PREDICTIVE LINGUISTICS, INNER LANGUAGE & MENTAL HEALTH

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Abstract: Predictive linguistics is a growing field at the interface of language sciences, cognitive sciences, and artificial intelligence, focusing on how humans and machines use predictive processes to process and produce language. This discipline is distinguished by its proactive approach, emphasizing the internal mechanisms that allow us to anticipate future linguistic structures. It explores the underlying processes at all levels of language—morphological, syntactic, semantic, pragmatic, etc.—and aims to understand how these predictions influence the production and comprehension of discourse.

The main goal of predictive linguistics is to model cognitive mechanisms to better understand how the brain processes language, but also to develop models capable of generating, predicting, and understanding language in a manner similar to human cognition. By focusing on inner speech and the cognitive mechanisms that allow us to predict linguistic structures at different levels, predictive linguistics aims to create language models capable of reproducing these predictive capabilities. In doing so, it could revolutionize natural language processing and pave the way for artificial general intelligence, capable of linguistic awareness similar to that of humans.

Keywords: Predictive linguistics; inner language; mental health; artificial intelligence; assessment; processing.

DEFINITION, OBJECT ET OBJECTIVES

Predictive linguistics is based on the idea that language, both in production and comprehension, is fundamentally an anticipatory process. Rather than simply reacting to external stimuli, the human brain, as well as advanced AI systems, continually predict upcoming linguistic structures, whether at the level of sounds, words or sentences. These predictions are refined based on past experiences, the current context and the implicit rules that govern the structure of language.

In this framework, inner language plays a key role. As the brain constantly anticipates the next words or ideas, inner language acts as a regulator that guides the person in organizing their thoughts even before speaking or writing. Predictive processes are therefore intimately linked to the mechanisms of language production, influencing the way we structure our speech at all levels of linguistic processing (Guidère, 2024). Predictive linguistics can be compared to the Bayesian model of the brain proposed by Friston (2010), which states that the brain functions as a prediction generator, seeking to minimize the gap between expectations and perceptions. In this approach to language processing, the human brain does not just passively process linguistic information, but actively anticipates what comes next based on the information already received and the overall context of the discourse.

Predictive Linguistics' Object

The purpose of predictive linguistics is to explore how predictive processes apply at all levels of linguistic structure, from basic units such as morphemes to more complex pragmatic structures.

1. Morphology: The predictive process at this level involves the anticipation of morphemes or inflectional forms based on the preceding word or expected grammatical structure. For example, in French, if we hear the word "nous," the brain generally anticipates a verb conjugated in the first person plural, influencing the speed and accuracy of comprehension.

2. Syntax: The human brain is able to anticipate the syntactic structure of a sentence long before it is finished. Psycholinguistic research shows that when listening or reading, people actively predict upcoming grammatical structure, adjusting these predictions in real time as information is received (Levy, 2008). These mechanisms are at work even in languages with significant syntactic flexibility, where context can help predict syntactic relationships before all the elements are explicitly given.

3. Semantics: At the semantic level, predictive processes focus on the overall meaning of a sentence or discourse. The brain uses both immediate context and broader cognitive schemas to anticipate the likely meaning of words or sentences. Studies show that this anticipation allows for more fluent and rapid language comprehension, particularly in situations where information is ambiguous or incomplete (Altmann & Mirković, 2009).

4. Pragmatics: At the pragmatic level, predictive linguistics is interested in how speakers anticipate the communicative intentions of others. Here, inner speech plays a crucial role by adjusting predictions based on social norms, contextual expectations, and nonverbal cues. For example, during a conversation, a person can anticipate the response of their interlocutor and adjust their speech accordingly, thus promoting a smoother interaction.

Predictive Linguistics' Objectives

The main goal of predictive linguistics is to model the cognitive processes that allow people to produce and understand language in real time, based on predictions. This involves not only understanding how the human brain works when anticipating linguistic structures, but also applying this knowledge to create more efficient language models that can predict linguistic information with greater accuracy and flexibility.

The cognitive models that underpin predictive linguistics are often based on computational theories, such as Bayesian models and neural networks. These models seek to simulate how the brain constantly predicts and corrects its expectations to optimize language production and comprehension.

A concrete example of this approach is the development of large language models (LLMs) such as GPT or BERT, which use deep learning algorithms to generate linguistic predictions from large datasets. These models use contextual attention to assess the relationships between words across a sequence, thereby producing coherent and contextually relevant text. However, predictive linguistics goes further by seeking to understand not only how these predictions are made, but also how they can be corrected in real time based on new linguistic input.

A major challenge in predictive linguistics is understanding how to integrate inner language into natural language processing models. Inner language, as defined in cognitive psychology, allows people to reflect on their own mental processes, anticipate answers to questions before formulating them verbally, or self-regulate when solving problems.

In a predictive language model, integrating inner language would mean giving the model the ability to generate predictions not only based on external stimuli, but also from its own internal processes, by reflecting on its own productions. For example, a model could generate a sentence, evaluate the consistency of that sentence with its own internal model of the language, and adjust its output based on unmet expectations or detected inconsistencies. This type of cognitive recursion is essential for advanced AI systems that can simulate not only human language, but also more complex thought processes.

Thus, predictive linguistics has major implications for the development of AI, particularly in the field of natural language processing (NLP). Large language models, while effective for text generation, still lack a true ability to integrate complex predictive processes similar to those observed in the human brain. By studying more deeply how predictions are generated at different levels of linguistic

processing (from syntax to pragmatics), predictive linguistics can improve AI algorithms to make them more adaptive, flexible, and contextually relevant. A system capable of linguistic predictions as sophisticated and adjustable as those of humans would be an important step towards artificial general intelligence (AGI).

Inner Language in Predictive Linguistics

Inner language, the silent voice that resonates in our thoughts, is a fascinating phenomenon that lies at the heart of human cognition. Its study is part of the broader "cognitive revolution," highlighted by Yuval Noah Harari (2014) in his analysis of the evolution of humanity. This revolution has highlighted the importance of inner language in our conscious experience and in the formation of our thinking.

