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Not peer-reviewed version

Comment on the Paper Titled ’The Origin of Quantum Mechanical Statistics: Insights from Research on Human Language’ (arXiv preprint arXiv:2407.14924, 2024)

Krzysztof Sienicki *

Posted Date: 2 December 2024

doi: 10.20944/preprints202411.2377.v1

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Article

Comment on the Paper Titled 'The Origin of Quantum Mechanical Statistics: Insights from Research on Human Language' (arXiv preprint arXiv:2407.14924, 2024)

Krzysztof Sienicki

Chair of Theoretical Physics of Naturally Intelligent Systems, Lipowa 2/Topolowa 19, 05-807 Podkowa Leśna, Poland, EU; niskrissienicki@gmail.com

Abstract: This analysis critically examines the application of quantum mechanical concepts—such as entanglement, indistinguishability, and Bose Einstein statistics — to language and cognitive processes as proposed in the paper. While the interdisciplinary approach is creative, significant theoretical and empirical challenges arise when translating quantum principles to human cognition. Key issues include the contextual and qualitative nature of cognitive processes, which differ fundamentally from the predictable, probabilistic behaviors observed in quantum systems. Cognitive phenomena are shaped by factors like emotional state, social context, and personal memory, which have no direct analogy in quantum mechanics. The assumption that words or cognitive "particles" are indistinguishable, as quantum particles are, overlooks the unique and dynamic contextual dependencies in language. Moreover, empirical support for such quantum-cognitive parallels remains limited, and the paper's application of quantum statistics to word frequency distributions may reflect a coincidental pattern rather than a fundamental process. This assessment suggests that while the paper's quantum analogies could foster new interdisciplinary discussions, they risk speculative overreach if treated as foundational principles for understanding cognition. Effective interdisciplinary integration would require rigorous empirical validation within cognitive science, as well as caution against reductionist interpretations that might simplify the rich complexities of human thought. Future research may benefit from more context-sensitive and evidence-based models that align more closely with established cognitive theories, thereby maintaining the intellectual richness of both quantum mechanics and cognitive science without forcing an untested theoretical bridge between them.

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1. Introduction

The exploration of parallels between quantum mechanics and cognitive science presents an intriguing interdisciplinary venture that challenges traditional boundaries between the physical and cognitive sciences. Quantum mechanics, a field known for its complex probabilistic models and concepts such as entanglement, indistinguishability, and Bose–Einstein statistics, provides a well-validated framework for understanding subatomic particles. Conversely, cognitive science encompasses the study of human thought, language, and perception—domains characterized by contextual, emotional, and social influences that resist straightforward quantification.

The paper under review[1] attempts to bridge these two disciplines, suggesting that quantum principles could model linguistic and cognitive processes. Concepts like quantum entanglement are analogized with contextual dependencies in language, while Bose–Einstein statistics are applied to explain word frequency distributions. The idea of "cognitons" is introduced as a quantum-inspired unit of meaning, and the paper posits that certain cognitive processes may inherently follow quantum probabilistic behaviors.

 doi:10.20944/preprints202411.2377.v1

However, several fundamental issues arise when translating quantum principles to human cognition. First, cognitive phenomena are fundamentally qualitative and context-dependent, shaped by factors such as emotional states, personal memories, and social interactions, which lack direct analogies in quantum mechanics. Second, language and thought are deeply embedded in personal and cultural contexts that provide unique, flexible meanings—unlike the indistinguishable nature of quantum particles, which lack such contextual variability.

Moreover, the application of Bose–Einstein statistics to language and cognition assumes a level of homogeneity and clustering that may not align with the inherent diversity of cognitive "particles." Additionally, while statistical patterns in language, such as those described by Zipf's law, may resemble certain quantum distributions, this resemblance is arguably coincidental rather than indicative of underlying quantum principles.

The aim of this analysis is to critically assess the theoretical and empirical basis for these proposed quantum-cognitive analogies, identifying areas where these parallels may overreach. While the interdisciplinary perspective is intellectually stimulating, the risk of speculative or reductionist interpretations is significant. By examining each major concept proposed in the paper—indistinguishability, contextual updating, and statistical dependence—this review seeks to clarify the limits of applying quantum mechanics to cognitive science and suggests that rigorous empirical validation is essential for such interdisciplinary models. Ultimately, this analysis advocates for caution in applying quantum models to human cognition, encouraging future research to pursue more context-sensitive and evidence-based approaches.

2. Overextension of Quantum Principles to Cognitive Processes

2.1. Quantum Entanglement and Semantic Dependencies: Fundamental Differences in Nature and Operation

In quantum mechanics, *entanglement* is a rigorously defined phenomenon where two particles share a single quantum state, meaning the measurement of one particle's state instantaneously determines the state of the other, regardless of distance. This behavior is deterministic in the sense that entangled states exhibit predictable, linked outcomes upon measurement. [2] Entanglement has a mathematical structure that allows for precise predictions, which are central to quantum theory's empirical successes.[3]

In contrast, *semantic interdependence* in language is inherently interpretative and context-driven. Words in a sentence do influence each other's meanings, but this influence is not deterministic and varies based on external factors such as audience interpretation and cultural context.[4] Unlike entangled particles, which exhibit a predictable form of interdependence, the influence of words on each other can shift dynamically. For example, the phrase "spring break" holds various meanings depending on its educational, cultural, or seasonal context. This variability illustrates that language does not exhibit the kind of precise, invariant interdependence seen in quantum systems.

