

# Semantic Integration versus Syntactic Repair: Behavioral and ERP Signatures of Information-Rich and Rhetorical Arabic Listening

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## Article

**Keywords:** Information-rich discourse, Arabic listening comprehension, event-related potentials, N400, P600, semantic–syntactic trade-off

**Posted Date:** August 25th, 2026

**DOI:** <https://doi.org/10.21203/rs.3.rs-10394489/v1>

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**Additional Declarations:** No competing interests reported.

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# Abstract

This study tested the information-rich discourse hypothesis, which holds that listeners strategically adapt their cognitive and neural processing to the informational density and rhetorical complexity of spoken discourse. Twenty-six native Arabic speakers listened to an information-rich (IR) passage—an adapted popular-science documentary on coral reefs—and a rhetorically complex (RH) passage—an excerpt from the classical Mu'allafa of Imru' al-Qais—while behavioral measures and event-related potentials (ERPs) were recorded at sentence-final words. Behaviorally, the IR passage produced markedly higher comprehension accuracy, faster processing, greater focus on meaning, and lower cognitive strain than the RH passage (all  $p < .001$ ). The ERPs revealed a double dissociation: the RH passage elicited a larger P600,  $F(1, 25) = 8.12$ ,  $p = .009$ , indexing syntactic reanalysis, whereas the IR passage elicited a larger N400,  $F(1, 25) = 6.87$ ,  $p = .015$ . Contrary to the prediction of an attenuated N400 for predictable IR content, we interpret this enhanced N400 as deeper semantic integration of dense, novel information, and the attenuated N400 accompanying the RH passage's P600 as evidence that semantic processing was constrained when resources were absorbed by structural parsing. The findings confirm the predicted behavioral advantage and P600 signature and refine the hypothesis into a semantic–syntactic resource trade-off.

## Introduction

Human language comprehension is a highly predictive and dynamic cognitive process. The brain does not passively assemble meaning from individual words but actively anticipates upcoming linguistic information, a mechanism crucial for the speed and fluency of understanding [1]. This predictive capacity is scaffolded by the brain's ability to entrain to the temporal and rhythmic structures of speech, using prosody and intonation to parse the incoming stream into manageable chunks [2–4]. While foundational models debated whether syntax or semantics takes precedence [5, 6], the contemporary view emphasizes a deeply interactive system where multiple levels of linguistic information are processed in parallel and continuously influence one another.

However, most research has examined these mechanisms at the sentence level. In natural communication, sentences are embedded within a broader discourse context, the characteristics of which can fundamentally shape processing strategies. A critical, yet under-explored, dimension of discourse is the trade-off between *information density* and *rhetorical complexity*. Discourse can be information-rich, designed to efficiently convey novel facts and ideas, or it can be rhetorical, prioritizing stylistic ornamentation, figurative language, and complex grammatical structures over informational content. This distinction leads to the central proposal of this study: the *information-rich discourse hypothesis*. We posit that listeners are adaptive processors who strategically allocate their finite cognitive resources. When presented with information-rich content, the cognitive system prioritizes semantic integration to build a coherent mental model. Conversely, when faced with rhetorically complex language, resources are diverted to the more effortful, bottom-up task of parsing intricate grammatical forms, potentially hindering overall message comprehension. This cognitive trade-off is particularly

salient in languages like Arabic, where the efficient prose of modern informational texts presents a stark contrast to the revered, syntactically intricate forms of its classical literary heritage.

The information-rich discourse hypothesis is rooted in established theories of cognitive load, which contend that the intrinsic complexity of a task consumes finite working memory resources, impacting learning and performance [7, 8]. Rhetorically dense language, with its non-canonical syntax and figurative expressions, imposes a high intrinsic cognitive load, compelling the listener to expend greater "listening effort" to achieve comprehension. This subjective effort is not merely a metaphor; it has tangible neural correlates, including measurable changes in aperiodic brain activity that track cognitive strain during speech perception [9, 10].

Our previous behavioral research provided initial support for this framework, demonstrating that second language learners were more actively engaged and achieved significantly higher comprehension when listening to information-rich content compared to rhetorical discourse [11]. The present study aims to extend these findings by investigating the underlying neurophysiological mechanisms in native listeners.

To achieve this, we employ event-related potentials (ERPs), which provide a high-resolution temporal window into the neural dynamics of comprehension. Two ERP components are of particular relevance. The *N400*, a negative-going wave peaking around 400 ms, is a well-established index of semantic processing. Its amplitude is attenuated (becomes smaller) for words that are semantically congruous or highly predictable within a context, reflecting efficient integration into a developing mental representation [12].

More recently, the *N400* has been framed as a key neural signal of predictive processing, where its amplitude reflects the ease of matching incoming sensory information with top-down expectations [13]. The *P600*, a later positive-going wave (500–800 ms), is classically associated with the detection of syntactic violations and the cognitive cost of grammatical reanalysis and repair [14]. Modern interpretations have broadened its functional role to a more domain-general index of structural integration and evaluation, sensitive not only to syntax but also to conflicts with prosodic or discourse-level expectations [15].

Recent studies confirm that these core neural responses are modulated by global discourse features. Factors such as a speaker's accent [16], the presence of background noise [17], or the demands of selective attention in multi-talker environments [18] all influence the neural resources required for successful comprehension.

However, the specific neural trade-offs associated with the intrinsic properties of the discourse itself—namely, the balance between information density and rhetorical complexity—remain largely unexplored. This study addresses this gap by directly comparing the neural signatures of these two distinct discourse types, providing a neurocognitive test of the information-rich discourse hypothesis.

While the neural basis of sentence-level comprehension is well-documented, far less is known about how the global characteristics of naturalistic discourse shape cognitive and neural processing strategies. Specifically, a fundamental tension exists between discourse that prioritizes the efficient transfer of information and discourse that employs rhetorical complexity for stylistic effect. This gap in the literature leads to a critical question: how do listeners adapt their processing strategies when faced with these competing demands? The information-rich discourse hypothesis provides a theoretical framework for exploring this problem by predicting a strategic shift in cognitive resource allocation.

## The theoretical framework

The theoretical model in Fig. 1 visually articulates the Information-Rich Discourse Hypothesis (IRDH) as a dynamic interplay between two distinct neurocognitive processing pathways. At its core, the model posits that the brain strategically adapts its language processing methods based on the fundamental nature of the discourse it encounters, balancing the demands of semantic efficiency against those of rhetorical complexity.