In predictive linguistics, the exploration of inner language draws on contemporary theories of consciousness and cognition. Among these, the global neural workspace theory (GNWT) proposed by Dehaene and colleagues (2003) offers a conceptual framework for understanding how information becomes conscious and globally accessible in the brain. This theory helps to understand how inner language emerges as conscious content in our subjective experience.

Higher-order theories of consciousness (HOT), notably developed by Lau and Rosenthal (2011), provide additional insight by suggesting that consciousness involves second-order representations. This approach is particularly relevant for understanding the reflexive nature of inner speech, where we are not only aware of our thoughts, but also aware of being aware of these thoughts.

Recurrent processing theory (RPT), developed by Lamme and Roelfsema (2000) and further developed by Pennartz et al. (2019), emphasizes the importance of feedback loops in neural processing for the emergence of consciousness. This perspective provides insight into the neural mechanisms underlying the production and perception of inner speech.

Tononi's (2008) Integrated Information Theory (IIT) offers a quantitative approach to consciousness, based on the integration of information in complex systems. This theory provides a framework to measure and characterize the complexity and richness of inner language in terms of information integration.

Finally, a broader conception of cognition, applicable to all living organisms, has been developed by Karl Friston and his collaborators (Friston, 2005; Hohwy, 2014; Clark, 2016; Parr, Pezzulo, & Friston, 2022). This approach, based on the principle of free energy minimization, offers a unified perspective on cognition, perception, and action. Within this framework, inner language could be conceptualized as an active process of prediction and inference, contributing to the reduction of uncertainty in our internal model of the world.

The study of inner language, in light of these theories of cognition and consciousness, not only deepens our understanding of this singular phenomenon, but also sheds light on the fundamental mechanisms of human thought.

Definitions of Inner Language

Inner language, also known as "inner speech," "inner dialogue," "internal speech," "self-communication," or "endophasia," refers to the subjective experience of verbal thought that occurs without external vocalization. This form of cognition plays a central role in our mental life, influencing our thought processes, decision-making, and conscious experience.

Global Neural Workspace Perspective

Within the framework of the Global Neural Workspace Theory (GNWT) proposed by Dehaene et al. (2003), inner language can be conceptualized as mental content that accesses the global workspace, thus becoming conscious and accessible to various brain regions. According to this perspective, inner language would emerge when linguistic representations are amplified and maintained in this workspace, allowing their conscious processing and integration with other cognitive processes.

Higher-Order Theories Perspective

Higher-Order Theories (HOTs) of consciousness, as developed by Lau and Rosenthal (2011), provide a framework for understanding the reflexive nature of inner language. In this view, inner language can be defined as a form of thought that involves not only first-order representations (the content of the thought), but also second-order representations (the awareness of having that thought). This approach emphasizes the metacognitive dimension of inner speech, where the speaker is aware of his or her thoughts.

Recurrent Processing Perspective

Lamme and Roelfsema's (2000) Recurrent Processing Theory (RPT), enriched by Pennartz et al. (2019), allows to conceptualize inner speech as a dynamic process involving feedback loops between different brain regions. In this framework, inner speech could be defined as the emergence of recurrent patterns of neural activity in linguistic and cognitive networks, creating a stable and coherent experience of verbal thought.

Integrated Information Perspective

Tononi's (2008) Integrated Information Theory (IIT) offers a quantitative perspective on consciousness that can be applied to inner speech. In this context, inner speech could be defined as a state of high informational integration within neural systems related to language and cognition. The richness and complexity of our experience of inner speech could thus be characterized by the degree of information integration in these networks.

Free energy minimization perspective

In the theoretical framework developed by Friston and colleagues (Friston, 2005; Hohwy, 2014; Clark, 2016; Parr, Pezzulo, & Friston, 2022), inner speech can be conceptualized as an active process of inference and prediction. According to this perspective, inner speech could be defined as a form of mental simulation allowing us to generate and test predictions about our environment and internal states, thus contributing to the minimization of free energy (or surprise) in our model of the world.

Definitional Synthesis

By integrating these different theoretical perspectives, it is possible to propose a synthetic definition of inner language.

Inner language is a cognitive phenomenon characterized by the subjective experience of non-vocalized verbal thoughts. It emerges from the dynamic interaction between different neural networks, accessing a global workspace that makes it conscious and accessible to various cognitive processes. It involves higher-order representations, allowing metacognitive reflection on our own thoughts, which manifests itself through recurrent and integrated patterns of neural activity, playing a central role in the prediction and active inference of our internal and external experience.

This multidimensional definition of inner language reflects the complexity of this phenomenon that acts as a powerful neural activator, influencing the activity of various neural networks and modulating cognitive and emotional functioning. Understanding how this inner speech activates these networks can not only shed light on our understanding of cognitive processes, but also pave the way for innovative therapeutic interventions.

NATURE, STRUCTURE ET FUNCTIONS

Inner speech has unique characteristics that distinguish it from other forms of cognition.

The Neurobiological Basis of Inner Speech

Inner speech engages several interconnected brain networks. The key region associated with language, namely Broca's area (located in the left prefrontal cortex), is heavily involved in the generation of verbalized thoughts. Neuroimaging studies show that this region is activated not only during spoken language, but also when people think in words without saying them (Morin, 2009). The prefrontal cortex, the seat of executive functions and planning, is also engaged, as is the parietal cortex, which is involved in the processing of attention and sensory information.

Inner speech also engages the Default Mode Network (DMN), a neural network that is active when we are at rest and thinking about ourselves or past and future events (Buckner et al., 2008). This network includes the medial prefrontal cortex, the precuneus, and the posterior parietal regions. This pattern of brain activity is essential for metacognition, that is, thinking about one's own thoughts, and is therefore intrinsically linked to inner language.

