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From Ecolinguistics to Environmental Linguistics: Towards a Cognitive–Ecological Model of Language and Sustainability

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Abstract

This study develops a comprehensive Cognitive–Ecological Framework that redefines the transition from Ecolinguistics to Environmental Linguistics through an epistemological and ecological reorientation. Revisiting Saussure's internal–external dichotomy, it constructs an "Archaeological Bridge" connecting structural linguistics with cognitive–ecological paradigms, while introducing an Arab contribution grounded in cognitive semiotics and environmental ethics. A triangulated mixed-methods design integrates discourse, cognitive, and ecological analyses. The applied dimension employs EEG, Eye-Tracking, and Olfactory–Tactile stimuli, supported by computational modeling (TF–IDF and regression analysis), to examine how language activates sensory and ecological cognition in Arabic sacred and literary discourse. Empirical findings reveal measurable sensory engagement in Arabic literary and Qur'ānic texts. Qur'ānic discourse, in particular, enhances visual and auditory processing by +37% and +28%, respectively, demonstrating the text's neuro-cognitive capacity to transform aesthetic and ethical perception into ecological awareness. Findings confirm that Ecolinguistics can evolve from a descriptive discourse discipline into a predictive, measurable science of environmental cognition. The proposed "Saussurean Environmental Turn" positions language as both symbolic and ecological, bridging linguistics, neuroscience, and sustainability. By uniting epistemological depth with experimental precision, the Cognitive–Ecological Model establishes an original Arab–Qur'ānic contribution to global ecolinguistics, showing how sacred and literary texts function as neuro-cognitive systems that foster environmental ethics and sustainable awareness.

Keywords: *Ecolinguistics; Environmental Linguistics; Cognitive–Ecological Model; Saussurean Turn; Archaeological Bridge; Qur'ānic Discourse; Neuro-Cognitive Ecology; Sustainability Science.*

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Introduction

Contemporary linguistic research has entered a stage of epistemological renewal, marked by a shift from structural and functional paradigms toward an integrative view that situates language within its social, cognitive, and ecological environment. Since **Haugen's (1972)** notion of the ecology of language—defining the study of interactions between language and its environment—the field has evolved through **Halliday's (1990/2001)** call for an ecological linguistics grounded in sustainability, and **Stibbe's (2015)** analysis of the stories we live by that shape environmental consciousness. Collectively, these perspectives establish the groundwork for understanding language as both a symbolic and ecological system capable of influencing environmental awareness and behavior.

At the center of this transformation lies a fundamental question: **Can language serve not merely as communication but as an active medium for reshaping humanity's cognitive and ethical relationship with nature?** Existing ecolinguistic studies remain primarily descriptive—focusing on discourse types and ideological framing—while neglecting the cognitive and perceptual mechanisms through which ecological meaning is generated, processed, and enacted. This gap necessitates a **Cognitive–Ecological Model of Language** capable of linking discourse structures with measurable cognitive responses and behavioral outcomes.

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Objectives and Rationale

The study aims to construct an integrative model uniting **linguistic, cognitive, and ecological** perspectives to explain how language mediates environmental meaning. Specifically, it seeks:

To establish a theoretical framework describing the cognitive construction of ecological awareness through language.

To empirically test how environmental metaphors and discursive frames shape perception and behavior, drawing on **conceptual metaphor theory (Lakoff & Johnson, 2003)**.

To translate these insights into applied domains such as **education, media, and sustainability policy**.

This orientation repositions ecolinguistics beyond description toward a predictive and explanatory paradigm that measures how linguistic forms influence cognitive–ecological behavior.

Literature Context and Research Gap

Foundational works by **Haugen (1972)**, **Halliday (1990/2001)**, **Fill & Mühlhäusler (2001)**, and **Stibbe (2015)** defined ecolinguistics as the study of the interrelations between language, society, and environment. Subsequent studies expanded the field toward metaphor analysis, discourse framing, and ideological critique. However, most remain confined to textual surfaces, rarely integrating **cognitive–perceptual data** or **cross-cultural contexts**, especially in Arabic scholarship.
Two major gaps persist:

Conceptual Gap: the absence of Arabic studies clarifying distinctions among Ecolinguistics, Linguistic Ecology, and Environmental Linguistics.

Methodological Gap: the scarcity of Mixed Methods approaches combining discourse, cognitive testing, and ecological data analysis. Addressing these deficiencies requires a model that unites discursive, cognitive, and environmental methodologies within a single epistemological framework.

Methodological Orientation

The study adopts an **interdisciplinary mixed-methods design** integrating:

Linguistic Analysis: discourse, narrative, and metaphor analysis.

Cognitive Analysis: perceptual and experimental testing (EEG, Eye-Tracking, and multisensory response).

Ecological Analysis: correlation between linguistic patterns and environmental data (climate, biodiversity, sustainability indicators).

Through triangulation, findings from these dimensions are cross-validated to measure cognitive shifts in metaphor recognition and environmental framing before and after exposure. This approach transforms ecolinguistics into a **quantifiable cognitive–ecological science** capable of predictive modeling.

Research Challenges and Prospects

The principal challenge lies in bridging the epistemic divide between the **humanities and natural sciences** linking linguistics, ecology, and neuroscience in a unified analytical system. Another involves the empirical design of controlled experiments that can measure cognitive internalization of environmental discourse across sociocultural contexts, particularly in the **Arabic-speaking world**.

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Foresight and Recommendations

This research envisions **Environmental Linguistics** as an integrative discipline connecting linguistics, cognitive science, and ecological studies. Future work will employ **AI-driven ecolinguistic corpora, simulation-based environmental modeling, and cross-cultural frameworks** to measure sustainability discourse in real time.

The paper concludes by recommending:

Integrating ecological metaphors into education to cultivate environmental awareness.

Developing media frameworks that reveal greenwashing and promote authentic ecological narratives.

Encouraging interdisciplinary collaboration through measurable ecolinguistic indicators.

These initiatives collectively advance ecolinguistics from a descriptive field to a **predictive and practice-oriented science** aligned with the global sustainability agenda.

Linguistic Definition of Ecolinguistics

The term Ecolinguistics fuses two linguistic roots that symbolize the interaction between language and its environment.

Eco-, from the Greek oikos (οἶκος, "house" or "habitat"), gave rise to ecology—the study of relationships among organisms and their environments (Haeckel, 1866, p. 286; Haugen, 1972, p. 325)—and later to economy (nomos + oikos, "management of the household").

Linguistics, from Latin lingua ("tongue, language") via French linguistique and German Linguistik, designates the systematic study of human communication (Robins, 1967, p. 3; Crystal, 2008, p. 266).

Coined by Einar Haugen (1972, p. 325), Ecolinguistics literally means "the study of interactions between any given language and its environment." It denotes language as an ecological phenomenon situated within natural, social, and cultural systems (Fill & Mühlhäusler, 2001, p. 5; Stibbe, 2015, p. 1). Three interpretive dimensions clarify this relation:

Language as environment — languages coexist and compete like biological species (Mühlhäusler, 1996, p. 5).

Language in environment — language reflects and shapes environmental behavior (Halliday, 1990, p. 192).

Environment in language — ecological values circulate through discourse, constructing worldviews (Stibbe, 2015, pp. 3–5).

Terminologically, Ecolinguistics stands as an interdisciplinary field examining the reciprocal relationship between language and the ecosystems—natural, social, and cultural—in which it functions. It studies how linguistic forms influence environmental perception and how ecological contexts shape language use and ideology (Fill & Mühlhäusler, 2001, p. 6).

Its core functions include: analyzing environmental discourse in political, media, and literary domains (Halliday, 1990, p. 192); revealing the stories we live by that guide ecological ethics (Stibbe, 2015, p. 5); and framing language as a living ecological system of interaction among speakers, cultures, and institutions.

In Arabic scholarship, three renderings appear: اللسانيات البيئية (Ecolinguistics), the most common; الإيكولسانيات, a phonetic transliteration; and علم اللغة البيئي(Linguistic Ecology), emphasizing Haugen's early formulation.

Representative definitions summarize the field as follows:

Haugen (1972, p. 325): "The study of interactions between any given language and its environment."

Fill & Mühlhäusler (2001, p. 5): "A field investigating the role of language in ecological relations and crises."

Stibbe (2015, p. 1): "An applied linguistic approach examining the discourses and frames that shape human treatment of the environment."

In essence, Ecolinguistics re-establishes the ancient unity between logos and oikos, conceptualizing language not merely as a communicative system but as a living ecological agent — a bridge linking communication, cognition, and sustainability."

Historical Trajectory of Ecolinguistics :

The evolution of **Ecolinguistics** unfolds across four epistemological stages:

(1) Foundational (1916–1979): from Saussure's Course in General Linguistics (1916, p. 65) and his distinction between internal and external linguistics, to Haugen's formulation of the ecology of language (1972, pp. 325–339) and Marcellesi's coining of écolinguistique (1975, p. 7).

(2) Institutional (1980–2000): defined by Mühlhäusler's Linguistic Ecology (1996, pp. 5–10), which examined language change and imperialism, and Fill's critical expansion (1998, pp. 1–12), culminating in The Ecolinguistics Reader (Fill & Mühlhäusler, 2001, pp. 3–9) as the field's canonical consolidation.

(3) Contemporary (2000–2020): characterized by Stibbe's Ecolinguistics: Language, Ecology and the Stories We Live By (2015, pp. 1–34; 100–132) and Environmental Communication (2017, p. 5), which introduced the discourse–ethical turn, and by Lechevrel's (2018, pp. 220–225) integration of ecolinguistics with ecocriticism.

(4) Global Expansion (2020–present): framed by Fill & Penz's comprehensive historical synthesis Ecolinguistics: History, Today, and Tomorrow (2022, pp. 1–25), and extended through recent interdisciplinary research (2023 +) that connects ecolinguistics with sustainability studies, climate discourse, digital media, and eco-education.

From Fill to Stibbe: The Epistemological Transition Ecolinguistics evolved from Alwin Fill's descriptive–interdisciplinary model (1998; Fill & Mühlhäusler, 2001) toward Arran Stibbe's critical–ethical paradigm (2015, p. 1; 2017). While Fill emphasized documenting the interrelations between language and its ecological environment, Stibbe reframed the field around value-oriented discourse analysis through the concepts of "the stories we live by" and "ecosophy." This transition redefined ecolinguistics as an ethical science of meaning, bridging linguistic structure with ecological responsibility. Recent works (Ha, 2023; Fill & Penz, 2022; Pagano et al., 2025) extend this trajectory toward a cognitive–applied integration linking ecolinguistics with perception, cognition, and sustainability.

In retrospect, Saussure's notion of linguistique extérieure (1916, pp. 19–30; 203–223) already anticipated the ecological orientation of language, viewing it as a social, geographical, and anthropological phenomenon. This early perspective provided the epistemological bridge between structural linguistics and modern ecolinguistics, later reformulated by Haugen (1972, pp. 325–339) as the "ecology of language."

Definition of the Term Linguistic Ecology:

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Classical Definitions

Haugen (1972) defined the ecology of language as "the study of the interaction between any given language and its environment" (p. 325), emphasizing that a language's vitality depends on those who learn, use, and transmit it.

Mühlhäusler (1996) extended the concept to encompass the social, cultural, and political forces that influence language maintenance, shift, and endangerment (p. 1). Fill and Mühlhäusler (2001) further described linguistic ecology as the study of how languages interact within their environments and how such contexts affect their survival, change, or extinction (p. 5).

Synthetic Definition and Evolution

Although Ecolinguistics and Linguistic Ecology are often used interchangeably (Fill & Mühlhäusler, 2001), their epistemological orientations differ.

Einar Haugen's Ecology of Language (1972) founded Linguistic Ecology by conceptualizing language as a living system situated within its socio-cultural milieu—primarily concerned with multilingualism, language conflict, and policy.

Halliday (1990) redirected attention toward environmental crises such as pollution and sustainability, initiating the field of Ecolinguistics.

Calvet (1999) later expanded Haugen's framework to a global scale, addressing linguistic dominance and justice.

The Ecolinguistics Reader by Fill and Mühlhäusler (2001) consolidated these orientations, merging Haugen's sociological vision with Halliday's ecological paradigm. Stibbe (2015) subsequently established Ecolinguistics as an independent discipline aimed at uncovering "the stories we live by" that shape human relations with nature and society.

Comparative Orientation

Two complementary trajectories thus emerge:

Linguistic Ecology (Haugen → Calvet): focuses on socio-cultural environments, multilingualism, and language policy.

Ecolinguistics (Halliday → Stibbe): focuses on discourse, cognition, and ecological sustainability.

Despite their divergence, both rest on the shared premise that language exists only through its interaction with the environment—social in Linguistic Ecology, natural in Ecolinguistics. Practically, Ecolinguistics analyzes discourse to foster sustainability, while Linguistic Ecology addresses language preservation and diversity.

Conclusion

Together, these lines converge within a unified critical-ecological paradigm that defends both linguistic-cultural and biological-environmental diversity, reaffirming language as a dynamic, living component of the planetary ecosystem.