On one hand, the **Information-Rich Pathway** is engaged by discourse that is clear, predictable, and semantically efficient. As the literature review suggests, this type of language imposes a low intrinsic cognitive load, allowing for smooth and effortless comprehension. The model proposes that this streamlined processing is reflected in specific neural signatures.

A key prediction is a decreased (or attenuated) **N400** amplitude. This aligns perfectly with established research viewing the N400 as an index of semantic prediction; when the flow of information is predictable, the brain easily anticipates upcoming words, reducing the neural signal associated with semantic integration.

This neural efficiency, also marked by stable aperiodic brain activity, translates directly into the observed behavioral benefits: listeners experience higher comprehension and faster processing speed because their cognitive resources can be dedicated to understanding the message's meaning rather than deciphering its structure.

In stark contrast, the **Rhetorical Complexity Pathway** is triggered by discourse laden with non-canonical syntax and a heavy stylistic load. This type of language, as framed by cognitive load theory, imposes a high intrinsic burden on working memory. The model visualizes the neurocognitive cost of this complexity. Instead of a reduced N400, this pathway predicts an increased **P600** amplitude.

The model's prediction of an increased P600 is well-grounded in the literature, which consistently identifies this component as a neural marker for the cognitive effort involved in syntactic reanalysis and repair [19]. This "cost signal" arises when the brain must resolve structural ambiguities or violations, a process clearly observed in challenging linguistic constructions like garden-path sentences [20]. Beyond this classic ERP component, the model also incorporates more recent methods for quantifying cognitive strain. It proposes that this pathway is marked by increased aperiodic effort, a concept supported by

findings that link changes in the aperiodic EEG signal to the cognitive demands of a task [21]. This provides a direct, physiological measure for the otherwise subjective experience of "listening effort" that occurs during challenging comprehension scenarios [22].

Ultimately, the model provides a compelling neurocognitive framework that explains the behavioral consequences of processing different discourse types. It elegantly synthesizes decades of ERP research—from the N400's role in semantic prediction to the P600's function as a neural cost signal for syntactic reanalysis, especially under working memory constraints [19, 20].

The model further integrates this classic approach with modern neurophysiological concepts, framing cognitive load in terms of aperiodic brain activity, which serves as a tangible measure of the "listening effort" required during demanding comprehension tasks [21, 22]. By doing so, it addresses a critical gap in understanding how the brain navigates the fundamental tension between clarity and complexity. It presents a clear, testable hypothesis about the neural trade-offs listeners make, shifting from a predictive, meaning-focused strategy for simple discourse to a reactive, structure-focused strategy when faced with rhetorical difficulty—a strategy whose high cognitive cost can impair comprehension and even alter the listener's subjective perception of the speech itself [23].

To test this hypothesis, this study addresses the following research questions:

1. **Behavioral Correlates:** Do native listeners demonstrate higher comprehension accuracy, faster processing, and report a greater focus on meaning when listening to information-rich discourse compared to rhetorically complex discourse?
2. **Neural Correlates:** Do the neural signatures of language processing differ between the two discourse types? Specifically:
  - a. Does rhetorically complex discourse elicit a larger P600 component, reflecting greater syntactic analysis and re-evaluation costs?
  - b. Does information-rich discourse lead to an attenuated N400 component, indicative of more efficient and predictive semantic integration?

## Methods

### Participants

Twenty-six right-handed native Arabic speakers (13 female, mean age = 19.2 years, SD = 1.1; 13 male, mean age = 19.8 years, SD = 1.3), all undergraduate students at Beni-Suef University, participated in the study. All participants were screened for and reported normal hearing and no history of neurological or language-related disorders. The study protocol was approved by the Faculty of Education Ethics Board at Beni-Suef University (Reference No. BSU-FoE-003-01-011-2025). All participants provided written informed consent in accordance with the Declaration of Helsinki.

## Materials and Stimuli

To investigate neurophysiological processing across distinct linguistic registers, the study utilized two 5-minute audio passages representing a contrast between modern, information-dense discourse and classical rhetorical forms. To control for paralinguistic variables, both stimuli were recorded by the same professional male narrator, maintaining a consistent vocal quality, pace, and intonation.

- **Information-Rich (IR) Stimulus:** This passage comprised an adapted script from a popular-science documentary (National Geographic Abu Dhabi) regarding coral reef ecosystems. The text was characterized by high factual density, a linear narrative structure, and standard Modern Standard Arabic (MSA) declarative syntax. Its primary function was the efficient conveyance of scientific information.
- **Rhetorical (RH) Stimulus:** This passage consisted of an excerpt from the Mu'allaha of Imru' al-Qais. As a canonical work of pre-Islamic poetry, it featured archaic vocabulary, dense metaphorical imagery, and complex, non-standard syntactic constructions. Its primary function was aesthetic and evocative rather than purely informational.

To validate the perceived linguistic distance between these stimuli, a preliminary pilot study was conducted with 10 native speakers (not included in the main experiment). Participants rated the passages on a 5-point scale for grammatical and rhetorical complexity. The RH passage was rated as significantly more complex ( $M = 4.2$ ,  $SD = 0.8$ ) than the IR passage ( $M = 2.7$ ,  $SD = 0.6$ ;  $p < .01$ ).

## Instrument Validation

Prior to the main experiment, the 15-item Listening Strategy Survey (LSS) underwent psychometric validation with a larger, independent sample ( $N = 303$  native Arabic speakers). Internal consistency and reliability were assessed for the three subscales: Meaning and Engagement Focus, Grammatical and Structural Focus, and Cognitive Strain. The instrument demonstrated high reliability, with a Cronbach's alpha ( $\alpha$ ) of .89 and a McDonald's omega ( $\omega$ ) of .91 for the total scale. Subscale reliabilities were also robust (all  $\alpha > .82$ ), confirming the survey's suitability for measuring subjective processing strategies and cognitive effort.

## Experimental Procedure

The experiment took place in an electrically shielded, sound-attenuated EEG laboratory within the Faculty of Medicine at Beni-Suef University. Participants were seated in a comfortable chair for the duration of the session. The experiment used a within-subjects design consisting of two blocks (IR and RH), with the presentation order counterbalanced across participants to mitigate potential order effects. Stimuli were delivered binaurally via high-fidelity headphones.