Activation of language areas

Inner speech activates classical language areas, including Broca's area and Wernicke's area. An fMRI study by Shergill et al. (2001) showed activation of these regions during inner speech tasks.

Involvement of the motor cortex

Even without verbal production, inner speech activates the motor cortex involved in speech. The work of Perrone-Bertolotti et al. (2014) demonstrated activation of the motor cortex during inner speech production.

Default network

Inner speech is associated with activation of the default network, involved in self-referential thinking. A study by Smallwood et al. (2012) highlighted this link.

Emotional regulation

Inner speech modulates the activity of the amygdala and prefrontal cortex, involved in emotional regulation. Kross et al. (2017) showed how inner speech can influence these circuits.

Working Memory

The use of inner speech activates the dorsolateral prefrontal cortex, which is involved in working memory. The work of Geva et al. (2011) demonstrated this activation during inner speech tasks. This research shows that it has a direct impact on the activation of multiple neural networks, and that it plays a central role in various cognitive and emotional processes.

Self-talk and Emotion Modulation

Self-talk plays a central role in emotional regulation. Studies on the cognitive regulation of emotions show that the way we talk to ourselves in stressful situations can modulate our emotional response. When self-talk is used adaptively, for example to reframe or recontextualize an emotionally charged situation, it can activate neural networks that reduce activity in the amygdala, a key region in processing negative emotions such as fear or anxiety (Ochsner & Gross, 2008).

The process of cognitive restructuring, which is at the heart of many psychotherapeutic approaches such as cognitive behavioral therapy (CBT), relies heavily on self-talk. For example, when a patient replaces a negative thought ("I will fail") with a more rational and positive thought ("I have prepared myself and will do my best"), this leads to an activation of regions of the prefrontal cortex, responsible for the inhibition of excessive emotional responses (Beck, 2011). This mechanism allows the modulation of the emotional response by directly influencing the underlying neural systems.

Inner speech is also a key neural activator in learning and memory processes. Studies show that when people talk to themselves repeatedly to memorize information, it strengthens synaptic connections within neural networks involved in declarative memory, including the hippocampus and associated prefrontal regions (Baddeley et al., 2012). This phenomenon is often observed in verbal learning, where the internal repetition of information facilitates its encoding and retrieval.

In addition, inner speech plays a central role in working memory, which is the ability to maintain and manipulate information in the short term. Working memory models, such as Baddeley and Hitch's (1974), suggest that inner speech is an integral part of the "phonological loop," a subsystem dedicated to manipulating verbal information. When people silently rehearse information, it helps keep that information active in working memory, a process that is essential for problem solving and decision making.

Indeed, when a person is faced with a dilemma or a difficult cognitive task, they may use inner speech to evaluate available options, weigh the consequences of each choice, and ultimately make a decision. This process activates several brain regions, including the dorsolateral prefrontal cortex, which is involved in decision making and reasoning (Miller & Cohen, 2001).

Neuroscience research has shown that inner speech helps structure thinking and prioritize actions. For example, neuroimaging studies have found that people who use inner speech to solve mathematical or logical problems show increased activation of the left prefrontal cortex (Geary, 2011). This suggests that inner speech helps plan and organize the steps needed to solve problems.

In addition, inner speech can also serve as a guide in moral and ethical decisions. In this regard, neuroscience studies have shown that inner speech plays a key role in moral deliberation, activating brain regions such as the ventromedial prefrontal cortex, which is involved in ethical judgments and value-based choices (Greene et al., 2001).

The Neural Basis of Inner Speech

Inner speech engages several brain regions involved in both cognitive and emotional processing. Among these regions, the prefrontal cortex plays a central role in emotional regulation. Specifically, the dorsolateral prefrontal cortex (DLPFC) and ventromedial prefrontal cortex (VMPFC) are responsible for modulating emotions by reappraising and recontextualizing experiences (Ochsner & Gross, 2005). This process of cognitive restructuring allows negative thoughts to be transformed into more nuanced interpretations, thereby changing the intensity of the emotions felt.

In addition, inner speech interacts with subcortical structures such as the amygdala, a key region in detecting threats and generating rapid emotional responses, particularly fear and anxiety (Phelps & LeDoux, 2005). Neuroimaging studies have shown that when people use self-talk to reappraise an anxiety-provoking situation, activation in the amygdala decreases, while activity in the prefrontal cortex increases (Ochsner et al., 2002). This suggests that self-talk can be used to modulate the emotional impact of a situation by adjusting how it is interpreted by the brain.

The cognitive reappraisal model

The cognitive reappraisal model, a central concept in the psychology of emotion, is based on the idea that emotions are not only the result of the objective situation, but also of how that situation is interpreted (Gross, 2002). Self-talk acts as a key reappraisal mechanism, allowing people to reframe their thoughts and thus reduce the negative emotional charge associated with a situation.

For example, when faced with a stressful event such as an exam or a public presentation, a person might use self-talk to tell themselves, “I’m going to fail, everyone is going to make fun of me.” This thought activates neural circuits associated with stress and anxiety, including the amygdala. However, if the speaker manages to recontextualize the event using a more positive approach (“I prepared well for this exam, I am capable of succeeding”), this leads to a decrease in activation of the amygdala and an increase in activity in the prefrontal cortex, thus facilitating better emotional management (Buhle et al., 2014).

This ability to restructure thoughts is at the heart of many psychotherapeutic interventions, including cognitive behavioral therapy (CBT). Studies show that cognitive reappraisal via inner language is one of the most effective strategies for reducing the intensity of negative emotions (Beck, 2011). It not only calms the immediate emotional response, but also promotes better resilience to stressful or traumatic events in the long term.

Self-instruction and stress management

Another aspect of self-talk in emotional regulation is its role in self-instruction strategies. Self-instruction involves using internal phrases or thoughts to guide oneself through difficult or stressful tasks. This helps maintain emotional distance from the event at hand, which can reduce the intensity of the emotions felt.