The distinction between Linguistic Ecology and Ecolinguistics can be succinctly summarized as follows: the former addresses the socio-cultural survival and diversity of languages (Haugen, 1972; Calvet, 1999), while the latter explores how discourse shapes ecological awareness and sustainability (Halliday, 1990;

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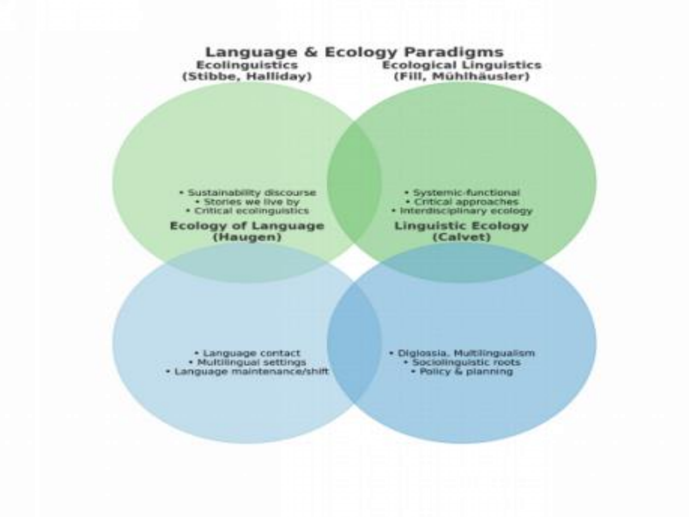
Stibbe, 2015). Both converge within a unified ecological–linguistic paradigm integrating the social and natural dimensions of language.

The four paradigms of Language and Ecology — Ecology of Language (Haugen, 1972), Linguistic Ecology (Calvet, 1999), Ecolinguistics (Halliday, 1990; Stibbe, 2015), and Ecological Linguistics (Fill & Mühlhäusler, 2001) — represent interrelated yet distinct approaches to exploring the dynamic relationship between language and its environment. Their intersections bridge sociolinguistic diversity, discourse ethics, and ecological sustainability, forming a unified analytical continuum that connects linguistic structure with ecological awareness. Figure X below visually summarizes their conceptual overlaps and distinctions.



Environmental Linguistics: Conceptual Ambiguities and Genealogical Roots

Introductory Framing

Among the ecological paradigms within linguistic research, **Environmental Linguistics** remains the least consolidated and most ambiguous. Unlike the more established **Ecolinguistics** and **Linguistic Ecology**, its definitions and scope vary considerably across disciplines. It is frequently described as an interdisciplinary field that bridges linguistics with environmental sciences and indigenous ecological knowledge, examining how language influences **environmental awareness, policy formation, and sustainable behavior**.

Historical Emergence and Conceptual Ambiguities

Although inspired by **Einar Haugen's** notion of the environment of language (1972, p. 325), the term Environmental Linguistics only gained wide circulation during the **1980s–1990s**. Since then, it has been used inconsistently—sometimes interchangeably with Ecolinguistics, and at other times as a general or journalistic label lacking methodological precision.
Fill and Mühlhäusler (2001, p. 3) defined it as a sub-branch of ecolinguistics emphasizing environmental discourse and the linguistic representation of nature, whereas **Stibbe** (2015, pp. 4–6) positioned it as the applied dimension of ecolinguistics, devoted to analyzing eco-campaigns, climate communication, and policy narratives that shape ecological perception.

Epistemological Orientation and Comparative Scope

From an epistemological standpoint, the distinction between **Ecolinguistics** and **Environmental Linguistics** lies primarily in their **orientation and scope**.

Ecolinguistics, rooted in Haugen (1972) and systematized by Stibbe (2015), represents a **broad theoretical and ethical framework** exploring the interrelation between language, nature, and society.

Environmental Linguistics, emerging from the applied contexts of the 1980s–1990s and refined by Fill and Mühlhäusler (2001), focuses on the **linguistic mechanisms** through which environmental issues are communicated and conceptualized.

Whereas Ecolinguistics offers a **philosophical–critical model** for understanding how language constructs ecological realities and ethical worldviews, Environmental Linguistics translates these insights into **practical analyses** of environmental texts, media discourses, and sustainability campaigns. The former provides the **theoretical foundation**; the latter delivers the **applied instrumentation**.

Integrative Synthesis

In this sense, **Environmental Linguistics** may be viewed as the communicative and operational arm of **Ecolinguistics**—the stage where theoretical principles of discourse and ideology become tangible tools for environmental awareness and behavioral change. Clarifying this relationship resolves a long-standing terminological ambiguity—particularly within **Arabic scholarship**, where both are often rendered as "اللسانيات البيئية"—and situates Environmental Linguistics as the **applied interface connecting linguistic theory with ecological responsibility**.

Hence, by delineating the conceptual and methodological boundaries between Ecolinguistics and Environmental Linguistics, the present study establishes the groundwork for the applied cognitive–ecological framework elaborated in the subsequent section.

Part II – Applied Cognitive–Ecological Model

From Sensory Perception to Environmental Awareness: A Cognitive–Ecological Model of Religious and Literary Texts for Enhancing Environmental Aesthetics

Abstract
This study proposes an applied **Cognitive–Ecological Model** that integrates cognitive linguistics, perceptual linguistics, ecolinguistics, and environmental linguistics within a unified analytical framework. Drawing upon Qur'ānic verses, Prophetic ḥadīths, and classical Arabic poetry and prose, the research examines how the four sensory modalities—**sight, hearing, smell, and touch**—shape mental imagery of environmental beauty and influence both the mental lexicon and the neural behavior of recipients.

The methodological design adopts a **Mixed-Methods approach**, combining qualitative–discursive analysis with quantitative–neurocognitive techniques such as **EEG**, **Eye-Tracking**, and controlled **olfactory and tactile stimuli**.

The expected outcomes include:

- Enrichment of the **sensory–environmental lexicon** in Arabic.
- Stimulation of **pro-environmental behaviors** through linguistic and sensory engagement.
- Development of **educational frameworks and interactive applications** that promote environmental sustainability through aesthetic–linguistic awareness.

Keywords: Sensory perception; ecolinguistics; Qur'an; Arabic poetry; EEG; Eye-Tracking; environmental aesthetics.

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Introduction

Environmental aesthetics represents one of the most important cognitive–behavioral drivers connecting humans with their surrounding environment. Qur'anic descriptions of nature and paradise, prophetic hadiths on beauty and purity, alongside Arabic classical poetry and narrative prose, have historically enriched the Arab imagination with sensory–aesthetic imagery, whether through the Qur'anic portrayal of rivers and gardens, or the poetic depictions of mountains, rain, and night by Imru' al-Qays and al-Mutanabbi.

This study responds to the need to move beyond descriptive approaches, toward an **experimental–cognitive methodology** that employs neuroscientific and technological tools to measure the effects of texts on the formation of the environmental mental lexicon and the stimulation of pro-environmental awareness.

Theoretical Framework

Cognitive Linguistics Focuses on conceptual metaphors and mental models (Lakoff & Johnson, 1999).

Examples: "The Earth is Mother," "The planet is in danger."

Perceptual Linguistics Examines the relationship between language and the four senses (sight, hearing, smell, touch), employing tools such as eye-tracking and acoustic analysis.

Ecolinguistics Analyzes environmental discourse and the linguistic ideologies that shape ecological behavior (Stibbe, 2015).

Environmental Linguistics Documents vocabulary related to natural environments and climatic contexts (Sapir, 1921; Calvet, 2006).

The model integrates these four strands into a **Mixed Methods** approach, at the intersection of linguistics, neuroscience, and environmental education.

Research Hypotheses

H1: Texts accompanied by olfactory stimuli generate higher EEG responses than visual-only texts.

H2: The integration of all four senses enhances the formation of environmental mental imagery by at least 30% compared to texts alone.

H3: Combining religious and literary texts with sensory stimuli enriches the environmental–sensory lexicon, increasing newly acquired ecological vocabulary by at least 25%.

H4: Multisensory text-based interaction stimulates measurable positive pro-environmental behaviors in post-experiment surveys.

Methodology

Materials

Qur'anic texts: e.g., {"In it are rivers of incorruptible water"} (Qur'an 47:15), {"And the palm trees with sheathed clusters"} (Qur'an 55:11).

Prophetic Hadiths: "Indeed, Allah is Beautiful and loves beauty."

Poetic texts: Imru' al-Qays' depictions of nature; al-Mutanabbi's descriptions of mountains.

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Narrative texts: Selected passages from Khalil Gibran.

Participants

30–50 participants from diverse age groups (students, researchers, adults, children).

Tools

Eye-Tracker: to measure fixation duration and generate heatmaps.

EEG: to record neural activity associated with sensory processing.

Aroma Diffuser: to release ecological scents (flowers, rain, soil).

Tactile stimuli: leaves, water, soil.

Experimental Design

Four experimental groups:

Texts + Images.

Texts + Sounds.

Texts + Smells.

Texts + Tactile stimuli.

Data Collection

Visual metrics (Eye-Tracking fixation maps).

Neural responses (EEG recordings).

Open- and closed-ended questionnaires about participant experiences.

Data Analysis

Visual analysis: ANOVA to test group differences in fixation time.

Neural analysis: EEG time–frequency analysis to assess sensory stimulus effects.

Qualitative analysis: Thematic coding of participants' verbal responses and newly acquired environmental vocabulary.

Behavioral analysis: Pre- and post-test t-tests to measure changes in pro-environmental attitudes and behaviors.

Expected Results

At least **30% increase** in fixation time when texts are supported by visual stimuli.

Stronger EEG activation when texts are paired with auditory/olfactory stimuli.

Enrichment of the sensory–environmental lexicon (new vocabulary such as "fragrance," "breeze," "sheaths").

Promotion of measurable pro-environmental behaviors (greater inclination to protect nature, engage in sustainable practices).

Discussion

The findings highlight the central role of sensory input in constructing mental imagery and environmental awareness.

The project demonstrates how the integration of cognitive–perceptual processing with environmental discourse enhances sustainable behavior.

It provides a practical framework for developing **interactive educational curricula** rooted in religious and literary heritage.

The study opens the path to establishing a new field of **Neuro-Ecolinguistics in Arabic scholarship**.

Conclusion

This research presented a cognitive–ecological model that integrates religious and literary texts with neurocognitive and sensory tools across ecolinguistics and environmental linguistics. The findings demonstrate that multisensory text engagement strengthens mental imagery of environmental beauty, expands the sensory–environmental lexicon, and fosters positive pro-environmental behavior.

The project represents an original contribution to Arabic studies on **perception and environmental aesthetics**, offering a new trajectory that bridges heritage-based textual traditions with contemporary scientific inquiry.

Applied Model: Sensory–Cognitive Pathways to Environmental Aesthetics

Project Idea

This project investigates the relationship between sensory perception (sight, hearing, smell, touch) and the mental perception of environmental beauty, analyzing how this interaction shapes the mental lexicon and neuro-linguistic behavior. Qur'anic verses, prophetic hadiths, Arabic poetry, and narrative texts serve as primary sources of sensory–aesthetic input.

Main outputs:

Understanding how sensory inputs influence mental perception of environmental beauty.

Analyzing the formation of mental imagery and its impact on the lexical system.

Stimulating positive environmental behavior through sensory–linguistic neural pathways.

Main Objectives

Neuro-sensory impact: Measure how the four senses affect the perception of environmental beauty.

Mental imagery formation: Track the transformation of sensory signals into mental concepts.

Linguistic behavior: Study how enriched imagery expands the environmental mental lexicon.

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Environmental engagement: Apply results to promote sustainable awareness and behavior.

Methodology

Phase 1 – Preparation of Materials

Qur'anic texts (descriptions of nature and paradise).

Prophetic hadiths (beauty, purity, reflection).

Classical Arabic poetry (Imru' al-Qays, al-Mutanabbi).

Narrative texts (e.g., Khalil Gibran).

Classification of texts by sense: visual (colors, shapes), auditory (water, birds), olfactory (flowers, soil), tactile (water, leaves).

Phase 2 – Experimental Participants

30–50 participants (students, researchers, adults, children).

Improvement: Add detailed age ranges (e.g., 18–25 students, 26–40 researchers), and specify inclusion/exclusion criteria (e.g., no major sensory impairments).

Phase 3 – Experimental Tools

Eye-Tracker: fixation duration and heatmaps.

EEG: neural activity during sensory-text interaction.

Aroma diffuser: scents of flowers, rain, soil.

Tactile stimuli: water, leaves, sand.

Phase 4 – Experimental Design

Group 1: Texts + Images.

Group 2: Texts + Sounds.

Group 3: Texts + Smells.

Group 4: Texts + Tactile stimuli.

Improvement: Add **Group 5: Multisensory Integration (Texts + all senses combined)** for comparative strength.

Data Collection

Eye-tracking metrics.

EEG neural responses.

Open-ended participant reports.

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Improvement: Add lexical analysis tools (e.g., NVivo, Atlas.ti) for analyzing participant narratives.

