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The mind-body-world unity: The predictive mind and the allostatic paradigm as a bridge between neuroscience and traditional Chinese medicine. A conceptual review

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ABSTRACT

This article explores areas of conceptual alignment and functional similarity between Traditional Chinese Medicine (TCM) and contemporary neuroscience, particularly the models of allostasis and the predictive mind, by comparing different theoretical frameworks to highlight heuristic analogies in the understanding of the human mind as a dynamic, embodied, and regulatory process. In TCM, *Qi* represents the vital energy that animates and connects physiological and psychological functions; in predictive neuroscience, mental activity emerges from the continuous interaction between predictive models and sensory signals, integrating perceptions, emotions, and bodily states to promote flexible and proactive adaptation to the environment. Both perspectives propose a systemic view in which mind and body co-emerge from the dynamic interaction between the individual and the environment. In the predictive mind model, persistent prediction errors can consolidate into dysfunctional patterns and contribute to the accumulation of allostatic load, thereby compromising multisystem regulation and promoting the development of chronic conditions; a functional analogy emerges in TCM, where imbalances in *Qi* reflect states of altered adaptation. In both views, illness arises from a dysfunction of regulatory processes. Healing aims to restore the dynamic balance of the mind-body-environment system, intervening before chronicity sets in. Mind-body practices are interpreted in light of contemporary neurobiology as tools for regulating communication between the brain and internal organs, reducing the allostatic load caused by chronic stress, and fostering adaptive psychophysiological balance.

"Mind is not in the head. It emerges from the interactions between brain, body, and world"

Francisco Varela

"The mind and the body are one single substance, and health consists in their harmony"

Huangdi Neijing

1. Introductory note

The present article aims to identify points of functional convergence between key concepts of Traditional Chinese Medicine (TCM) and contemporary neuroscience, particularly the models of allostasis and the predictive mind. As a preliminary clarification, it is worth noting that the concepts examined belong to fundamentally different epistemic traditions: TCM, rooted in Taoist thought and Chinese cosmology, uses symbolic and energetic frameworks based on qualitative categories, while neuroscience is grounded in formal models and empirical data, emphasizing measurement, replication, and experimental validation. The parallels drawn here are not meant to force an integration of distinct paradigms, but rather to suggest functional analogies that may open meaningful interdisciplinary dialog (see Box 1 for caveats in comparative analysis and related bibliography).

2. Complexity in ancient thought and contemporary neuroscience

In Chinese medical cosmology, the human being is conceived as a microcosm reflecting the macrocosm, embedded within a hierarchical triadic structure of Heaven-Human-Earth. Each level corresponds to a

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different dimension of the natural order: Heaven refers to universal laws and cosmic rhythms, Earth to concrete and material manifestations, while Human occupies an intermediate position of mediation between these poles. This triadic structure does not imply a linear mechanistic causality, but rather a systemic principle of correspondence and resonance (*ganying*), according to which physiological, emotional, and mental processes emerge from the dynamic alignment of different levels of natural organization (Lee, 2018). The *Huangdi Neijing* states: "Man responds to Heaven and Earth; his body is shaped according to the forms of the world; the movements of *Qi* correspond to the rhythms of Heaven". The principle of *ganying* describes the body as an open, resonant system, in constant exchange with the cosmos. As Lee writes (Lee, 2018): "The human organism is a resonant system translating macrocosmic rhythms into microcosmic physiological processes; the doctor's art lies in restoring this resonance".

This cosmological framework shapes the understanding of the human psyche and its relationship to the body. For ancient Chinese philosophers and physicians, the psychic dimension was not a transcendent or metaphysical entity separate from the body. On the contrary, the mind was seen as the result of the harmonious organization of vital processes, closely linked to physiology and the organism's internal balance. According to TCM, the mind emerges from the integrated activity of the internal organs, particularly the Heart, which serves as the "residence of the *Shen*", that is, of consciousness, mental clarity, and emotions (*Huangdi Neijing*, *Suwen*, ch. 8; translated in (Unschuld and Tessenow, 2011)). In ancient Eastern philosophy, mind and body are inseparable manifestations of a single dynamic vital principle (*Qi*) that animates every natural phenomenon and bodily function, integrated into a living system in constant balance with its environment. *Qi*, often translated as "vital breath" or "life energy", is described both as a substance and as a driving force of life, closely connected to *Yin* and *Yang*, the opposing and complementary forces that govern natural harmony. The ancient ideogram for *Qi* (pronounced "chi") is composed of two parts (or radicals): one depicts rising vapor, the other a grain of rice (upper inset in Fig. 1). The ideogram represents the fundamental nature of *Qi*, both dense and material (the grain), and energetic and rarefied (the vapor); in essence, Earth and Heaven. This concept, also present in Greece as *pneuma* and in India as *prana*, is closely related to breath and thus to life in its most essential and original manifestation (Maciocia, 2007; Bottaccioli and Bottaccioli, 2024a). With the evolution of medicine, *Qi* came to be recognized as the energetic and physiological foundation of every psychic manifestation: it is what gives form and cohesion to the entire organism. Health depends on the individual's ability to maintain harmonic resonance between Heaven-Human-Earth through the balanced flow of *Qi* (Fig. 1).