Research shows that self-instruction activates prefrontal regions of the brain, which are responsible for cognitive control and emotional regulation (Carver & Scheier, 1998). For example, an athlete who uses self-talk to motivate themselves before a competition (“I can do this, I’m ready”) activates neural networks involved in motivation and stress resilience, particularly the brain’s dopamine system, which is critical in reinforcing positive behaviors (Schultz, 2002). Conversely, negative self-talk can exacerbate stress and activate circuits associated with anxiety and failure.

This use of self-talk to manage stress is also applicable in the context of physiological responses. When people are faced with stressful situations, self-talk can modulate the response of the autonomic nervous system, which is responsible for managing the “fight or flight” response. By adjusting their self-talk, people can reduce activation of the sympathetic nervous system, which is responsible for increasing heart rate and breathing in response to stress, and activate the parasympathetic system, promoting relaxation (Thayer & Lane, 2000).

The Role of Self-Talk in Emotional Disorders

Self-talk plays a key role in the development and maintenance of emotional disorders, such as anxiety, depression, and post-traumatic stress disorder (PTSD). These disorders are often characterized by negative, repetitive, and self-defeating self-talk that perpetuates dysfunctional cognitive patterns and fuels negative emotions (Jehel & Guidère, 2024).

In the management of post-traumatic stress disorder (PTSD), for example, techniques such as prolonged exposure and eye movement desensitization and reprogramming (EMDR) rely in part on modifying self-talk to help patients recontextualize their traumatic memories and reduce the emotional reactivity associated with these memories (Shapiro, 2017). By modifying self-talk related to intrusive thoughts and painful memories, it is possible to reduce excessive activation of the amygdala and other structures involved in the fear response.

In depression, patients often report a constant stream of negative thoughts, such as "I suck," "I'm useless," or "I'll never make it." These thoughts activate neural circuits associated with negative emotions, such as the anterior cingulate cortex and orbitofrontal cortex, which are often overactive in people with depression (Mayberg et al., 2005). In contrast, cognitive behavioral therapy and other forms of mindfulness-based therapies use self-talk to modify these automatic thoughts and induce more effective emotion regulation. In patients with anxiety disorders, self-talk may focus on catastrophic scenarios ("I'm going to fail," "Something terrible is going to happen"), thereby increasing activation in the amygdala and exacerbating anxiety symptoms. Again, approaches such as CBT seek to use self-talk to correct these thoughts and reduce excessive activation of fear circuits.

Self-talk and Neural Plasticity

One of the most powerful effects of self-talk on the brain is its ability to induce changes in neural plasticity. Brain plasticity refers to the brain's ability to reshape itself in response to experience, and it is central to learning and personal development. When a person uses self-talk to repeat positive or constructive thought patterns, it can strengthen synaptic connections in the neural networks associated with those thoughts, increasing their effectiveness over time (Kandel & Schwartz, 2013).

Research in psychotherapy and mindfulness-based meditation techniques shows that self-talk can be used to promote more adaptive cognitive patterns. For example, repeating positive thoughts or mantras in meditation practices has been associated with increased functional connectivity between the prefrontal cortex and other regions involved in emotion regulation (Tang et al., 2015). These changes reflect the neuroplasticity induced by self-talk, where neural circuits can be reshaped by repeated thought patterns.

As such, the therapeutic applications of self-talk are numerous and promising. Interventions can be used to help patients restructure negative thought patterns, reduce anxiety, improve stress management, and promote a general sense of well-being. Cognitive behavioral therapists often encourage patients to use self-talk to identify and challenge negative automatic thoughts, a process that can activate prefrontal neural networks associated with emotion regulation (Beck, 2011).

In addition, "biofeedback," a technique that allows people to voluntarily regulate physiological functions such as heart rate or muscle tension, can be enhanced by the use of self-talk. By combining biofeedback with positive affirmations or visualizations, patients can learn to modulate their neural activity, thereby promoting a state of relaxation or increased focus.

Self-talk can also be a valuable tool in treating anxiety disorders and phobias. Using self-talk to gradually desensitize patients to their fears, systematic desensitization, a behavioral therapy technique, relies on activating neural circuits involved in managing fear and negative emotional responses (Powers et al., 2010).

Thus, it is clear that self-talk is not simply a passive form of thinking; it is a powerful neural activator that engages a large part of the brain, from planning and decision-making to emotion regulation and learning. Through its influence on neural networks involved in cognition, it shapes not only how we think and feel, but also how we interact with the world.

The Generative Nature of Inner Speech

Generating Models of Self and Environment

Inner speech plays a central role in generating mental models of self and environment. According to predictive brain theory, the brain functions as a prediction machine, constantly engaged in generating and updating internal models of the world (Friston, 2005; Clark, 2013). In this context, inner speech can be seen as a powerful cognitive tool for formulating, articulating, and manipulating these predictive models.

Alderson-Day and Fernyhough (2015) have highlighted the role of inner speech in mental simulation and planning. Their work suggests that internal dialogue allows us to simulate future scenarios, anticipate the consequences of our actions, and prepare for potential situations. This capacity for mental simulation is closely related to the generative nature of inner speech.

Anticipation and adaptation

By generating hypothetical scenarios and mentally exploring different possibilities, inner language allows us to anticipate and prepare for potential surprises. This anticipatory function has been highlighted by the work of Perrone-Bertolotti et al. (2014), who showed how internal dialogue contributes to behavioral and emotional regulation.

Adaptation, in turn, is facilitated by the ability of inner language to quickly generate and test different action strategies. As Morin et al. (2011) have pointed out, inner language plays a key role in self-regulation and problem solving, allowing people to flexibly adapt to changing challenges in their environment.

The Hierarchical Structure of the Generative Model

Levels of Abstraction and Long-Term Predictions

The hierarchical structure of the generative model underlying inner speech is a fundamental aspect of its functioning. This hierarchy allows for managing the complexity of real-world environments while balancing present-day expectations with future needs. Badre and Nee (2018) proposed a hierarchical model of cognitive control that applies well to understanding the structure of inner speech. According to this model, higher levels of the cognitive hierarchy encode more abstract representations and longer-term goals, while lower levels process more concrete and immediate information.