2.2. Objectivity and Measurability in Quantum Mechanics vs. Interpretative Fluidity in Language

Quantum mechanics is distinguished by its focus on *measurable*, *objective quantities* such as position, momentum, and spin. These properties allow quantum states to be quantified, observed, and predicted with remarkable accuracy, providing a cornerstone of quantum theory's empirical rigor.[5] The outcomes of quantum experiments are reproducible, offering a level of objectivity that grounds the discipline.

In contrast, *linguistic meaning is not a directly measurable quantity*. Assigning "energy levels" or probabilistic states to words, as suggested in the paper, may oversimplify the interpretative and subjective qualities of language. Meaning is contextually bound and often varies across individuals and cultures, shaped by personal experiences and societal factors. For example, "light" can imply illumination, minimal weight, or even a spiritual symbol, depending on context. Such interpretative fluidity contrasts with the rigid state-based approach in quantum mechanics.[6]

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2.3. *Subjective Experience and Cultural Variation in Language vs. Quantum Universality*

Quantum mechanics operates under principles that are *universally applicable* across time and space. In theory, an entangled state between two particles behaves identically regardless of external context, adhering to a universality that allows quantum mechanics to produce reliable predictions under varied conditions.[7]

Language, however, is inherently shaped by *cultural and personal factors*. Words and phrases carry distinct meanings within different cultural or social frameworks, meaning language operates under a level of contextual dependence absent in quantum mechanics. For instance, the word "freedom" elicits diverse interpretations across cultures, reflecting different political, social, and personal values. This cultural variability suggests that language operates according to influences that are fundamentally different from the uniform, context-independent behaviors observed in quantum systems.[8]

2.4. *Risks of Reductionism in Cognitive Science and Linguistics*

Applying quantum principles directly to cognitive and linguistic domains risks *reductionist interpretations* that might overlook the complexity of human cognition and language. Quantum mechanics is a physical science that describes microphysical phenomena with high accuracy, but cognitive science encompasses a broader range of variables—emotional, social, and environmental—that cannot be entirely captured through probabilistic interactions alone.[9]

Studies in cognitive science reveal that factors such as emotional valence and individual memory heavily influence how meaning is processed and retained. Such elements introduce a richness in human cognition that quantum mechanics, as a physical framework, does not account for. Applying quantum concepts to cognitive and linguistic domains may lead to *oversimplified models* that do not reflect the true complexity of human thought.[10]

The paper's analogy between quantum mechanics and linguistic meaning, while creative, may be overextended without stronger empirical or theoretical support. Language and meaning involve processes—such as cultural adaptability, subjective interpretation, and contextual variation—that are not compatible with the strict, measurable principles of quantum mechanics. The fields of cognitive science and linguistics involve layers of complexity beyond probabilistic modeling and deterministic interdependence, which quantum mechanics cannot easily replicate. Future research might benefit from examining cognitive phenomena through frameworks more appropriate for the unique characteristics of language and thought, reserving quantum analogies for instances where meaningful, measurable parallels can be drawn.

3. The Concept of "Cognitons" and Energy Levels in Language

3.1. *The Physical Definition of Energy Levels vs. Linguistic Frequency*

In quantum mechanics, *energy levels* are concrete, quantifiable states that a particle can occupy, determined by its interactions and governed by rigorous physical laws. These levels are empirically validated and have precise implications for a particle's behavior and properties. For example, in atomic physics, electrons occupy specific energy levels around a nucleus, and transitions between these levels are well-understood and measurable events with physical consequences.[3]

In the paper, however, *words are assigned "energy levels" based solely on their frequency of occurrence* in a text. This frequency-based approach lacks the empirical foundation that defines energy levels in physics. The meaning of words in language does not operate on fixed, quantifiable scales like those of energy levels in quantum mechanics. Words serve dynamic, context-driven roles that do not have absolute "states" or measurable energies, making the notion of assigning them a quantitative energy value problematic. Unlike particles in physical systems, the role of words and their frequency can vary drastically based on the content, style, and purpose of the text.

 doi:10.20944/preprints202411.2377.v1

3.2. Over-Simplification of Linguistic Nuance

Language is a rich, multi-dimensional system where word frequency does not equate to semantic importance. Words with low frequency can carry profound or essential meaning in certain contexts. For instance, in literary works, rare words often serve as metaphors, symbols, or thematic anchors. Their significance may be disproportionately high relative to their frequency, as seen in works of poetry or classical literature, where unique vocabulary choices can create emotional resonance or convey complex ideas.

By reducing words to mere frequency counts, the "cogniton" model risks overlooking the nuanced roles that individual words play within a text. Language involves *subtleties of tone, connotation, and syntax* that do not map neatly onto a simplistic frequency-based "energy level" model. As cognitive scientists argue, meaning is not simply a function of occurrence but is also determined by context, syntactic structure, and pragmatic elements like the speaker's intent and the audience's interpretation.[6] The concept of cognitons does not account for these factors, leading to a potentially reductive view of linguistic meaning.

3.3. Misalignment with Bose–Einstein Statistics

The paper attempts to apply Bose–Einstein statistics to linguistic patterns, arguing that frequent words occupy lower "energy levels" similar to how bosons cluster in a minimal energy state. In quantum systems, however, this clustering effect is a result of specific physical constraints and interactions, where particles like photons or atoms occupy the same energy state under low-temperature conditions, leading to phenomena such as Bose–Einstein condensation.