In the West, a dualistic conception of the human being developed with late antique philosophy and Christian theology, beginning with Augustine (4th century), and reached full formulation in the 17th century with René Descartes. With his *Meditations on First Philosophy* (1641), Descartes laid the foundations of modern science by radically distinguishing between soul and body, that is, between "res cogitans", the immaterial, thinking, and eternal substance, and "res extensa", the extended and perishable matter of which the human body is composed (Descartes, 2001). The dualistic view became the dominant paradigm in the history of Western thought: it profoundly influenced modern science, shaping theoretical approaches, research methodologies, and educational models based on the separation between mental and physical domains. This framework also permeated popular culture, which tends to conceive of the mind as a rational, symbolic, moral, and spiritual essence, distinct from the body and its material functions. On one hand, dualism facilitated the development of rigorous naturalistic inquiry, contributing significantly to the accumulation of knowledge about the biological foundations of life. On the other hand, over more than two centuries, it gradually undermined the idea of the human being as a unified and integrated entity.

In recent decades, however, interdisciplinary approaches such as Psychoneuroendocrineimmunology (PNEI) have brought the mind-body unity back to the center of scientific investigation. These approaches show that the psychic, nervous, endocrine, and immune systems are intimately connected and in constant interaction, opening the way to a more integrated, complex, and dynamic conception of the human being (Bottaccioli and Bottaccioli, 2020; Bottaccioli et al., 2019). Today, evolutionary psychologists and theorists of the embodied mind affirm that the psyche is an emergent, dynamic, and situated process, that finds its roots, expressions, and fundamental purposes in biological life (Varela et al., 1991; Barsalou, 2008; Ziemke, 2016; Clark, 2008). Contemporary neuroscience is converging toward an integrated view of human experience, in which mental and physiological processes are

Box 1
Epistemological caveats for a comparative dialog.

Traditional Chinese Medicine (TCM) is rooted in a symbolic-energetic and cosmological framework, whereas contemporary models of predictive neuroscience and allostasis are situated within a biological-computational paradigm. Any comparison between concepts belonging to such different theoretical frameworks must be conducted on a comparative and functional level, thereby avoiding incautious attempts to reduce one system to the other, or to suggest an ontological integration between epistemologically heterogeneous categories.

A first limitation concerns the incommensurability of the paradigms involved, and the resulting risk of "epistemic appropriation". Core concepts in TCM, such as *Qi*, *Zang-Fu*, meridians, *Yin-Yang*, and the Five Phases, are embedded in a symbolic-relational cosmology that integrates physiology, ethics, observation of nature, and clinical practice. Attempts to assimilate these concepts to neurophysiological or computational categories (such as interpreting *Qi* as information flow or meridians as anatomical correlates) may yield appealing metaphors but are not epistemologically justified. In this process, TCM risks being absorbed into the conceptual framework of Western science, losing its theoretical autonomy and being transformed into an object to be "validated," rather than recognized as a coherent system of knowledge in its own right. As noted by scholars in intercultural medicine (Kleinman, 1978; Zhan, 2009), this dynamic reflects a form of epistemic appropriation in which a non-Western knowledge system is reinterpreted through criteria foreign to its original horizon, without due recognition of its legitimacy and specificity.

A second crucial distinction lies in the different conceptions of knowledge in the two models. In TCM, knowledge arises from the qualitative observation of patterns, rhythms, correspondences, and cyclical transformations over time. Concepts such as *Yin-Yang* or the Five Phases do not describe measurable entities, but dynamic relationships among phenomena, forming a type of systemic and analogical thinking (Kavoussi, 2007; Brosnan, 2016). Contemporary neuroscience, by contrast, is based on an epistemology of measurement, where the validity of a model depends on its experimental verifiability, the reproducibility of data, and the mathematical modeling of processes.