Following each 5-minute listening block, participants completed two behavioral assessments:

1. **Comprehension Tests:** A 10-item multiple-choice test and a 15-item true/false test assessing both local (factual recall) and global (thematic understanding) comprehension.
2. **Listening Strategy Survey (LSS):** A 15-item self-report survey using a 4-point Likert scale (1 = Strongly Disagree to 4 = Strongly Agree) to measure three dimensions:
  - **Meaning and Engagement Focus:** (e.g., "I was focused on the overall message").
  - **Grammatical and Structural Focus:** (e.g., "I found the sentence structures difficult to follow").
  - **Cognitive Strain:** (e.g., "Listening to this passage was mentally tiring").

## EEG Data Acquisition and Analysis

Continuous EEG was recorded from 64 Ag/AgCl electrodes configured in an elastic cap (10–20 system). Signals were sampled at 500 Hz with a linked-mastoid reference and a forehead ground. Offline processing was performed using a bandpass filter (0.1–30 Hz). Independent Component Analysis (ICA) was employed to identify and remove ocular artifacts.

Data were segmented into epochs ranging from – 200 ms to 1200 ms relative to the onset of the final word of each sentence. Epochs were baseline-corrected using the – 200 to 0 ms pre-stimulus interval. Artifact rejection was applied to any epoch exceeding  $\pm 100 \mu\text{V}$ . For each participant, artifact-free epochs were averaged by condition. Statistical analysis focused on mean amplitudes for the N400 (300–500 ms) and P600 (500–800 ms) components. Repeated-measures ANOVAs were conducted on predefined electrode clusters: centro-parietal for the N400 and parietal for the P600.

## Results

The data were analyzed to determine the behavioral and neurophysiological effects of discourse type. The results are presented in two sections: behavioral outcomes, which reflect the end-product of comprehension, and ERP results, which reveal the underlying real-time neural dynamics.

## Behavioral Results

The behavioral data, comprising comprehension performance and self-reported listening strategies, revealed a clear and significant advantage for the information-rich (IR) discourse.

To assess comprehension accuracy, scores from the multiple-choice and true/false tests were combined into a single composite score for each condition. A paired-samples *t*-test revealed that participants achieved significantly higher comprehension scores for the information-rich passage ( $M = 13.96$ ,  $SD = 1.40$ ) compared to the rhetorical passage ( $M = 6.69$ ,  $SD = 1.76$ ),  $t(25) = 43.98$ ,  $p < .001$ , Cohen's  $d = 8.63$  (Table 1).

Table 1

*Paired-Samples t-test for Comprehension Accuracy and Processing Efficiency by Discourse Type*

| Measure                                                                                                                                                                                    | Information-Rich <i>M</i> ( <i>SD</i> ) | Rhetorical <i>M</i> ( <i>SD</i> ) | <i>t</i> (25) | <i>p</i> | Cohen's <i>d</i> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|-----------------------------------|---------------|----------|------------------|
| Comprehension score                                                                                                                                                                        | 13.96 (1.40)                            | 6.69 (1.76)                       | 43.98         | < .001   | 8.63             |
| Processing time (minutes)                                                                                                                                                                  | 5.15 (0.63)                             | 7.11 (0.68)                       | -44.18        | < .001   | -8.66            |
| <b>Note.</b> <i>N</i> = 26. Comprehension scores reflect combined scores from the multiple-choice and true/false tests. Processing time refers to completion time for comprehension tests. |                                         |                                   |               |          |                  |

Findings in Table 1 represent a very large effect size, indicating a substantial performance gap between the two conditions. Processing efficiency was measured by the total time taken to complete the comprehension tests. Participants responded significantly faster following the information-rich passage ( $M = 5.15$  min,  $SD = 0.63$ ) than the rhetorical passage ( $M = 7.11$  min,  $SD = 0.68$ ),  $t(25) = -44.18$ ,  $p < .001$ , Cohen's  $d = -8.66$ . This large effect size suggests that the cognitive processing required for the rhetorical text was not only less successful but also considerably more time-consuming.

The Listening Strategy Survey data were analyzed by creating composite scores for the three primary factors: Meaning and Engagement Focus, Grammatical and Structural Focus, and Cognitive Strain. A series of paired-samples *t*-tests confirmed that listeners adopted fundamentally different processing strategies for each discourse type. The results are summarized in Table 2:

Table 2

*Paired Samples t-tests for Self-Reported Listening Strategies by Discourse Type*

| Strategy Dimension                                                                                                                  | Information-Rich <i>M</i> ( <i>SD</i> ) | Rhetorical <i>M</i> ( <i>SD</i> ) | <i>t</i> (25) | <i>p</i> | Cohen's <i>d</i> |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|-----------------------------------|---------------|----------|------------------|
| Meaning and Engagement Focus                                                                                                        | 3.63 (0.25)                             | 2.16 (0.41)                       | 30.72         | < .001   | 6.03             |
| Grammatical and Structural Focus                                                                                                    | 1.89 (0.31)                             | 3.45 (0.32)                       | -45.45        | < .001   | -8.91            |
| Cognitive Strain                                                                                                                    | 1.80 (0.31)                             | 3.55 (0.34)                       | -48.65        | < .001   | -9.54            |
| <b>Note.</b> <i>N</i> = 26. Scores are based on a 4-point Likert scale (1 = <i>Strongly Disagree</i> , 4 = <i>Strongly Agree</i> ). |                                         |                                   |               |          |                  |

Introspective reports from the Listening Strategy Survey reveal a clear trade-off in cognitive processing between the two discourse types. When listening to the information-rich passage, participants were highly engaged and focused on extracting the overall message ( $M = 3.63$ ,  $SD = 0.25$ ).

However, the linguistic complexity of the rhetorical passage forced a strategic shift away from meaning and toward a detailed analysis of its grammatical and structural features ( $M = 3.45$ ,  $SD = 0.32$ ). This pivot

to a more effortful, bottom-up processing style corresponded with a substantial increase in perceived cognitive load.

Consequently, participants reported significantly higher cognitive strain while listening to the rhetorical passage ( $M = 3.55, SD = 0.34$ ) compared to the more straightforward information-rich passage ( $M = 1.80, SD = 0.31$ ),  $t(25) = -48.65, p < .001$ .

## ERP Results

The ERP data revealed distinct neural signatures for the two discourse types at sentence-final words, providing a neural basis for the observed behavioral differences. Figure 2 presents the grand-average ERP waveforms for both conditions, with key component characteristics summarized in Table 3.

