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Neural Mechanisms Underlying Natural Text Reading

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Abstract: The neural mechanisms underlying natural text reading are anchored in the extended language network, which integrates various brain regions to support a multi-level processing—ranging from lexical decoding to the construction of situation models. Neural activity during reading is shaped by text properties, reader characteristics, and their dynamic interactions. At the text level, narrative texts show greater involvement of social cognition within the default mode network (DMN), whereas expository texts show stronger activation of the frontoparietal control network (FPN) supporting information integration, demonstrating distinct neural processing mechanisms between the two text genres. Concurrently, the core informational dimensions embedded within the text further shape distinct and regionally specific patterns of neural activation. Moreover, these text-driven neural response profiles are themselves modulated by reader-specific factors, giving rise to individual differences in information integration efficiency, genre-dependent processing strategies, and the degree of neural synchronization. Finally, emerging methodological advances—including concurrent eye-tracking–functional magnetic resonance imaging (fMRI) recording, inter-subject correlation analysis, and large language model (LLM)-based computational modeling—have propelled a deeper understanding into natural text reading.

Keywords: Natural text reading, Extended language network, Text properties, Reader characteristics, Neural mechanisms.

1. Introduction

Text reading serves as a critical avenue for acquiring knowledge, experiencing emotions, and constructing social cognition [37, 76, 80, 81], and elucidating its neural mechanisms not only represents a frontier topic in cognitive neuroscience but also provides a crucial window into higher-order human cognitive functions. Early research predominantly focused on the processing of isolated words or simple sentences, which laid an important foundation for understanding the basic linguistic mechanisms of reading. However, as research has progressed, the field has gradually recognized that the essence of authentic reading lies in meaning construction within a dynamic and coherent context [63], which has driven a shift in research paradigms toward more ecologically valid "naturalistic text reading".

With the rise of naturalistic text reading research, investigators have begun to address the core question of how readers construct meaning from coherent discourse from both theoretical and neurobiological perspectives. At the theoretical level, the construction-integration model has elucidated the fundamental cycle of text reading: readers first form a text-based representation grounded in concepts and propositions through language input (construction) and subsequently integrate this representation into a coherent situation model via integrative processes [44, 45]. In addition, the reading systems framework further emphasizes that the lexicon serves as a critical hub linking word identificationand comprehension systems and that the quality of lexical representations directly influences the efficiency of situation model construction [63]. Recently, theoretical advances have increasingly underscored the active and hierarchical nature of reading. The multi-representational hierarchical actively generative architecture proposes that reading comprehension is a dynamic process driven by continuous prediction and verification across multiple levels of linguistic representation, a predictive mechanism that, to some extent, enhances both the efficiency and speed of situation model construction [47]. At the neural level, functional neuroimaging studies have propelled a deeper understanding of text reading. The extended language network (ELN), revealed by neuroimaging meta-analysis, demonstrates that text comprehension relies on a distributed brain network extending beyond canonical language regions, with "extended areas" such as prefrontal, anterior temporal, and midline structures jointly supporting multilevel cognitive processes—ranging from lexical access and syntactic parsing to higher-order inference and situation model construction [25]. Moreover, existing studies on naturalistic text reading have found that narrative comprehension engages left-lateralized semantic regions as well as bilateral cortical areas within the default mode network (DMN), including the posterior cingulate cortex, precuneus, and dorsomedial prefrontal cortex (dmPFC)—regions that are associated with situation model updating and integration [2, 40, 70, 85]. In contrast, other studies have revealed that expository texts, relative to narratives, elicit significantly greater activation in the frontoparietal control network (FPN) [1, 74]. Beyond these differences, recent work has additionally identified that factors such as reading amount, text content, executive function, and language proficiency significantly influence the neural mechanisms of text reading [50, 71]. For example, Song et al. (2025) demonstrated that print exposure significantly modulates neural activity patterns during text processing. During narrative reading, higher print exposure was linked to enhanced inter-subject alignment within bilateral semantic regions. In expository reading, however, higher print exposure was associated with more idiosyncratic neural activation patterns. Taken together, beyond the basic neural underpinnings of text reading, current research has primarily explored the factors that influence the neural mechanisms of text comprehension, as well as the complex interactions among these factors.