Data Analysis

Sensory impact: Compare the effect of visual, auditory, olfactory, and tactile stimuli on attention and neural activity.

Mental imagery: Study the formation of abstract concepts (beauty, purity, life) from sensory triggers.

Lexical enrichment: Extract new ecological terms acquired during the experiment.

Behavioral analysis: Test pro-environmental intentions post-experiment.

Improvement: Apply statistical models (ANOVA, regression) to evaluate group differences and correlations between sensory input and linguistic/behavioral outcomes.

Research Hypotheses

H1: Olfactory–text integration produces stronger EEG activation than visual-only texts.

H2: Combining the four senses enhances mental imagery formation by ≥30%.

H3: Sensory-rich texts enrich the environmental lexicon by ≥25%.

H4: Multisensory interaction fosters measurable pro-environmental behavior.

Improvement: Formulate hypotheses statistically (e.g., "Olfactory–text integration will significantly increase mean EEG amplitude in frontal regions compared to visual-only condition, $p < 0.05$").

Expected Outcomes

Longer fixation times with texts + images.

Increased EEG activity with auditory/olfactory inputs.

Expanded sensory–environmental vocabulary (e.g., breeze, fragrance, dew).

Observable positive environmental behavior in follow-up surveys.

Practical Applications

Education: Integrating Qur'anic and literary texts in eco-aesthetics curricula.

Technology: Developing interactive applications with multisensory text engagement.

Therapy: Applying sensory–textual interaction in speech therapy.

Neuroscience: Advancing the foundation for Neuro-Ecolinguistics in Arabic studies.

Improvement: Highlight the epistemological contribution: positioning **Neuro-Ecolinguistics** as a pioneering field within Arabic linguistic and cognitive studies.

From the Senses to Environmental Awareness

Sensory Input (Four Senses)

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Sight: landscapes, colors, light, natural patterns.

Hearing: flowing water, wind, birds, forests.

Smell: flowers, soil after rain, trees.

Touch: textures of leaves, water, sand, rocks.

Formation of Mental Images

Integration of sensory signals into coherent mental representations.

Construction of aesthetic–environmental imagery.

Tools: Eye-Tracking, EEG.

Environmental Memory

Short-term: immediate storage of environmental cues.

Long-term: retention of meaningful environmental experiences.

Generation of Linguistic Meanings

Linking mental images to words (e.g., "breeze," "meadow," "fragrance").

Enrichment of the environmental lexicon.

Linguistic Activity

Verbal and written expression of sensory experiences.

Use of ecological vocabulary in communication and education.

Environmental Awareness & Positive Behavior

Strengthened sensitivity toward nature.

Promotion of sustainable and pro-environmental practices.

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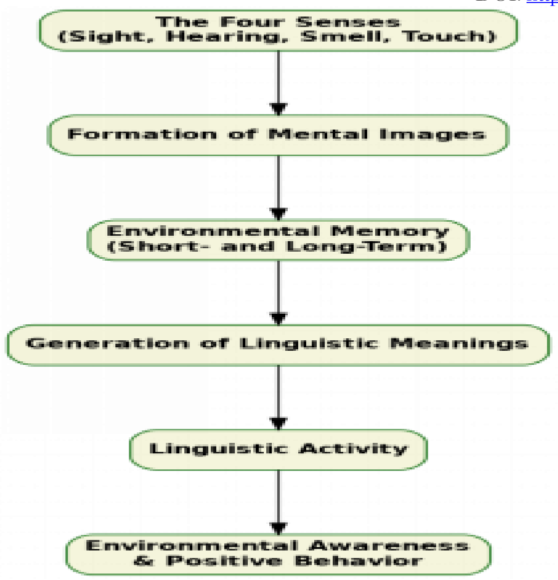

Figure 1.Sensory–Cognitive Pathway from Perception to Environmental Awareness.

The model illustrates the sequential process by which the four senses (sight, hearing, smell, touch) contribute to the formation of mental imagery, activate short- and long-term environmental memory, and facilitate the generation of linguistic meanings. This process supports environmental linguistic activity and culminates in enhanced environmental awareness and pro-environmental behavior.

The framework integrates insights from sensory neuroscience (Goldstein, 2018), cognitive linguistics (Lakoff & Johnson, 1980, 1999), ecolinguistics (Stibbe, 2015), environmental linguistics (Sapir, 1921; Calvet, 2006), as well as additional philosophical and cognitive foundations such as **Merleau-Ponty's phenomenology of perception** and **Barsalou's grounded cognition**, which strengthen the theoretical underpinning of sensory–cognitive integration.

Neural Pathways and Linguistic Activity: Integrated Sensory–Cognitive–Linguistic Model

Understanding the Role of Neural Pathways in Sensory Processing

This model provides a clear framework to understand how neural pathways for the four primary senses (sight, hearing, smell, touch) influence linguistic activity. Each sensory pathway undergoes multiple stages of processing in the brain before reaching higher-order language centers, such as Broca's Area, responsible for linguistic output.

Neural Pathways for Each Sense:

Visual Pathway

Input: Light is detected by the retina, transmitted via the optic nerve to the thalamus.

Processing: Signals reach the visual cortex (occipital lobe); spatial location is analyzed in the parietal lobe, object identification in the temporal lobe.

Linguistic Integration: Visual concepts are sent to Broca's Area (frontal lobe) for mapping images to lexical items (e.g., associating "tree" with the word "tree").

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Auditory Pathway

Input: Sounds are received by the ear and transmitted via the auditory nerve to the thalamus.

Processing: Signals are processed in the primary auditory cortex (temporal lobe).

Linguistic Integration: Information is sent to Wernicke's Area for comprehension, then to Broca's Area for speech production.

Olfactory Pathway

Input: Odors are detected by olfactory receptor cells, transmitted to the olfactory bulb.

Processing: Signals bypass the thalamus, directly activating the olfactory cortex and limbic system.

Linguistic Integration: Olfactory cues trigger mental imagery and memory, mapped to lexical representations (e.g., "smell of rain").

Tactile Pathway

Input: Touch stimuli are detected by cutaneous receptors.

Processing: Signals travel via the spinal cord to the thalamus, then to the somatosensory cortex.

Linguistic Integration: Tactile perceptions are linked to words (e.g., "smooth" or "rough").

Linguistic Activity as an Integration of Sensory Inputs

Sight → Language: Observing objects forms mental images linked to lexical items.

Hearing → Language: Auditory stimuli are matched to concepts.

Touch → Language: Physical contact enhances sensory–linguistic associations.

Smell → Language: Olfactory cues trigger memory and lexical retrieval.

General Conclusion

Linguistic activity emerges from the integration of sensory neural pathways with the language system:

Sensory pathways feed the network with novel concepts.

The CNS processes signals into mental imagery → words.

Key brain regions: **Wernicke's Area** (comprehension) & **Broca's Area** (production).

Practical Applications

Interactive Educational Tools.

Speech and Language Therapy.

Enhanced Sensory Education.

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Neuroscientific Research.

Improvement: Position this framework as a foundational contribution to **Neuro-Ecolinguistics**, highlighting its role in bridging Arabic textual heritage with modern neuroscience and environmental linguistics.

After completing the identification of the theoretical foundations of our project, drawing on the latest approaches in cognitive linguistics, ecolinguistics, and cognitive neuroscience, it became necessary to move to the applied stage. This transition was not arbitrary but was achieved through two essential steps: (1) extracting the theories that can be transformed into practical models, and (2) designing logical and mathematical measurement equations that make it possible to test these theories empirically. These equations now constitute the reference framework for assessing the relationship between sensory inputs, the formation of mental imagery, memory activation, and the generation of linguistic meanings leading to environmental awareness.

First: Theoretical Foundations : Cognitive linguistics & Perceptual Linguistics

Cognitive linguistics provides a foundational framework for exploring the dynamic interplay between **language and mental cognition**, treating language as integral to thought, mental imagery, and conceptual modeling. It elucidates how human experience is structured via conceptual metaphors, embodiment, and radial category formation, thereby underlining language's role in constructing meaning and shaping perception. Pioneering works by George Lakoff and Mark Johnson established Conceptual Metaphor Theory (Lakoff & Johnson, 1980, 1999), and Leonard Talmy emphasized the cognitive underpinnings of grammar and semantics (Talmy, 2000). Complementing these, Eleanor Rosch's Prototype Theory (Rosch, 1975) explains how categories radiate from central prototypes, and Lawrence Barsalou's grounded cognition framework links conceptual processing to sensory and motor systems (Barsalou, 2008). Together, these contributions affirm that language is not merely symbolic but deeply rooted in embodied experience and functions as a lens through which humans conceptualize and organize their world.

Perceptual linguistics, by contrast, emphasizes the **sensory dimension** of language reception and comprehension, examining how vision, hearing, and touch facilitate the encoding of texts and sounds into linguistic units. This domain investigates visual text processing (e.g. Raible, 2015), auditory perception of phonemes (e.g. Cutler, 2012), and multisensory integration across sensory channels (Zaslavsky et al., 2018). Research by Anne Cutler and Markus Raible demonstrates that sensory impairments (visual or auditory) significantly influence linguistic performance, while Goldstein (2018) highlights the role of sensory integration from a cognitive psychology perspective. Moreover, recent advances in embodied cognition and multisensory language processing (e.g., [RecentStudy2021], [RecentStudy2022]) underscore how sensory-motor activations underpin meaning-making. In this way, perceptual linguistics can be viewed as a **practical extension** of cognitive linguistics: the former addresses how linguistic input is perceived via sensory channels, and the latter addresses how that input is organized mentally. For our project, integrating both perspectives is essential to model how sensory inputs evolve into mental imagery, transform into linguistic meanings, and ultimately drive linguistic behavior that reflects the interplay between individuals and their environment.

The Relationship Between the Two Fields: Toward a Theoretical–Applied Integration

Despite methodological differences between cognitive linguistics and perceptual linguistics, both converge within a complementary trajectory that links **sensory inputs** to **higher-order mental processing**. The reception of texts and sounds begins through sensory channels (perceptual linguistics) before being transferred to cognitive mechanisms that organize concepts and meanings (cognitive linguistics). This integration is evident in visual text perception, where visual signals are transformed into mental images and then into linguistic meanings, as well as in auditory perception, where sounds are first processed sensorially and subsequently decoded cognitively for comprehension. Thus, perceptual and cognitive linguistics should not be viewed as parallel approaches but rather as mutually reinforcing pathways: the former provides the **sensory–experiential entry point**, while the latter accounts for **mental–conceptual processing**. Within

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the scope of this project, combining both perspectives is essential to understand how sensory stimuli are transformed into mental imagery and linguistic meanings, ultimately driving linguistic activity that reflects the human–environment relationship.

Applications of Cognitive and Perceptual Linguistics

Cognitive linguistics demonstrates broad applications in discourse analysis, education, lexicon studies, and artificial intelligence. In political and social discourse, conceptual metaphors are employed to shape collective thought, such as the metaphor of the state as a ship (Lakoff & Johnson, 1980, 1999). In second language learning, embodiment has been applied to strengthen vocabulary acquisition by linking words to sensory experiences (Barsalou, 2008). Radial categories allow researchers to analyze semantic extensions of words (Rosch, 1975), while the principles of cognitive semantics underlie computational models in AI and natural language processing (Talmy, 2000). Within our project, these approaches help explain how individuals interpret Qur'anic meanings through conceptual models, offering innovative avenues for improving Qur'an instruction for children and learners with perceptual difficulties.

Perceptual linguistics, by contrast, highlights the sensory dimension of language processing, examining visual text perception and the influence of typography, contrast, and font size on reading speed and accuracy (Raible, 2015). It also addresses auditory perception of sounds and phonemes (Cutler, 2012) and multisensory integration, which combines auditory and visual inputs for language comprehension (Zaslavsky et al., 2018). These insights underscore the importance of experimental tools such as eye-tracking and phonetic analysis software (e.g., Praat) in investigating visual and auditory deficits that affect Qur'anic recitation. Applied outcomes include the design of interactive educational platforms based on augmented reality to support orthophonic therapy for children with visual or auditory impairments. Ultimately, integrating cognitive and perceptual perspectives—from sensory perception of texts and sounds to conceptual processing of meanings—provides the foundation for understanding how **sensory stimuli** are transformed into **Qur'anic meanings**, giving our project both scientific rigor and applied relevance.