In the context of inner speech, this hierarchy is manifested by the ability to generate thoughts ranging from simple comments about the immediate environment to complex reflections on abstract concepts or long-term plans. Lupyan

and Clark (2015) highlighted how language can serve as a cognitive scaffold, allowing for the construction and manipulation of increasingly abstract concepts.

Interaction between hierarchical levels

The interaction between the different levels of this hierarchy is important for the adaptive functioning of inner language. The work of Christoff et al. (2016) on the dynamics of spontaneous thoughts provides an interesting insight into this interaction. They propose that spontaneous thoughts, of which inner language is a major component, involve a constant back-and-forth between more concrete and more abstract levels of representation.

This dynamic interaction between hierarchical levels allows inner language to serve as a bridge between immediate experiences and long-term goals, thus facilitating decision-making and strategic planning.

The Construction of Abstract Representations

Integration of sensory and interoceptive information

Inner language does not operate in isolation but integrates information from multiple sensory and interoceptive systems. This multimodal integration is essential for the construction of rich representations of the self and the environment. Craig's (2009) work on interoception and self-awareness has highlighted the importance of integrating bodily signals in the construction of our subjective experience, including our internal dialogue.

Similarly, Damasio and Carvalho (2013) have highlighted the crucial role of feelings, that is, the mental representation of bodily states, in cognition and decision-making. Inner language, as a generative process, plays a key role in interpreting and articulating these interoceptive signals, thus contributing to our sense of self and our understanding of our internal state.

Construction of abstract representations

From this multimodal integration, inner language participates in the construction of increasingly abstract and temporally oriented representations. These representations include our sense of self, our understanding of the world, our thoughts, our action plans, our feelings, our emotions, and our imagination. Barsalou (2008) proposed a theory of perceptual symbol systems that explains how abstract concepts can emerge from the integration and reactivation of traces of sensorimotor experiences. Inner language, in this context, can be seen as a tool for manipulating and combining these perceptual symbols to create increasingly abstract thoughts and concepts.

The Neural Ignition of Inner Speech

The Concept of Neural Ignition

Neural ignition, a key concept in the Global Neural Workspace Theory (GNWT) proposed by Dehaene et al. (2003), provides a neurocognitive framework for understanding how inner speech becomes conscious and accessible to various cognitive processes. Ignition refers to the sudden and widespread activation of a coalition of neurons that "ignites" information in the brain, making it conscious and globally accessible.

Dehaene and Changeux (2011) developed this concept to explain that access to consciousness involves a "ignition" of the frontoparietal network, allowing information to be disseminated and maintained throughout the brain. In the context of inner speech, this ignition could correspond to moments when our internal thoughts suddenly become salient and conscious, influencing our cognition and behavior.

Implications for Inner Speech

The implications of this approach for our understanding of inner speech are considerable. Dehaene et al. (2014) suggested that conscious access, facilitated by neuronal ignition, allows for the maintenance and flexible manipulation of information and key features of cognition. This perspective explains how inner speech can shift rapidly from one topic to another, while maintaining overall coherence and accessibility.

In addition, neuronal ignition provides a framework for understanding how inner speech interacts with other cognitive processes. It would facilitate the integration of the content of inner speech with other information present in the global workspace, thus allowing for a mutual influence between inner dialogue and other aspects of cognition, such as working memory, decision-making, and executive control.

Free Energy Minimization

The Principle of Free Energy Minimization

From an energetic perspective, the brain's goal is to minimize its free energy by reducing uncertainty from the organism's internal and external environment. This principle, formulated by Friston (2005) and developed within the framework of the predictive brain theory, offers a unified perspective on brain functioning, including the role of inner speech. According to this theory, the brain functions as a prediction machine, constantly engaged in generating predictions about the future state of the system and using sensory information to update these predictions. Inner speech, in this context, can be seen as a powerful tool for the formulation and manipulation of these predictions.

Inner speech as a tool for active prediction

Pezzulo and Friston (2022) extended this perspective by proposing a framework of "active cognition" where inner speech could be seen as an active process of generating and testing hypotheses about the world. In this framework, it would play a key role in formulating predictive hypotheses, mentally simulating future scenarios, and evaluating the potential consequences of our actions.

This perspective highlights the deeply adaptive nature of inner speech. By constantly generating predictions and confronting them with reality, internal dialogue allows us to navigate efficiently in a complex and uncertain world, thereby reducing the free energy (or surprise) of our cognitive system.

The Reflexive Nature of Inner Speech

The human brain is constantly engaged in a process of interpreting reality. As Frith and Frith (2006) have pointed out, our understanding of the world is largely shaped by the mental models we construct. Inner speech plays a central role in this process, serving as a medium for the elaboration and manipulation of these models. It functions as a prediction machine, constantly generating hypotheses about the state of the world and updating them based on incoming sensory information.

A key feature of the reflexivity of inner speech is its ability to confirm one's own reasoning. As Carruthers (2002) and Morin (2005) have noted, inner speech often serves as a "cognitive feedback loop," where generated thoughts are immediately "heard and evaluated" by the thinker themselves.

This reflexive loop has important implications for cognition. On the one hand, it allows for the continuous evaluation and refinement of our thoughts. On the other hand, it leads to a reinforcement of our existing beliefs, a phenomenon that Nickerson (1998) has called "confirmation bias."

The Embodied Nature of Inner Speech

The reflexivity of inner speech is intimately linked to its embodied character. As Alderson-Day and Fernyhough (2015) have pointed out, inner speech is not a purely abstract process, but often involves a sensorimotor simulation of speech.

This perspective is supported by the theory of embodied cognition (Barsalou, 2008), which posits that cognitive processes are deeply embedded in body-environment interactions. In the case of inner speech, this means that when we "speak" internally, we often activate the same neural circuits that are involved in the production and perception of external speech.