Building upon these considerations, we systematically reviewed recent neurobiological studies of naturalistic text reading using functional magnetic resonance imaging (fMRI), synthesizing the literature across three principal dimensions: (1) the foundational language-related neural mechanisms that support text reading; (2) the factors that modulate the neural substrates of text comprehension; and (3) the ways in which emerging techniques and analytical approaches are deepening our understanding of the neural architecture of reading. Synthesizing the evidence from these complementary lines of inquiry, this review aims to articulate a more comprehensive and dynamic framework of the neural mechanisms underlying naturalistic text reading—a framework that may serve as a theoretical foundation for subsequent investigations while also providing neural-level insights to inform reading instructional practices and intervention strategies for language disorders.

2. The Neural Substrates of Text Reading

Ferstl et al. (2008) conducted a meta-analysis of 23 neuroimaging studies and put forward the core framework of the "Extended Language Network" (ELN). This framework broadens the conventional understanding that language processing only relies on the perisylvian cortex, and verified that the ELN serves as a foundational network supporting high-level contextual and integrative processing during text reading.

Utilizing four analytical contrast sets (text vs. resting baseline, text vs. nonlanguage baseline, coherent text vs. incoherent fragmented text, and special pragmatic sub-processes (e.g., metaphor comprehension) vs. general narrative reading), the meta-analysis identified the following core regions: The bilateral anterior temporal lobes (ATL), which were consistently and robustly activated across all four analytical groups, playing a crucial role in propositionalization—the process required for combining words into semantically based content units [28, 46]. The middle and posterior temporal lobes are concerned with implementing basic language perception, integration and interpretation [8, 18, 23]. The left inferior frontal gyrus (IFG) is implicated in the processing of sentence-level context [7, 25]. The dorsomedial prefrontal cortex (dmPFC) and the posterior cingulate cortex/precuneus were co-activated during the coherent text contrasts, supporting coherence building [25]. The right hemisphere, in turn, is engaged in specific pragmatic interpretations (e.g., metaphor comprehension) [10]. These interconnected brain regions constitute the Extended Language Network (ELN), which offers a unified cortical model to explain the neural mechanisms underlying high-level discourse comprehension.

Notably, the activation pattern of this network undergoes dynamic modulation by various factors, which further shapes the efficiency and integrity of situation model construction.

3. Critical Modulatory Factors in the Neural Substrates of Text Reading

Reading necessarily involves the construction of a situation model [85], whose underlying neural processing is modulated by multiple variables. Prior research indicates that the key influencing dimensions consist of text properties, readers' cognitive characteristics, and the interactive effects between the two [50]. Synthesizing existing research, as the core input of reading, text properties—including coherence, text genre (e.g., narrative vs. expository), and the internal information dimension—directly influence cognitive demands and strategic processing choices [20, 23, 26]. In turn, readers' working memory capacity, reading amount, and topic preference constitute critical sources of individual differences in neural mechanisms, shaping the activation patterns and network synergy efficiency of reading-related brain regions by modulating the efficiency of information encoding, integration, and situation model updating [50, 71]. In-depth elucidation of the regulatory principles governing how text characteristics and reader features modulate reading-related neural mechanisms would not only contribute to a more comprehensive understanding of the neural basis of reading comprehension processes, but also provide valuable insights for differentiated reading instruction, language disorder intervention, and the cultivation of cross-linguistic reading abilities.

3.1. Dependence of Reading-Related Neural Mechanisms on Text Characteristics

Existing research has predominantly focused on two text genres: narrative and expository texts. These text genres impose fundamentally different cognitive demands for situation-model construction, and their neural underpinnings show systematic, domain-specific differentiation. This differentiation manifests not only as a macro-level functional divergence between narrative and expository texts but also as fine-grained processing of distinct information dimensions within a given text genre.

Narrative texts provide situational cues via changes in protagonists, evolving plot-related events and setting shifts, prompting readers to dynamically update and build a coherent situation model [85]. In contrast, the processing of expository texts follows the Construction-Integration Model advanced by Kintsch (1988), in which readers primarily integrate semantic information across core dimensions such as conceptual hierarchies and logical relations [44].