In language, frequency distributions of words typically follow Zipf's law, where a small number of words are highly frequent while many words are rare. This distribution reflects pragmatic and communicative efficiency, not a "condensate" of words at a low-energy state. The Bose–Einstein analogy may be misleading because it suggests that word frequency distribution results from physical clustering, rather than cognitive and communicative factors. Zipf's law is driven by natural language use and reflects tendencies toward brevity and redundancy, but it does not imply a physical constraint that forces high-frequency words into "low-energy" positions.[7]

3.4. The Concept of "Cognitons" as a Forced Analogy

The introduction of "cognitons" as discrete units of meaning mimics the concept of quanta in physics, where particles like photons or electrons exist in quantifiable, discrete amounts. However, meaning in language is not easily quantifiable in this way. *Cognitive processing of language* is complex and does not operate on discrete units but rather through associative networks where meaning can be flexible and distributed across connections within a neural or semantic network.[10] The notion of a "cogniton" might appeal as a metaphor but lacks empirical basis for capturing the fluid, interpretative aspects of human language.

In cognitive science, language processing involves *distributed representation*, where words and meanings are not isolated units but interact across layers of context, syntax, and semantic association. A model that reduces this complexity to discrete "cognitons" risks losing the interpretative richness that defines human language. Moreover, the idea of cognitons suggests a rigidity to meaning that does not align with how language is experienced or understood.

3.5. Potential Risks of Oversimplification

By focusing on frequency and analogy to energy levels, the "cogniton" model *risks ignoring the depth and variability* of linguistic meaning. Words with similar frequency can convey vastly different emotional or symbolic meanings depending on context. Furthermore, this approach neglects other linguistic dimensions such as *syntax*, *grammar*, and *metaphor*—all of which play crucial roles in shaping meaning but cannot be captured within an energy-based model.

 doi:10.20944/preprints202411.2377.v1

Linguistic meaning is sensitive to its context, affected by factors like the narrative structure, the genre of the text, and the purpose of communication. The “energy level” analogy may simplify certain patterns in word usage, but it fails to address the richness of *symbolic and affective meaning* inherent to language. This simplification could lead to inaccurate conclusions if used to model more complex aspects of cognition or language processing, as it risks misrepresenting the nature of human language and thought.

While the concept of "cognitons" and the analogy to Bose–Einstein statistics present an interesting theoretical model, they may oversimplify language’s complexity. Linguistic meaning is driven by context, purpose, and syntax, which do not align with the strict, measurable properties of energy levels in physics. The metaphor of "cognitons" as units of meaning, though appealing, lacks empirical grounding and may not capture the multi-dimensional, interpretative qualities that characterize language. Future research might benefit from exploring language through frameworks that respect these unique characteristics, using cognitive or associative models better suited to the fluid nature of meaning rather than imposing quantum analogies.

4. Assumption of Indistinguishability in Language

4.1. Indistinguishability in Quantum Mechanics vs. Semantic Uniqueness in Language

In quantum mechanics, indistinguishability is a well-defined property that applies to identical particles, such as electrons or photons, of the same type. Quantum entities that occupy the same quantum state are genuinely indistinguishable, meaning that no physical property allows one particle to be differentiated from another. This indistinguishability is essential to quantum statistics and explains why particles like bosons can occupy the same state in phenomena like Bose-Einstein condensation.[5]

In language, however, identical words are distinguishable based on context. A word like "spring" can mean different things—such as a season, a coiled object, or an action (*e.g.*, to jump)—depending on the context in which it is used. The relational context of a word within a sentence, paragraph, or broader discourse provides unique information that distinguishes each instance of the word. This contextual dependence contradicts the quantum mechanical notion of indistinguishability, as each instance of a word may carry distinct semantic nuances shaped by its position, surrounding words, and overall meaning within a sentence or text.[4]

4.2. Contextual Variability and Pragmatic Meaning in Language

Words in human language derive meaning not only from their inherent definitions but also from their *contextual interactions* with other words. This aspect of language is integral to the of *pragmatic and semantic flexibility* human communication. For instance, the meaning of “light” can vary significantly depending on whether it appears in a scientific article discussing light waves, a novel describing the weight of a feather, or a religious text symbolizing enlightenment. Unlike identical particles in quantum systems, where one particle cannot be differentiated from another in the same state, words are defined by their relational context, which makes each occurrence unique.[6]

This *contextual variability* undermines the paper’s assumption that words in a text can be treated as indistinguishable entities. The meaning of a repeated word is often shaped by its syntactic and semantic environment, making it fundamentally distinguishable. For example, the word “bank” in a sentence about finance means something entirely different from “bank” in a context about rivers. Treating these as indistinguishable entities overlooks the crucial role that contextual information plays in language processing.

4.3. Dependence on Sequential and Hierarchical Structure in Language

Another key difference is that language is sequential and hierarchical. Words are organized in specific orders, and their meanings often depend on their sequential position within a sentence or

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paragraph. For example, in the sentence "The spring season brings flowers," the word "spring" is clearly contextualized as a season, whereas in "He fixed the broken spring on the door," "spring" refers to a mechanical component. This sequential dependency is a property of natural language that does not have an analogy in quantum mechanics, where particles do not rely on sequential order or hierarchical structure to convey information.[7]

The *hierarchical structure* of language—such as the nested dependencies in complex sentences—further distinguishes it from quantum systems. Unlike particles, which lack dependencies based on order, language relies on both linear progression and hierarchical organization to convey meaning. Ignoring this structure by treating words as indistinguishable risks oversimplifying language to a level where its unique properties are lost.

