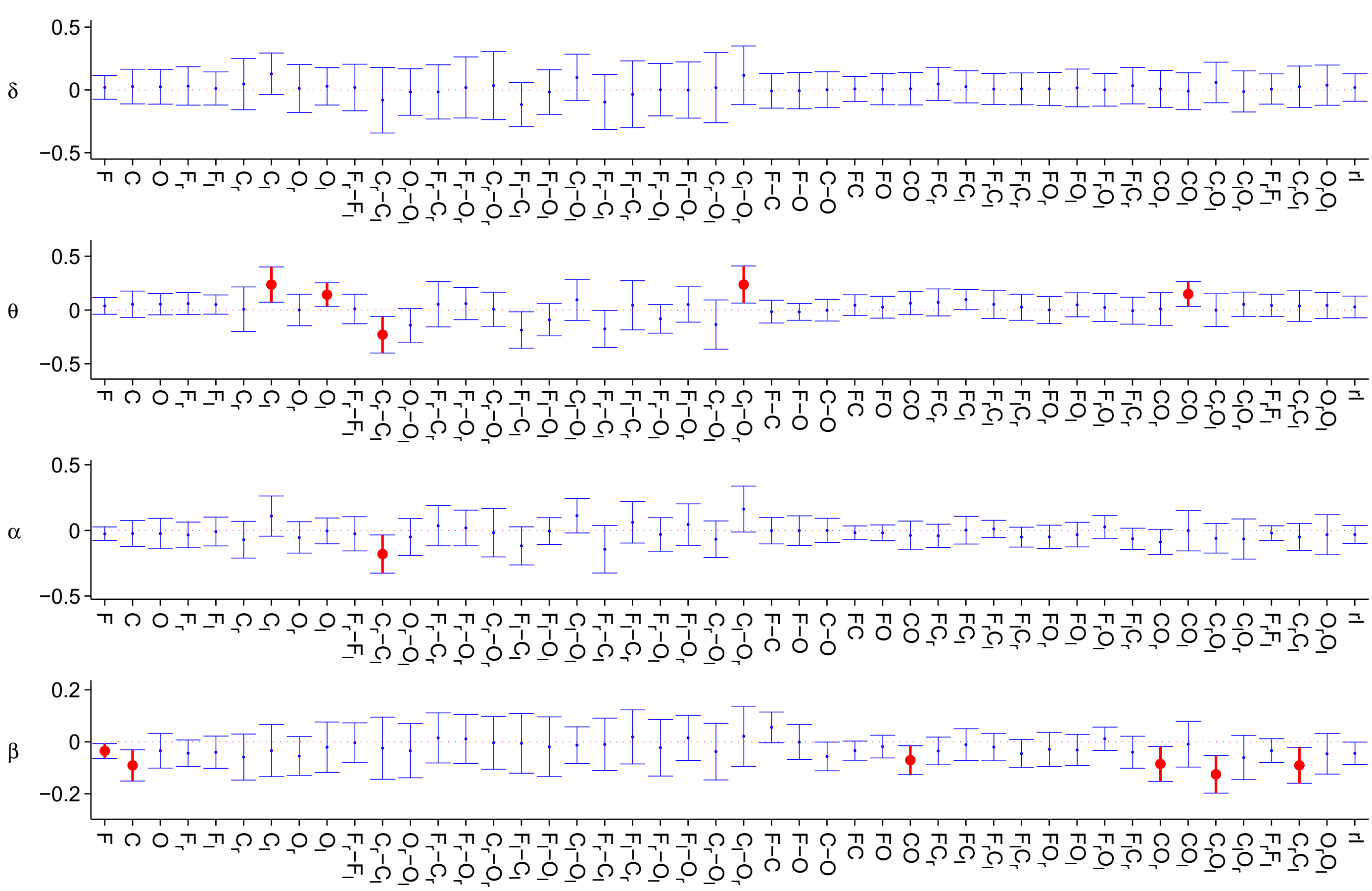

Fig. 8. Analysis of the $\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$ contrast through the COH features in Table A2, evaluated on different ROIs. The 95%-confidence intervals for the considered differences are shown by vertical bars. Red spots highlight COH ROIs with significant differences (p-values ≤ 0.05). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