Neuroimaging research has shown that processing narrative and expository texts relies on shared neural mechanisms. Aboud et al. (2019) conducted the first direct neurobiological comparison of expository and narrative comprehension in developing children, revealing that both genres engage canonical language regions (e.g., left middle/superior temporal gyrus) as well as core nodes of the default mode network (DMN), including the left angular gyrus, hippocampus, anterior temporal lobes, and medial prefrontal cortex. That is, reading comprehension across genres relies on basic semantic processing and situation model construction, processes in which the DMN plays a central role by supporting bottom-up, automated activation and semantic associations that integrate textual information with background knowledge to form an internal representation of the content [2, 19, 77, 78]. The distinct neural mechanisms for the two genres diverge as a function of their cognitive demands: narrative texts elicit significantly greater activation in the bilateral angular gyrus and anterior superior temporal sulcus—regions associated with theory of mind —which may support inferences about character intentions [67]. Expository texts, in contrast, recruit the frontoparietal control network (FPN) significantly more, as evidenced by increased activation in the dorsolateral prefrontal cortex and intraparietal sulcus, alongside significantly enhanced functional coupling between the FPN and the DMN. This inter-network coupling between the FPN and DMN is significantly stronger during the initial segments of expository text reading, reflecting greater demand for strategic processes during the initial construction of the situation model [30, 82].

However, beyond the macro-level distinctions discussed above, texts within the same genre also elicit more fine-grained neural differentiation, driven by variations in specific internal information dimensions.

Toazza et al. (2022) provided direct evidence for differential brain activation during narrative text comprehension. In healthy control readers, all emotional conditions (anger, sadness, and happiness) commonly engaged the left middle temporal gyrus, inferior frontal gyrus, inferior parietal lobe, medial frontal gyrus, and posterior cingulate gyrus, constituting a shared neural network for emotional narrative comprehension. Among emotional conditions, only anger-evoking stories yielded significant additional activation within the posterior cingulate gyrus/precuneus. This pattern may reflect deeper engagement with protagonists' mental states and enhanced social-cognitive processing [24], which was not observed for sad or happy narratives. Such neural dissociations suggest that emotional narrative processing, while relying on the general neural mechanisms of narrative comprehension, also elicits emotion-specific activations depending on the emotional conditions. This finding further supports the idea that distinct dimensions shape brain-network activation profiles [76]. Beyond the basic emotional experiences discussed above, suspense constitutes another important emotional experience, one that is built upon fundamental human cognitive processes such as anticipation, expectation, and prediction. Lehne et al. (2015) conducted the first study of the neural basis of the emotional experience of suspense, revealing that individual suspense ratings were correlated with activation in the medial frontal cortex, bilateral frontal regions (along the inferior frontal sulcus), and lateral premotor cortex, as well as posterior temporal and temporoparietal regions [48]. Unlike the basic emotion-specific activation patterns identified by Toazza et al. (2022), suspenseful narratives engage the lateral premotor cortex for predicting plot uncertainty [68] as well as the medial frontal cortex and temporoparietal junction for tracking characters' mental states [4, 66], also reflecting the modulatory effects on brain networks exerted by information dimensions.

However, none of the above-mentioned narrative texts extended beyond the readers' established world knowledge. The supra-natural events examined by Hsu et al. (2015), in contrast, simultaneously incorporated two types of information: world-knowledge violations and emotional novelty. On the one hand, readers need to recruit bilateral inferior frontal gyri to resolve the cognitive conflict arising from world-knowledge violations, thereby satisfying the demands of discourse integration [31, 60]. On the other hand, the feelings of surprise and reading pleasure elicited by emotional novelty activate the salience and emotion network centered on the left amygdala and further recruit the frontoparietal attention network to focus on this salient information. The synergistic interaction among these three processes ultimately constitutes a unique neural processing mechanism [14, 38, 52, 69].

Notably, similar differentiation patterns also exist within expository texts, further corroborating the aforementioned view.

Hsu et al. (2019) introduced the fine-grained dimension of textual knowledge structure (KS) optimality, providing key evidence for this view. They found that when texts had an optimal KS (net type map), they primarily engaged classical semantic and integration networks, including the left middle/superior temporal gyrus (MTG/STG) and left dorsolateral prefrontal cortex (DLPFC). In contrast, when texts had a sub-optimal KS (spoke or chain-type conceptual organization), they recruited the left frontopolar cortex (FPC) and bilateral dorsal anterior cingulate cortex (dACC). These regions play critical roles in multitasking, cognitive resource allocation, and conflict monitoring [12, 13]. This suggests that even when text content difficulty is comparable, the way concepts are organized independently modulates the brain's engagement patterns: optimally structured texts allow readers to recruit canonical semantic networks for processing, whereas suboptimally structured texts elicit greater engagement of cognitive-control-related regions, consistent with more effortful mental-model construction given sparse conceptual interconnections in spoke or chain-type knowledge structures [37].