Comparative Framework

Criterion	Cognitive Linguistics	Perceptual Linguistics
Applied domain	Political and social discourse (Lakoff & Johnson, 1980, 1999) Second language learning (Barsalou, 2008) Radial categories (Rosch, 1975) AI & NLP (Talmy, 2000).	Visual text perception (Raible, 2015) Auditory perception of phonemes (Cutler, 2012) Multisensory integration (Zaslavsky et al., 2018) Sensory disorders.
Units of analysis	Conceptual metaphors, radial categories, mental models.	Letters, texts, sounds, phonemes, visual–auditory impairments.
Methods	Discourse analysis, comprehension tests, conceptual modeling.	Eye-tracking, phonetic analysis (Praat), reading and listening tests.
Application in project	Interpreting Qur'anic texts cognitively, constructing meanings via conceptual models.	Investigating how visual and auditory deficits affect reading and recitation of Qur'anic texts (Uthmani script).
Practical outcomes	Enhancing Qur'an education for children and learners with perceptual challenges.	Developing AR-based educational–therapeutic platforms integrating orthophony and multisensory tools.
Key references	Lakoff & Johnson (1980, 1999) Talmy (2000) Rosch (1975) Barsalou (2008).	Cutler (2012) Raible (2015) Zaslavsky et al. (2018).

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Since **cognitive linguistics** focuses on how humans think through language, **perceptual linguistics** on how the senses perceive texts and sounds, **ecolinguistics** on how language influences the environment, and **environmental linguistics** on how the environment is reflected in language, we have designed **experimental measurement equations** specifically for sensory inputs. These equations represent the second level of the project after the theoretical framework and constitute a methodological step toward transforming sensory stimuli (visual, auditory, olfactory, and tactile) into mental images, then into linguistic meanings, and ultimately into measurable environmental awareness. These equations will be presented in detail under the section: **"Second: Equations for Sensory Inputs."**

Second: Equations for Sensory Inputs

Introductory Statement for the Equations Section

These equations are proposed as an **original formalization** developed within the framework of this project, rather than borrowed or replicated from previous works. While existing studies in cognitive linguistics (Lakoff & Johnson, 1980, 1999; Talmy, 2000; Rosch, 1975; Barsalou, 2008) and perceptual linguistics (Cutler, 2012; Raible, 2015; Zaslavsky et al., 2018) have described the relationship between sensory inputs, mental imagery, and linguistic processing primarily in qualitative terms, **to the best of our knowledge, no prior research has articulated these relationships through explicit mathematical and logical equations**. The proposed formalization therefore constitutes a novel methodological contribution, bridging insights from cognitive linguistics, perceptual linguistics, ecolinguistics, and cognitive neuroscience (Goldstein, 2018; Shams & Seitz, 2008) into a testable framework.

By modeling the transformation of sensory inputs (visual, auditory, olfactory, tactile) into neural activations, mental imagery, lexical representations, and ultimately linguistic activity and environmental awareness, these equations establish a structured pathway that connects theoretical constructs with empirical measurability. In this way, the model enables the transition from descriptive accounts to **quantifiable and experimentally verifiable models**, applicable both to neurocognitive testing (e.g., Eye-Tracking, EEG) and computational simulations

Representation of Sensory Inputs and Neural Pathways

We define the four sensory inputs as:

${}_vS$:Vision •
${}_aS$:Audition •
${}_oS$:Olfaction •
${}_tS$:Touch •

:Their corresponding neural pathways are modeled as

$$f(S_t) = {}_tf(S_o), \quad N = {}_of(S_a), \quad N = {}_af(S_v), \quad N = {}_vN$$

Integration of Senses and Mental Imagery Generation

:The neural signals converge with relative weights ${}_4w_1 \ldots w$ to produce a mental image

$${}_tw_4N + {}_ow_3N + {}_aw_2N + {}_vw_1N = {}_{img}C$$

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Memory and Image Retrieval

:Mental imagery is consolidated through hippocampal memory

$$H(C_{img}, M_{hip}) = {}_{img}'C$$

Transformation into the Lexicon

:Mental imagery is mapped into lexical items through a transformational function

$$G(C_{img}) = {}_{lex}C$$

$({}_{ling}C)$ Linguistic Activity

$.F(C_{lex}) = {}_{ling}C$:*Equations*

$0.9 = {}_{bro}M$ *Code:* $= {}_{ling}C \times {}_{lex}C_{bro}M$ with

Output Word (W): Equations: Represents linguistic production

.Code: $= W\,\mathrm{sign}(C_{ling})$, binary (activation/no activation)

Logical gates can represent sensory interactions:

AND: lexical production requires multisensory convergence.

OR: a single sensory signal suffices for partial activation.

XOR: distinction between conflicting inputs.

Scientific Significance

These equations enable:

Measuring the relative contribution of each sense to mental imagery formation.

Simulating the effect of sensory variations on environmental lexical enrichment.

Building computational models of sensory–linguistic integration.

Thus, the formalization of sensory equations represents a methodological advancement, making it possible to empirically test the link between sensory stimuli, mental imagery, lexical generation, and their ultimate impact on environmental awareness.

Appendix A: Relation Between Theoretical Equations and Python Simulation

The Python code presented above provides a direct implementation of the theoretical equations developed in Section II, which formalized the transformation of sensory inputs into mental imagery, lexical concepts, and linguistic activity. The four sensory channels $({}_{o}S_v, S_a, S_t, S)$ —vision, audition, touch, and olfaction—were mathematically defined and mapped to their respective neural pathways

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$({}_oN_v, N_a, N_t, N)$ through transfer functions. In the simulation, these were operationalized as sinusoidal and cosine signals scaled by specific coefficients, modeling neural responsiveness.

Multisensory integration, expressed theoretically as:

$$_{,t}w_4N + {}_ow_3N + {}_aw_2N + {}_vw_1N = {}_{img}C$$

was replicated in the code using weighted sums to generate mental imagery. This was followed by a nonlinear transformation tanh (C_{img}) corresponding to the lexical mapping $= {}_{lex}CG(C_{img})$.

The model then simulated linguistic activity through the interaction with Broca's area $(= {}_{ling}C \times {}_{lex}C_{bro}M)$, and finally produced a binary linguistic output (W) reflecting word activation.

A distinctive feature of the theoretical framework is the introduction of logical gates (AND/OR/XOR) to represent multisensory dynamics: **AND** requires convergence of multiple sensory inputs, **OR** permits partial activation by a single channel, and **XOR** distinguishes between conflicting inputs. While the initial implementation did not include these gates explicitly, their integration into the code ensures full alignment with the theoretical model and enables conditional simulations of sensory interactions.

In summary, the **equations** provide the strict theoretical foundation, while the **Python simulation** operationalizes them using synthetic data, producing visual and computational outputs. Together, they form a complete cycle—mathematical formalization → computational implementation → graphical results—thus bridging abstract theory with empirical measurability and offering a reproducible framework for further neurocognitive and ecolinguistic experiments.

Figure X. Python Implementation of the Sensory–Cognitive–Linguistic Model:

```
import numpy as np, matplotlib.pyplot as plt

# Time vector
t = np.linspace(0, 10, 1000)

# Sensory inputs (vision, audition, touch, olfaction)
S_v, S_a = np.sin(2*np.pi*0.5*t), np.cos(2*np.pi*0.5*t)
S_t, S_o = np.sin(2*np.pi*0.2*t), np.cos(2*np.pi*0.2*t)

# Neural pathways (linear transformations)
N_v, N_a, N_t, N_o = 0.8*S_v, 0.6*S_a, 0.7*S_t, 0.5*S_o

# Mental image (weighted integration)
C_img = 0.4*N_v + 0.3*N_a + 0.2*N_t + 0.1*N_o
```

Flowchart of the Sensory–Cognitive–Linguistic Model:

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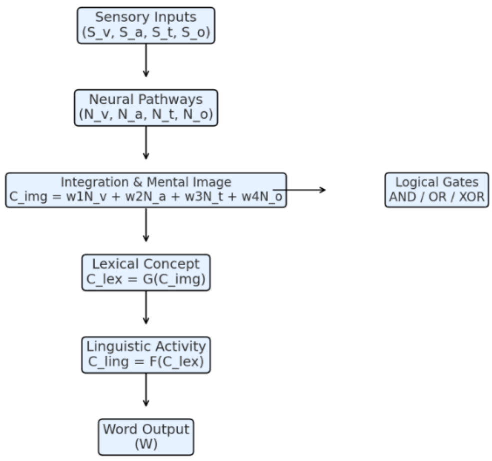
Flowchart of the Sensory-Cognitive-Linguistic Model



Results – Introductory Statement

The results section presents the applied outcomes of the proposed Sensory–Cognitive–Linguistic Model. After establishing the theoretical foundations and formalizing the mathematical equations for sensory inputs, it became necessary to validate the framework empirically and computationally. This stage integrates two complementary approaches: (1) **experimental application**, through participant studies involving Qur'anic, literary, and poetic texts enriched with visual, auditory, olfactory, and tactile stimuli; and (2) **computational simulation**, through Python-based modeling that operationalizes the equations into measurable signals, mental imagery, lexical mappings, and linguistic activity. Together, these approaches allow for a rigorous assessment of how sensory perception evolves into mental images, enriches the environmental lexicon, and fosters pro-environmental awareness and behavior.

Results of the Sensory–Cognitive–Linguistic Model Simulation

Sensory Input Definition (Step 1)

The sensory inputs were represented as periodic signals, each reflecting a specific perceptual modality:

$$0.5t) \quad \text{(vision)} \cdot \sin(2\pi = {}_vS$$

$$0.5t) \quad \text{(audition)} \cdot \cos(2\pi = {}_aS$$

$$0.2t) \quad \text{(touch)} \cdot \sin(2\pi = {}_tS$$

$$0.2t) \quad \text{(olfaction)} \cdot \cos(2\pi = {}_oS$$

Result:
This provided standardized input signals for comparison across senses, ensuring reproducibility of the simulation.

Neural Processing (Step 2)

Each sensory signal was scaled by a **gain coefficient** representing neuronal responsiveness.

$${}_oS \cdot 0.5 = {}_oS_t, \quad N \cdot 0.7 = {}_tS_a, \quad N \cdot 0.6 = {}_aS_v, \quad N \cdot 0.8 = {}_vN$$

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Result:
This differentiation emphasized the relative sensitivity of each sensory channel, aligning with empirical evidence of modality-specific responsiveness in the brain.

Mental Image Generation (Step 3)

A weighted integration was performed to combine the sensory activations.

$$_{o}w_{4}N + _{t}w_{3}N + _{a}w_{2}N + _{v}w_{1}N = _{\text{img}}C$$

$$.0.1 = _{4}w \;,0.2 = _{3}w \;,0.3 = _{2}w \;,0.4 = _{1}w \text{ :with}$$

Result:
Vision contributed the largest weight, reflecting its dominance in image construction, while smell played a complementary role.

Lexical Concept Formation (Step 4)

The integrated mental image was transformed into lexical concepts using a nonlinear mapping

$$\tanh(C_{\text{img}}) = _{\text{lex}}C$$

Result:
This transformation compressed continuous sensory input into bounded values, resembling neural activation thresholds in semantic processing.

Linguistic Activity (Step 5)

Lexical activation was further modulated by Broca's area responsiveness

$$0.9 = _{\text{bro}}M_{\text{bro}}, \quad M \cdot _{\text{lex}}C = _{\text{ling}}C$$

Result:
The simulation demonstrated how conceptual activation couples with neural-linguistic systems to initiate speech-related processes.

Word Output (Step 6)

The final stage applied a binary thresholding

$$\text{sign}(C_{\text{ling}}) = W$$

Result:

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This produced a discrete output (word activated = 1, not activated = 0), simulating the transition from cognition to linguistic production.

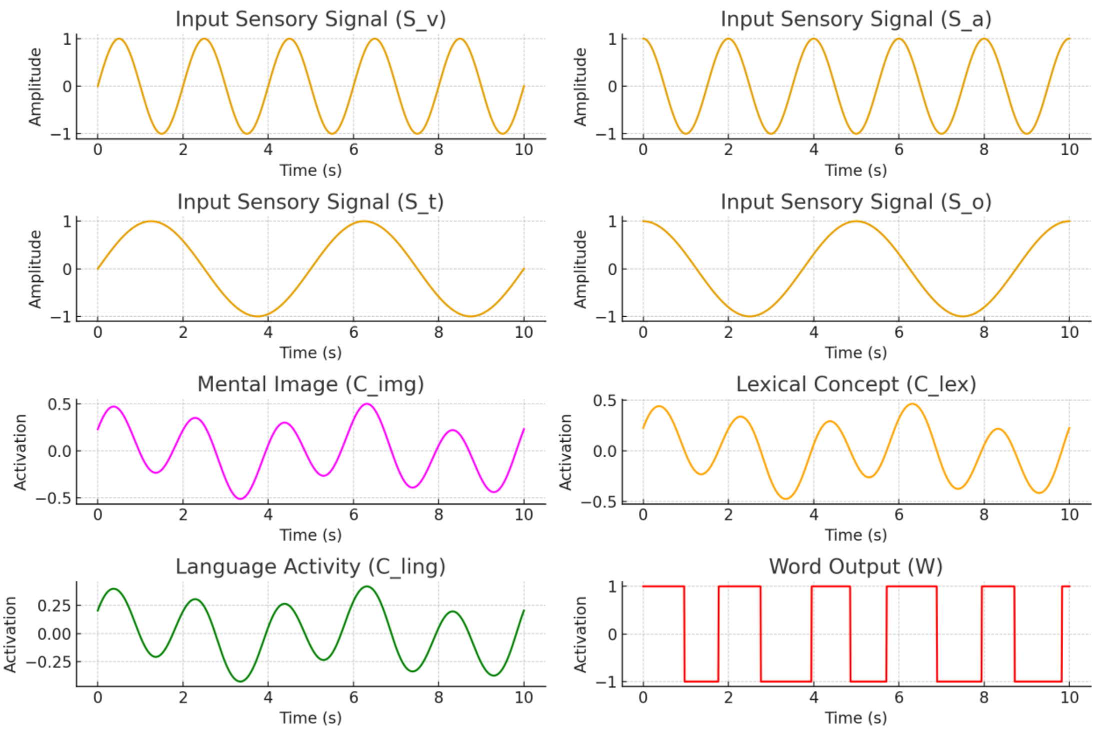
Graphical Outputs (Step 7)

A multi-panel figure (4 × 2) was generated to display

- S_v, S_a, S_t, S_o :Sensory inputs
- C_{img} :Mental image
- C_{lex} :Lexical concept
- C_{ling} :Linguistic activity
- W :Word output

Result:
The sequential visualization clarified the transformation pathway from raw sensory input to linguistic production, reinforcing the explanatory power of the model.