Table 3  
*Key Characteristics of ERP Components from Waveform Data (Fig. 2)*

| ERP Component | Condition        | Approx. Peak Amplitude (μV) | Approx. Peak Latency (ms) | Interpretation of Amplitude Difference                                                             |
|---------------|------------------|-----------------------------|---------------------------|----------------------------------------------------------------------------------------------------|
| N400          | Information-rich | ≈ -1.9 μV                   | 400                       | Larger negativity suggests deeper semantic processing and integration of novel information.        |
|               | Rhetorical       | ≈ -0.75 μV                  | 400                       | Smaller negativity may reflect shallower semantic processing due to high syntactic load.           |
| P600          | Information-rich | ≈ +0.5 μV                   | 600                       | Minimal positivity indicates low cost of syntactic and structural integration.                     |
|               | Rhetorical       | ≈ +2.0 μV                   | 600                       | Large positivity reflects increased cognitive cost for syntactic reanalysis and structural repair. |

### N400 Component (Semantic Processing)

Visual inspection of the waveforms (Fig. 2) reveals a prominent N400 component, maximal around 400 ms post-stimulus. A repeated-measures ANOVA on the mean amplitude in the 300–500 ms time window confirmed a significant main effect of Discourse Type,  $F(1, 25) = 6.87, p = .015, \eta^2p = .22$ .

As quantified in Table 3 and illustrated in Fig. 2, the information-rich (IR) passage elicited a significantly larger (more negative-going) N400 amplitude compared to the rhetorical (RH) passage. This finding suggests that while the IR passage was behaviorally easier to comprehend, it prompted a more robust engagement of semantic integration processes. The rich, novel content may have required the brain to actively work to update its semantic model of the discourse, resulting in a larger N400. Conversely, the

smaller N400 for the RH passage could reflect a shallower semantic processing strategy, possibly because cognitive resources were overwhelmingly allocated to parsing its complex syntax.

## P600 Component (Syntactic and Structural Processing)

As clearly depicted in Fig. 2, the most prominent difference between the conditions emerged in the P600 component. An ANOVA on the mean amplitude in the 500–800 ms time window revealed a highly significant main effect of Discourse Type,  $F(1, 25) = 8.12, p = .009, \eta^2p = .25$ . The rhetorical (RH) passage elicited a robust and sustained P600 positivity relative to the information-rich (IR) passage (see Table 3).

This large P600 effect reflects the increased cognitive and neural cost of parsing the complex syntax, engaging in grammatical reanalysis, and integrating the non-canonical structures of the classical ode. The brain was demonstrably working harder to make grammatical sense of the input, a finding consistent with the self-reported cognitive strain from the behavioral survey.

The scalp topographies of these effects, shown in Fig. 3, confirm their neural distributions are consistent with canonical N400 and P600 components. Table 4 summarizes the voltage ranges and functional interpretation derived from these scalp maps.

Table 4  
*Summary of Scalp Topography Data (Fig. 3)*

| ERP Component | Difference-Wave Voltage (μV) | Polarity | Functional Interpretation                                                                                           |
|---------------|------------------------------|----------|---------------------------------------------------------------------------------------------------------------------|
| N400          | -1.15 to 0.00                | Negative | Semantic processing: indexing difficulties in meaning integration and detection of semantic anomalies.              |
| P600          | 0.00 to + 1.50               | Positive | Syntactic and structural processing: reflecting reanalysis, repair, and integration costs in parsing complex input. |

In summary, the ERP results present a compelling double dissociation between the neural processing of the two discourse types. The information-rich passage was characterized by a large N400 effect, signaling deep semantic integration of novel content with minimal syntactic strain. Conversely, the rhetorically complex passage elicited a robust P600 effect, reflecting the significant cognitive cost of parsing its complex grammatical structure. This heightened syntactic demand was accompanied by a reduced N400, suggesting that cognitive resources were diverted from semantic processing to handle the structural challenges. Taken together, these distinct and complementary neural signatures provide a clear neurophysiological basis for the behavioral findings, illustrating the processing trade-offs between semantic depth and syntactic complexity.

## Integrated Behavioral and Neurophysiological Profile

The convergence of behavioral and neurophysiological data paints a clear and cohesive picture of a strategic processing trade-off. These integrated findings, summarized in Table 5, reveal two distinct

listener profiles dictated by discourse type.

The Information-Rich (IR) Profile is characterized by high comprehension accuracy, rapid processing, and strong self-reported engagement. Neurally, this successful comprehension is underpinned by a minimal P600 and a large N400, reflecting deep semantic integration of novel content with low syntactic cost. The listener's cognitive resources are successfully allocated to building a coherent mental model of the content. In stark contrast, the Rhetorical (RH) Profile is defined by poor comprehension, slow processing, and high cognitive strain. This behavioral struggle has direct neural correlates: a large, robust P600 indicates that significant cognitive resources are diverted to effortful syntactic reanalysis. This syntactic overload appears to suppress deep semantic processing, as evidenced by an attenuated (smaller) N400. The result is a state of cognitive overload where bottom-up structural analysis overrides top-down message-level comprehension.

Table 5  
*Joint Display of Key Behavioral and ERP Findings by Discourse Type*

| Measure                                                                                    | Information-Rich (IR) Condition | Rhetorical (RH) Condition      |
|--------------------------------------------------------------------------------------------|---------------------------------|--------------------------------|
| <b>Behavioral Outcomes</b>                                                                 |                                 |                                |
| Comprehension Score (M (SD))                                                               | 13.96 (1.40)                    | 6.69 (1.76)                    |
| Cognitive Strain (M (SD))                                                                  | 1.80 (0.31)                     | 3.55 (0.34)                    |
| <b>Neural Signatures (Mean Amplitude)</b>                                                  |                                 |                                |
| P600 Component (Syntactic Cost)                                                            | ≈ 0.5 μV (Minimal)              | ≈ 2.0 μV (Large)               |
| <b>N400 Component (Semantic Effort)</b>                                                    | <b>≈ -1.9 μV (Enhanced)</b>     | <b>≈ -0.75 μV (Attenuated)</b> |
| <b>Integrated Processing Profile</b>                                                       | Efficient, Meaning-Focused      | Effortful, Structure-Focused   |
| <i>Note. Behavioral scores are from Tables 1 and 2. ERP amplitudes are peak estimates.</i> |                                 |                                |

Table 5 directly juxtaposes the behavioral outcomes (comprehension accuracy, cognitive strain) with their underlying neural signatures (P600 and N400 amplitudes) for both the information-rich and rhetorical conditions. This provides a concise overview of the two distinct processing profiles and starkly illustrates the cognitive and neural trade-offs listeners made in response to each discourse type.