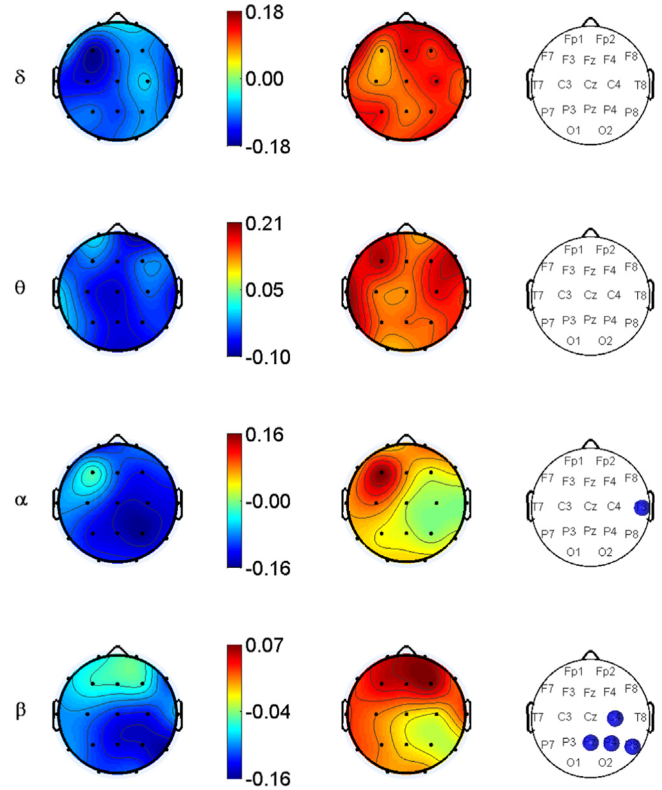

Fig. 9. Analysis of the contrast between misaligned and aligned conditions through the PSD features of different subbands. Lower and upper limits of the 95%-confidence intervals for the considered differences are respectively shown in subplots (a) and (b). The map of the regions with significant differences (p-values ≤ 0.05) are shown in subplots (c).

revealed by considering different ROIs, mainly involving the β rhythm in the centro-posterior region of the head. In particular, lower values of β coherence are observed for the misalignment conditions in the right centro-occipital (CO_r), contralateral central (C_rC_l), cross-hemispheric centro-occipital (C_rO_l) and fronto-central (FC) patterns. It should be noticed that the right central, temporal and parietal regions appear to be more involved in the significant differences observed between alignment and misalignment within the β rhythm, compared to the respective contralateral regions. According to the analysis performed with individual pair of channels, a less broad but significant difference in the CO_r coherence (weaker for misalignment) is observed also within the α band. On the other hand, θ left centro-occipital (CO_l) coherence appears stronger for the misalignment condition, supporting the same reverse trend observed in the previous analysis of the present work. The results of the analysis of different brain ROIs suggest some notable aspects of the complex framework representing the differences of coherence patterns between aligned and misaligned conditions, in accordance with related findings in previous literature [34].

6. Conclusions

The language system integrates the activity of different neural resources involved in specific aspects of sentence processing. Information processing of linguistic productions hangs on expectation-based constraints. On the micro-pragmatic level of utterances, expectations may regard activation degrees of contents or their informational packaging. The most typical information articulation is when Given contents pattern with topical, and New contents with focal packaging. When this pattern is overturned,

