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A Bibliometric Analysis of Event-Related Potential (ERP) Research on Metaphor Processing

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Abstract

This study presents a bibliometric analysis of Event-Related Potential (ERP) research on metaphor processing published from 2005 to 2025. Using CiteSpace software and data sourced from the Web of Science Core Collection, this analysis systematically reviews publication trends, identifies influential journals, authors, and institutions, and outlines the intellectual landscape of ERP studies on metaphor processing. The findings reveal a significant increase in publications, with contributions spanning cognitive neuroscience, psychology, and linguistics. Co-citation and keyword analyses identifies several major thematic clusters, including hemispheric lateralization, embodied cognition, the temporal dynamics of semantic integration, attentional and executive functions, bilingual metaphor comprehension, and conceptual expansion related to creativity. The results show that metaphor processing is a dynamic, multifaceted process that flexibly engages cognitive and neural resources depending on metaphor familiarity, context, and individual differences. Additionally, suggestions for future work in this area are provided.

Keywords: ERP, Metaphor processing, Bibliometric analysis, CiteSpace

1. Introduction

Metaphor was long regarded as a rhetorical device, functioning as a decorative element in language that departs from literal expression. Within this traditional framework, metaphor was considered a purely linguistic phenomenon, with little connection to cognition or thought. This view was fundamentally challenged when Lakoff and Johnson (1980) introduced the Conceptual Metaphor Theory (CMT) in their influential work *Metaphors We Live By.* They argued that metaphor is not limited to language but is deeply rooted in human cognition and behavior. According to this theory, metaphor plays a central role in how individuals conceptualize abstract ideas through more concrete experiences, suggesting that the human conceptual system is inherently metaphorical.

In the subsequent decades, extensive experimental and theoretical investigations on metaphor flourished, indicating an increasing academic focus on this topic (Glucksberg, 2001; Gibbs, 2017). Many scholarly journals started to regularly feature research on metaphor. During this time, experts in neurolinguistics and psycholinguistics made notable advances by publishing diverse studies that examined the cognitive and neural mechanisms involved in metaphor comprehension. The study of ERP applications in metaphor research is of great importance. Firstly, tracking the millisecond-level time course of metaphor comprehension with ERP sheds light on the neurocognitive mechanisms that support cross-domain mapping and meaning integration, thereby advancing our understanding of how the brain processes figurative language and informing educational and clinical approaches to populations with metaphor-processing difficulties. Secondly, prevailing psycholinguistic models of sentence comprehension are built primarily on studies of literal language and thus overlook the distinctive comparison and categorization operations demanded by metaphors; ERP evidence provides the fine-grained temporal constraints needed to refine these models and to incorporate the unique processing stages that metaphor entails.

2. Method

2.1 Data Collection

The bibliometric data were obtained using an advanced query within Clarivate's Web of Science (WoS) Core Collection, which includes databases such as the Social Sciences Citation Index (SSCI), Science Citation Index Expanded (SCI EXPANDED), Arts & Humanities Citation Index (A&HCI), and the Conference Proceedings Citation Index Social Science & Humanities (CPCI SSH). WoS was selected as the primary source due to its long-established rigorous editorial standards and its compatibility with CiteSpace (Peng & Khatin Zadeh, 2023; Yuan & Sun, 2023).

The data were retrieved based on the following fields:

1. TS =("ERP" OR "event-related potential*" OR "N400" OR "P600") AND (metaphor*). This query targeted articles in which ERP-related terms co-occur with metaphor-related terms in the title, abstract, or keywords.

2. Time span: 2005–2025.

3. Document Type=article OR review.

4. (The asterisk (*) is used as a wildcard in Web of Science to capture variations of a word. For instance, metaphor retrieves metaphor, metaphors, and metaphorical.)

All records were exported in "Full Record and Cited References" plain-text format (.txt) for analysis in CiteSpace 6.4.R11. The extracted metadata included author names, institutional affiliations, journal sources, publication years, and cited references, which enabled downstream analyses of publication trends, intellectual structures, and emerging research fronts in ERP-based metaphor studies.

An initial set of 203 papers was retrieved from 13 WoS categories spanning psychology, neuroscience, linguistics, and behavioral science. Because the study focused on ERP applications in metaphor research within these domains, only those categories were retained. After manual screening of titles and abstracts, 187 articles remained for bibliometric and visualization analyses.

2.2 Instrument

CiteSpace 6.4.R11, a bibliometric analysis and visualization tool (Chen, 2004, 2006, 2017; Chen et al., 2010; Chen & Song, 2019), was used to examine thematic structures and emerging trends in the dataset. CiteSpace constructs co-citation networks of authors, references, countries, and institutions, thereby revealing research patterns and pivotal developments. In this study, both co-citation and keyword co-occurrence analyses were performed to identify influential references, map intellectual structures, and highlight key research hotspots in ERP-based metaphor processing.