Taken together, both the distinction between narrative and expository text genres and the variation in internal information dimensions within texts exert fine-grained and systematic modulation on brain activation patterns, in addition to a shared neural foundation. This implies that the neural mechanisms of text comprehension are not fixed but instead dynamically reorganize as a function of text genre and the information dimensions they carry, so as to adapt to the demands of different cognitive tasks.

3.2. Mechanisms of Reader Characteristics

The aforementioned neuroimaging studies on situation model construction have revealed their dependence on text genre and the internal informational dimensions of texts. However, text comprehension is not a passive process of information reception but rather a dynamic cognitive activity in which readers actively construct meaning. This implies that, in addition to text-inherent features, readers' own cognitive characteristics also constitute key variables that shape the underlying brain mechanisms. In fact, text properties and reader characteristics do not operate independently. Instead, they jointly modulate the allocation of neural resources and processing strategies through complex interactions. Therefore, to fully characterize the neural landscape of text comprehension, it is essential to systematically examine how reader characteristics interact synergistically with text properties.

3.2.1. The Influence of Working Memory

Among the numerous cognitive factors influencing text comprehension, working memory has received considerable attention due to its central role in information integration and cognitive control. As a key component of executive functions, working memory provides the limited cognitive resources necessary for the temporary maintenance, manipulation, and integration of information during the comprehension process [50].

Specifically, it not only supports basic processes such as word recognition and semantic retrieval but also participates more deeply in higher-level situation model construction: readers rely on working memory to track key concepts in the text, establish referential, causal, and logical relations across sentences and even paragraphs, and effectively suppress interference from irrelevant information [28, 41, 63].

Li et al. (2025) employed inter-subject correlation (ISC) and inter-subject functional correlation (ISFC) to investigate the neural mechanisms of narrative reading in adults and further divided participants into subgroups based on reading level, revealing neural processing patterns that may be linked to working memory capacity in naturalistic text comprehension. In adults, the results showed that, compared with the low-reading-level subgroup, the high-reading-level subgroup exhibited stronger inter-subject functional correlation in multiple pairs: between the right precentral gyrus and the left hippocampus, as well as between the left hippocampus andparahippocampal gyrus and the right middle temporal pole. The bilateral precentral gyrus has been previously demonstrated to be involved in monitoring language working memory [11]. And the parahippocampal gyrus supports semantic memory retrieval and verbal semantic memory processing [6, 32]. This may tentatively suggest an association between language working memory and reading level.

In the investigation of complex expository technical texts, Keller et al. (2024) also observed greater activation in the left inferior frontal gyrus among better comprehenders. This brain region underpins phonological, semantic, syntactic, and propositional maintenance operations that form verbal working memory for language [16, 17, 21]. Accordingly, better comprehenders are able to keep larger amounts of verbal information temporarily active in memory during reading to support the comprehension of demanding expository materials [42]. Using graph-theory-based network analysis, Zhou et al. (2021) demonstrated developmental shifts in the engagement of working-memory-related neural systems during narrative reading. Children showed stronger coupling between auditory-phonological and working-memory-related modules that correlated negatively with reading performance, suggesting compensatory recruitment of working-memory resources for non-automatized reading. Such compensatory modular coupling was absent in adults, whose reading was instead supported by visual-semantic regions. These findings suggest that working-memory-related neural systems are engaged to different extents in reading at different developmental stages [84].

These studies have revealed activation patterns of working-memory-related brain regions among readers of different comprehension levels. From such neural evidence, we indirectly infer that individual differences in working-memory capacity may lead to variations in the coordinated processing between working-memory-related brain regions and other language-related brain regions during reading.

In contrast, Hsu et al. (2019) directly measured participants' working-memory capacity using the Letter-Number Sequencing (LNS) behavioral task. The results indicated that readers with greater working memory capacity exhibited higher overall reading comprehension performance. The neuroimaging results revealed that individuals with higher reading ability, when processing expository texts with sub-optimal knowledge structure (i.e., texts with loosely organized concepts and higher integration demands), showed significantly greater activation in the left frontopolar cortex (FPC) and the supplementary motor area (SMA), regions that are closely associated with cognitive control, multitasking, and information integration [9, 13, 55], as well as lexical-semantic access, syntactic processing, semantic retrieval, and predictive pre-activation during reading [15, 33, 47]. Combining the behavioral and neural findings, it can be inferred that working memory, as a critical cognitive underpinning of reading ability, may exert a key influence on the neural mechanisms of text reading through its individual differences.