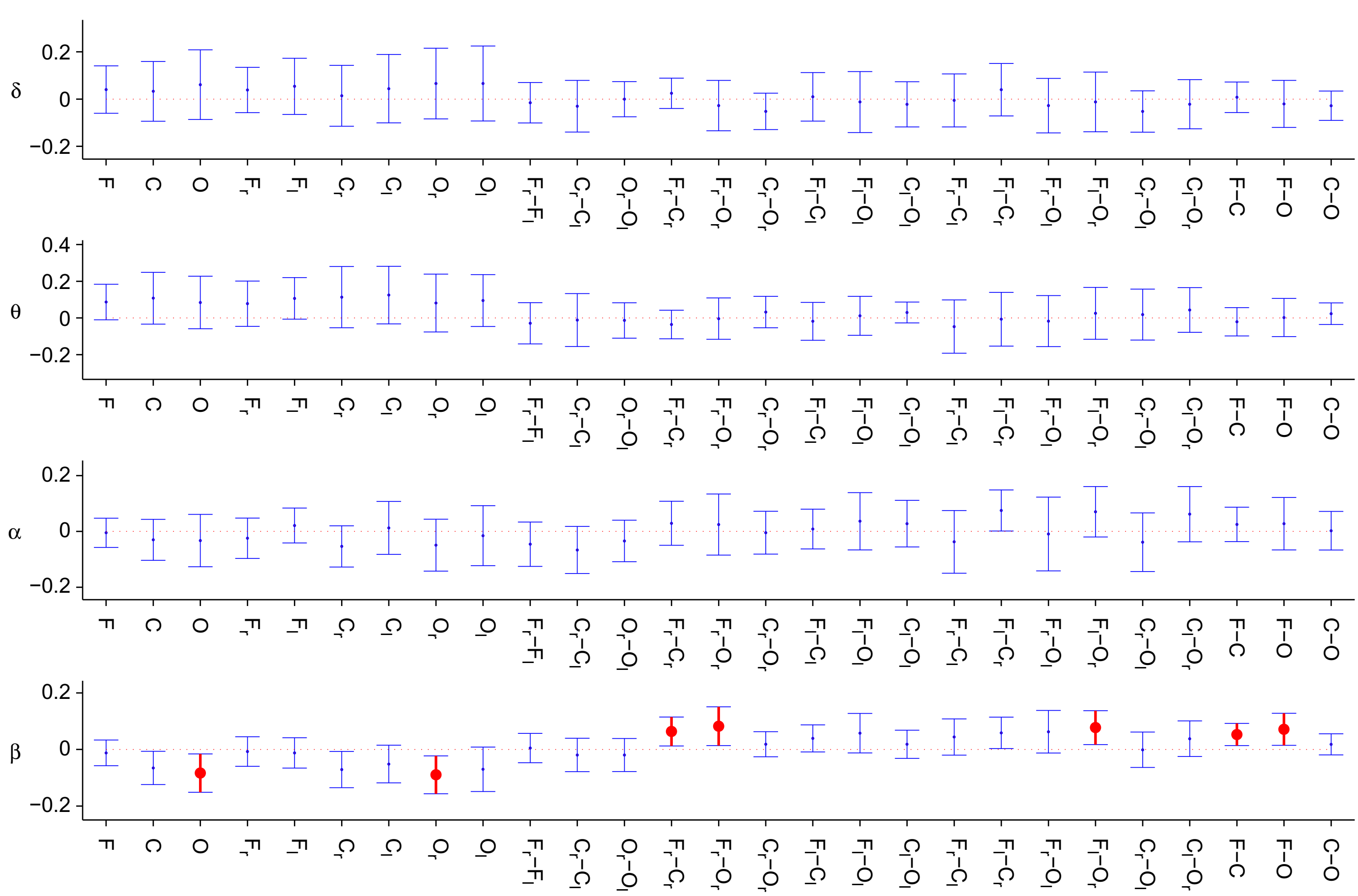

Fig. 10. Analysis of the contrast between misaligned and aligned conditions through the PSD features in Table A1, evaluated on different ROIs. The 95%-confidence intervals for the considered differences are shown by vertical bars. Red spots highlight PSD ROIs with significant differences (p-values ≤ 0.05). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

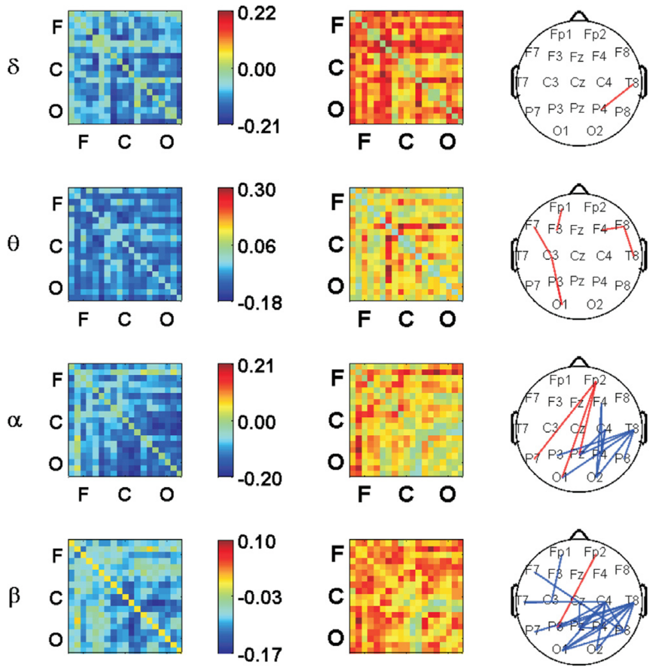

Fig. 11. Analysis of the contrast between misaligned and aligned conditions through the COH features of different subbands. Reported links indicate the presence of significant differences (p-values ≤ 0.05) in coherence. Greater coherence in $\mathcal{F}/\mathcal{G}$ is shown in red, while greater coherence in $\mathcal{T}/\mathcal{G}$ is shown in blue. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

participants must review their predictions on the communicative dynamism of the upcoming utterance, which eventuates in additional processing demands. The present study examined the processing effects of manipulating informational statuses as to obtain aligned and misaligned configurations between the Given/New state of some information and its linguistic presentation as Topic or Focus in context.