3. Results

3.1 Publication Years, Journals and Productive Authors

Annual publication counts for studies applying ERPs to metaphor research have been tracked from 2005 onward and are summarized in Figure 1. Overall, metaphor-processing studies that employ event-related potentials expanded markedly from 2005 to 2025. In the mid-2000s, publication counts were modest, with only a few studies appearing in 2005, but output accelerated during the 2010s and reached its highest level in the early 2020s, peaking in 2021. This sustained rise confirms the field's escalating interest in using ERP methodology to investigate metaphor processing. Importantly, the pattern parallels the wider literature on metaphor, where publication output has likewise followed a steady upward trajectory over the past decade.

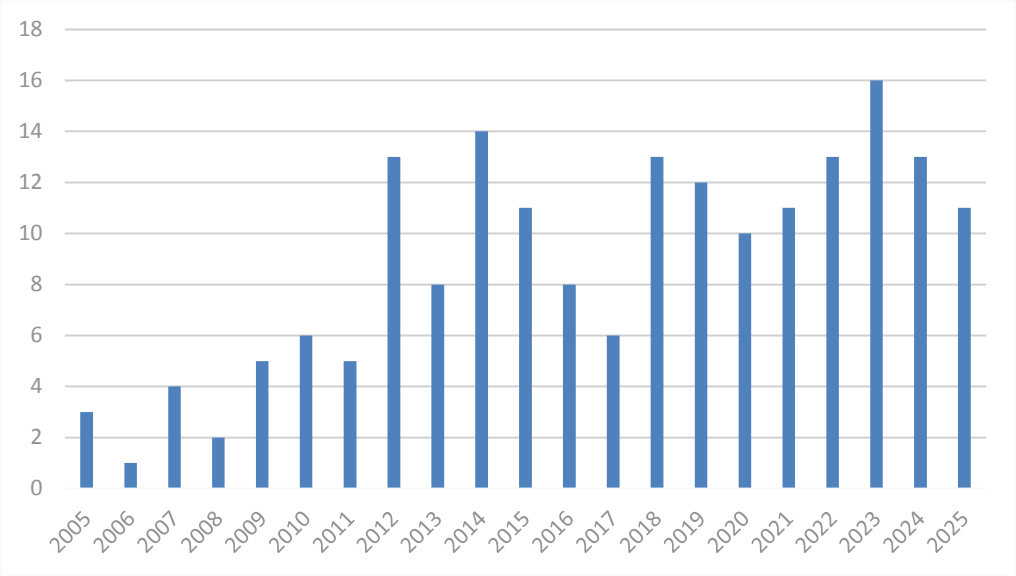

Figure 1. Annual publication on ERP Studies on metaphor processing in WoS

These 187 ERP-based metaphor studies were published across dozens of journals spanning cognitive neuroscience, psychology, and linguistics. Table 1 lists the ten journals that published the most articles in this area of research. The most prolific venues include Frontiers in Psychology (20) and the Journal of Neurolinguistics (15). Other leading outlets are Brain and Language (13) and Brain Research (12), reflecting the neurocognitive emphasis of this literature. Notably, several high-impact neuroscience and psychology journals published approximately 7 to 10 relevant articles. Most of these top journals fall within cognitive neuroscience and psycholinguistics; this pattern underlines the interdisciplinary nature of ERP-based metaphor studies. The distribution mirrors general metaphor research, where leading journals are likewise rooted in psychology or linguistics. Researchers aiming to publish in this field should note that venues such as Frontiers in Psychology and the Journal of Neurolinguistics have been especially receptive to ERP-metaphor work.

Table 1. Top 10 most prolific journals on ERP studies on metaphor processing

Ranking	Journals	The number of published papers
1	Frontiers in Psychology	20
2	Journal of Neurolinguistics	15
3	Brain and Language	13
4	Brain Research	12
5	Frontiers in Human Neuroscience	10
5	Psychophysiology	10
7	Brain and Cognition	7
7	Neuropsychologia	7
7	PLOS ONE	7
10	Language, Cognition and Neuroscience	5

The authorship data in Table 2 highlight a small group of scholars who have made especially large contributions to the field. Wang tops the list with 20 publications, and Chen follows with 15, together constituting two leading figures in ERP-based metaphor research. Next, Coulson contributes 13 influential papers on figurative language, whereas Bambini has 12 studies focused on the neuropragmatics of metaphor. Several other researchers, including Lai and Li, each have about ten publications, showing that both established and newer investigators are actively advancing the field. The roster is geographically diverse: Wang and Chen are affiliated with institutions in China; Coulson works in the United States; and Bambini is based in Europe. Such a distribution underscores worldwide interest in the neural basis of metaphor comprehension and reflects a wider trend in metaphor studies—North America and Europe continue to produce the most output, while China and other regions are steadily gaining prominence..