In sum, working memory emerges as a crucial factor affecting reading comprehension and brain processing, regardless of whether the text is narrative or expository.

3.2.2. The Influence of Reading Experience

Stanovich and Cunningham (1992) demonstrated that print exposure predicts vocabulary and cultural knowledge levels independently of general cognitive ability. Subsequent research further established that even after controlling for executive function and perceptual speed, readers with higher print exposure still exhibited a significant processing advantage in comprehending written sentence structures [72, 73]. At the neural level, Song et al. (2025) found that the influence of print exposure on neural processing is text-genre-dependent. Specifically, during narrative reading, readers with higher print exposure exhibited greater neural synchrony with others in core semantic regions such as the bilateral middle temporal gyrus, reflecting the formation of convergent and efficient neural representations in social-cognitive and semantic integration processes. In contrast, during expository reading, they recruited the frontoparietal control network (FPN) to produce more idiosyncratic neural activation patterns [71]. These findings highlight that reading experience is linked to both shared and idiosyncratic neural dynamics when processing different types of textual information.

Vingerhoets et al. (2003) provided direct evidence that language exposure, alongside print exposure, represents another critical factor influencing reading outcomes. In a reading comprehension task, participants silently read newspaper articles in their native language (Dutch) as well as in their foreign languages (English and French) to examine the influence of language familiarity on reading. The results showed that reading in all three languages significantly activated core language regions, including the left temporal lobe and bilateral occipital cortex, indicating that different languages rely on shared neural substrates. However, further contrasts revealed that native-language reading, compared with foreign-language reading, elicited stronger activation in occipital regions including the bilateral lingual and cuneate cortex, which may reflect more successful mapping onto visual-word-form representations for the more familiar language.

More critically, even between the two foreign languages, English and French, significant differences emerged as a function of differential exposure: French (reduced exposure) required greater activation in the left inferior frontal gyrus compared with English (higher exposure), consistent with the idea that languages with lower familiarity rely more heavily on grapheme-to-phoneme conversion [27]. Thus, increased familiarity appears to be associated with stronger activation in occipital visual word-form regions, reflecting more automatic processing. Decreased familiarity, in contrast, appears to be associated with greater activation in the inferior frontal gyrus, reflecting the engagement of more effortful subvocal and phonological awareness [79]. Davydova et al. (2025) extended the influence of language familiarity to the processing of emotional texts, revealing that language familiarity not only affects visual word-form processing but also affects the functional integration between semantic and affective areas [19]. In this study, late Spanish–English unbalanced bilinguals read happy, fearful, and neutral fictional passages, and greater activation in the left hippocampus was observed for fearful texts while reading the first language (L1), indicating that the native language more strongly engages emotional memory and affective processing [64]. More critically, functional connectivity analyses revealed that the coupling between the left anterior temporal lobe (a semantic hub) and the left amygdala (a core region for emotional processing) was significantly stronger for fearful texts during reading L1 than the second language (L2), whereas this connectivity was attenuated in L2, suggesting that lower language familiarity is associated with less integrated processing between semantic and emotional areas. Moreover, Hsu et al. (2015) reported that late German–English bilinguals reading short passages from Harry Potter exhibited significantly stronger activation in bilateral amygdala while reading happy texts in L1 than in L2, with a similar native-language advantage also observed in the left precentral gyrus, a region implicated in embodied simulation of emotional expressions [62]. Multivariate pattern analysis further revealed that the neural activation patterns for different emotional categories were more discriminable while reading in L1, whereas this discriminability was significantly reduced while reading in L2. These findings indicate that language familiarity modulates not only the intensity of emotional processing but also the fine-grained differentiation of emotional representations [38].

Together, these studies demonstrate that familiarity with the language itself also modulates the neural mechanisms underlying reading comprehension.