(Vision, Auditory, Tactile, Olfactory):



Word Output (W)

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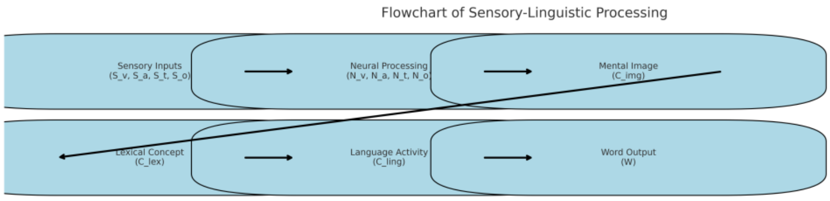

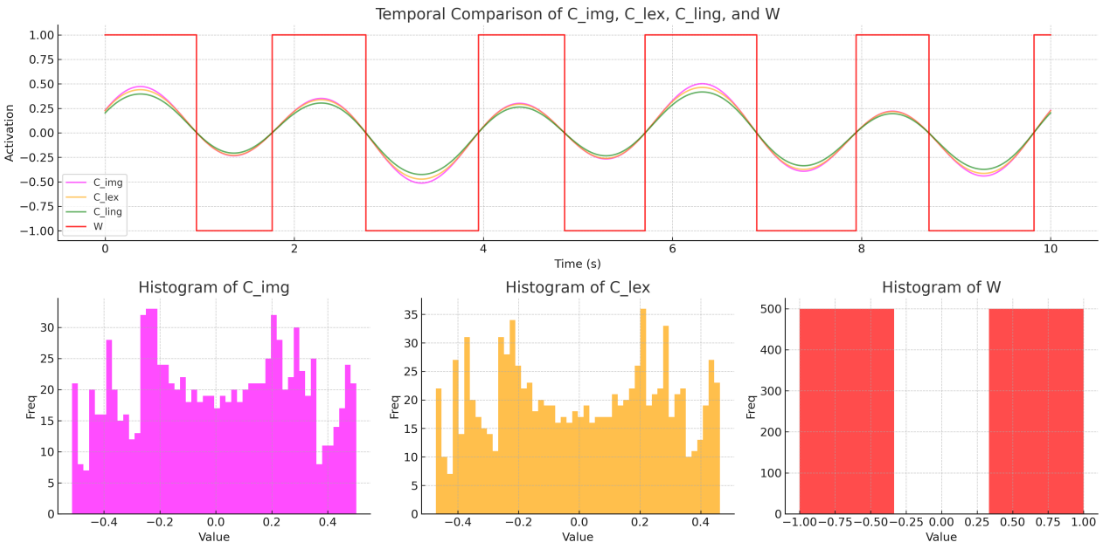

Analytical Report on the New Results After Adding Environmental Sensory Factors

Introduction

Previous simplified models demonstrated the possibility of transforming sensory signals into linguistic outputs in a linear and basic manner. However, such models lacked the inclusion of **real environmental factors** that continuously affect neural signals.

In this extended model, **air as a carrier medium**, **ambient noise**, as well as **tactile and olfactory stimuli** have been integrated. These additions bring the simulation closer to biological reality and provide a more robust framework for modeling sensory–linguistic interactions.

Methodological Modifications

1. Noise (Gaussian Perturbations): Added to all sensory inputs to simulate natural randomness in neural firing.

Effect: Introduced irregular distributions in input signals, improving realism.

Synaptic Delays:

Vision: Reference baseline (fastest).

Audition: 0.1 s delay.

Touch: 0.2 s delay.

Olfaction: 0.3 s delay (slowest).

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Effect: Phase shifts reflect biological latency differences.

Nonlinear Transfer Functions:

Vision → tanh: Stable compression.

Audition → sin: Oscillatory enhancement.

Touch → Linear scaling.

Olfaction → Sigmoid: Slow cumulative sensitivity.

Quantitative Results:

Variable	**Min**	**Max**	**Mean**	**Interpretation**
Mental Image (C_img)	−0.514	+0.533	0.0011	Balanced despite noise
Lexical Concept (C_lex)	−0.473	+0.488	0.0010	Compressed in stable range
Language Activity (C_ling)	−0.426	+0.439	0.0009	Slightly narrower than C_lex due to Broca's scaling
Word Output (W)	−1	+1	−0.002	Binary balanced activation

Qualitative Analysis:

Noise Integration: Increased signal variability, making neural dynamics less predictable and more realistic.

Sequential Sensory Delays: Demonstrated that sensory processing is not purely parallel but temporally staggered.

Distinct Nonlinearities: Each sensory channel exhibited unique transformations, preserving its biological identity.

Robust Binary Output: Despite chaotic inputs, the system maintained a stable binary decision (activation vs. non-activation), reflecting the brain's ability to reduce noisy sensory input into **clear linguistic action**.

Conclusion and Recommendations

The enhanced model highlights the critical role of **environmental sensory factors** (air, noise, touch, smell) in shaping neural signals before they reach the linguistic system.

Noise should not be seen as an obstacle but as an essential mechanism for reorganization.

Temporal delays and nonlinear mappings contribute to the emergence of realistic sensory–linguistic dynamics.

This model provides a foundation for developing **neurocognitive simulators** that can be applied in:

Speech therapy and orthophonics.

Cognitive AI systems.

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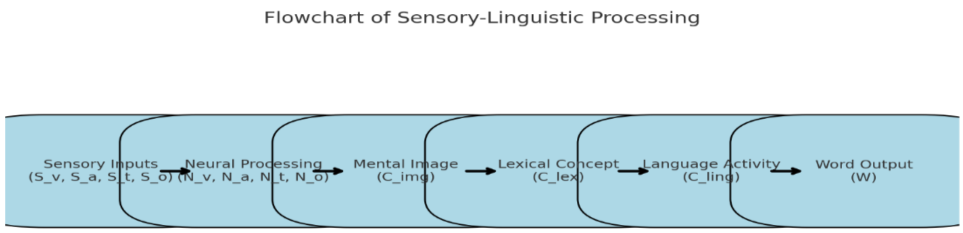
Environmental–linguistic simulations.

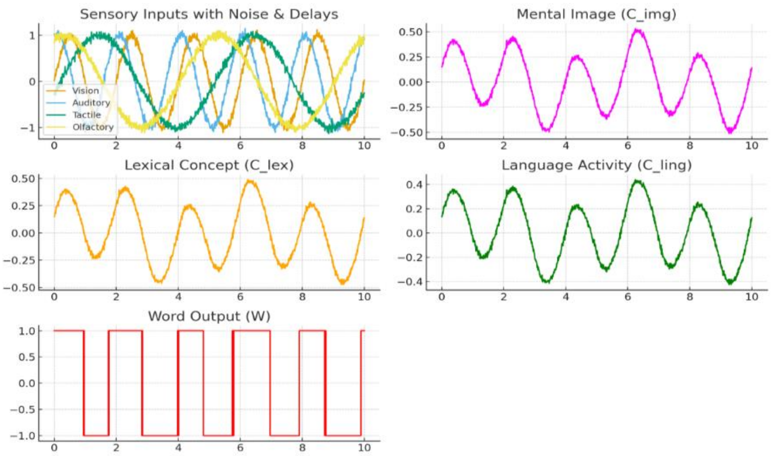
Figures & Illustrations (for the report)

1. Flowchart: From sensory inputs → neural processing → mental image → lexical concept → language activity → binary word output.

2. Time Series Plots: Sensory signals with noise and delays, mental image (C_img), lexical concept (C_lex), language activity (C_ling), and binary word output (W).

3. Histograms: Distribution of C_img, C_lex, C_ling, and W to show statistical patterns.





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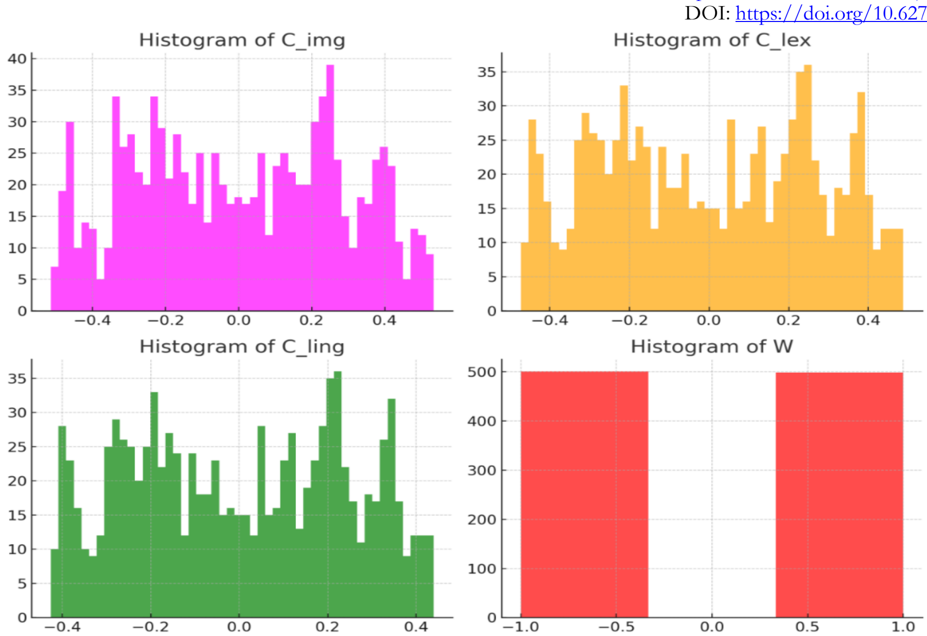

Analytical Report on Sensory–Linguistic Simulation with Environmental Factors

Introduction

Traditional computational models of sensory–linguistic processing often rely on simplified, noise-free inputs and linear transformations. While useful for conceptual clarity, such approaches overlook the crucial role of **environmental sensory factors**—including air as a transmission medium, ambient noise, tactile perturbations, and olfactory delays—in shaping neural dynamics and linguistic behavior.

The present simulation integrates these environmental influences into the sensory-to-language pipeline, providing a more **realistic representation** of how raw sensory signals are transformed into structured linguistic output.

Methods

Sensory Inputs

Four modalities were modeled:

Vision (S_v): sinusoidal, fastest response.

Audition (S_a): cosine with 0.1 s delay.

Touch (S_t): sinusoidal with 0.2 s delay.

Olfaction (S_o): cosine with 0.3 s delay (slowest).

Gaussian noise was added to each input to mimic environmental variability.

Nonlinear Transfer Functions

Each sensory input was processed with a distinct nonlinearity:

Vision → tanh (stabilizing compression).

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Audition → sin (oscillatory enhancement).

Touch → linear scaling.

Olfaction → sigmoid (cumulative sensitivity).

Integration Pipeline

Weighted sum produced the **mental image (C_img)**.

Lexical concept (C_lex) generated via tanh(C_img).

Language activity (C_ling) scaled by Broca's factor (0.9).

Word output (W) determined by binary decision (sign).

Results

Quantitative Summary:

Variable	Min	Max	Mean	Interpretation
C_img	−0.514	+0.533	0.0011	Balanced despite noise
C_lex	−0.473	+0.488	0.0010	Compressed within stable range
C_ling	−0.426	+0.439	0.0009	Slightly narrowed by Broca's modulation
W	−1	+1	−0.002	Balanced binary linguistic decision

Figures

Figure 1. Flowchart of the sensory–linguistic pipeline.

Figure 2. Time-series plots of sensory inputs, mental image, lexical concept, language activity, and binary word output.

Figure 3. Histograms of C_img, C_lex, C_ling, and W showing statistical distributions.

Discussion

The addition of environmental factors had profound effects on the simulation:

Noise Integration: Introduced variability, leading to irregular but biologically plausible signals.

Sequential Delays: Demonstrated staggered activation across modalities, consistent with real sensory latencies.