Table 2. Top 10 most productive authors for ERP studies on metaphor processing

Ranking	Authors	The number of published papers
1	Wang, H.L.	20
2	Chen, H.J.	15
2	Coulson, S.	13
4	Bambini, V.	12
4	Lai, V.T.	10
4	Li, Y.	10
4	Tang, X.M.	7
8	Faust, M.	7
8	Goldstein, A.	7
8	Jankowiak, K.	5

The University of California system emerges as the leading institutional contributor, accounting for 15 publications, a figure that reflects the influential ERP work on metaphor conducted by scholars such as Seana Coulson at UC San Diego. As shown in Table 3, Adam Mickiewicz University in Poland (11) and Dalian University of Technology in China (9) also rank prominently, indicating robust research clusters at these institutions. Bar-Ilan University in Israel follows with seven papers, driven in part by Mira Faust's pioneering investigations into novel metaphors. Several other institutions, including Anhui Polytechnic University in China, IUSS Pavia in Italy, Pennsylvania State University in the United States, and the University of Jyv äskyl ä in Finland, each contributed six publications. The prominence of both Chinese and European universities underscores the international scope of ERP metaphor research. In sum, although a handful of authors and centers lead the field, the geographical distribution of output remains diverse, reflecting a global convergence of neurolinguistic inquiry.

Table 3. Top 10 most productive institutions for ERP studies on metaphor processing

Ranking	Institutions	The number of published papers
1	University of California System	15
2	University of California, San Diego	12
3	Adam Mickiewicz University	11
4	Dalian University of Technology	9
5	Bar-Ilan University	7
6	Anhui Polytechnic University	6
6	IUSS Pavia	6
6	Pennsylvania Commonwealth System of Higher Education (PCSHE)	6
6	Pennsylvania State University	6
6	University of Jyv äskyl ä	6

3.2 Document Co-citation Analysis

Document co-citation network of ERP-based metaphor studies (2005–2025). Each node represents a cited reference; node size reflects the citation frequency, and links represent co-citation ties between references. Prominent nodes (larger and centrally connected) indicate influential works forming the intellectual base of this research area. The document co-citation network constructed from the 187 article dataset reveals the intellectual foundations of ERP-based metaphor research from 2005 to 2025. The top 50 papers with the highest citation counts in each 3-year interval were selected by applying a three-year time slice. The results are shown in Fig. 2. The network consists of 284 nodes and 564 links, with a largest connected component containing 753 nodes, accounting for over 70% of the total. The top 5 articles in the area of metaphor processing research are shown in Table 4.

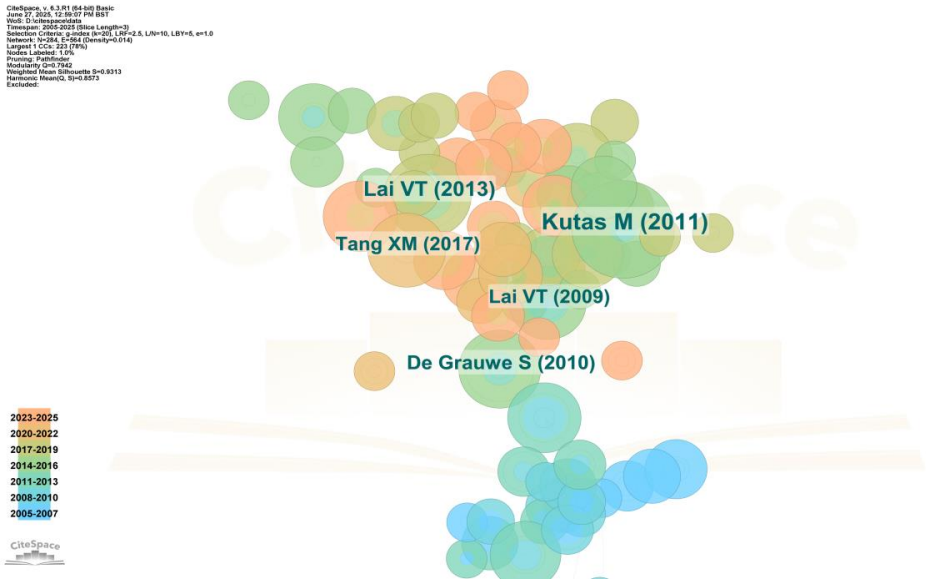

Figure 2. Critical publications in metaphor research

Table 4. The top 5 most cited publications in ERP studies on metaphor processing

Ranking	Citation count	Author (year)	Publication name	Journal or press
1	19	Kutas (2011)	Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP).	Annual review of psychology
2	12	Lai (2013)	ERP evidence for conceptual mappings and comparison processes during the comprehension of conventional and novel metaphors	Brain and language
3	14	De Grsuwe (2010)	Electrophysiological insights into the processing of nominal metaphors	Neuropshychologia
4	11	Lai (2009)	Comprehending conventional and novel metaphors: An ERP study	Brain research
5	11	Tang (2017)	Comprehension of scientific metaphors: Complementary processes revealed by ERP	Journal of Neurolinguistics

The most prominent nodes in the network represent a mixture of empirical studies and methodological reviews that have been extensively cited over the past two decades. One of the most central and frequently co-cited works is Kutas and Federmeier (2011), which provides a comprehensive review of the N400 component and its role in semantic and contextual processing. Their findings have been instrumental in guiding ERP metaphor studies, particularly in understanding how figurative meanings emerge in real-time brain activity. Given that metaphor comprehension involves integrating novel or non-literal meanings, the N400 serves as a reliable neural marker, making this review an indispensable reference point.