A scientific interpretation of Chinese medicine that overlooks these epistemological differences risks reducing its conceptual richness to reductionist categories, incapable of grasping its internal logic.

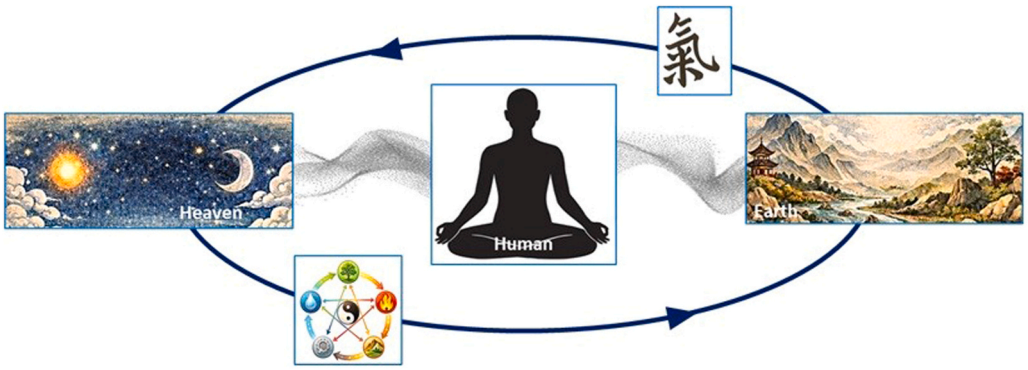

Fig. 1. The Heaven-Human-Earth triad as a structured system of energetic resonance and transformation, with the human situated at the interface of cosmic and terrestrial forces. In the ideogram for *Qi* (upper inset), the upper right radical represents curls of vapor, while the lower left depicts a grain of rice. Bidirectional blue curved arrows signify the reciprocal and continuous circulation of *Qi* between the celestial and earthly realms, governed by the dialectic of Yin-Yang and modulated by the Five Phases (lower inset). Health arises from the dynamic harmony of *Qi* flowing in accordance with the laws of Heaven, the rhythms of the Earth, and the human capacity to align with both.

understood as co-emergent aspects of the same self-regulating vital process (Barsalou, 2008; Ziemke, 2016; Clark, 2008). Several key concepts from systems theory and modern perspectives on the mind-body relationship reveal striking points of contact with the approach proposed by TCM (Kaptchuk, 2000). According to Edgar Morin (Morin, 2022), life is an auto-eco-organizational process, in which every living system constructs and sustains itself in relation to its environment through circular and feedback dynamics. Although any comparison between contemporary Western science and the Eastern medico-philosophical tradition must acknowledge the ontological and methodological incommensurability of the concepts involved and maintain the dialog on a comparative and functional level (Box 1), the convergence between the two epistemic models on the unity of psyche-body-world is increasingly evident.

3. Mind-body unity: from TCM to the neuroscience of interoception

According to TCM, the mind is not separate from the internal organs: each *Zang-Fu* (organ and viscus) is associated not only with physiological functions but also with psychological and emotional dimensions. The Heart (*Xin*) governs the *Shen* (mind or spirit), responsible for consciousness, mental vitality, and emotional stability; the Liver (*Gan*) is linked to the *Hun*, the principle of action and psychic planning; the Spleen (*Pi*) supports the *Yi*, which governs intelligence and capacity for concentration; the Lungs (*Fei*) house the *Po*, the corporeal soul linked to the Earth, which dissolves after death and is psychically associated with sensory perception and introspection; the Kidneys host the *Zhi,* which represents volition and inner strength, the force that gives stability to the personality. In this conception, psychological states and emotions are not merely mental phenomena, but functional expressions of the internal organs, each embodying a specific pattern of physiological and energetic activity. The relationship is bidirectional: each organ is associated with a predominant emotion, but at the same time, an emotion can affect its corresponding organ (Maciocia, 2007). Two directions of influence can thus be identified: from body to psyche, and from psyche to body. In the first movement, the internal organs affect emotional states: for example, an excess of Liver *Yang* may produce anger; a deficiency of Lung *Qi*, sadness; a Kidney *Qi* deficiency, fear; an excess of Heart *Yang*, manic euphoria; a Spleen *Qi* deficiency, excessive rumination or obsessive thoughts. In the reverse direction, an altered mental state can damage the organs. In sum, each organ (*Zang*) is linked to an emotion and a mental activity, and that emotion or mental activity, in turn, can feed back onto the corresponding organ. This functional bidirectionality between internal organs and psychic functions avoids mind-body dualism without falling into either biological or spiritual reductionism (Bottaccioli and Bottaccioli, 2024a, 2024b).