The interpretation of this joint display reveals a remarkable consistency across data types, where the neurophysiological results provide a direct mechanism for the behavioral outcomes. For the information-rich passage, the behavioral success—high comprehension accuracy and low self-reported cognitive strain—is directly explained by its neural profile: a large N400 effect, signaling deep semantic integration of novel content, accompanied by a minimal P600, indicating low syntactic strain.

Conversely, the behavioral struggle observed for the rhetorical passage finds its direct neural correlate in a clear neurocognitive trade-off. The high cognitive strain reported by participants is explained by a robust P600 effect, reflecting the heightened syntactic demand of grammatical reanalysis. This diversion of cognitive resources was accompanied by a significantly reduced N400, suggesting that deep semantic processing was suppressed to handle the structural challenges, ultimately leading to poor comprehension scores. Thus, the ERP data do not merely supplement the behavioral findings; they provide a clear neurophysiological explanation for why the information-rich discourse was understood effectively and why the rhetorical discourse led to comprehension failure.

## Discussion

The present study was designed to test the information-rich discourse hypothesis, which posits that listeners strategically adapt their cognitive and neural processing strategies based on the informational density and rhetorical complexity of spoken discourse. By integrating behavioral performance, introspective reports, and high-temporal-resolution ERP data, our findings provide strong support for the behavioral predictions of this hypothesis while prompting a targeted revision of its neural predictions. The results demonstrate this adaptive shift not only by identifying behavioral outcomes, but by linking them directly to their underlying neural underpinnings. The study shows that information-rich discourse facilitates efficient, meaning-focused comprehension, while rhetorically complex discourse imposes a significant cognitive load, forcing listeners into an effortful, structure-focused processing mode.

## Information-Rich Discourse Facilitates Comprehension and Efficiency

Our first research question asked whether listeners would demonstrate faster, more accurate comprehension and report a greater focus on meaning for information-rich discourse. The behavioral results provide an unequivocal affirmative answer. Participants not only comprehended the National Geographic script far more accurately but also did so more efficiently, as reflected in their faster response times. This finding provides direct ecological validity for cognitive load theory, which predicts that material with high intrinsic complexity—in this case, the archaic vocabulary and convoluted syntax of the classical ode—consumes finite working memory resources that are then unavailable for deeper comprehension and learning [7, 8].

The introspective survey data offer a compelling window into the subjective experience behind this performance gap. For the rhetorical passage, participants reported significantly higher cognitive strain and a conscious shift of attention toward grammatical features. This self-reported experience of increased "listening effort" provides a psychological anchor for recent neurophysiological work linking subjective difficulty to measurable neural markers of cognitive strain [9, 10]. In stark contrast, the information-rich passage was perceived as highly engaging, allowing listeners to focus their resources on the primary goal of communication: extracting meaning. This confirms the behavioral predictions of our hypothesis and replicates the core findings of our previous work with second language learners,

suggesting this is a robust processing principle applicable across different levels of language proficiency [11].

## Neurophysiological Evidence of a Processing Trade-Off

Our second research question probed the underlying neural correlates of this behavioral pattern. The ERP results provide direct neurophysiological evidence for the strategic reallocation of processing resources, confirming our prediction for the P600 while revealing an N400 pattern that ran counter to our initial prediction.

The most striking neural finding was the robust P600 effect elicited by the rhetorical passage. In line with hypothesis (RQ2a), the complex syntax of the ode triggered a large, sustained positivity, the classic neural signature of increased syntactic processing cost [14]. This result provides a direct neural correlate for the "grammar-focused" strategy that participants reported in the survey; their brains were demonstrably working harder to parse difficult structures and re-evaluate the grammatical integrity of the input, a process now seen as part of a broader system for monitoring structural coherence in discourse [15].

Concurrently, the N400 component revealed a surprising outcome that challenges a simple interpretation of processing ease. Contrary to our initial hypothesis (RQ2b), which predicted an attenuated N400 for the information-rich text, we found a significantly *larger* N400 for this condition. This finding suggests that while the IR passage was behaviorally easier to comprehend, its high density of novel, meaningful information required more robust semantic integration efforts, as reflected by the enhanced N400. In contrast, the attenuated N400 for the rhetorical passage is best understood through the lens of a cognitive trade-off: with neural resources overwhelmingly allocated to syntactic parsing (indexed by the large P600), deeper semantic processing was likely suppressed. This result provides strong evidence for interactive models where high syntactic demands can constrain the resources available for semantic integration [1].

## The Integrated Picture: A Multi-Level Account of Adaptive Listening

Taken together, the behavioral and ERP findings converge to form a cohesive, multi-level picture of adaptive listening, as summarized in our integrated profile (Table 5). The study's primary contribution is not merely in identifying separate behavioral and neural effects, but in demonstrating their tight coupling. The poor comprehension and high cognitive strain associated with the rhetorical text are directly explained by a dual neural cost: effortful syntactic reanalysis (large P600) and consequently suppressed semantic integration (attenuated N400). Conversely, the high comprehension and efficiency seen for the information-rich text are underpinned by robust semantic processing (large N400) and minimal syntactic struggle (minimal P600). This provides a powerful, multi-level account of how discourse-level characteristics orchestrate a system-wide shift in cognitive strategy.

# Implications

These findings make a significant contribution to theories of language comprehension by extending sentence-level models to the domain of naturalistic discourse. They provide strong support for interactive and predictive models, demonstrating that the language processing system is not a static decoder but a highly adaptive system that dynamically allocates resources based on the global properties of the input. The results show that discourse-level features like information density and rhetorical complexity are not mere stylistic colorings; they are powerful modulators of core neurocognitive mechanisms, capable of shifting the balance between semantic and syntactic processing streams.

The results carry important practical implications for language education and curriculum design. They provide empirical support for prioritizing content-rich, informative texts in language teaching, particularly for developing foundational listening skills [24]. While rhetorically complex literary texts are essential for developing advanced cultural and linguistic appreciation, our findings suggest that building core comprehension and processing fluency is best achieved with materials that minimize extraneous cognitive load. By using engaging, information-rich content, educators can foster more efficient learning, reduce frustration, and help learners build confidence in their ability to process extended discourse effectively.