4.4. Semantic Identity as Dynamic and Variable

The *identity of a word's meaning is dynamic* and varies across uses, settings, and even between speakers or cultural backgrounds. This dynamic nature of meaning implies that a word's identity is not fixed in the way that a particle's quantum state is. Quantum particles are described by immutable quantum properties like spin, charge, and mass, but the *semantic identity of words is fluid* and shaped by social, cultural, and individual influences. For instance, in contemporary contexts, words like "viral" or "cloud" have meanings distinct from their older or more literal meanings, influenced by technological advancements and cultural trends.

Unlike quantum particles, which are indistinguishable in shared states by definition, words often reflect the evolving nature of human language and thought, making each instance of a word potentially unique. The paper's approach may overlook this essential variability, thus failing to capture the way language adapts over time and across contexts.[10]

4.5. Risks of Over-Simplifying Linguistic Complexity

By adopting an indistinguishability assumption for words, the paper risks *over-simplifying the complexities of linguistic meaning*. Language operates on layers of meaning that encompass connotations, cultural contexts, and individual interpretations, which go beyond simple repetition or frequency. When words appear multiple times in a text, each instance interacts with different parts of the discourse and builds on prior context. This interaction makes each occurrence of a word meaningful in its own right and not simply a repetition of a previous occurrence.

In cognitive science, *semantic processing* involves associative networks that take into account not only word repetition but also patterns of association, frequency, and novel usage. Treating all occurrences of a word as equivalent ignores the depth of *semantic and pragmatic interpretation* that accompanies language processing, risking a reductionist view of human language.

The assumption of indistinguishability in language fails to capture the unique characteristics of linguistic meaning. Words are context-sensitive and relational, with meanings that adapt based on surrounding text, syntax, and broader discourse. Unlike quantum particles, words cannot be accurately modeled as indistinguishable entities, as each occurrence within a language context has the potential for unique meaning shaped by its specific context. This analysis suggests that future linguistic models should account for the context-dependence and flexibility inherent in language, rather than imposing quantum principles where they may not apply.

5. Analysis on Contextual Updating as a Mechanism for Statistical Dependence

5.1. The Mechanism of Contextual Updating in Language vs. Quantum Entanglement

In quantum mechanics, entanglement refers to a phenomenon where the quantum state of one particle is directly correlated with the state of another, even across vast distances. When two particles are entangled, the measurement of one's state instantaneously determines the state of the other, a relationship that is independent of external context and purely governed by quantum laws.[2]

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This entanglement produces statistical dependencies between particles that remain consistent and predictable, rooted in the physical properties of the particles themselves.

In language, however, *contextual updating* is a dynamic, adaptive process that arises from the interaction between individual cognition, prior knowledge, and cultural context. When a reader encounters each new word or phrase, they continuously adjust their interpretation of the text based on previous words, phrases, and the broader discourse. This updating mechanism is not strictly governed by statistical dependence or probabilistic interdependence in the way quantum entanglement operates. Instead, it reflects *associative learning* and neural processing patterns that integrate past experience, memory, and cultural nuances, leading to an adaptive understanding of language.[6]

5.2. Associative Learning and Neural Networks in Language Processing

In cognitive science, language processing is more commonly explained through *neural networks* and *associative learning models*, where words, phrases, and concepts are interconnected through networks of associations rather than quantum entanglement. For instance, *connectionist models* of language suggest that our understanding of each word is influenced by a network of previous experiences, memories, and knowledge that the brain associates with that word or concept. These associations are strengthened through repeated exposure and reinforced connections, rather than instantaneous dependence akin to quantum entanglement.[11]

The mechanism of contextual updating in language involves continuously adjusting interpretations and meanings based on context and memory, integrating elements of syntax, semantics, and pragmatics. This adaptive process reflects complex, learned patterns rather than fixed probabilistic dependencies. For example, idiomatic expressions and metaphors—like “kick the bucket” meaning “to die”—rely on learned cultural associations rather than an interdependent "state" with other words, challenging the idea that language processing has statistical dependencies similar to entanglement.[10]

5.3. Complexity of Cognitive Dependencies in Language

Language processing depends on *layered dependencies* shaped by syntax, semantics, and pragmatics, each influenced by personal experience and culture. These dependencies are often context-dependent and evolve based on historical language use, idiomatic expressions, and cultural connotations. For example, the interpretation of phrases like “hot topic” or “cold shoulder” relies on context and familiarity with idiomatic English, rather than inherent statistical dependencies. Unlike quantum entanglement, where dependencies are invariant and precisely measurable, dependencies in language processing are flexible, context-sensitive, and non-linear, making them difficult to model with statistical dependencies akin to quantum entanglement.[4]

Furthermore, language is shaped by long-term memory and cultural encoding that influence individual interpretation. Different readers may interpret the same text differently based on their background knowledge, experiences, and personal associations with certain words. This variability contrasts with the predictability of entangled states, highlighting a fundamental difference between cognitive dependencies in language and entanglement in quantum systems.

5.4. Historical Usage and Evolving Meanings in Language

Unlike quantum particles, words and phrases evolve over time, acquiring new meanings and connotations that reflect changing cultural contexts. Historical usage plays a significant role in how words are understood; for example, the term “virus” has different connotations in biological, technological, and social contexts. This evolving nature of language challenges the idea of statistical dependence in the manner of quantum entanglement, where states do not evolve based on external social or historical influences.[9]

Words and phrases are embedded in cultural contexts that shape and reshape their meanings over time, influenced by factors such as technology, social change, and popular usage. This contextual fluidity in language undermines the notion of fixed dependencies and points to the importance of

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understanding language as a culturally adaptive system rather than one governed by probabilistic entanglement.