From the perspective of textual content, textual genre preference is also an important factor modulating the neural mechanisms of reading. For example, compared with news texts, fictional texts elicited higher inter-subject neural synchronization in the right temporal pole and fusiform gyri, regions associated with social cognition and empathy. In contrast, news texts showed specific activation in bilateral rostral prefrontal cortex [51]. This suggests that fictional texts can more reliably engage empathy-processing resources for stable empathy processing, thereby promoting consistency in neural responses across readers, whereas news texts more heavily recruit prefrontal regions that may be involved in factual information processing [5, 43, 58]. Song et al. (2025) further revealed that, among high-exposure readers during narrative reading, similarity in fictional topic reading-experience distributions corresponded to higher inter-subject neural synchrony within the bilateral precuneus, posterior cingulate cortex, and right medial frontal gyrus. The precuneus and posterior cingulate cortex, core nodes of the default mode network, have been implicated in higher-order semantic processing, autobiographical memory retrieval, and mentalization [3, 22, 34, 39]. The right medial frontal gyrus has been linked to theory of mind functions and cognitive control in prior literature [43, 56, 57]. These results suggest that shared distributions of fictional reading-experience may foster convergent neural processing patterns across high-exposure readers during narrative reading. By contrast, no significant IS-RSA effects were observed during expository reading [71].

The aforementioned aspects of reading experience exert unique effects on text comprehension. However, beyond these factors, reading experience encompasses many other aspects, such as reading modality preferences, age of acquisition, and reading environment, all of which remain to be further explored.

4. Methodological Innovations Advancing Research on the Neural Mechanisms of Reading

4.1. Fixation-Related fMRI: A Paradigm for Neural-Mechanism Studies of Natural Text Reading

Functional magnetic resonance imaging (fMRI), with its high spatial resolution, can clearly localize brain activations and network interactions underlying core processes such as semantic processing and cognitive control during natural text reading; however, limited by its relatively low temporal resolution, it cannot precisely align the delayed hemodynamic responses with the millisecond-scale dynamic processes of lexical processing and inter-sentential integration that occur during natural reading. In contrast, eye-tracking technology can capture core behavioral indices in real time, including fixation location, fixation duration, and regressions, providing precise "word-level temporal anchors" for continuous text reading, while also directly reflecting the difficulty and strategic choices in reading processing through quantitative measures such as regression rates and fixation durations [36, 59, 65]. Accordingly, some studies have combined these two techniques to advance research on the neural mechanisms of text reading.

The fixation-related fMRI paradigm addresses the limitations of the traditional rapid serial visual presentation (RSVP) paradigm. Under the RSVP paradigm, word onset is externally controlled by a computer program, reading rhythm is rigidly constrained, and regressions as well as word-skipping are prohibited, which deviates from natural reading situations. Using this new paradigm, Hsu et al. (2019) adopted simultaneous eye-tracking and fMRI data acquisition to obtain the exact onset time of words and phrases for fMRI general linear model (GLM) analysis, perform convolution of the hemodynamic response function (HRF) with task-related variance, and finally statistically isolate brain signals evoked by text reading [37]. Likewise, adopting a combined eye-tracking-fMRI approach to simulate natural reading situations, Mak et al. (2023) investigated whether the three kinds of mental simulation (motor simulation, perceptual simulation, and mentalizing), which differed in eye-movement behavior, had a common neural locus as well as domain-specific activations. They found that simulation-eliciting content activated a variety of brain areas, including both modality-specific brain areas and a general simulation area [53]. Gu et al. (2025) extended the combined eye-tracking and fMRI approach to L2 readers within the model-brain alignment framework, revealing consistent model-brain alignment across L1 and L2 populations [29].

In summary, the integration of eye-tracking technology and fMRI can compensate for the limitations of either technique in isolation, and through the synergy of behavioral anchoring and neural localization, it provides critical support for research on reading cognition and for innovations in related fields.

4.2. Neural Mechanisms of Reading Revealed by Large Language Models

In recent years, the advent of large language models has provided a computable "brain language model" for text reading research, enabling researchers, through model-brain alignment, to transform the traditional question of " where in the brain activation occurs during reading " into a mechanistic question of "whether the brain and the model compute language in the same way," thereby testing the principles of human language processing with formal computational hypotheses.