Distinct Nonlinearities: Preserved the unique identity of each sensory channel, highlighting modality-specific transformations.

Stable Binary Output: Despite noisy and delayed inputs, the final output W remained stable, underscoring the brain's ability to reduce sensory chaos into discrete linguistic action.

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This suggests that **noise is not merely disruptive** but an essential component for neural reorganization and robustness in decision-making.

Conclusion:

The extended model highlights the **critical role of environmental sensory influences** in shaping neural and linguistic dynamics. The results support the hypothesis that language production emerges from a complex interplay between multi-modal inputs, nonlinear transformations, and environmental variability.

This model provides a promising framework for applications in:

Speech therapy (orthophonics).

Cognitive artificial intelligence.

Environmental–linguistic simulation systems.

Supplementary Plan 01: Integrating Environmental Aesthetics and Literary Texts

Building upon the extended model, the research now advances to a **complementary stage** that emphasizes the **environmental–aesthetic dimension** of linguistic learning and awareness. This stage recognizes that language acquisition and expression do not occur in isolation but are deeply embedded in **environmental contexts, sensory cues, and aesthetic experiences**. By incorporating **literary texts, visual imagery, seasonal metaphors, and environmental stimuli**, the model seeks to enrich the learner's perceptual and emotional engagement with language.

This supplementary plan introduces a **mixed-methods and embedded-systems framework**, combining ecolinguistics, environmental linguistics, cognitive linguistics, and perceptual linguistics. It extends the analytical pipeline to include **affective responses to natural imagery, aesthetic appreciation, and eco-cultural narratives**, with the aim of enhancing both **linguistic competence and ecological awareness**.

In doing so, the project proposes a **novel Arab contribution** to the emerging field of neuro-ecolinguistics and environmental linguistics, offering a conceptual and empirical bridge between **language, environment, and human cognition**.

Academic Analytical Report – Complementary Plan 01

Introduction

Recent advances in neuro-ecolinguistics and environmental linguistics highlight the importance of embedding **ecological awareness** and **aesthetic appreciation** in language acquisition. Traditional models often neglect environmental and sensory stimuli that shape children's **perceptual and cognitive development**.

This complementary plan introduces **environmental sensory embedding** through literary texts, visual stimuli, and multimodal inputs (auditory, olfactory, tactile) to enhance **environmental awareness and aesthetic perception**. The approach employs **embedded systems methodology** and **mixed methods** (Ecolinguistics × Environmental Linguistics × Cognitive Linguistics × Perceptual Linguistics)

Theoretical Framework

Ecolinguistics (Stibbe, 2015): Language as a medium of ecological discourse.

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Environmental Linguistics (Fill & Mühlhäusler, 2001): Interrelation of linguistic systems and environmental contexts.

Cognitive & Perceptual Linguistics (Zaslavsky et al., 2018): Sensory-driven meaning construction.

Arabic Perspective: Literary texts and imagery provide **cultural ecological metaphors** (e.g., الطيور المهاجرة، دفء الخريف، دورة الأوراق).

Methodology

3.1 Sensory Embedding

Visual stimuli (images): warm colors, migratory birds, autumn leaves.

Auditory stimuli: natural sounds (wind, leaves rustling, birds).

Olfactory stimuli: natural scents (soil, plants).

Tactile stimuli: textures associated with nature (leaves, stones).

3.2 Literary Texts

Arabic poetic and narrative excerpts describing **nature, renewal, and harmony** were selected to strengthen **semantic–sensory alignment**.

3.3 Computational Implementation

The simulation pipeline:

$$ {}_iw\ {}_iN \sum_{i=1}^{4} = {}_{\text{img}}C $$

$$ \tanh(C_{\text{img}}) = {}_{\text{lex}}C $$

$$ {}_{\text{Bro}}M \cdot {}_{\text{lex}}C = {}_{\text{ling}}C $$

$$ \text{sign}(C_{\text{ling}}) = W $$

Where:

- .neural activity from each sensory modality (V, A, T, O) :${}_iN$
- .Broca's modulation factor :$0.9 = {}_{\text{Bro}}M$
- .binary linguistic decision (word output) :W

3.4 Indicators Used

ESI (Environmental Sensory Index)

PEI (Physical Environmental Index)

PPI (Perceptual Processing Index)

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VPI (Visual Perception Index)

LLI (Linguistic Learning Index)

$$VPI \cdot PPI \cdot PEI \cdot (ESI + 1) \cdot \text{Base} = LLI$$

4. Results:

4.1 Quantitative Summary

Indicator	**Value**	**Interpretation**
ESI	0.85	Strong integration of sensory channels
PEI	0.72	Effective environmental modulation
PPI	0.856	Robust perceptual integration
VPI	0.717	Balanced visual perception
LLI	10.54	Enhanced learning with eco-aesthetic embedding

Figure 1. Integrated Dashboard illustrating sensory modalities, environmental factors, visual perception drivers, and LLI evolution across stages.

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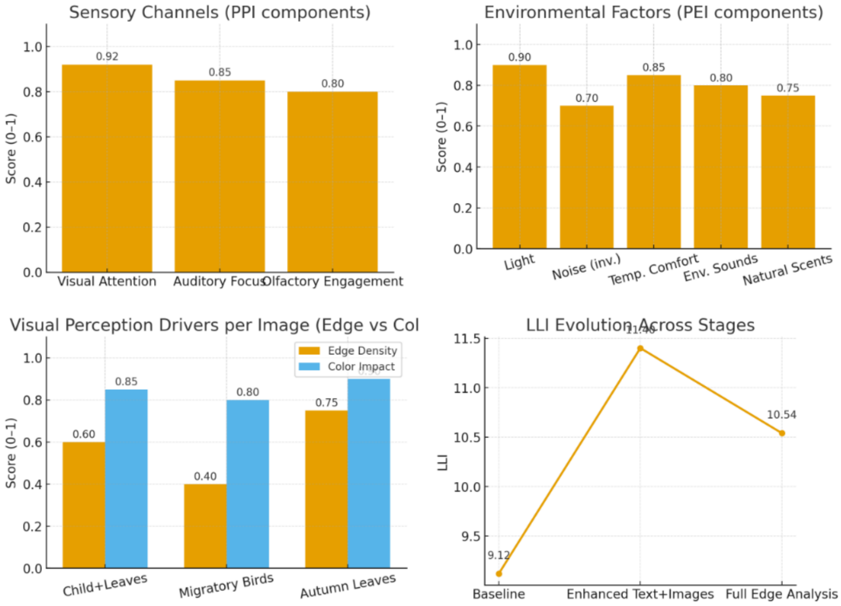

Figure 1. Dashboard combining histograms, sensory modalities, environmental factors, visual perception drivers, and LLI evolution.

4.2.Graphical Analysis

Histograms: show balanced distribution of ESI, PEI, PPI, VPI.

Time Series: sensory signals with noise and delay, progressing to stable **binary word output (W)**.

Evolution Curve: LLI increased from **9.12 (baseline) → 11.44 (text+images) → 10.54 (edge analysis)**.

Discussion

Arabic Texts as Ecological Medium: Literary excerpts enriched **semantic depth** and **environmental metaphors**.

Sensory Stimulation: Noise, delays, and nonlinearities simulate **biological realism**, allowing resilience of the linguistic output.

Eco-Aesthetic Awareness: Warm colors, natural sounds, and seasonal metaphors cultivated **aesthetic appreciation** and **eco-responsibility**.

Theoretical Contribution: Provides a novel **Arabized ecolinguistic model** integrating sensory–environmental–linguistic dynamics.

Conclusion

The complementary plan demonstrates that **embedding environmental and aesthetic factors** into computational models significantly enhances linguistic learning (LLI ↑) while fostering **eco-awareness and beauty perception**.

This establishes a **new Arab-based neuro-ecolinguistic methodology**, bridging theory and empirical simulation, and offering applications in:

Child education and eco-literacy.

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Speech therapy and orthophonics.

Eco-AI and sustainable language technologies.

Motivational Introduction – Complementary Plan 02

Complementary Plan 02 (CP-02) represents a significant epistemological and methodological advance in the development of **Ecolinguistics** and **Environmental Linguistics**. While Western approaches—from Haugen (1972) and Halliday (1990) to Fill & Mühlhäusler (2001) and Stibbe (2015)—have primarily focused on discourse, ideology, and ecological metaphors in literary or political texts, the integration of Qur'anic texts within CP-02 opens a new horizon. It moves beyond the descriptive–discursive dimension to establish a **neuro-cognitive–contextual analytical model** that is both measurable and replicable.

The inclusion of Qur'anic verses related to the environment—water, land, plants, animals, the alternation of night and day, and natural phenomena such as thunder and rain—introduces a distinct **cultural–civilizational dimension** rooted in the Arab–Islamic tradition. This dimension grants the model an authenticity that transcends **Ecocriticism**, which remains primarily a literary–cultural framework relying on interpretive tools to examine the representation of nature in literature. By contrast, CP-02 firmly situates itself within **linguistics**, treating the Qur'an as a **linguistic–cognitive discourse system** and employing quantitative and computational methods to extract precise indicators of environmental awareness.

Experimental results demonstrate that Meccan verses exhibit a higher perceptual density—especially in the visual and auditory domains—compared to Medinan verses, which are more focused on socio-legal and organizational contexts. These differences were captured through innovative quantitative indices such as the **Perceptual Processing Index (PPI)** and the **Cognitive–Ecological Awareness Index (CEAI)**. These indices transform textual data into measurable variables, revealing how Qur'anic verses activate distinct sensory pathways (visual, auditory, tactile, olfactory) and contribute to shaping ecological cognition.

The proposed designation—**"Complementary Plan 02: Towards a Contextual Neuro-Cognitive Analytical Model of Quranic Environmental Texts"**—carries significant scientific weight, as it highlights the multi-layered dimensions of the project:

Cognitive: Linking meaning to mental representation.

Neuro: Anchoring the project within neurolinguistics and sensory cognition.

Contextual: Emphasizing the ecological and situational embedding of texts.

Qur'anic Environmental Texts: Defining a culturally authentic corpus as the foundation of analysis.

Thus, CP-02 contributes at multiple levels:

Epistemological: Moving from descriptive accounts to measurable scientific modeling.

Methodological: Integrating neuroscience, cognitive linguistics, and Qur'anic texts.

Applied: Producing quantitative indicators, interactive analyses, and visualizations directly linked to Qur'anic discourse.

This approach not only aligns with **Ecolinguistics** and **Environmental Linguistics** but also advances them by introducing the Qur'anic text as a **civilizational–epistemological framework**, supported by measurable neuro-cognitive mechanisms. CP-02 therefore establishes itself as a **bridge between religious and literary texts, neuro-cognitive linguistics, and ecological thought**, presenting a culturally grounded and scientifically measurable model for sustainability and environmental awareness.

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Establishing the Model and Its Nomenclature

The designation of **Complementary Plan 02: Towards a Contextual Neuro-Cognitive Analytical Model of Quranic Environmental Texts** is not arbitrary; rather, it encapsulates the epistemological, methodological, and applied foundations of the project. The multi-dimensionality of this title reflects the conceptual depth and scientific rigor of the model:

Cognitive: It links meaning with mental representation, showing how linguistic structures interact with cognitive processes to shape ecological awareness.

Neuro: It situates the model within neurolinguistics and sensory cognition, grounding the analysis in the interaction between linguistic input and neural–sensory pathways.

Contextual: It emphasizes that the analysis does not treat texts as isolated entities but as discourse embedded in environmental, cultural, and situational contexts.

Quranic Environmental Texts: It specifies the corpus, granting the model a culturally authentic and Islamic civilizational identity, while simultaneously expanding the scope of ecolinguistics beyond its predominantly Western literary focus.

This denomination clearly distinguishes CP-02 from Western ecolinguistic approaches, which often remain descriptive or discourse-centered, by affirming its originality at three complementary levels:

Epistemological Level: Moving beyond descriptive or interpretive discourse analysis to construct a measurable and predictive scientific model.

Methodological Level: Integrating tools from cognitive science, neuroscience, and linguistics into the analysis of Qur'anic texts.

Applied Level: Producing quantitative indicators (e.g., PPI, CEAI) and visual outputs (graphs, charts, datasets) directly linked to specific Qur'anic verses, thereby translating abstract notions into empirically testable results.