5.5. Limitations of the Contextual Updating Analogy

The analogy of contextual updating to quantum entanglement may therefore oversimplify the complexity of language by treating it as a system governed by fixed statistical dependencies. While quantum entanglement describes a purely physical relationship that creates predictable correlations, language operates within the realms of neuroscience, psychology, and culture. This multidisciplinary nature of language processing involves layered meanings and contextual interpretations that go beyond simple statistical dependence.

Language processing in humans engages *distributed neural mechanisms* that allow for flexible adaptation to new information, with layers of associations built through personal, cultural, and societal factors. Quantum statistics, by contrast, do not account for the qualitative influences that shape our interpretation of language. Treating contextual updating as an entanglement-like dependency fails to capture the nuances of language as a social, adaptive, and individually interpreted phenomenon.[7]

The concept of contextual updating in language does not align with quantum entanglement's fixed, statistical dependencies. Language processing in humans reflects associative learning and neural connections shaped by personal experience, cultural context, and historical usage, each adding layers of meaning that are not easily modeled by quantum statistics. Future models of language processing may benefit from incorporating the adaptive, context-sensitive nature of human cognition rather than drawing strict analogies to quantum principles, which may be better suited to modeling physical rather than cognitive systems.

6. Analysis on Application of Statistics to Language Without Sufficient Empirical Support

6.1. The Physical Basis of Bose–Einstein Statistics vs. Linguistic Frequency Distributions

Bose–Einstein statistics describe the distribution of identical, indistinguishable particles (bosons) that can occupy the same quantum state simultaneously, particularly at low temperatures. In physical systems, these statistics arise due to specific quantum mechanical principles, such as indistinguishability and symmetrization (the requirement that identical bosons have symmetric wave functions), which lead to phenomena like Bose–Einstein condensation.[3] This clustering effect occurs under particular conditions and has been experimentally observed in subatomic and atomic particles such as photons and helium-4 atoms.

In language, however, *words are neither identical nor indistinguishable in the quantum sense*. Words in a text are distinct in meaning, function, and relational context, with variations in frequency largely driven by communicative and pragmatic factors. Treating words as if they are "indistinguishable particles" might be a forced analogy because words carry individual semantic loads and contextual implications, which are absent in quantum particles.[6] Thus, applying Bose–Einstein statistics to language frequency data could oversimplify the unique properties of words and their nuanced roles within sentences and discourse.

6.2. Zipf's Law and Word Frequency Distributions in Language

Word frequencies in natural languages often follow Zipf's law, which states that the frequency of a word is inversely proportional to its rank in the frequency list. This results in a characteristic distribution where a few words (like "the," "is," and "and") are highly frequent, while the vast majority appear infrequently. Zipf's law is frequently observed across different languages and texts, arising from the need for efficient communication and cognitive constraints on information processing. [12]

Zipf's law and other statistical models in linguistics explain word frequency distributions through sociolinguistic and cognitive factors rather than physical constraints. For example, high-frequency words serve connective or grammatical roles that enhance processing fluency, while

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low-frequency words carry more specific semantic information, aligning with cognitive efficiency. The clustering observed in Zipf's distribution differs fundamentally from the clustering in Bose–Einstein condensation, as it is driven by practical language usage rather than quantum principles.

6.3. Homogeneity Assumption in Bose–Einstein Statistics and Linguistic Diversity

Bose–Einstein statistics imply a degree of homogeneity in the particles or entities being modeled, as bosons are identical in nature and lack distinguishing features. This assumption does not hold for language, where words vary in meaning, function, and syntactic role. Unlike particles in Bose–Einstein condensates, words in language are not homogeneous units; they vary significantly in semantic richness, emotional weight, and cultural resonance.[4]

For instance, function words like "and" or "the" perform a different role in sentences compared to content words like "freedom" or "technology." This heterogeneity challenges the application of Bose–Einstein statistics, which assume a level of uniformity incompatible with the diversity and complexity of language. Applying Bose–Einstein models to word frequencies might overlook these distinctions, misrepresenting the structural and functional variability essential to linguistic meaning.

6.4. Alternative Explanations for Frequency Clustering in Language

The clustering observed in language, where certain high-frequency words appear much more often than others, can be explained by cognitive and communicative principles rather than Bose–Einstein statistics. Linguistic models based on information theory and Markov chains suggest that word choice is influenced by factors like sentence structure, topic coherence, and predictability rather than physical clustering. In *corpus linguistics* and computational models, these probabilistic approaches have been shown to accurately capture patterns in language without needing quantum mechanical assumptions.[13]

Moreover, natural language often involves contextual dependencies and topic specific word choices that reflect the topic or genre rather than a universal statistical rule. For example, words like "goal," "field," and "score" are likely to appear together in a sports context but not necessarily in unrelated contexts. This dependency on context introduces variability incompatible with the uniform statistical assumptions behind Bose Einstein distributions.