Probing the power spectrum of frequency bands, it has been found that θ, α and β bands are significantly involved in online processing of information units more or less consistently matching with activation states of their notional contents. A summary of the observed brain processing correlates in the case of aligned or misaligned Information Structure is reported in Table 1. Particularly, it has been highlighted that misaligned packaging triggers synchronization effects (ERS) in the θ band, and desynchronization effects (ERD) in α and β bands, in conformity with their expected relation to greater or lesser efforts, according to previous literature. Moreover, the obtained results show different connectivity patterns depending on the analyzed conditions, highlighting a complex and dynamic interplay between specific EEG rhythms and concurrent language comprehension processes. We interpret these results as indicative of a greater cognitive investment in response to the overturning of expectations about the ongoing discourse model. In our view, this, together with recent findings in the same direction [1], sheds a different light on the actual processing strategies of Information Structure units. The cost of processing Given/New or Topic/Focus information is determined, on the one hand, by the way these two levels intersect in particular contexts and,

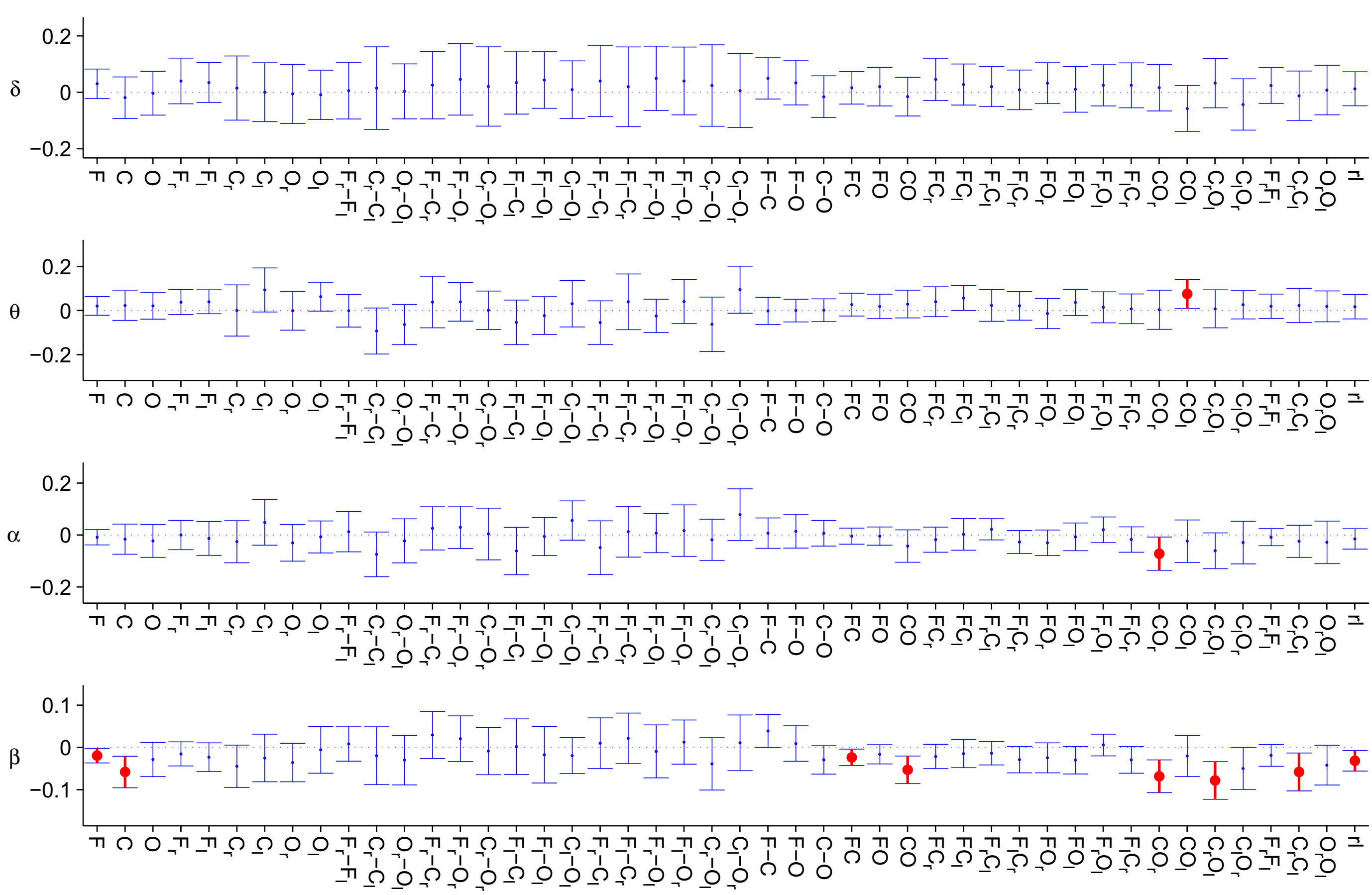

Fig. 12. Analysis of the contrast between misaligned and aligned conditions through the COH features in Table A2, evaluated on different ROIs. The 95%-confidence intervals for the considered differences are shown by vertical bars. Red spots highlight COH ROIs with significant differences (p-values ≤ 0.05). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

Table 1
Summary of the PSD and COH correlates of brain processing in case of sentences with aligned and misaligned Information Structures..

Band	Contrast		