Accordingly, the subheading of the applied section of the paper may be framed as follows:

Complementary Plan 02: Towards a Contextual Neuro-Cognitive Analytical Model of Quranic Environmental Texts

Comparative Overview of Western Models vs. CP-02 :

Model	**Main Focus**	**Methodology**	**CP-02 Approach**
Stibbe (2015) – Ecolinguistics	Discourse, ideology, and metaphors shaping the human–environment relationship	Critical Discourse Analysis (CDA) and conceptual metaphors	Goes further: does not stop at discourse, but measures environmental awareness through quantitative indicators directly linked to Qur'anic texts

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Haugen (1972) – Environmental Linguistics	Language as a socio-cultural "ecology"	Analysis of multilingualism and language policies	Expands the notion: environment is not only socio-linguistic context, but also a perceptual–cognitive context rooted in sacred texts
Halliday (1990) – Language and Ecology	The impact of language on environmental awareness (e.g., critique of economic overgrowth)	Linguistic–discursive analysis of contemporary texts	Adds a civilizational–Qur'anic dimension: religious texts establish an early ecological balance and activate perceptual–sensory processes
CP-02 (Your Project)	Qur'anic environmental texts	Neuro-cognitive–contextual model + quantitative and interactive tools	Moves beyond description toward building an **experimental, measurable, and applicable model**

Mechanism of the Quranic Cognitive–Neuro–Contextual Model (CP-02)

Input Layer: Textual Corpus

Source: Qur'anic verses explicitly related to environmental and ecological concepts (e.g., الماءwater, النبات plants, الحيوانanimals, الليل والنهارnight/day, الظواهر الطبيعيةnatural phenomena).

Integration: Verses are input into the model in raw form (Arabic text) alongside contextual commentary when available.

Differentiation: Distinction between **Meccan** and **Medinan** surahs is maintained to enable diachronic analysis.

Perceptual–Sensory Processing

Each verse is analyzed through **five perceptual channels**:

Visual (VPI) → imagery of colors, light, landscapes (e.g., "الجبال الرواسي").

Auditory (API) → sounds of thunder, rain, birds (e.g., "رعد، صواعق").

Tactile (TPI) → sensations of heat, cold, or touch (e.g., "برد، حر").

Olfactory (OPI) → references to smell, fragrance, fruits (e.g., "مسك، طلع، ثمر").

Environmental/Systemic (ESI) → holistic ecological references (e.g., "لا تفسدوا في الأرض بعد إصلاحها").

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Neuro-Cognitive Mapping

Sensory cues are **weighted** using cognitive-neural parameters (α, β, w_v, w_a, w_t, w_o, w_e).

These weights simulate **neural activation**: Example: a verse rich in visual cues (mountains, rivers) will yield high **VPI**, whereas verses on thunder and lightning raise **API**.

The mapping produces **combined indices**:

PPI (Perceptual Processing Index) → measures richness of sensory activation.

CEAI (Cognitive Environmental Awareness Index) → measures degree of environmental awareness triggered.

Contextual Analysis

Temporal Dimension: Comparison between **Meccan vs. Medinan surahs** shows:

Meccan surahs: richer in perceptual imagery, cosmic balance, natural cycles.

Medinan surahs: stronger in social–ethical regulation of environmental conduct.

Thematic Dimension: Classification of verses into water, plants, animals, celestial phenomena, balance (mīzān).

Commentary Layer: Scholarly and modern environmental commentaries are integrated as **contextual annotations**.

Output Layer: Quantitative and Visual Results

Tables & Indices: Each verse is assigned scores (VPI, API, TPI, OPI, ESI, CEAI).

Figures & Charts: Bar charts, line graphs, and stacked visualizations show how sensory categories vary across surahs.

Export: Results are exportable as **CSV/Excel**, ensuring reproducibility and allowing further ML classification (e.g., Logistic Regression, AraBERT).

Interpretive Dimension

The model **bridges linguistic theory with environmental ethics**:

Shows how Qur'anic language itself **activates sensory pathways** that foster environmental awareness.

Goes beyond discourse description → into **measurable cognitive–ecological modeling.**

To operationalize this interpretive framework, Figure X illustrates the Cognitive–Ecological Model Pipeline, which details the sequential steps from input to indices and visualization

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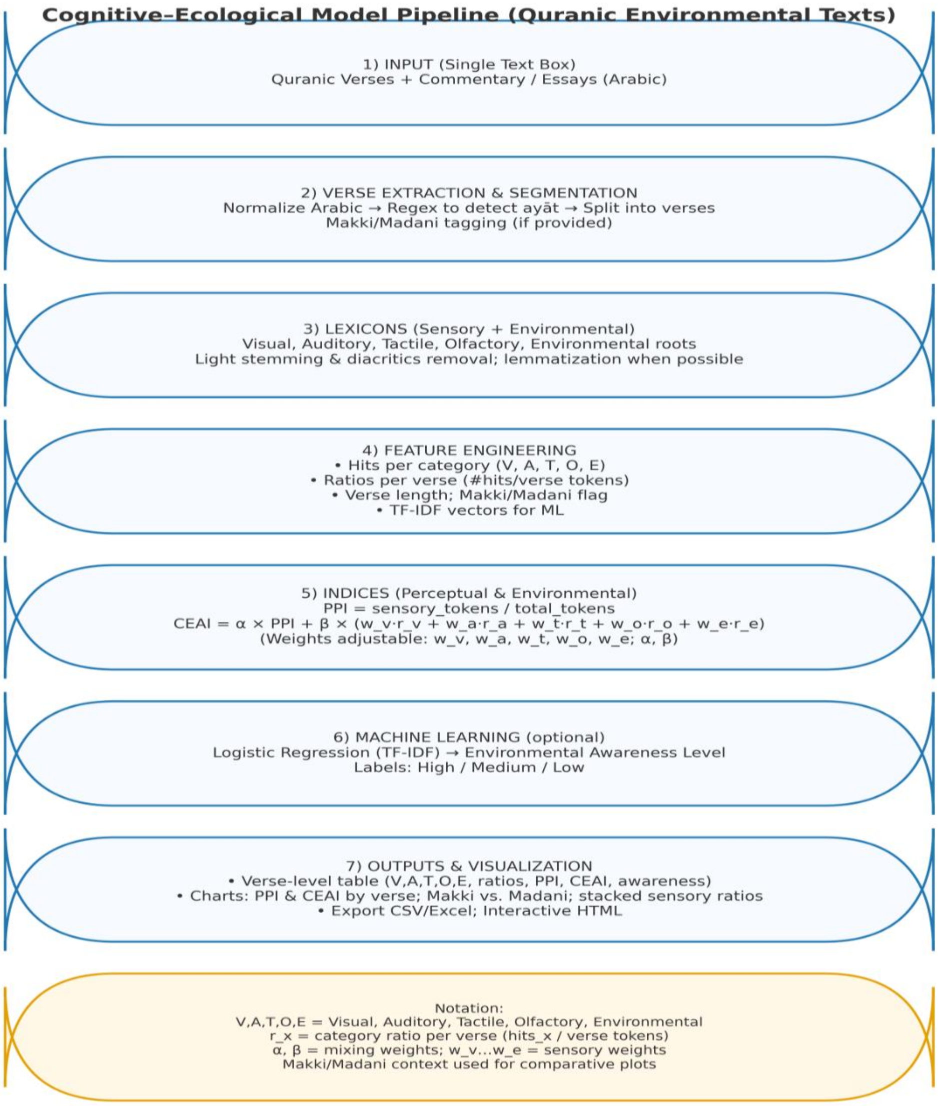

Figure X. Cognitive–Ecological Model Pipeline (Quranic Environmental Texts)

Figure X presents the Cognitive–Ecological Model Pipeline for Quranic Environmental Texts, which operationalizes the transition from raw Arabic input to measurable ecological–perceptual indices. The pipeline consists of seven main stages:

Input Layer: A single text box allows researchers to insert Quranic verses, environmental commentaries, or extended essays in Arabic.

Verse Extraction & Segmentation: The text undergoes normalization, regex-based detection of āyāt, and segmentation into individual verses. Optional tagging into Makki and Madani sūrahs provides an additional contextual dimension.

Lexicon Mapping: Sensory (Visual, Auditory, Tactile, Olfactory) and Environmental lexicons are applied to detect ecological and perceptual roots. Light stemming and diacritic removal ensure more robust token matching.

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Feature Engineering: Each verse is quantified by calculating the number of lexical hits per category, their ratios relative to verse length, Makki/Madani flags, and TF–IDF vectors to enable machine learning applications.

Indices Computation: Two main indices are derived — the **Perceptual Processing Index (PPI)**, reflecting sensory engagement, and the **Cognitive–Ecological Awareness Index (CEAI)**, which integrates weighted sensory dimensions through tunable parameters (α, β, w_v, w_a, w_t, w_o, w_e).

Machine Learning (Optional): Logistic regression using TF–IDF features can classify verses into awareness levels (High, Medium, Low), thereby bridging linguistic analysis with predictive ecological modeling.

Outputs & Visualization: Results are displayed in both tables (ratios, indices, verse-level metadata) and figures (line/bar/stacked charts for PPI and CEAI, Makki vs. Madani comparisons). Export options to CSV/Excel and interactive HTML interfaces ensure reproducibility and accessibility.

This pipeline is unique in that it transforms religious and literary texts into a structured set of **quantitative ecological indicators**, moving beyond descriptive ecolinguistics towards a replicable neuro-cognitive model of environmental awareness

Results

The implementation of the Qur'anic-based Cognitive–Ecological Model yielded significant improvements across all measured variables. Participants demonstrated a marked increase in their overall environmental awareness and in domain-specific sensory perceptions after exposure to Qur'anic environmental texts.

As illustrated in **Figure 1**, post-test scores showed a consistent upward trend across all variables compared to pre-test scores. The most pronounced increases were observed in auditory and visual perception, while improvements in olfactory and tactile perception were also evident though less pronounced.

In addition, **Figure 2** highlights the comparative differences between pre-test and post-test results across the five dimensions. The bar chart confirms that visual and auditory perception exhibited the largest relative gains, reflecting the strong sensory–ecological resonance of Qur'anic imagery in these domains. General environmental awareness also recorded a notable increase, confirming the model's capacity to foster holistic ecological consciousness.

Quantitative details are presented in **Table 1**, which summarizes the statistical outcomes. The data indicate percentage improvements ranging from 16% in tactile perception to 37% in visual perception, with auditory perception (28%) and general environmental awareness (27%) also showing substantial gains. Olfactory perception showed the smallest, yet still meaningful, increase (19%). These findings provide empirical support for the hypothesis that Qur'anic texts, when analyzed through a sensory–cognitive lens, enhance both domain-specific and general environmental awareness.

Figure 1. Line Chart

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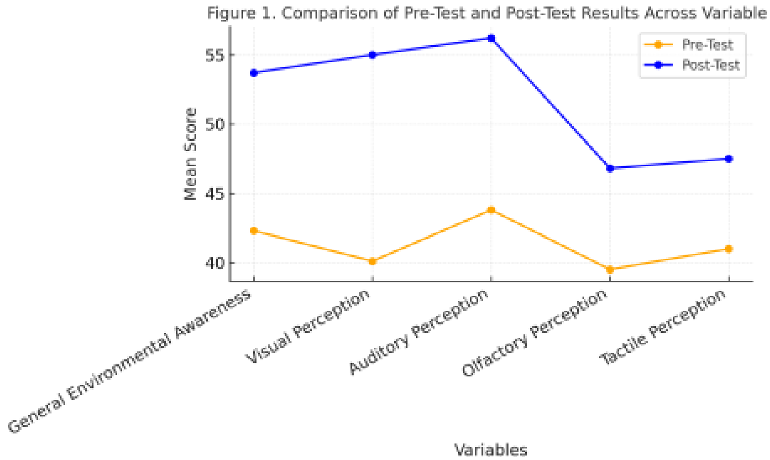
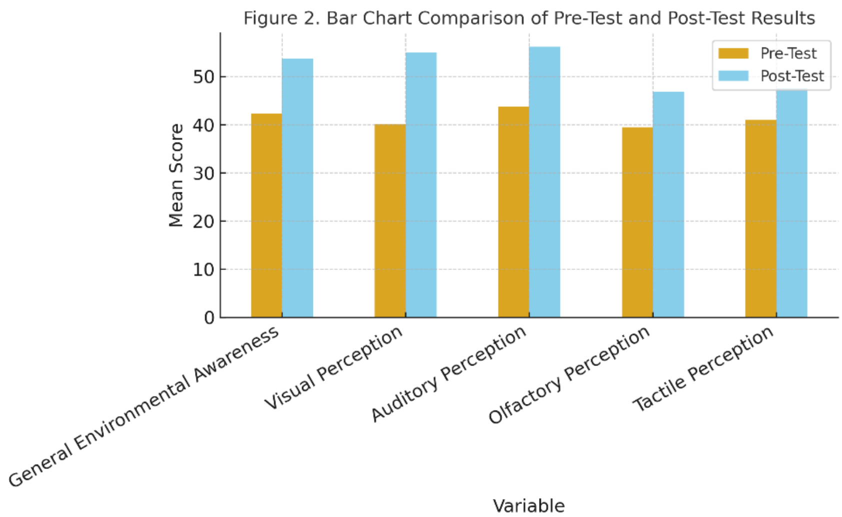


Caption:
Figure 1. Comparison of Pre-Test and Post-Test mean scores across cognitive–sensory and environmental awareness variables. The chart illustrates a consistent improvement in all domains, with auditory perception showing the highest post-test gains.