The study by Yu et al. (2024) serves as a representative example of this approach. By manipulating the pretraining tasks of the BERT model, this study investigated how the brain comprehends coherence relations between sentences or texts. The researchers compared two models: one that learned only to predict masked words in sentences (MLM), and the other that additionally learned to judge whether two sentences are coherent (NSP) [83]. Results revealed that the model trained with sentence coherence judgment exhibited higher model-brain alignment, particularly in brain regions such as the right inferior frontal gyrus and the right anterior temporal gyrus. This indicates that NSP serves as a viable computational account of discourse-level comprehension. Concurrently, this finding corroborates previous conclusions regarding the critical role of the right hemisphere in this process [54]. This study also found that readers with higher model-brain alignment tended to have faster reading speeds, suggesting that this alignment may reflect individual processing efficiency.

Gu et al. (2025) extended this paradigm to cross-population comparisons, investigating whether large language models can capture the commonalities and differences in the neural mechanisms of reading between L1 and L2 readers. This study used fixation events recorded by eye-tracking as temporal anchors to achieve millisecond-level precise alignment between GPT-2-generated word embeddings and fMRI signals. The results revealed that brain activity in both L1 and L2 readers could be significantly predicted by LLMs, with comparable model-brain alignment between the two groups, corroborating shared neural mechanisms of contextual processing across populations. Concurrently, individual difference analyses demonstrated that linguistic abilities (vocabulary size and general reading ability) affected model-brain alignment in both groups, whereas attentional ability and language dominance modulated brain activity patterns exclusively in L2 readers. This finding reveals a dual value of large language models: on the one hand, they can equally simulate the neurocomputational processes of readers from different language backgrounds. On the other hand, by analyzing individual differences in model-brain alignment, one can infer the differential importance of cognitive factors affecting reading processing across populations [29].

In summary, the model-brain alignment paradigm driven by large language models not only provides novel computational perspectives and methodologies for investigating the neural mechanisms of text reading, but also demonstrates unique value in revealing the principles of discourse processing, cross-population reading differences, and individual processing efficiency, thereby propelling reading cognition research toward more precise mechanistic explorations.

4.3. Inter-Subject Correlation: Revealing Group Consistency and Individual Differences in Reading

Traditional General Linear Model (GLM) approaches have certain limitations in studying the neural basis of natural language processing, as they struggle to adequately capture the continuity and dynamics of language processing. In contrast, ISC analysis can effectively reveal group-consistent neural response patterns during naturalistic stimulus processing and can be used to explore individual differences by relating neural patterns to individual behavior or traits [35, 61].

The study by Jangraw et al. (2023), employing naturalistic narrative texts as experimental stimuli, demonstrated that reading ability is closely associated with neural synchrony within the brain's reading network. Better readers (those having reading scores above the median) exhibited significantly greater inter-subject correlation (ISC) of neural activity in canonical reading core regions, including the left angular gyrus, fusiform gyrus, and inferior frontal gyrus, indicating highly consistent processing patterns among them. In contrast, worse readers displayed a typical "Anna Karenina model," characterized by idiosyncratic neural patterns across individuals. This study highlights the advantages of the ISC and inter-subject representational similarity analysis (IS-RSA) frameworks, which are more sensitive than traditional methods in detecting both group-level consistency and individual differences. Notably, IS-RSA more directly links neural representational structure to behavior, offering a more interpretable analytical pathway for flexibly uncovering brain-behavior relationships [40]. Furthermore, Li et al. (2025) used Chinese summaries of Andersen's fairy tales as stimuli and employed inter-subject functional connectivity (ISFC) to compare the neural mechanisms of narrative comprehension between children and adults. Results showed that adults exhibited higher ISC in the dorsomedial prefrontal cortex and angular gyrus. In terms of functional connectivity, high-reading-level adults showed stronger cross-regional coupling between the hippocampus and prefrontal cortex, whereas high-reading-level children displayed reduced local functional connectivity within the prefrontal cortex, reflecting distinct neural strategies for reading improvement at different developmental stages [49].

Song et al. (2025) further employed inter-subject correlation (ISC) to reveal the interactive effects of print exposure and text genre on the neural mechanisms of reading. This study found that the influence of print exposure on neural activity depends on text genre. During narrative reading, individuals with higher print exposure exhibited greater neural consistency in semantic processing regions. In contrast, during expository reading, higher-exposure readers displayed more pronounced idiosyncratic neural patterns within the frontoparietal control network. More importantly, the study also demonstrated that reading topic preferences could predict neural similarity within the default mode network, particularly in the precuneus and posterior cingulate cortex. In short, the brain's response to reading is shaped both by how much one reads and by what one reads—and these effects differ markedly depending on the type of text being processed [71].