	$\mathcal{F}/\mathcal{N}$ vs $\mathcal{T}/\mathcal{N}$	$\mathcal{F}/\mathcal{G}$ vs $\mathcal{T}/\mathcal{G}$	Misaligned vs Aligned
δ	Greater Fp_2-F_7 coherence level, and lower left posterior and centro-occipital coherence levels for $\mathcal{T}/\mathcal{N}$	–	More strength of few short range intra-hemispheric coherence patterns for misalignment
θ	Greater long-range cross-hemispheric coherence, and lower right posterior and fronto-occipital coherence levels for $\mathcal{T}/\mathcal{N}$	Greater left temporal power for $\mathcal{F}/\mathcal{G}$; lower left ipsilateral short-range coherence and right short-range fronto-temporal coherence for $\mathcal{T}/\mathcal{G}$	More strength of few short range intra-hemispheric coherence patterns for misalignment
α	Larger power in central, parietal and temporal regions for $\mathcal{F}/\mathcal{N}$	Greater posterior connectivity involving T_4 for $\mathcal{T}/\mathcal{G}$	Lower power levels for the misalignment; lower coherence in the posterior region for misalignment and more strength of few antero-posterior long-range cross-hemispheric connectivity patterns for alignment
β	Larger PSD in the right centro-parietal region for $\mathcal{F}/\mathcal{N}$; lower ipsilateral long-range (antero-posterior) connectivity and cross-hemispheric fronto-temporal (F_8-T_3) coherence level for $\mathcal{T}/\mathcal{N}$	Greater posterior connectivity involving T_4 and greater central and centro-posterior coherence for $\mathcal{T}/\mathcal{G}$; greater cross-hemispheric fronto-parietal coherence for $\mathcal{F}/\mathcal{G}$	Lower power levels for the misalignment; lower coherence in the posterior region for misalignment and more strength of few antero-posterior long-range cross-hemispheric connectivity patterns for alignment

on the other hand, by the way their intersection either meets or collides with the addressees' anticipation strategies in text decoding.

Appendix A

See Tables A1 and A2.

Table A1
PSD features: definitions and corresponding ROIs.