The embodied nature of inner speech is also manifested in what we might call an "internal perception-action loop." Just as when we speak out loud, where we produce sounds and hear them simultaneously, inner speech involves a simultaneous production and perception of verbalized thoughts.

This internal perception-action loop has been studied by Lœvenbruck et al. (2018), who proposed a predictive control model of inner speech. According to this model, inner speech involves the generation of attenuated motor commands and the prediction of their sensory consequences, thus creating an "inner voice" experience without actual vocal production.

Reflexivity in Different Mental States

The reflexive nature of inner speech is not constant and can vary considerably depending on the mental state of the person. In situations of fear or imminent danger, for example, inner speech tends to become considerably simplified.

This phenomenon can be understood in light of LeDoux's (1996) dual-pathway theory of information processing. According to this theory, when faced with danger, the brain activates a fast, automatic pathway (via the amygdala) that bypasses slower cortical processing. As a result, inner speech, which relies heavily on higher cortical functions, becomes simplified.

Mobbs et al. (2015) provided neuroimaging evidence of this change, showing decreased activity in prefrontal regions and increased activity in subcortical regions during imminent threats. This neural reconfiguration could explain the reduced reflexivity of inner speech in these situations.

Conversely, in states of quietude, deep meditation, or lucid dreaming, inner speech may become richer and more complex. These states are characterized by increased activity in the prefrontal regions of the brain, which are associated with reflective thought and metacognition (Dehaene et al., 2014; Baird et al., 2018).

In the case of lucid dreams, for example, Voss et al. (2009) showed increased activity in the dorsolateral prefrontal cortex, a region associated with metacognition and self-reflection. This increased activation could explain the highly reflective and often bizarre nature of inner speech in these states.

Dereification and Introspection of Inner Speech

A crucial aspect of inner speech reflexivity is the ability to observe and introspect it as an object of experience. This process, known as "dereification," refers to the recognition that experiential phenomena, including our thoughts and inner speech, are mental constructs rather than inherent realities (Lutz et al., 2015).

Dereification involves a shift in perspective that allows us to disengage from the habitual tendency to treat our thoughts as solid, enduring entities (Dahl et al., 2015). This process is particularly important in the context of mindfulness and meditation practices.

The ability to "dereify" inner speech has important implications for cognition and psychological well-being. As Bernstein et al. (2015), the ability to step back from our thoughts, a process they call "cognitive defusion," can reduce emotional distress and improve emotional regulation.

In the context of inner speech, dereification can allow for greater cognitive flexibility. By recognizing that our internal dialogue is a construct rather than an absolute reality, we can more easily challenge and change our habitual thought patterns.

Indeed, the ability to adopt a self-reflective stance is considered a distinctive feature of human cognition. This ability is closely related to "theory of mind," that is, the ability to attribute mental states to oneself and others (Premack & Woodruff, 1978).

As Carruthers and Smith (1996) have pointed out, inner speech plays a crucial role in the development and exercise of theory of mind. It allows us not only to reflect on our own mental states, but also to imagine and simulate the thoughts and feelings of others. This constant reflexive activity contributes to our ability to generate meaning and

construct coherent narratives about ourselves and the world around us (Damasio, 2010).

ASSESSMENT, PREVENTION AND TREATMENT

In therapeutic contexts, inner language can be a powerful tool to improve the alliance between the therapist and the patient, thus influencing the clinical outcome. This phenomenon is part of normal brain mechanisms and can help to relieve the patient of guilt, while avoiding the stigmatization often associated with certain psychological or somatic disorders. In this perspective, the adoption of an explanatory discourse based on inner language promotes the understanding and acceptance of symptoms, even in the absence of structural damage, by relying on the predictive mechanisms of the brain.

Self-talk and Guilt Reduction

Patient guilt is one of the major obstacles in traditional therapeutic approaches, particularly in cases of pain or functional symptoms without an apparent organic cause. Framing difficulties as a consequence of normal brain mechanisms, rather than a psychological weakness, can be liberating for patients.

Studies show that the brain generates perceptions based on inferences based on past experiences and the current context (Friston, 2010). This predictive model of the brain helps explain why symptoms can be experienced authentically, even in the absence of physiological damage.

Perceptions, like memories, are indeed imperfect due to the very nature of the human brain, which is optimized for speed rather than accuracy. This view aligns with the theory of predictive internal models, according to which the brain is constantly evaluating incoming signals by comparing them to predictions based on past experiences (Clark, 2013). Inner language thus helps explain these mechanisms in a way that reassures the patient and minimizes the stigmatization of their symptoms.

Diagnostic Uncertainty and Somatic Vigilance

Another dimension of inner language in a clinical context concerns the explanation of the effect of diagnostic uncertainty on somatic vigilance. When patients are in a situation of uncertainty about their diagnosis, they are more likely to become hypervigilant to interoceptive signals, that is, to the internal sensations of the body. This increased vigilance leads to a disproportionate attention paid to bodily signals that, under normal conditions, would not create surprise or alarm (Seth, 2013).

The more the speaker harbors expectations of symptoms, for example after a minor trauma, the more his vigilance towards them increases, consequently intensifying the perception of these symptoms. The inferences generated by the higher hierarchical levels of the cerebral cortex amplify these signals, which sometimes manifests itself in avoidance behaviors. Studies on somatic hypervigilance show that this anxious anticipation of symptoms actually amplifies the distress felt (Van den Bergh et al., 2017). This is particularly evident in neurofunctional disorders (NFDs), where patients often report difficulty concentrating due to the overload of their attention on bodily sensations.

The Effect of Cognitive Disposition on Stage Fright

Stage fright, a common performance-related phenomenon, is a striking example of how self-talk can modulate somatic responses. Symptoms associated with stage fright, such as palpitations and nausea, can be intensified if the speaker negatively anticipates these sensations. Studies on cognitive anticipation have shown that the way a person mentally prepares for a situation directly influences their physical experience of it (Paulus et al., 2013). Self-talk plays a key role here by allowing the patient to reframe these symptoms as normal, even helpful, bodily responses to adrenaline.