Another highly influential contributor is V. T. Lai, whose works span multiple years and have been consistently cited. Lai and Curran (2009) and Lai and Curran (2013) are particularly notable for their ERP studies on conventional versus novel metaphors. These experiments showed that novel metaphors, which require greater semantic integration, typically elicit larger N400 amplitudes and sometimes late positive components (LPC), reflecting both the difficulty and the salience of processing non-conventional meanings. Lai et al. (2015) further elaborated on these findings by incorporating contextual manipulations that affected

metaphor interpretation. These studies not only provided experimental validation for cognitive theories of metaphor but also helped operationalize metaphor novelty within electrophysiological paradigms.

Tang et al. (2017) also feature prominently in the network. Their study investigated the temporal dynamics of metaphor comprehension in Chinese, offering evidence for cross-linguistic variation in ERP responses to metaphor. The co-citation of this study suggests increasing attention to metaphor processing beyond English, reflecting a more global approach to figurative language research. Similarly, De Grauwe et al. (2010) conducted one of the earliest ERP studies to explore bilingual metaphor comprehension, showing that non-native speakers may process figurative language differently depending on metaphor familiarity and proficiency. The strong co-citation of these two studies highlights the integration of bilingualism and cross-cultural perspectives into the neurocognitive study of metaphor.

What emerges from the network is a well-integrated body of research that combines cognitive neuroscience, psycholinguistics, and experimental semantics. The centrality of studies focusing on ERP components (particularly N400 and LPC), metaphor conventionality, and bilingualism suggests a shared concern with how figurative language is processed in real time, across both linguistic and cultural boundaries. These highly co-cited documents form the methodological and theoretical backbone of ERP metaphor research.

3.3 Co-occurring Terms Analysis

Terms that occur frequently often signal emerging trends or focal areas within a research field (Chen, 2004). Table 5 lists the terms with a frequency greater than 10. The keyword co-occurrence analysis provides a complementary perspective by mapping the major research topics and concepts frequently addressed in ERP metaphor studies. As shown in Figure 2, the network of co-occurring terms centers on several high-frequency keywords. Not surprisingly, general terms such as “metaphor”, “language”, and “comprehension” rank among the most common, confirming that the core concern of these studies is metaphor comprehension in language. More revealing are the specific cognitive and linguistic terms that occupy central positions in the network. Notably, “N400” stands out as a high-frequency keyword, underscoring its importance as a conceptual anchor in studies of semantic processing. Its frequent co-occurrence with terms such as “metaphor comprehension”, “semantic integration”, and “novelty” indicates that a significant portion of the literature is concerned with how figurative language, especially metaphors.

Table 5. Co-occurring terms with high frequency

Count	Central	Keyword	Count	Central	Keyword	Count	Central	Keyword
62	0.06	language	25	0.13	context	16	0.13	dynamics
56	0.05	comprehension	23	0.05	n400	14	0.02	words
43	0.08	integration	22	0.05	language comprehension	14	0.04	sentences
40	0.14	brain potentials	19	0.1	metaphor	12	0.05	potentials
38	0.11	time course	19	0.05	right hemisphere	12	0.08	activation
31	0.11	metaphor comprehension	17	0.06	working memory	11	0.02	scientific metaphors
26	0.04	brain	16	0.1	attention			

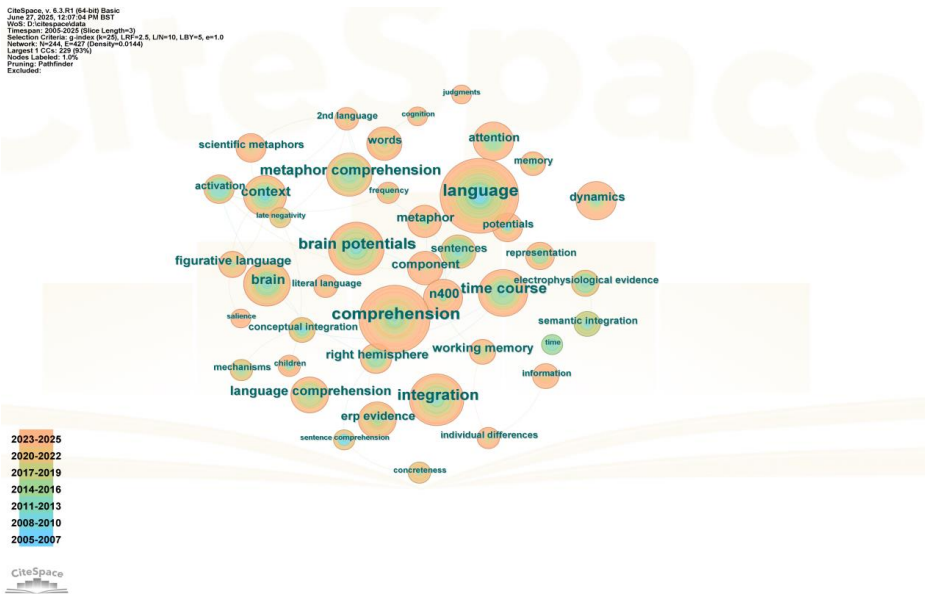

Figure 3. Keyword co-occurrence network

3.4 Cluster Interpretations

Keyword clusters identified by CiteSpace in the co-occurrence network. Each cluster (numbered #0 to #6) is a group of closely related keywords, labeled by an algorithmically extracted term that represents the cluster's theme. The colored blocks on the timeline (top) indicate the active years of publications in each cluster, and the silhouette values (all above 0.9) denote high internal consistency of the clusters. The clustering of keywords yields seven major thematic clusters, each representing a prominent research theme within ERP metaphor studies. These clusters, labeled #0 through #6 in Figure 3, encapsulate the recurring combinations of concepts in the literature. Below, we interpret each cluster and its significance for the field.