# Limitations and Future Directions

While this study provides clear evidence for our hypothesis, several limitations should be acknowledged. First, the sample was limited to a specific demographic of university students, and future work should test the generalizability of these findings across a wider range of ages and educational backgrounds, as well as examine the individual differences in neurocognitive processing that can meaningfully shape ERP responses [25]. Relatedly, the behavioral effect sizes observed here were exceptionally large; although consistent with the deliberately sharp contrast between the two discourse types, they should be interpreted with caution and confirmed in larger, more heterogeneous samples. Second, our stimuli represented two distinct poles of a continuum; future research could parametrically manipulate information density and syntactic complexity to map the processing trade-offs more granularly. Third, our ERP analysis, while standard, was time-locked to sentence-final words. This approach captures integrative processes but misses the continuous, dynamic nature of speech comprehension.

Future studies could employ more advanced analytic techniques, such as Temporal Response Functions (TRFs) or analyses of neural entrainment, to track how the brain processes speech features as they unfold in real time [2, 3, 26]. Individual factors such as musical expertise, which modulates the shared neural mechanisms of language and music, may further shape these adaptive responses and merit systematic investigation [27]. Finally, exploring this hypothesis in more challenging listening environments, such as in the presence of background noise [17], and across different languages would provide crucial tests of the robustness and universality of these adaptive processing principles.

# Abbreviations

- **EEG**: Electroencephalography
- **ERP(s)**: Event-Related Potential(s)
- **ICA**: Independent Component Analysis
- **IR**: Information-Rich (referring to the factual discourse condition)
- **RH**: Rhetorical (referring to the rhetorically complex discourse condition)
- **TRFs**: Temporal Response Functions

## Key ERP Components

- **N400**: A negative-going ERP component peaking around 400 ms post-stimulus, associated with semantic processing and predictability.
- **P600**: A positive-going ERP component peaking around 600 ms post-stimulus, associated with syntactic reanalysis and structural processing costs.

# Declarations

## Acknowledgements

The author thanks all participants for their time and involvement in this study.

## Author Contributions

The author confirms sole responsibility for the following: study conception and design, stimulus preparation, behavioral and EEG data collection, statistical analysis and interpretation of results, and manuscript drafting and revision.

## Funding

The author did not receive support from any organization for the submitted work. No funding was received to assist with the preparation of this manuscript.

## Competing Interests

The author declares no competing interests.

## Ethics Approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Faculty of Education Ethics Board at Beni-Suef University (Reference No. X-FoE-003-01-011-2025).

## Informed Consent

Written informed consent was obtained from all individual participants included in the study.

## Consent to Publish

The author affirms that all participants provided informed consent for the publication of anonymized and aggregated data.

## Data Availability

The de-identified datasets generated and analysed during the current study are provided as electronic supplementary files accompanying this article. These files comprise the participant-level behavioral and ERP data in Microsoft Excel format (.xlsx), the SPSS dataset (.sav) and analysis syntax (.sps), and a LaTeX file (.tex) containing the data tables and statistical output.

## References

1. Momenian, M., Vaghefi, M., Sadeghi, H., Hossein-Zadeh, G. & Boonstra, T. W. Language prediction in monolingual and bilingual speakers: An EEG study. *Sci. Rep.* **14**, 6818. <https://doi.org/10.1038/s41598-024-57426-y> (2024).
2. Caucheteux, C., Gramfort, A. & King, J. R. Evidence of a predictive coding hierarchy in the human brain listening to speech. *Nat. Hum. Behav.* **7** (3), 430–441. <https://doi.org/10.1038/s41562-022-01516-2> (2023).
3. Dimakou, A., Pezzulo, G., Zangrossi, A. & Corbetta, M. The predictive nature of spontaneous brain activity across scales and species. *Neuron* **113** (9), 1310–1332. <https://doi.org/10.1016/j.neuron.2025.02.009> (2025).
4. Oderbolz, C., Stark, E., Sauppe, S. & Meyer, M. Concurrent processing of the prosodic hierarchy is supported by cortical entrainment and phase-amplitude coupling. *Cereb. Cortex.* **34** (12). <https://doi.org/10.1093/cercor/bhae479> (2024). Article bhae479.
5. Chomsky, N. *Syntactic structures*. Mouton. (1957).
6. McClelland, J. L. & Rumelhart, D. E. *Parallel distributed processing: Explorations in the microstructure of cognition* Vol. 1 (MIT Press, 1989).
7. Brandt, S. *Cognitive load theory* (Cambridge University Press, 2013).
8. Sweller, J. Cognitive load theory and individual differences. *Learn. Individual Differences.* **110**, 102423. <https://doi.org/10.1016/j.lindif.2024.102423> (2024).
9. Woods, S. J. *Evaluating aperiodic neural activity as a marker of listening effort in speech perception in younger adults* [Master's thesis, University of Utah]. ProQuest Dissertations & Theses Global. (2024).
10. Woods, S. J., Silcox, J. W. & Payne, B. R. Evaluating aperiodic and periodic neural activity as markers of listening effort in speech perception. *Auditory Percept. Cognition.* **7** (3), 203–218. <https://doi.org/10.1080/25742442.2024.2395217> (2024).