Recent neuroscientific evidence confirms the core intuition of TCM on the inseparable unity between psyche and body (Azzalini et al., 2019). Signals from the internal organs, continuously transmitted to the brain via vagal and spinal pathways, contribute to spontaneous brain dynamics observed during resting state, modulating the activity of a broad neural network that includes both cortical and subcortical structures, commonly referred to as the "central autonomic network" (Valenza et al., 2019). This network integrates bodily signals and coordinates physiological and affective responses, exerting a significant influence on perceptual, emotional, and cognitive processes. The coherence between visceral signals and brain activity refers to the temporal and dynamic synchronization between bodily rhythms (e.g., cardiac, respiratory, or gastric) and electrical or metabolic oscillations in the brain. Typically, high coherence is associated with more efficient processing of bodily signals, greater interoceptive awareness, and improved emotional stability, contributing to the conscious experience of the embodied self (Park and Blanke, 2019; Candia-Rivera et al., 2024; Engelen et al., 2023). One example of such integration is represented by "heartbeat-evoked potentials", which reflect brain electrical activity synchronized with afferent signals from the heart. These potentials were proposed to serve as an index of dynamic heart-brain communication, whereby rhythmic cardiac fluctuations modulate spontaneous neural activity, thus contributing to interoceptive representation and bodily self-awareness (Tanaka et al., 2025). Similarly, rhythmic gastric activity has been linked to slow fluctuations in resting-state brain activity, suggesting that bidirectional gut-brain axis may influence the temporal dynamics of consciousness and cognition (Azzalini et al., 2019; Rebollo et al., 2018). Psychopathological conditions, such as anxiety disorders, depression, and psychosomatic syndromes, are often characterized by misalignments between visceral signals and brain responses, typically accompanied by reduced interoceptive sensitivity and diminished bodily awareness. The resulting impairments in emotional regulation may manifest as alexithymia or as clinically unexplained somatic symptoms, which can be traced back to dysfunctions in the communication mechanisms between body and brain (Seth, 2013; Khalsa and Lapidus, 2016).

This neuroscientific description finds a conceptual parallel in the energetic view of TCM, which holds that health depends on the harmonious circulation of *Qi* between the internal organs (*Zang-Fu*) and the mind (*Shen*). In TCM, an excess or deficiency of *Qi* can influence emotional and cognitive states; in contemporary neuroscience, disrupted processing of bodily signals can disturb the neural patterns that support bodily awareness and psychological balance (Maciocia, 2007; Bottaccioli and Bottaccioli, 2024a). Both models recognize the central role of mind-body integration in maintaining psychosomatic harmony:

while TCM describes this harmony as the balanced flowing of vital *Qi*, contemporary neuroscience interprets it as functional coherence between bodily signals and brain networks. Therefore, the mind cannot be reduced to a mere byproduct of neural activity but must be understood as a distributed phenomenon, arising from the continuous, bidirectional interaction between brain and viscera. Despite differences in language and theoretical framework, both traditions converge in recognizing that consciousness, emotion, and cognition are embodied processes, emerging from the ongoing interplay between the somatic and the mental dimensions.

From this standpoint, it may be hypothesized that traditional Chinese practices facilitate an integrated modulation between bodily functions and mental processes, contributing to the restoration of neurovisceral coherence and psychophysiological balance (Tang et al., 2015). Breathing offers an illustrative example. EEG studies have shown that slow, controlled breathing techniques are associated with increased power in the alpha and beta frequency bands, i.e., patterns linked to states of relaxation and emotional regulation (Kumar et al., 2025; Angioletti et al., 2022). These practices modulate the coherence and coupling between the respiratory phase and the amplitude of neural oscillations, enhancing fronto-parietal synchronization between breathing and EEG activity (Dlouhy et al., 2025). Moreover, natural breathing has been shown to synchronize the electrical activity of limbic structures such as the amygdala and hippocampus, areas involved in emotion, memory, and behavior (Zelano et al., 2016), and magnetoencephalography studies confirm the existence of a cortico-subcortical network coupled to the respiratory rhythm (Kluger and Gross, 2021). Similarly, Taoist philosophy and Qigong practice assign a central role to respiratory rhythm in the harmonization of organic and mental functions: regular breathing promotes the flow of *Qi*, supporting emotional balance and vitality. Empirical research has shown that Yoga and pranayama practices can facilitate intersystem entrainment, wherein respiratory, cardiac, and neural oscillations become synchronized through slow, controlled breathing (Zaccaro et al., 2022). Slow voluntary breathing (4–6 breaths per minute) has been shown to increase heart rate variability and respiratory sinus arrhythmia, both indicators of enhanced parasympathetic tone and more effective self-regulation (Laborde et al., 2022). Importantly, beyond physiological benefits, these practices were found to reduce anxiety and emotional tension, facilitating a state of calmness and affective well-being (Kurdziel et al., 2025).