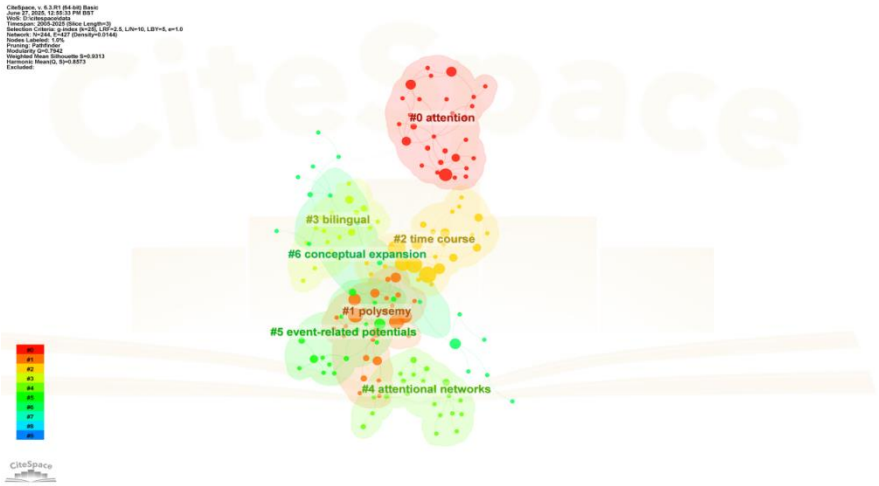

Figure 4. Cluster view of keyword co-occurrence

Cluster #0 is the largest and densest group in the keyword-based clustering and is labeled "attention." Within this cluster, keywords such as attention, inhibition, and working memory frequently co-occur, and many of the cluster's top-ranked references explicitly manipulate or assess these cognitive constructs. Representative studies include Lai and Curran (2013), who employed a dual-task paradigm to show that dividing attention increases the N400 elicited by novel metaphors, suggesting greater semantic-integration load. De Grauwe et al. (2010) demonstrated that working-memory capacity modulates late positivity when bilingual readers interpret metaphoric versus literal sentences, linking executive resources to figurative processing depth. Tang et al. (2017) further reported that individual differences in inhibitory control predict the amplitude of the late anterior negativity during Chinese metaphor comprehension, implying that suppressing literal meanings is effortful for some readers. Converging evidence from behavioral work, such as Giora et al. (2014) on inhibitory costs in metaphor re-formulation, supports this electrophysiological pattern. Metaphor often taxes cognitive-control mechanisms: readers must suppress pre-potent literal interpretations, sustain multiple meaning candidates, and flexibly shift to a cross-domain mapping. Consequently, Cluster #0 makes clear that beyond purely linguistic variables, attentional allocation and executive functions are key components of figurative-language processing.

Cluster #1 is labeled as "polysemy". This cluster groups studies dealing with lexical ambiguity and multiple meanings in relation to metaphors. Polysemy refers to a word having multiple related meanings (e.g., "cold" meaning temperature vs. unemotional). This cluster's appearance signifies a research thread exploring how metaphorical meanings relate to literal or other senses of a word, and how the brain distinguishes or switches between them. ERP research in this vein often asks whether metaphoric meanings of a polysemous word are accessed directly or via literal meanings. Some EEG evidence suggests that metaphoric and metonymic senses (i.e. related meanings) show unique brain response patterns, supporting the idea that the brain represents these meanings distinctly (Klepousniotou et al., 2012).

For example, Klepousniotou et al. (2012) reported unique ERP patterns for metaphoric compared with metonymic interpretations, suggesting that the mental lexicon represents these senses separately. Complementary evidence comes from Rataj et al. (2018), who showed that polysemous verbs with figurative meanings elicit larger N400 amplitudes than their literal counterparts, pointing to increased semantic-integration demands. In a bilingual context, Jankowiak et al. (2017) demonstrated that interpreting polysemous metaphors in a second language involves additional late negativities, implying greater effort in resolving meaning competition. For instance, one study found that polysemous words (with metaphorical senses) produced different ERP effects than truly homonymous words, indicating that division within polysemy was electrophysiologically supported (Klepousniotou et al., 2012). Cluster #1, therefore, highlights interest in the semantics of metaphoric words – how the mental lexicon handles words that carry both literal and figurative meanings. This line of work has implications for theories like the graded salience hypothesis (Giora, 1997), which predicts differences in processing depending on the familiarity or salience of a word's meanings.