6.5. Lack of Empirical Evidence for Quantum Statistics in Language

The application of Bose–Einstein statistics to language lacks empirical support and does not provide predictive value for understanding linguistic or cognitive processes. While frequency distributions in language resemble certain statistical patterns in physical systems, this resemblance may be coincidental rather than indicative of underlying quantum phenomena. Language is shaped by pragmatic, social, and cognitive factors that govern how individuals choose and use words in a given context.[10]

Additionally, linguistic theories and models grounded in psycholinguistics and sociolinguistics account for word choice, syntactic structure, and meaning construction without needing to invoke quantum mechanics. Without empirical studies to support the relevance of Bose–Einstein statistics to language, applying these principles remains speculative and may misrepresent the processes that govern word frequency distributions in human communication.

Applying Bose–Einstein statistics to word frequencies in language may provide a superficial mathematical fit but lacks the empirical and theoretical support to justify its use in cognitive or linguistic modeling. Word frequencies in language are better explained by models that reflect the cognitive, social, and contextual influences that shape human language. Future research on word frequency distributions might benefit from focusing on frameworks like Zipf's law and information theory, which align more closely with the principles of language and cognition than quantum statistics.

 doi:10.20944/preprints202411.2377.v1

7. Analysis on the Failure to Differentiate Cognitive Processes from Physical Quantum Phenomena

7.1. Quantum Mechanics and Probabilistic Modeling

Quantum mechanics is a highly successful physical theory that models subatomic particles and their probabilistic behaviors using principles like *superposition* and *entanglement*. Quantum phenomena are governed by strict mathematical rules, where probabilities represent well-defined potential states that collapse into specific outcomes upon measurement.[3] This probabilistic nature is objective, measurable, and repeatable, forming the basis for reliable predictions in physical systems.

In contrast, cognitive processes are *complex*, *dynamic*, and influenced by subjective experiences, which makes them inherently less predictable and measurable than quantum systems. Human cognition is shaped by numerous factors, including emotional states, social interactions, personal memories, and environmental contexts. These factors introduce a layer of variability and individuality that resists the strict probabilistic modeling seen in quantum mechanics. Cognitive processes do not collapse into a single "state" upon observation; instead, they are often fluid, with multiple interpretations, influenced by subjective factors that lack a clear analogy in quantum mechanics.[6]

7.2. Cognitive Variability and the Influence of Personal Context

Human cognition is not only probabilistic but also deeply contextual. Cognitive processes are shaped by personal experiences, cultural background, and situational factors that vary from person to person. For example, a person's interpretation of a story may differ based on their own life experiences, current mood, and social context. This interpretative flexibility contrasts with quantum mechanics, where particles follow objective rules independent of individual perception.

Additionally, personal memories and associative learning play significant roles in shaping cognition. For instance, one person may associate the word "freedom" with political rights, while another associates it with artistic expression. This variability in associations and interpretations underscores that human cognition is not purely probabilistic but rather qualitatively driven by layers of unique, subjective experiences.[11] This qualitative variability is challenging to encapsulate within a quantum framework, where probabilistic states and entanglement are mathematically defined and do not depend on personal or cultural variations.

7.3. The Role of Emotion and Social Context in Cognitive Processing

Cognitive processes are significantly affected by emotional states and social contexts, elements that are not found in quantum systems. For instance, emotional responses like anxiety or excitement can influence memory recall, decision-making, and perception, altering cognitive states in ways that are unpredictable and deeply personal. Social interactions also shape cognition through shared cultural meanings, social norms, and interpersonal dynamics. Unlike quantum mechanics, which operates independently of emotional or social influences, human cognition is embedded within social contexts that shape how information is processed, interpreted, and recalled.[14]

The paper's attempt to apply quantum principles to cognition may therefore overlook the importance of these non-quantifiable factors. For instance, decision-making is not simply a matter of probabilistic choice; it involves values, preferences, social pressures, and emotional factors. This complexity goes beyond the probabilistic collapse of quantum states and instead points to a multi-dimensional model of cognition that integrates both subjective and social dimensions.

7.4. The Challenge of Modeling Human Cognition with Quantum Probabilities

Quantum probabilities are mathematically precise and apply to systems where all potential outcomes can be rigorously defined and measured. However, human cognition involves ambiguous, often ill-defined outcomes that cannot be readily encapsulated in quantum probabilities. For instance, understanding a metaphor or interpreting an artwork does not involve collapsing to a single "true"

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interpretation but instead allows for multiple, concurrent meanings. These interpretations are influenced by context, prior knowledge, and personal insights that vary widely among individuals.[8]

In cognitive psychology, dual-process theories (e.g., intuitive *vs.* analytical thinking) and other models of mental processing account for the layered complexity of human thought, recognizing that cognitive processes are multi-faceted and often conflicting. The use of quantum probabilities in such scenarios might impose an artificial constraint on cognition, reducing it to simplistic probabilistic terms that overlook the interpretive richness of human thought.

7.5. Potential Oversimplification of Human Cognition

Applying quantum principles to cognition might risk oversimplifying the intricacies of mental processes. Cognitive science recognizes that thought, memory, and perception are influenced by complex networks of associations within the brain, shaped by neurobiological, experiential, and environmental factors. Quantum mechanics, on the other hand, applies to subatomic particles without such contextual influences. Models that ignore the neurobiological and social layers of cognition might risk a reductionist view that fails to account for the qualitative depth of human experience.[4]

Additionally, consciousness and subjective experience remain challenging to model within any purely probabilistic or deterministic framework. Human cognition cannot be fully described by probabilistic states alone because it encompasses personal meaning, self-awareness, and qualitative judgment. Applying a quantum model to cognition might ignore these unique aspects, potentially leading to an incomplete or overly mechanistic understanding of the mind.[7]

The assumption that cognitive processes operate under quantum principles may oversimplify the complex, qualitative nature of human cognition. Cognitive processes in the brain are shaped by factors such as emotion, personal context, and social interactions, none of which have clear analogies in quantum mechanics. Future cognitive models might benefit from approaches that incorporate both quantitative and qualitative dimensions, better capturing the interpretive richness and contextual variability inherent to human thought.