Feature	**Description**
P_F	Mean power in the frontal region
P_C	Mean power in the centro-temporal region
P_O	Mean power in the parieto-occipital region
$P_{F,r}$	Mean power in the right hemispheric frontal region
$P_{F,l}$	Mean power in the left hemispheric frontal region
$P_{C,r}$	Mean power in the right hemispheric centro-temporal region
$P_{C,l}$	Mean power in the left hemispheric centro-temporal region
$P_{O,r}$	Mean power in the right hemispheric parieto-occipital region
$P_{O,l}$	Mean power in the left hemispheric parieto-occipital region
P_F-P_C	Fronto-central power gradient
P_F-P_O	Fronto-occipital power gradient
P_C-P_O	Centro-occipital power gradient
$P_{F,r}-P_{F,l}$	Frontal hemispheric power asymmetry
$P_{C,r}-P_{C,l}$	Centro-temporal hemispheric power asymmetry
$P_{O,r}-P_{O,l}$	Parieto-occipital hemispheric power asymmetry
$P_{F,r}-P_{C,r}$	Right fronto-central power gradient
$P_{F,l}-P_{C,l}$	Left fronto-central power gradient
$P_{C,r}-P_{O,r}$	Right centro-occipital power gradient
$P_{C,l}-P_{O,l}$	Left centro-occipital power gradient
$P_{F,r}-P_{O,r}$	Right fronto-occipital power gradient
$P_{F,l}-P_{O,l}$	Left fronto-occipital power gradient
$P_{F,r}-P_{C,l}$	Cross-hemispheric fronto-central power gradient
$P_{F,l}-P_{C,r}$	Cross-hemispheric fronto-central power gradient
$P_{C,r}-P_{O,l}$	Cross-hemispheric centro-occipital power gradient
$P_{C,l}-P_{O,r}$	Cross-hemispheric centro-occipital power gradient
$P_{F,r}-P_{O,l}$	Cross-hemispheric fronto-occipital power gradient
$P_{F,l}-P_{O,r}$	Cross-hemispheric fronto-occipital power gradient

Table A2
COH features: definitions and corresponding ROIs.

Feature	**Description**
H_F	Mean coherence in the frontal region
H_C	Mean coherence in the centro-temporal region
H_O	Mean coherence in the parieto-occipital region
$H_{F,r}$	Mean coherence in the right hemispheric frontal region
$H_{F,l}$	Mean coherence in the left hemispheric frontal region
$H_{C,r}$	Mean coherence in the right hemispheric centro-temporal region
$H_{C,l}$	Mean coherence in the left hemispheric centro-temporal region
$H_{O,r}$	Mean coherence in the right hemispheric parieto-occipital region
$H_{O,l}$	Mean coherence in the left hemispheric parieto-occipital region
H_F-H_C	Fronto-central coherence gradient
H_F-H_O	Fronto-occipital coherence gradient
H_C-H_O	Centro-occipital coherence gradient
$H_{F,r}-H_{F,l}$	Frontal hemispheric coherence asymmetry
$H_{C,r}-H_{C,l}$	Centro-temporal hemispheric coherence asymmetry
$H_{O,r}-H_{O,l}$	Parieto-occipital hemispheric coherence asymmetry
$H_{F,r}-H_{C,r}$	Right fronto-central coherence gradient
$H_{F,l}-H_{C,l}$	Left fronto-central coherence gradient
$H_{C,r}-H_{O,r}$	Right centro-occipital coherence gradient
$H_{C,l}-H_{O,l}$	Left centro-occipital coherence gradient
$H_{F,r}-H_{O,r}$	Right fronto-occipital coherence gradient
$H_{F,l}-H_{O,l}$	Left fronto-occipital coherence gradient
$H_{F,r}-H_{C,l}$	Cross-hemispheric fronto-central coherence gradient
$H_{F,l}-H_{C,r}$	Cross-hemispheric fronto-central coherence gradient
$H_{C,r}-H_{O,l}$	Cross-hemispheric centro-occipital coherence gradient
$H_{C,l}-H_{O,r}$	Cross-hemispheric centro-occipital coherence gradient
$H_{F,r}-H_{O,l}$	Cross-hemispheric fronto-occipital coherence gradient
$H_{F,l}-H_{O,r}$	Cross-hemispheric fronto-occipital coherence gradient
$H_{F,C}$	Fronto-central coherence
$H_{F,O}$	Fronto-occipital coherence
$H_{C,O}$	Centro-occipital coherence
H_{F,C_r}	Right fronto-central coherence
H_{F,C_l}	left fronto-central coherence
H_{F_r,C_l}	Cross-hemispheric fronto-central coherence
H_{F_l,C_r}	Cross-hemispheric fronto-central coherence
H_{F,O_r}	Right fronto-occipital coherence
H_{F,O_l}	Left fronto-occipital coherence
H_{F_r,O_l}	Cross-hemispheric fronto-occipital coherence
H_{F_l,O_r}	Cross-hemispheric fronto-occipital coherence
H_{C,O_r}	Right centro-occipital coherence
H_{C,O_l}	Left centro-occipital coherence
H_{C_r,O_l}	Cross-hemispheric centro-occipital coherence
H_{C_l,O_r}	Cross-hemispheric centro-occipital coherence
H_{F_r,F_l}	Contralateral frontal coherence
H_{C_r,C_l}	Contralateral central coherence
H_{O_r,O_l}	Contralateral occipital coherence
$H_{r,l}$	Cross-hemispheric coherence

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