Cluster #2 is labeled as "time course". This cluster reflects studies centered on the temporal dynamics of metaphor processing. It contains keywords like time course, ERP components, N400, late positivity, indicating that these papers dissect when different cognitive processes occur as a metaphor is being understood. Research in Cluster #2 typically analyzes ERP waveforms to identify early vs. late effects: for example, an early N400 effect might indicate initial difficulty in integrating a metaphor, while a later positivity (such as a P600 or Late Positive Complex) might relate to reanalysis or the creation of a new interpretation. The cluster label "time course" emphasizes that metaphor comprehension is a process unfolding over hundreds of milliseconds, and understanding its chronology is crucial (Coulson & Van Petten, 2002; De Grauwe et al., 2010; Regel et al., 2011).. Indeed, a consistent finding is that novel metaphors tend to elicit a larger N400 than literal phrases at around 300–500 ms, followed by a late negativity or P600 reflecting integrative processing or insight. By clustering these studies together, CiteSpace reveals that tracing the progression from early lexico-semantic processing to later meaning integration serves as a common objective across many ERP investigations. This cluster shows how the strength of ERPs (millisecond resolution) is harnessed to advance metaphor theory: it allows researchers to argue, for example, whether metaphors are initially treated as anomalies by the brain and only later "get" their meaning (Miller, 2025), or whether familiar metaphors bypass such initial difficulty.

Cluster #3 is labeled as "bilingual". The presence of a bilingual cluster indicates a significant

body of work on metaphor processing in second-language (L2) learners or bilingual individuals. These studies, marked by keywords such as second language, bilingual, L2 metaphor, investigate how non-native speakers comprehend metaphors compared to native speakers (Miller, 2025). Key questions include whether L2 speakers experience greater difficulty (as reflected in larger N400s or delayed ERP responses) when understanding metaphors, and how proficiency or exposure modulates this. The cluster's emergence corroborates that metaphor comprehension is an active topic in second-language research. For instance, some findings have shown that "second-language learners tend to use metaphors incorrectly or in odd contexts", and metaphor understanding can be challenging for L2 speakers. ERP studies extend this by showing differences in brain responses: recent research finds that L2 users often exhibit more effortful processing for novel metaphors (e.g., prolonged N400 effects) compared to native speakers (Miller, 2025; Littlemore, 2015).

Cluster #4 is labeled as "attentional networks". This cluster, related to #0, appears to drill down specifically into the neural networks of attention involved in metaphor comprehension. While Cluster #0 broadly covers attention in cognitive terms, Cluster #4's label attentional networks suggests an interest in identifying particular brain circuits or patterns (perhaps using techniques like functional connectivity or network analysis) that underpin the role of attention in metaphor (Posner & Petersen, 1990; Corbetta & Shulman, 2002). It may include studies that combine ERPs with neuroimaging or that look at how attentional load influences neural signatures. The distinction between #0 and #4 implies that some researchers have approached the attention question at a system level. In essence, Cluster #4 reinforces the importance of attention but emphasizes mapping it onto brain networks and specific ERP markers.

Cluster #5 is labeled as "event-related potentials". This cluster is explicitly labeled with the methodology itself, reflecting a collection of papers focused on the ERP technique and component findings in metaphor research. Its keywords likely include specific ERP components (N400, P600) and perhaps methodological terms (e.g. electrophysiology, EEG coherence). Cluster #5 signals that some publications are either methodological in nature or serve as reference works summarizing ERP findings on metaphors and semantics. For instance, a comprehensive review of ERP studies on figurative language might fall in this cluster (Kutas & Federmeier, 2011; Bambini et al., 2016). The label also emphasizes the central role of the ERP method in this research domain, to the extent that it constitutes an independent cluster. Within this cluster, researchers discuss how various ERP components reflect distinct cognitive processes involved in metaphor processing. For example, N400 is linked to semantic activation/integration difficulties, whereas a P600 or late anterior negativity might reflect re-interpretation or conflict resolution.

Cluster #6 is labeled as "conceptual expansion". The final cluster points to a fascinating line of inquiry connecting metaphor processing with creativity. "Conceptual expansion" refers to the cognitive process of extending or restructuring conceptual knowledge, which is thought to be central to creative thinking. In the context of metaphors, especially novel ones, listeners or readers often must expand their conceptual frameworks to see the connection between disparate domains (e.g., understanding "Time is a thief" requires expanding the concept of time to include features of a thief). Recent ERP studies explicitly frame novel-metaphor

comprehension as a laboratory model of conceptual expansion. For instance, Abraham, Rutter, and Hermann (2021) showed that novel metaphors elicit a large N400, indexing initial semantic incongruity, followed by a late positive component whose amplitude varies with individual creative ability. A similar pattern appears in second-language users: Miller et al. (2025) found prolonged N400 effects and delayed integration for L2 readers, suggesting that conceptual expansion is more effortful when conceptual representations are less entrenched. Cluster #6, therefore, embodies the intersection of metaphor and creativity research, showing that metaphors are not just a linguistic curiosity but also a gateway to understanding how people generate and understand new ideas.