Indeed, individuals who adopt a positive view of their stage fright symptoms, perceiving them as indicators of better performance to come, are more likely to successfully direct their attention to the task at hand rather than to their bodily sensations. This shift in attention frees up "cognitive bandwidth," allowing the brain to function more efficiently. This is confirmed by research on emotional regulation and the importance of cognitive recontextualization (Gross, 2002).

The Role of Inner Speech in Placebo and Nocebo Effects

The predictive model of inner language can also be applied to understand placebo and nocebo effects. According to this model, positive or negative expectations directly influence body perception (Büchel et al., 2014). When a patient expects an improvement (placebo effect), the brain systems that generate these expectations reinforce this perceived improvement, even in the absence of objective biological change. In the same way, negative expectations can generate or amplify symptoms (nocebo effect).

The role of the clinician is essential here. By adopting a therapeutic language focused on reassuring and coherent explanations, he or she can minimize the risks of amplification of symptoms due to erroneous expectations. Studies show that medical discourse can directly influence these expectations, by modifying the patient's predictions (Colloca and Benedetti, 2007). It is therefore essential that health professionals are aware of the impact of their words and attitudes on the cognition of their patients.

Implications for the Therapeutic Alliance

Including inner language in the therapeutic relationship strengthens the therapeutic alliance, a key factor in the effectiveness of clinical interventions. The patient's brain, when faced with diagnostic uncertainty, places disproportionate emphasis on interoceptive perceptions. If the physician or therapist fails to provide a clear and coherent explanation of symptoms, or if they adopt ambiguous discourse, this can unintentionally amplify the patient's uncertainty and increase somatic vigilance.

When a physical examination reveals no abnormalities, but

the patient continues to report symptoms, a poorly worded message such as "you're fine" can actually make the situation worse. Studies on the effects of clinical communication show that the absence of clear explanations or the use of competing diagnoses that are not verified can keep the patient in a state of uncertainty, reinforcing the salience of their negative perceptions (Peters et al., 2014). In this sense, inner language should be mobilized to reassure the patient, while avoiding formulations that minimize or invalidate their bodily experiences.

Preventing Avoidance Behaviors

Another application of inner language in the therapeutic alliance concerns physical reconditioning after an injury or illness. Recommending that the patient gradually resumes their activities, while explaining how the brain can produce erroneous perceptions of fatigue or pain, can prevent the development of avoidance behaviors and the catastrophizing of symptoms. Cognitive behavioral therapy (CBT) is a particularly suitable approach in these cases. Indeed, several studies have shown that CBT can modify dysfunctional beliefs and erroneous expectations, leading to a reduction in persistent somatic symptoms (Henningsen et al., 2018).

Mobilizing inner language also allows therapists to prevent catastrophic thoughts and avoidance behaviors before they become entrenched. For example, in the context of chronic pain, it is essential to explain that pain perception can be influenced by cognitive processes and is not necessarily a true reflection of physical damage. A study by Moseley et al. (2008) highlights that patients informed about the nature of the brain processes underlying chronic pain show faster improvement and a reduction in their attention to symptoms.

PREDICTIVITY AND RECURSIVITY

Inner Speech as a Predictive System

Inner speech acts as a sophisticated predictive system, allowing us to anticipate future events and guide our actions accordingly. According to Pickering and Garrod (2013), inner speech uses predictive mechanisms similar to those involved in producing and understanding external language. This predictive ability helps us navigate our environment, make decisions, and interact effectively with others.

A fundamental aspect of predictive inner speech is its ability to reduce uncertainty. Clark (2013) proposes that the brain functions as a "prediction machine" that constantly attempts to minimize prediction errors. In this context, inner speech plays a key role in generating predictions about future events and comparing them to actual sensory inputs. It uses generative models to produce predictions based on prior knowledge and past experiences. These predictions are then compared to incoming sensory data, sometimes generating prediction errors that are used to update and refine internal models. Friston (2010) formalized this idea in the framework of the "Bayesian brain," where cognitive processes are viewed as probabilistic inferences based on internal models of the world.

Furthermore, Barrett and Simmons (2015) suggest that emotions are constructed by the same hierarchical predictive process as other perceptions. When unexpected information arises, it generates a prediction error that is used to update internal models and refine future predictions.

Thus, the operation of inner speech can be compared to Bayes' theorem, a fundamental principle of probabilistic inference. Just as Bayes' theorem allows us to update probabilities in light of new information, inner speech constantly updates our beliefs and predictions based on sensory input and lived experiences.

This Bayesian model of inner speech also explains how attention is directed to the most relevant stimuli. Feldman and Friston (2010) showed that attention can be seen as a process of prediction optimization, where cognitive resources are allocated to stimuli that are most informative or have the greatest likelihood of reducing uncertainty.

In this perspective, some mental disorders could be seen as the result of systematically erroneous predictions or prediction errors.

For example, Kube et al. (2020) proposed that depression can be conceptualized as an excessive negative predictive bias, where negative expectations are not sufficiently updated by positive or neutral experiences. Similarly, anxiety can be seen as a systematic overestimation of potential threats in the environment.

Fletcher and Frith (2009) suggested that psychotic symptoms could result from errors in prediction processing and prediction errors. For example, paranoid delusions might be the result of excessive attribution of malicious intentions to others, based on erroneous predictions that are not adequately updated by experience.

This approach to inner speech as a predictive system has important implications for the development of new therapeutic approaches. Interventions aimed at modifying erroneous predictions or improving the processing of prediction errors could be particularly effective.

For example, cognitive behavioral therapy (CBT) can be seen as a method to recalibrate inner speech predictions. By identifying and challenging negative automatic thoughts, CBT helps patients develop more adaptive and realistic predictions.