8. Epistemological Analysis

8.1. The Epistemological Foundation of Quantum Mechanics vs. Cognitive Science

Quantum mechanics is grounded in a rigorous framework of experimental validation and mathematical formalism, primarily at subatomic scales. Concepts like superposition, entanglement, and indistinguishability have been repeatedly tested and confirmed through experiments, forming a reliable, predictive science of particle behavior.[3] Quantum principles apply within a closed, well-defined domain, where phenomena are reproducible under controlled conditions.

Cognitive science, on the other hand, lacks direct experimental evidence for these principles. Human cognition operates on an entirely different scale — biological and phenomenological rather than quantum — and is influenced by neural, psychological, and social factors that add layers of complexity not found in subatomic systems. Cognitive processes are thus studied through probabilistic models, neural networks, and associative mechanisms, with no empirical evidence that they follow quantum principles such as entanglement or superposition.[6] The translation of these concepts into cognitive science, therefore, lacks an empirical basis and risks theoretical overreach.

8.2. Indistinguishability and the Unique Identity of Cognitive and Linguistic Entities

In quantum mechanics, *indistinguishability* implies that identical particles of the same type cannot be differentiated from each other within a given state. This property underpins Bose-Einstein statistics, where identical particles cluster in the same state. However, in cognitive science, entities like ideas, memories, or words are context dependent and semantically unique. Each instance of a concept or word is influenced by prior experience, cultural context, and individual interpretation, factors that inherently distinguish one cognitive “entity” from another.[4]

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Assuming cognitive entities exhibit quantum indistinguishability overlooks the influence of personal and contextual meaning in human cognition. For example, the concept of "home" evokes unique associations for each person. This variability challenges the uniformity assumed in quantum mechanics, suggesting that cognitive science needs frameworks that embrace the distinctiveness of ideas rather than treating them as identical units.

8.3. The Challenge of Empirical Validation Across Scales and Disciplines

Quantum mechanics operates with a high degree of empirical validation in its native domain, subatomic particles, where controlled experimental setups can isolate variables and produce measurable outcomes. By contrast, cognitive science deals with complex, multi-scale processes—from molecular interactions in neurons to high-level mental phenomena like thought and language—making it difficult to validate theories that rely on principles from quantum mechanics.

Cognitive processes cannot be easily isolated or measured with the precision seen in quantum physics. Human thought is embedded in a social and cultural context, and the variability of individual cognition further complicates experimental replication. This discrepancy in scales and conditions between cognitive science and quantum mechanics introduces epistemological challenges: testing cognitive theories based on quantum mechanics requires methodologies and metrics that currently do not exist in cognitive science.[8]

8.4. Risks of Constructing Untested Theoretical Bridges

Suggesting that cognitive phenomena operate under quantum principles risks creating *untested theoretical bridges* between quantum mechanics and cognitive science. While analogies between quantum phenomena and cognitive processes may be thought-provoking, their predictive or explanatory power remains largely speculative. Models of cognition that rely on quantum states, entanglement, or indistinguishability may not provide insights into actual cognitive mechanisms, as they rely on assumptions that have not been empirically verified in cognitive science.[10]

The risk here is twofold: first, applying quantum concepts without empirical grounding could lead to theoretical confusion and second, it could potentially hinder the development of cognitive models that are better suited to capturing the biological, psychological, and social dimensions of human thought. Cognitive science has developed robust theories, such as connectionist models and dual-process theories, that reflect the complexity of thought without imposing quantum principles that may not apply outside of physics.

8.5. Interdisciplinary Rigidity and the Need for Validation

For an interdisciplinary bridge between quantum mechanics and cognitive science to be credible, it requires rigorous empirical and theoretical validation across both disciplines. In particular, applying quantum mechanics to cognitive science should be done only if there is concrete evidence that cognitive phenomena exhibit behaviors resembling quantum states or entanglement under controlled conditions. Without such evidence, the application of quantum mechanics to cognition remains speculative, as cognitive science has yet to demonstrate any phenomena that adhere to quantum mechanical behavior.

Moreover, the interdisciplinary nature of such a model demands frameworks that accommodate the diverse methodologies and epistemologies of each field. Cognitive science relies on observational, experimental, and computational methods that differ significantly from the mathematical formalism of quantum physics. As a result, any proposed quantum-cognitive model must respect the epistemological constraints and methodological rigor of both fields to avoid reducing cognition to a mechanistic process that fails to account for the richness of human thought and behavior.

The epistemological challenges of applying quantum mechanics to cognitive science highlight the need for rigorous interdisciplinary validation. Cognitive science and quantum mechanics operate within distinct domains, with fundamentally different methods, assumptions, and objects of study. Suggesting that cognitive phenomena could be modeled as quantum states risks creating an untested

 doi:10.20944/preprints202411.2377.v1

theoretical bridge that may obscure rather than illuminate the complexities of human cognition. Future research might benefit from focusing on frameworks that are empirically validated and tailored to the unique properties of cognition, avoiding untested analogies that may not align with cognitive science principles.