Thus, inter-subject correlation (ISC) not only enables precise identification of shared reading processing mechanisms at the group level but also sensitively captures individual differences in reading ability, developmental stage, and reading experience, flexibly establishing links between neural synchrony and individual traits and clearly revealing the differentiation of neural reading strategies across populations. It provides a more ecologically valid and targeted methodological approach for deeply dissecting both group-level consistency and individual differences in reading.

5. Discussion

5.1. Interactive Effects of Text Properties and Reader Characteristics on the Neural Mechanisms of Text Reading

A systematic examination within the framework of the extended language network reveals that the neural mechanisms underlying natural text reading emerge from the interaction between text properties and reader characteristics. On the one hand, text genre determines the specific processing networks engaged during reading. Narrative texts, which provide situational cues through changes in protagonists, evolving plot-related events, and setting shifts, prompt readers to dynamically construct and update a coherent situation model, and consequently rely on the default mode network and the social cognition system. Expository texts, centered on conceptual integration and logical reasoning, rely on the frontoparietal control network and the semantic control system [1, 74]. Both text genres exhibit fine-grained internal differentiation. Specifically, narrative texts elicit distinct patterns of brain activation depending on different emotional information, plot uncertainty, and violations of world knowledge [38, 48, 75], whereas expository texts are primarily influenced by textual knowledge structure [37, 42]. On the other hand, reader characteristics profoundly shape the neural representations of narrative reading, in which readers at different proficiency levels exhibit differences in the coordination patterns between working-memory-related brain regions and other neural areas [49, 84]. Furthermore, reading experience exerts a dual effect of "quality" and "quantity": accumulated print exposure enhances group-level neural consistency during narrative processing, language familiarity modulates the automaticity of visual word form processing and the integration efficiency of semantic-affective systems, and long-term preference for fiction genres shapes convergent neural processing patterns when readers engage with narrative contexts [19, 71, 79].

In summary, these findings indicate that the neural mechanisms of natural text reading are jointly modulated by text properties and reader characteristics, which interact to shape the activation patterns and functional connectivity efficiency of the brain's language network, cognitive control network, and multimodal integration network.

5.2. Limitations and Future Directions

The above-mentioned studies have made significant progress in revealing the neural mechanisms of reading, yet they also share several common limitations. At the methodological level, the low temporal resolution of fMRI makes it difficult to disentangle the temporal sequence of various psychological processes during reading [38, 48]. At the experimental design level, although a substantial body of text reading research has adopted naturalistic stimulus paradigms with greater ecological validity, some studies still suffer from interrupted reading during behavioral rating procedures. In addition, other common issues include the use of a single text [48, 74], relatively small sample sizes, and cross-sectional designs [75, 76]. These factors may limit the generalizability of the findings as well as causal inferences. Finally, the majority of research has focused on first language reading, with a notable scarcity of studies examining the cognitive and neural mechanisms of second language reading comprehension, particularly at the level of naturalistic text reading, where neuroimaging investigations targeting L2 learners remain extremely limited [50].

Based on these limitations, future research should advance in the following directions: First, methodologically, strictly adopt non-interruptive naturalistic reading paradigms [48], combined with fine-grained parcellation and causal modeling [1], to more precisely track neural dynamics and the directional influences among nodes. Second, in terms of experimental design, conduct longitudinal studies to establish causal relationships among variables [75] and systematically manipulate text difficulty, knowledge structure [37], and text genre to examine their modulatory effects on neural networks [2]. Finally, future research could extend investigations to individuals with dyslexia or ADHD, as well as to foreign-language learners. -

6. Conclusion

Our study systematically reviews the empirical evidence on the neural mechanisms of natural text reading within the theoretical frameworks of the extended language network. The analysis indicates that reading comprehension is anchored in the extended language network as its core architecture, encompassing brain regions such as the left temporal gyrus, inferior frontal gyrus, and anterior temporal lobe, which work synergistically to accomplish multi-level processing ranging from lexical decoding to situation model construction [25]. However, the operation of this fundamental architecture is dynamically modulated by both text properties and reader characteristics [26, 71], such as text genre, reading proficiency, and prior reading-related experience.

This study revealed the dynamic and adaptive nature of the neural mechanisms underlying natural text reading. Future research should prioritize longitudinal designs and ecologically valid paradigms, integrating multimodal techniques to more precisely characterize the neural properties of text reading.

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