4. Discussion and Implication

The bibliometric findings illustrate a vibrant and evolving research landscape at the intersection of metaphor studies and cognitive neuroscience. Over the past two decades, ERP-based metaphor research has made significant strides in mapping out when and how the brain processes metaphoric language, and the results largely align with, yet also extend, the broader metaphor literature. A key trend is the focus on the hemispheric processing of metaphors. Early theories often posited a special role for the right hemisphere (RH) in metaphor and figurative language, but subsequent evidence has been mixed. Our analysis shows that this topic remains central (e.g., through keywords and clusters related to "right hemisphere" and "figurative language"). The co-citation network and cluster #2 (time course) indicate that many studies have scrutinized hemispheric differences using ERP measures. In general, the consensus emerging from these studies is nuanced: rather than metaphors being categorically a RH function, it appears that factors like familiarity and salience determine hemispheric engagement. For instance, highly conventional metaphors might be processed similarly to literal language (primarily by the left hemisphere language network), whereas novel metaphors might recruit additional RH resources due to their low semantic salience. This pattern supports the Graded Salience Hypothesis (Giora, 1997, 2003), which argues that the brain's processing depends on the salience (familiarity and conventionality) of the meaning, rather than a strict literal–metaphorical dichotomy. Indeed, results from ERP studies have lent credence to this view: as noted earlier, "novel metaphors seem to elicit larger N400 amplitudes than conventional metaphors" (Bambini, 2016) and sometimes engage additional neural circuits, indicating extra processing effort.

Another prominent theme is the embodied cognition basis of metaphor processing. The cluster analysis (with a cluster explicitly labeled "embodied cognition") and co-citation of foundational works (Lakoff & Johnson, 1980; Gibbs, 2006) underscore that many ERP studies are motivated by or testing the idea that understanding metaphors involves simulating sensory-motor experiences. The discussion in our results touched on how conceptual metaphor theory (CMT) posits that abstract concepts are grounded in concrete, bodily experiences. ERP research has contributed importantly to this debate by providing neural evidence of embodiment. For example, several studies have reported that metaphors involving action or the body (e.g., "grasping an idea") can modulate early sensory-motor ERP components or yield N400 effects that differ when a prior motor context is present. Such results suggest that readers/listeners may be partially engaging the same neural circuits for

action when processing an action-metaphor, supporting the claim that "sensorimotor systems are engaged in simulating the concepts" in metaphor comprehension. The embodied perspective has been invigorated by these neuroscientific findings: the co-occurrence network's inclusion of terms like "motor", "body", "simulation" (implied by cluster #3's content) reflects studies linking metaphor to motor resonance or emotion simulation in the brain. Overall, the ERP literature has provided objective evidence that goes beyond introspection or behavioral data, showing that metaphors tied to sensory-motor domains can trigger measurably different brain responses.

ERP research has been instrumental in delineating the temporal sequence and identifying neural markers of metaphor comprehension. Before electroencephalography became commonplace, investigators relied on reaction times and accuracy, leaving the mental operations largely opaque. The advent of ERPs illuminated these processes, and the N400 component has emerged as a pivotal index. Evidence from studies grouped under the "event related potentials" and "time course" clusters consistently places the N400, peaking about 300 to 500 ms after the critical word, at the centre of semantic integration difficulty (Coulson & Van Petten, 2002; Kutas & Federmeier, 2011). Repeated demonstrations of enlarged N400 amplitudes for metaphoric expressions—especially novel ones—relative to literal controls indicate that the brain initially registers a semantic mismatch or elevated integration load (Bambini et al., 2016; Miller, 2025). This early challenge subsides as meaning consolidates, a shift reflected in a reduced N400 and the appearance of later components such as the Late Positive Complex and frontal slow waves, which are linked to reanalysis and insight (De Grauwe et al., 2010; Regel et al., 2011). Several investigations report a graded N400 pattern in which literal sentences evoke the smallest responses, conventional metaphors a moderate response, novel metaphors a larger response, and anomalous sentences the largest, supporting a continuum of processing effort rather than a categorical split (Miller, 2025).

This analysis also shows how research on special populations and contexts has deepened our understanding of metaphor processing. The "bilingual" cluster (3) and the frequent appearance of keywords such as "children" and "ASD" (Autism Spectrum Disorder) reveal sustained efforts to test the generality of metaphor theories in learners, developing children, and clinical groups. These studies are indispensable for assessing theoretical scope. For example, several ERP investigations with autistic participants have asked whether social-pragmatic challenges impair comprehension of nonliteral language; some report intact performance when stimuli are tightly constrained, thus challenging the assumption of a universal metaphor deficit in autism (Gold & Faust, 2010; DiCriscio & Troiani, 2017). Co-citation patterns suggest that such mixed outcomes have redirected attention to task format, language proficiency, and contextual support. Parallel work on bilinguals shows that proficient second-language users ultimately arrive at accurate interpretations but often display prolonged N400 effects, particularly for culturally specific metaphors, indicating greater processing effort (Miller et al., 2025).