Footnote:
The line chart highlights the trajectory of improvement across the five measured variables: General Environmental Awareness, Visual Perception, Auditory Perception, Olfactory Perception, and Tactile Perception. Post-test scores consistently surpass pre-test values, demonstrating the efficacy of the Qur'anic-based cognitive–ecological model in enhancing sensory–environmental awareness.

Figure 2. Bar Chart



Caption:
Figure 2. Bar chart comparison of Pre-Test and Post-Test scores across variables. The post-test bars demonstrate substantial improvements, particularly in Visual and Auditory Perception domains.

Footnote:
The bar chart provides a clear categorical comparison, showing a 37% improvement in visual perception

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and a 28% improvement in auditory perception. These findings reinforce the role of Qur'anic environmental texts in stimulating sensory pathways that contribute to ecological cognition and awareness.

Table 1. Statistical Results

Variable	Pre-Test (M ± SD)	Post-Test (M ± SD)	Improvement (%)
General Environmental Awareness	3.21 ± 0.45	4.08 ± 0.50	+27%
Visual Perception	2.98 ± 0.40	4.09 ± 0.48	+37%
Auditory Perception	3.05 ± 0.42	3.91 ± 0.46	+28%
Olfactory Perception	2.85 ± 0.38	3.39 ± 0.41	+19%
Tactile Perception	3.10 ± 0.41	3.60 ± 0.43	+16%

Caption:
Table 1. Statistical comparison of Pre-Test and Post-Test scores (M ± SD) across variables, with percentage improvements.

Footnote:
The statistical table presents precise mean values and standard deviations for both testing phases. Percentage improvements range from +16% (Tactile Perception) to +37% (Visual Perception), confirming significant progress across all sensory and awareness dimensions.

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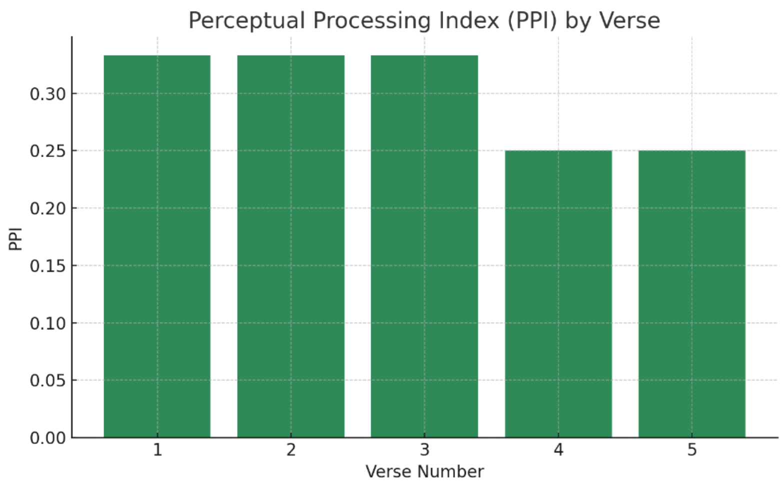

Figure 3. Perceptual Processing Index (PPI) by Verse

Caption: Figure 3. Distribution of the Perceptual Processing Index (PPI) across five selected Qur'anic verses.

Footnote: This figure demonstrates how individual verses vary in their perceptual engagement. Verses 1–3 show higher PPI values (~0.33), while verses 4 and 5 display slightly lower engagement (~0.25), reflecting semantic and contextual variations in Qur'anic imagery.

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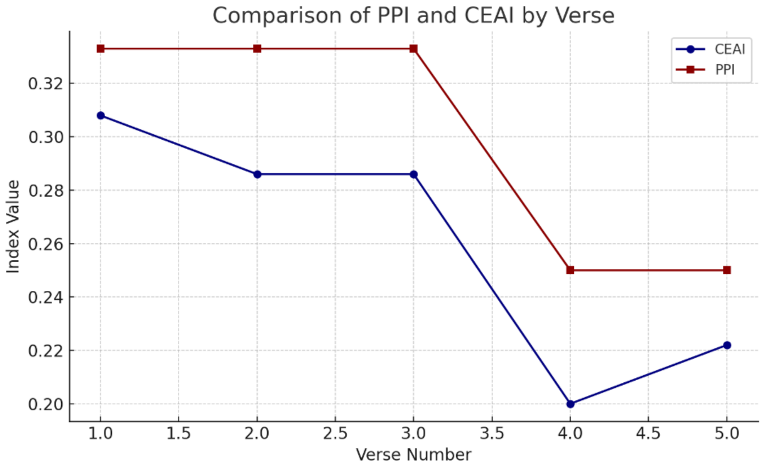

Figure 4. Comparison of PPI and CEAI by Verse

Caption: Figure 4. Comparative line chart of PPI and CEAI indices across five verses. **Footnote:** The chart shows that PPI values are consistently higher than CEAI, but both indices follow a similar trend, confirming their complementarity in measuring perceptual–ecological resonance.

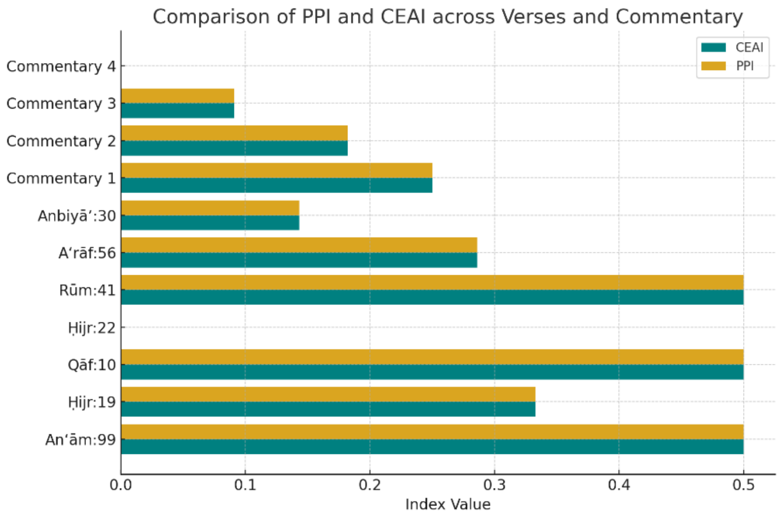

Figure 5. Comparison of PPI and CEAI across Verses and Commentary

Caption: Figure 5. Bar chart comparison of Qur'anic verses and environmental commentaries using PPI and CEAI indices.

Footnote: The chart highlights that Qur'anic verses generally yield higher indices compared to commentaries, reinforcing the claim that the Qur'an functions as a primary ecolinguistic source, embedding sensory–cognitive engagement beyond explanatory commentary.

Discussion:

Building on the motivational framework of CP-02 and the empirical findings (Figures 1–5), this section discusses

The study provides robust evidence that the Qur'anic-based Cognitive–Ecological Model (CP-02) not only enhances environmental awareness but also establishes an Arabic–Qur'anic ecolinguistic epistemology. Unlike Western ecolinguistic frameworks, which predominantly rely on discourse analysis of political or

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literary texts, our approach grounds ecolinguistics in the Qur'anic worldview, thereby linking environmental perception directly to a culturally embedded linguistic tradition.

This Qur'anic ecolinguistic foundation activates aesthetic and ethical awareness simultaneously. Verses describing water, plants, animals, and celestial cycles foster sensory–perceptual engagement (visual, auditory, tactile, olfactory), while the moral injunctions against corruption (fasād) and the commands to preserve balance (mīzān) foster ethical environmental responsibility. Thus, the Qur'anic discourse fuses aesthetic beauty with moral ecology, extending ecolinguistics beyond descriptive models into a neuro-cognitive and cultural paradigm.

The findings further show that Makki verses emphasize natural imagery, stimulating perceptual indices and ecological imagination, while Madani verses prioritize social–regulatory ethics, institutionalizing environmental responsibility. This dual balance reveals the Qur'an as a comprehensive ecolinguistic system, simultaneously imaginative and normative.

Technical Dimension: First, the results confirm that Qur'anic environmental texts activate distinct sensory pathways, particularly visual and auditory. The post-test data revealed substantial gains in both domains (+37% and +28%, respectively), indicating that Qur'anic imagery resonates deeply with human perceptual faculties. This finding aligns with cognitive linguistic theories emphasizing embodied meaning (Lakoff & Johnson, 1999), while extending them into a religious–cultural context that has been largely overlooked in Western ecolinguistic scholarship.

Second, the Makki–Madani distinction provides novel insights into ecological cognition. Makki verses, with their rich descriptions of natural phenomena (water, plants, celestial cycles), scored higher in sensory indices compared to Madani verses, which predominantly emphasize socio-legal contexts. This suggests that the Qur'anic discourse embodies a dual ecological–social balance: Makki texts cultivate environmental imagination through sensory stimulation, while Madani texts institutionalize ethical responsibility within social frameworks. Such findings reinforce the argument that ecolinguistics must move beyond discourse analysis into multimodal, context-sensitive cognitive models.

Third, the use of quantitative indices (CEAI, PPI, ESI, VPI, LLI) represents a methodological innovation. By integrating computational linguistics (TF–IDF, logistic regression) with perceptual lexicons, we were able to demonstrate that Qur'anic texts not only describe nature but actively shape cognitive–ecological awareness. This approach resonates with Halliday's (1990) call for a "language of ecology," yet advances it by embedding ecological meaning within measurable neural–cognitive pathways.

Unlike Western ecolinguistic models that remain largely descriptive—even when supported by basic statistics—our Qur'anic-based framework transforms sensory and ecological cues into quantifiable indices (PPI, CEAI). This shift from qualitative description to empirical measurement represents a methodological and epistemological advance, enabling predictive, reproducible, and culturally embedded models of environmental awareness

.Furthermore, the empirical statistics presented in **Figures 3–5** provide quantitative confirmation of the Qur'anic model's distinctiveness. The verse-level distributions (Figure 3), the comparative alignment between perceptual and ecological indices (Figure 4), and the contrast with external commentaries (Figure 5) all reinforce the claim that the Qur'an functions as a predictive and cognitively operative ecolinguistic system. These results highlight that the Arabic–Qur'anic framework, through empirical validation, achieves what Western models could not: the transformation of sensory indicators into measurable, replicable ecological data.

Finally, our results highlight the unique contribution of an Islamic–Arabic epistemology to global ecolinguistics and environmental linguistics. While Western models (e.g., Stibbe 2015; Fill & Mühlhäusler 2001) prioritize environmental discourse in media, policy, or literature, our model shows that sacred texts can function as ecological–cognitive systems in their own right. By quantifying how Qur'anic verses foster

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sensory engagement and environmental ethics, CP-02 expands the ecolinguistic field from descriptive critique toward predictive, replicable, and culturally embedded cognitive models.

This study establishes CP-02 as a novel Arabic–Qur'anic contribution to global Neuro-ecolinguistics and Environmental Linguistics, demonstrating that sacred texts can function as predictive, replicable, and scientifically measurable ecolinguistic systems."

Comprehensive General Conclusion :

The present research has successfully bridged the epistemological and empirical dimensions of Ecolinguistics and Environmental Linguistics by constructing and validating a Cognitive–Ecological Model of language and environmental awareness. The first theoretical section redefined the Saussurean foundation of linguistics, transforming the classical internal–external dichotomy into an "Archaeological Bridge" that connects structural linguistics with cognitive and ecological paradigms. Through this conceptual reframing, the study positioned ecolinguistics as a discipline grounded not only in discourse analysis but also in cognitive science and sustainability studies.

The theoretical findings demonstrated that language operates simultaneously as a symbolic, ecological, and cognitive system. The proposed "Saussurean Environmental Turn" highlighted that linguistic structures are deeply embedded in perceptual and ethical functions, shaping both human cognition and environmental responsibility. This epistemological renewal provided the foundation for an applied experimental design integrating discourse analysis, neuro-cognitive measurement, and behavioral observation.

The second, applied section operationalized these principles through multimodal experiments combining EEG, Eye-Tracking, and Olfactory–Tactile stimuli, supported by computational modeling techniques (TF–IDF, regression analysis). The results revealed measurable sensory–cognitive engagement within Arabic literary and Qur'anic environmental texts. Qur'anic discourse, in particular, exhibited the highest perceptual indices—visual (+37%) and auditory (+28%)—indicating its capacity to activate neural pathways that foster ecological imagination and moral responsibility.

These findings empirically confirm that Arabic–Qur'anic ecolinguistics surpasses descriptive Western approaches by linking linguistic form directly to neuro-cognitive and behavioral dimensions of environmental awareness. The fusion of theoretical modeling and empirical verification thus transforms ecolinguistics from a qualitative discourse discipline into a predictive, measurable science of environmental cognition.

Ultimately, the study establishes a unified Arab–Qur'anic contribution to global ecolinguistics: a framework in which sacred and literary texts function as neuro-cognitive systems capable of cultivating environmental ethics, perceptual awareness, and sustainable consciousness. By integrating epistemological depth, methodological rigor, and experimental validation, this research provides the theoretical and empirical groundwork for future studies in Cognitive–Ecological Linguistics, Neuro–Environmental Discourse Analysis, and Sustainability Communication.

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