9. Conclusions

In concluding our analysis, it's essential to recognize the creative contribution of the paper in attempting to bridge the fields of quantum mechanics and cognitive science. The analogies drawn between quantum principles—like entanglement and indistinguishability—and linguistic or cognitive phenomena are intellectually intriguing and open the door to new interdisciplinary discussions. However, we must critically assess the *limits of these analogies* and the potential pitfalls they introduce.

1. **Quantum Concepts vs. Linguistic and Cognitive Realities**: Quantum mechanics is fundamentally a physical science, grounded in well-defined mathematical structures and validated through precise experimentation at subatomic scales. Applying concepts such as entanglement, indistinguishability, and Bose–Einstein statistics to cognitive entities or language risks oversimplifying the richly layered, context-dependent nature of human thought and communication. While certain statistical patterns in language may incidentally resemble quantum statistical distributions, this resemblance does not imply that cognition operates according to the same principles.[4]
2. **Qualitative and Contextual Complexity of Human Cognition**: Cognitive science recognizes that language and thought are deeply qualitative and context-sensitive, shaped by emotional, social, and experiential factors. The paper's quantum analogies, while conceptually interesting, do not account for this complexity. Unlike quantum systems, where particles behave predictably under specific conditions, words and ideas are interpreted within unique personal and cultural contexts that resist straightforward statistical or probabilistic modeling.[6]
3. **Need for Empirical and Theoretical Validation**: Suggesting that cognitive processes inherently operate under quantum principles is a *hypothetical bridge* that lacks direct empirical support in cognitive science. For such interdisciplinary applications to be credible, they require rigorous empirical validation within the domain of cognition. Otherwise, these analogies may risk diverting attention from well-established cognitive models that account for associative learning, neural processing, and memory mechanisms, which are fundamental to understanding language and thought.
4. **Risks of Reductionism and Speculative Interpretations**: Applying quantum mechanics to language and cognition without sufficient evidence could lead to reductionist interpretations that overlook the nuances of human experience. Quantum mechanics, as it is currently understood, operates within a precise physical framework that may not easily transfer to the study of meaning, memory, or perception. Reducing cognitive phenomena to quantum states or entanglements may obscure more than it illuminates, particularly when the complex influences on cognition (such as emotion, cultural background, and individual personality) lack clear parallels in quantum theory.
5. **Potential for Interdisciplinary Dialogue with Caution**: Although the paper's quantum analogies may overreach, they do provide an interesting foundation for interdisciplinary dialogue. Exploring the relationship between cognitive processes and complex systems in physics might inspire new theoretical approaches, as long as such explorations remain *grounded in empirical rigor* and avoid speculative leaps. For instance, applying principles of network theory or probabilistic modeling from physics to language processing could yield insights without imposing strict quantum mechanics where it may not apply.

9.1. Final Thoughts and Future Directions

The intersection between quantum mechanics and cognitive science is an exciting frontier, yet one that demands careful, evidence-based exploration. While quantum analogies present an intellectually

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stimulating perspective, they should be approached with caution to avoid the risks of speculative interpretation or reductionist modeling. Future research could benefit from refining these analogies through empirical studies that seek to identify verifiable cognitive phenomena that may resemble complex systems in physics, without prematurely assuming that cognition operates under quantum laws.

9.2. Conclusion on the Paper's Contribution

The paper presents an intriguing effort to link quantum mechanics with human cognition, challenging traditional boundaries between the physical sciences and the humanities. However, its core claims would benefit from empirical validation and a clearer distinction between cognitive processes and quantum systems. While it paves the way for exciting theoretical exploration, the transition from hypothesis to practical application in cognitive science remains underdeveloped, requiring further validation and thoughtful analysis.

References

1. Aerts, D.; Argüëlles, J.A.; Beltran, L.; de Bianchi, M.S.; Sozzo, S. The Origin of Quantum Mechanical Statistics: Some Insights from the Research on Human Language, 2024, [arXiv:q-bio.NC/2407.14924].
2. Bell, J.S. On the Einstein Podolsky Rosen paradox. *Physics Physique Physics* **1964**, *1*, 195–200.
3. Dirac, P.A.M. *The Principles of Quantum Mechanics*; Oxford University Press, 1981.
4. Chomsky, N. *Syntactic Structures*; Mouton: The Hague, 1957.
5. Schrödinger, E. Die gegenwärtige Situation in der Quantenmechanik. *Naturwissenschaften* **1935**, *23*, 823–828.
6. Fodor, J.A. *The Modularity of Mind*; MIT Press, 1981.
7. Aerts, D. Quantum Structure in Cognition. *Journal of Mathematical Psychology* **2009**, *53*, 314–348.
8. Piaget, J. *The Origins of Intelligence in Children*; International Universities Press, 1952.
9. Wilce, A. Quantum Logic and Probability Theory **2017**. Spring 2019 Edition.
10. Busemeyer, J.R.; Bruza, P.D. *Quantum Models of Cognition and Decision*; Cambridge University Press, 2012.
11. Rumelhart, D.E.; McClelland, J.L. *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*; MIT Press, 1986.
12. Zipf, G.K. *Human Behavior and the Principle of Least Effort*; Addison-Wesley Press, 1949.
13. Landauer, T.K.; Dumais, S.T. A Solution to Plato's Problem: The Latent Semantic Analysis Theory of Acquisition, Induction, and Representation of Knowledge. *Psychological Review* **1997**, *104*, 211–240.
14. Gallese, V. The Shared Manifold Hypothesis: From Mirror Neurons to Empathy. *Journal of Consciousness Studies* **2003**, *10*, 33–50.