Future work on ERP and metaphor should draw on several theoretical traditions rather than relying on a single explanatory lens. Our review shows that investigators often align either with embodied accounts, which highlight sensorimotor simulation (Gibbs, 2006), or with

pragmatic frameworks that emphasise contextual inference (Giora, 2003). This bifurcation risks fragmented interpretations. Experiments that directly compare competing predictions or unify complementary elements can provide more decisive evidence. For example, a study could examine whether sensorimotor activation appears within the first 300 to 500 ms of comprehension or only after metaphorical meaning has been established, thereby evaluating both embodied and symbol based accounts in a single design.Peng et al. (2023) urge scholars to interpret findings through multiple perspectives; following this advice would help avoid premature allegiance to any single model and recognise that metaphor understanding likely rests on a coalition of mechanisms. Concretely, researchers should present results in ways that speak simultaneously to the Graded Salience Hypothesis and to Conceptual Metaphor Theory, which would enrich discussion and situate new data within the wider scholarly dialogue.

Second, our review underscores how task design and stimulus characteristics shape ERP findings. Differences in outcomes frequently arise from variations in materials or procedures that Peng et al. (2023) refer to as "task properties." Future work should therefore manipulate and report variables such as metaphor familiarity, transparency, syntactic structure, and contextual length, all of which influence neural responses (Bambini et al., 2016; Cardillo et al., 2020). Familiarity, now recognised as a key determinant, is examined more often than features like syntax, yet overlooking those features may obscure critical effects. Using identical metaphor targets embedded in sentences that differ only in structure or context would help isolate specific contributors to processing difficulty. Stimulus modality offers another important avenue. Most ERP studies rely on written text, but extending paradigms to spoken or pictorial metaphors could reveal how presentation format modulates the timing and magnitude of neural signatures (Desai et al., 2018). Researchers should also explore how context operates across participant groups; for example, a rich narrative might reduce or even eliminate differences in metaphor comprehension between autistic and neurotypical individuals. Such questions enhance ecological validity and ensure that observed ERP disparities reflect metaphor processing rather than extraneous task demands.

Third, the current ERP literature on metaphor still faces several practical and conceptual limitations that future work should address. One concern is the limited linguistic and cultural scope of current work. Most studies have focused on Indo-European languages, primarily English and, to a lesser extent, Mandarin, leaving it uncertain whether key findings generalise to typologically distant languages or to writing systems that do not use an alphabet. Broadening the language sample would allow researchers to test whether hallmark effects such as the metaphor-related N400 also emerge in languages with fundamentally different metaphor conventions. Participant diversity also warrants greater attention. Most experiments rely on adult university students, yet developmental data are crucial for mapping how metaphor comprehension and its neural correlates mature from childhood into adolescence. Longitudinal ERP projects could determine the age at which children begin to show adult-like N400 and late-positive responses to figurative language (Friedrich & Friederici, 2005). Publication practices present an additional challenge. Citation patterns in our bibliometric analysis reveal a strong focus on classic theories, while null findings and replication attempts

receive fewer citations. Incorporating preregistered reports and systematically including under-cited studies in meta-analyses would help balance the evidence base and enhance reliability. Methodologically, the field has relied heavily on grand-average waveforms, but advanced analytic approaches can capture subtler effects. Single-trial modelling and multidimensional pattern classification have already proved valuable in other ERP domains (King & Dehaene, 2014).

5. Conclusion

This bibliometric review offers a detailed account of two decades of ERP research on metaphor processing, charting its growth, leading contributors, principal themes, and emerging directions. Publication output has risen steadily since the early 2010s, and a wide range of journals and laboratories now engages with the topic. Influential works anchored in Conceptual Metaphor Theory (Lakoff & Johnson, 1980) and in neurolinguistic research on the N400 component (Kutas & Federmeier, 2011) continue to shape empirical agendas. Co-citation and keyword analyses reveal six interlocking themes: hemispheric lateralisation, embodied mechanisms, dynamics of semantic integration, attentional and executive influences, bilingual comprehension, and creative expansion in novel metaphors. Together, these strands show that ERP studies address fundamental questions about how figurative meaning is constructed in the mind and instantiated in the brain.

The review also demonstrates the value of bibliometric tools for synthesising an interdisciplinary and sometimes fragmented literature. Visualizing citation networks and keyword clusters provides a coherent overview that draws attention to well-established findings, such as the precise temporal course of metaphor comprehension at the millisecond level and the influence of contextual factors and prior experience, as well as to less-explored areas, including developmental changes and cross-cultural variation. Current evidence supports integrative models, showing that metaphor processing involves both left and right hemispheric resources in flexible combinations and can proceed through multiple routes depending on metaphor familiarity, linguistic context, and the background of the reader.

These insights have practical implications. In education, they inform strategies for introducing figurative language to second-language learners; in clinical settings, they guide assessment of figurative-language difficulties after brain injury or in autism spectrum conditions. More broadly, the findings underscore that metaphors are not mere stylistic ornaments but windows onto core cognitive operations such as abstraction, analogy, embodiment, and creativity. By tracing the field’s development from 2005 to 2025, this review confirms that researchers have made substantial progress in mapping the neural underpinnings of metaphor comprehension while acknowledging its complexity and richness. The conclusions refine theoretical models of language processing and offer guidance for applied contexts, from classrooms to therapeutic communication. Finally, the study itself illustrates how systematic bibliometric mapping can yield actionable insights and provide a structured roadmap for both newcomers and established scholars in cognitive neuroscience.

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