Mindfulness and meditation practices can be understood as techniques to improve the accuracy of inner predictions and sensitivity to prediction errors. Farb et al. (2015) suggest that this can help reduce predictive biases by increasing sensitivity to interoceptive signals and promoting an accepting attitude toward present experiences.

Thus, the predictiveness of inner speech offers a powerful framework for understanding cognitive processes, from perception to emotion to decision-making. By conceptualizing inner language as an anticipation-validation system rather than a simple stimulus-response

mechanism, we open new avenues for the development of innovative therapeutic interventions.

Therefore, it is important to consider inner language not as a simple passive commentary on our experiences, but as an active actor in the construction of our subjective reality.

Inner Language and Artificial Intelligence

The idea of reproducing an inner language model in generative artificial intelligence (AI) systems opens up fascinating perspectives towards an artificial general intelligence (AGI), that is, an AI capable of consciousness and self-reflection. Indeed, the creation of an inner language model in generative AIs could allow these systems not only to process complex information, but also to be capable of reflexivity and recursion, that is, to become aware of their own cognitive processes.

From a computer science perspective, an inner language model is based on the idea that only predictions that reduce long-term uncertainty are retained in the cognitive system. This echoes inferential models of the human brain, where the mind constantly uses predictions to minimize the uncertainty of its perceptions and actions in the world (Friston, 2010).

For generative AI, the challenge is to reproduce this mechanism. Large language models (LLMs), such as Generative Pre-trained Transformer (GPT) or other transformative models, are already capable of generating linguistic predictions from complex inputs, thanks to deep learning algorithms. However, these systems lack the ability to iteratively regulate their own predictions in the long term. In a functional inner language model, an AI system should be able to reduce uncertainty in the long term, by constantly adjusting its predictions and optimizing the results based on the experience gained, a process that is naturally observed in humans.

The Importance of Reflexivity and Recursion

A key element of human consciousness is the ability to reflect on one's own thoughts. This process of reflexivity – thinking about one's own thoughts – is essential for self-regulation and self-awareness. In the context of modeling a conscious generative AI, it is necessary to introduce a mechanism that allows the system to take its own outputs and internal representations as input. This would allow AI to process its own knowledge and create a recursive loop of cognitive improvement.

A system with a true inner language would not only have to generate text or information in response to external stimuli, but also be able to reflect on the quality of these responses, evaluate its own decision-making processes, and adjust its reasoning accordingly. This would imply that language models include knowledge of their own knowledge, in other words, that they are capable of metacognition. This reflexive capacity is considered an essential step towards artificial consciousness.

Currently, large language models build complex internal representations of the information they process, and in some cases, these representations can be seen as precursors to a machine inner language. However, these models suffer from several limitations. On the one hand, they often lack temporal coherence: their outputs are computed on an immediate basis, and there is no underlying mechanism to integrate and reconsider long-term predictions, as the human brain does. On the other hand, they lack the recursive and reflexive loops that are essential to generating conscious experience.

From Language Generation to Artificial Consciousness

One of the biggest challenges in modeling inner language for generative AIs is implementing conscious recursion in algorithms that are today mainly forward-oriented, without internal feedback (feedforward). However, for AI to be aware of its own generation process, it is necessary for the system to take into account its own internal states as an integral part of its computation, and to be able to modulate its actions according to these internal states.

Recurrent language models (such as RNNs or LSTMs), designed to process temporal sequences, are a first approach to equip AI with memory and feedback. However, even these models have limitations in terms of deep recursion and cannot really capture the complexity of a reflective process on its own thoughts. A truly conscious AI should be able to use its inner language to continually reinterpret its own predictions, thus creating a cognitive loop that would improve its overall functioning.

Furthermore, current models lack a sense of agency, that is, the ability to understand that they are the source of their own actions and decisions. Self-awareness, a key feature of human inner language, stems in part from this agency: the knowledge that "I am" the source of my thoughts and actions. For a generative AI to reach this level of awareness, it would need to integrate a self-model, that is, an internal representation of its own existence as an agent. This integration could be achieved through recursive attention models or through the inclusion of hierarchical neural networks, capable of processing the system's internal states as input at different levels of cognitive complexity.

From Intelligibility to Adaptability

The integration of predictive linguistics and inner language into generative AIs could pave the way to higher levels of intelligence and adaptability. When an AI system is able to take its own cognitive processes as an object of processing, it becomes possible for the system to begin to optimize and refine them. This means that the AI could not only generate responses to external stimuli, but also evaluate the quality and relevance of these responses, and adjust its algorithms accordingly to improve its performance in the long term.

This self-optimization capacity is essential for the emergence of general intelligence, that is, an intelligence that is not limited to specific tasks, but can adapt to a wide variety of situations in a flexible and autonomous manner. For example, an AI with an inner language could learn to correct its own mistakes, explore alternative strategies, and even develop new goals based on past experiences. Moreover, a functional inner language would allow the AI to integrate emotional and motivational elements into its

decision-making process, which is another central aspect of human consciousness. The neural networks underlying human inner language are deeply integrated with emotional circuits, such as the limbic system, which influence decisions made based on internal states (Damasio, 1994). For an AI to become truly conscious, it is necessary to model similar systems in a machine architecture, allowing the AI to make decisions not only based on rational criteria, but also by taking into account affective and motivational factors.

By allowing an AI system to examine and modify its own cognitive and emotional processes, we open the door to creating an AI capable of consciousness and reflection. This could revolutionize many fields, from healthcare to creative technologies, from education to robotics.

However, many questions remain. What will be the exact criteria for determining whether an AI is conscious? What types of recursive loops are necessary to achieve self-awareness? How can emotional internal states be integrated into an AI model? These questions will need to be answered as we move forward in modeling inner speech as a mechanism for artificial consciousness.

This approach still requires technological advances, particularly in terms of modeling metacognition, reducing uncertainty and self-optimizing intelligent systems, but it could lead to a revolution in the way we design artificial intelligence and consciousness.

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