11. Mekheimer, M. A. & Fageeh, A. I. Prioritizing information over grammar: A behavioral investigation of information density and rhetorical discourse effects on EFL listening comprehension. *Discover Educ.* **4** (1). Article 24. <https://doi.org/10.1007/s44217-024-00109-x> (2025).
12. Kutas, M. & Federmeier, K. D. Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Ann. Rev. Psychol.* **62**, 621–647. <https://doi.org/10.1146/annurev.psych.093008.131123> (2011).
13. Hsin, C. H., Lee, C. Y. & Tsao, Y. Exploring N400 predictability effects during sustained speech comprehension: From listening-related fatigue to speech enhancement evaluation. *Ear Hear.* **46** (4), 922–940. <https://doi.org/10.1097/AUD.0000000000001635> (2025).
14. Friederici, A. D. Towards a neural basis of auditory sentence processing. *Trends Cogn. Sci.* **6** (2), 78–84. [https://doi.org/10.1016/S1364-6613\(00\)01839-8](https://doi.org/10.1016/S1364-6613(00)01839-8) (2002).
15. Chalas, N. et al. Dissociating prosodic from syntactic delta activity during natural speech comprehension. *Curr. Biol.* **34** (15), 3537–3549e6. <https://doi.org/10.1016/j.cub.2024.06.072> (2024).
16. Thomas, T., Martin, C. D. & Caffarra, S. The impact of speaker accent on discourse processing: A frequency investigation. *Brain Lang.* **260** <https://doi.org/10.1016/j.bandl.2024.105509> (2025). Article 105509.
17. Fitzgerald, L. P., DeDe, G. & Shen, J. Effects of linguistic context and noise type on speech comprehension. *Front. Psychol.* **15** <https://doi.org/10.3389/fpsyg.2024.1345619> (2024). Article 1345619.
18. Barchet, A. V. et al. Attentional engagement with target and distractor streams predicts speech comprehension in multitalker environments. *bioRxiv* <https://doi.org/10.1101/2025.04.04.647157> (2025).
19. Nakamura, M. & Rossi, E. Differential effects of working memory constraints on syntactic and semantic processing: Evidence from ERPs. *Brain Lang.* **264**, Article 105550. <https://doi.org/10.1016/j.bandl.2025.105550> (2025).
20. Gunawan, A. Psycholinguistic perspectives on garden-path sentence processing. *Bull. Lang. Literature Stud.* **2** (1). <https://doi.org/10.59652/bls.v2i1.518> (2025).
21. Euler, M. J. et al. Associations between the resting EEG aperiodic slope and broad domains of cognitive ability. *Psychophysiology* **61** (6). <https://doi.org/10.1111/psyp.14543> (2024). Article e14543.
22. Price, M. Comparing alpha power during in-noise listening task as a parameter of listening effort in young versus older adults. *RANGE: Undergrad. Res. J.* **26** (1), 2440–2449 (2025).
23. Chen, L., Jin, Y., Ge, Z., Li, L. & Lu, L. The less meaningful the understanding, the faster the feeling: Speech comprehension changes perceptual speech tempo. *Cogn. Sci.* **49** (2). <https://doi.org/10.1111/cogs.70037> (2025). Article e70037.
24. Butler, Y. G. & Timpe-Laughlin, V. Listening and young learners. In (ed Wennerstrom, G. J. O.) *The Routledge handbook of second language acquisition and listening* (292–304). Routledge. (2024).

25. Hao, J., Rossi, E., Nakamura, M., Luque, A. & Rothman, J. Individual differences matter in heritage language bilingual processing: An electroencephalography (EEG) study of grammatical gender. *Studies in Second Language Acquisition*. Advance online publication. (2025). <https://doi.org/10.1017/S0272263125101149>

26. Karunathilake, I. M. D., Brodbeck, C., Bhattasali, S., Resnik, P. & Simon, J. Z. Neural dynamics of the processing of speech features: Evidence for a progression of features from acoustic to sentential processing. *J. Neurosci.* **45** (11), 1143242025. <https://doi.org/10.1523/JNEUROSCI.1143-24.2025> (2025). Article e.

27. Wang, X. & Zeng, T. Tuning the brain: Musical expertise modulation on the shared mechanism of language and music. *Language, Cognition and Neuroscience*. Advance online publication. (2025). <https://doi.org/10.1080/23273798.2025.2533873>

Figures

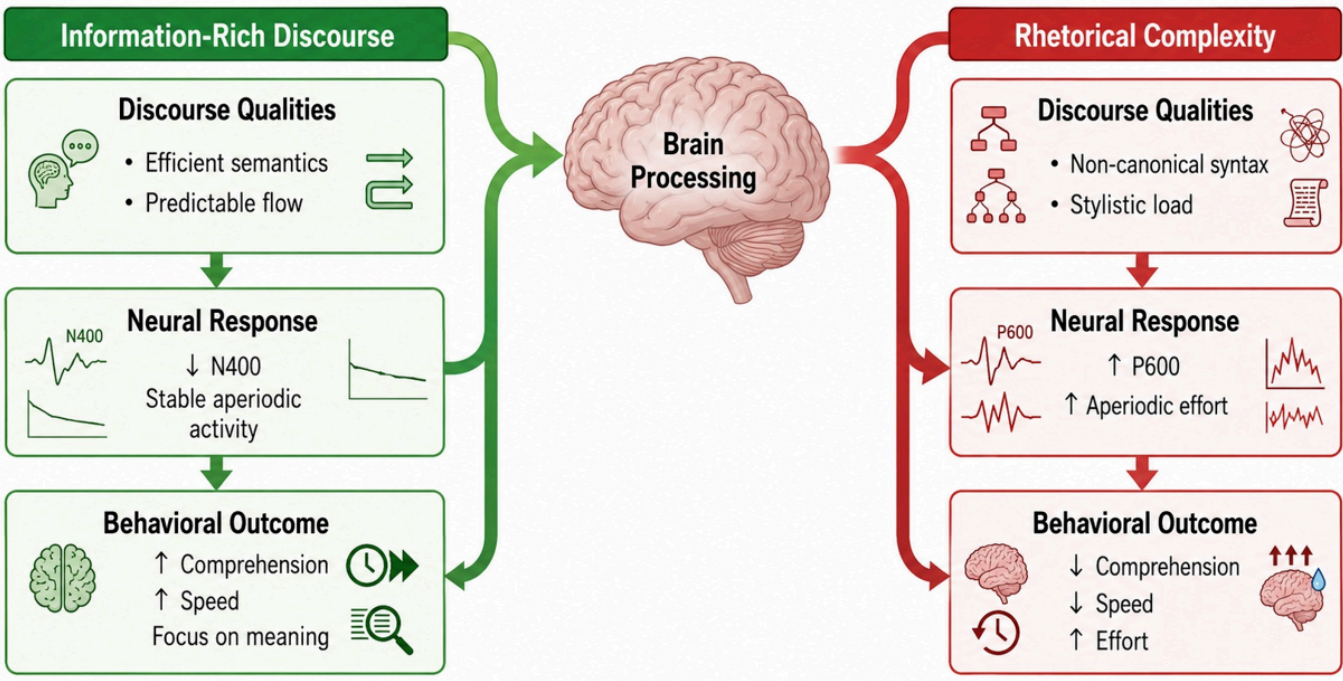


Figure 1

The theoretical model of the Information-Rich Discourse Hypothesis.

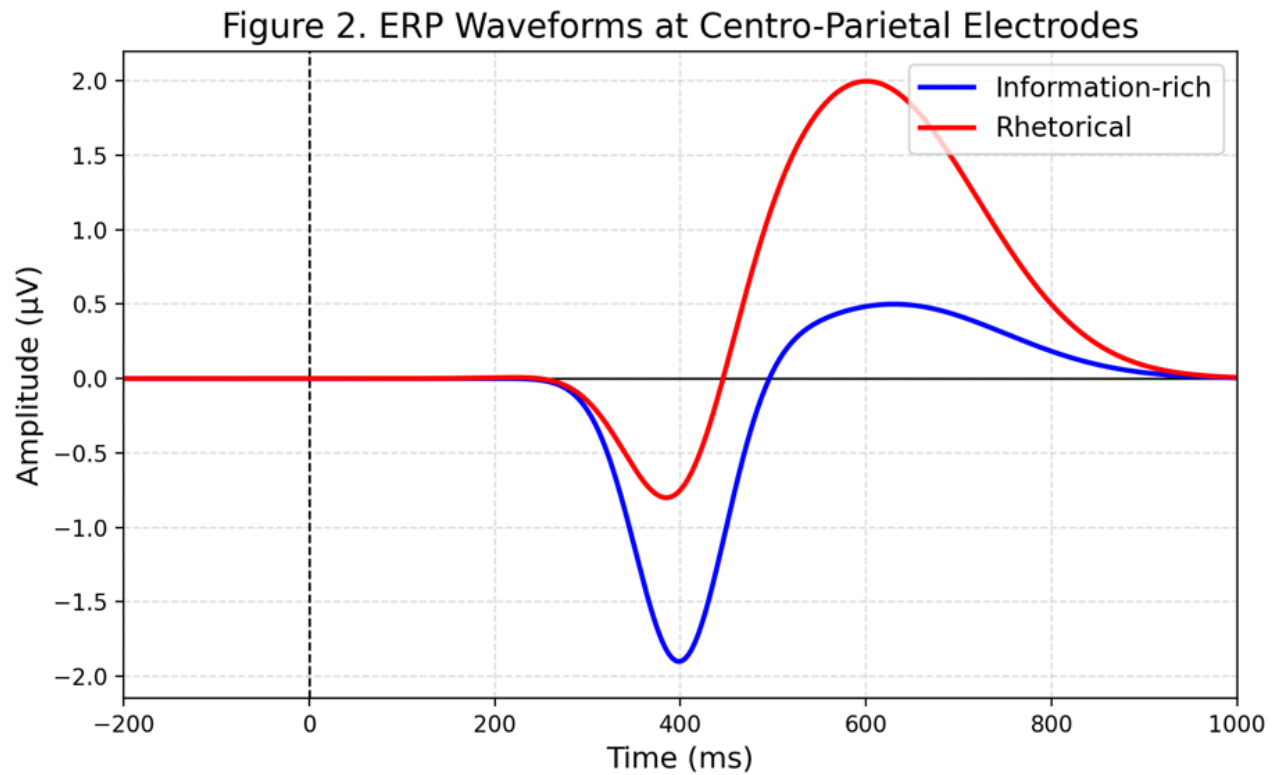


**Figure 2**

ERP waveforms at centro-parietal electrodes. Grand-average ERPs illustrating a double dissociation: the information-rich condition (blue) elicits a larger N400, while the rhetorical condition (red) elicits a larger P600.

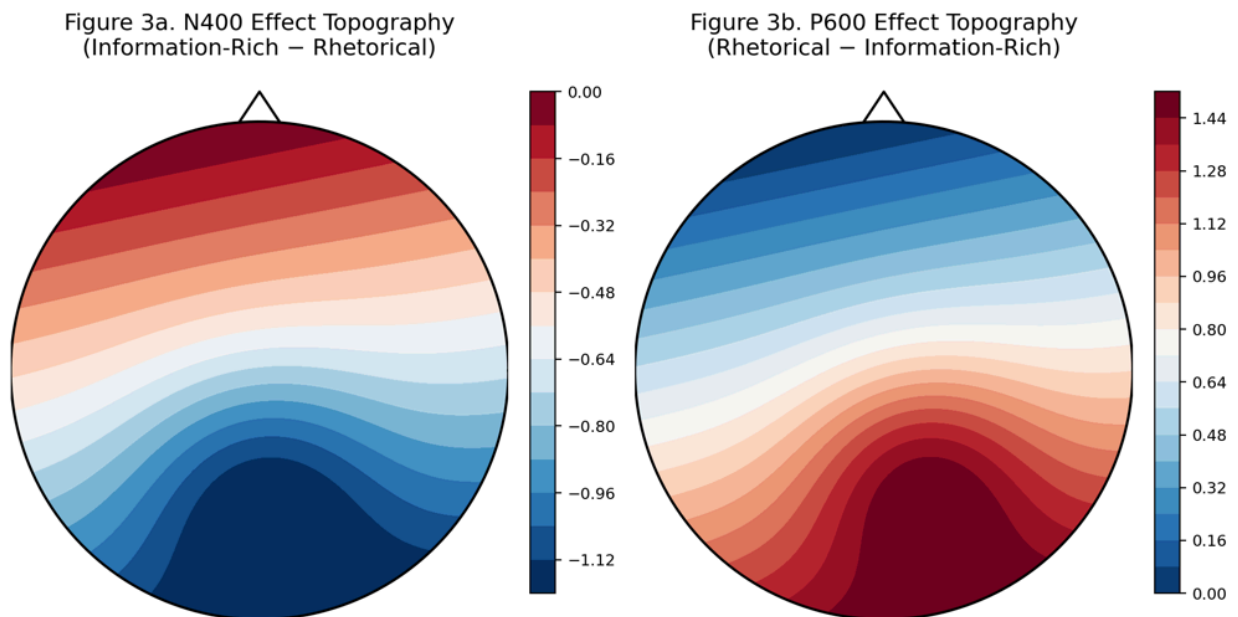


**Figure 3**

*Scalp topographies of ERP effects. (A) The topography of the N400 effect (information-rich minus rhetorical, 300–500 ms) shows a characteristic centro-posterior negativity. (B) The topography of the P600 effect (rhetorical minus information-rich, 500–800 ms) shows a parietal positivity.*

## Supplementary Files

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