4. Allostasis requires a predictive mind-brain system

The theory of allostasis, formulated by Peter Sterling and Joseph Eyer in the late 1980s (Sterling and Eyer, 1988), represents a significant evolution in contemporary biological thought. It moves beyond the classical homeostatic model, which is based on a reactive and rigidly corrective regulation of internal parameters. According to the allostatic model, the organism does not merely correct deviations from internal equilibrium but anticipates future organism's needs, actively regulating physiological functions to optimally prepare for environmental challenges. For example, in trained individuals, blood glucose levels and heart rate increase before physical activity begins, along with the activation of thermoregulatory mechanisms: the body does not simply "react" but "predicts and anticipates". To perform this function, the mind-brain system must use internal models of the body and the environment, built and updated through experience and memory (echoing a fundamental principle of cybernetics: "A good regulator of a system must be a model of that system" (Conant and Ashby, 1970)).

In recent decades, neuroscience has profoundly transformed our understanding of the mind and brain. The "predictive mind" paradigm (Clark, 2013; Hohwy, 2016) encompasses a set of theoretical and conceptual approaches that offer compelling hypotheses about how the brain constructs experience and plans action to optimize energy balance, thereby serving allostasis (Kleckner et al., 2017). This body of theory posits that the brain is not a passive receiver of stimuli, but operates as a probabilistic prediction machine, constantly using internal models of the world and the body to actively generate hypotheses and expectations about its future states. The brain has no direct access to the external world and the internal state of the body (the "hidden causes" of its neural dynamics); it can only infer them from the sensory traces they produce. Through hypotheses and expectations generated by its internal models, the mind-brain system reconstructs the most probable causes of the inherently ambiguous and noisy sensory inputs. This perspective is known as "predictive coding". Within the mind-brain system, higher hierarchical units send predictive signals to lower levels, forecasting their activity: higher levels integrate multimodal sensory information into more abstract predictive schemas related to bodily identity, emotional states, and context, while lower levels process more immediate and concrete sensory features. Top-down predictions are continuously compared to incoming sensory signals: when the predictions match the input, the contents of the internal models (i.e., the descending simulations) are consolidated as perceptions of the world. When predictions do not match sensory inputs, prediction errors are generated and transmitted upward through the hierarchical network, fueling a dynamic process of learning and adaptation. A crucial role in this process is played by "precision weighting", the estimation of the relative precision (or reliability) of both sensory signals and internal predictions. This mechanism determines how much weight to assign to prediction errors: if a sensory signal is deemed precise and reliable, the mind-brain system gives it more importance and updates internal models more rapidly; if the signal is noisy or uncertain, the system tends to rely more on its own predictions. In this way, the mind-brain system achieves a dynamic balance between predictions and sensory signals, optimally adjusting their influence depending on context and estimated reliability (Clark, 2013; Hohwy, 2016; Yon and Frith, 2021) (Fig. 2).

The model of "active inference" is situated within this framework (Friston, 2010; Pezzulo et al., 2018; Seth and Friston, 2016; Chanes and Barrett, 2016). Active inference extends the predictive paradigm by asserting that the mind-brain system, in addition to updating its internal models in response to prediction errors (perception/learning), can guide motor activity to modify the sampling of environmental signals, so to bring reality in line with expectations (action/adaptation). In other words, prediction and action are complementary expressions of a single inferential process. Perception, action, and cognition thus emerge from the continuous interaction between top-down predictions (from internal models), bottom-up prediction errors, and the modulation of their precision, enabling flexible and predictive adaptation to the environment.

Importantly, predictive coding applies also to the perception and regulation of internal bodily states, thus supporting interoception and allostasis. In the case of "interoceptive active inference" (Pezzulo et al., 2018; Seth and Friston, 2016; Chanes and Barrett, 2016), the mind-brain system contributes to the regulation of bodily equilibrium (by modulating autonomic balance, heart rate, respiration, hormone secretion, or immune function) to minimize the discrepancy between predicted and actual internal bodily states. Within this framework, awareness of bodily states and emotions, as well as the visceromotor regulation of bodily parameters, are the result of probabilistic predictions through which the mind-brain system infers the causes of signals arising from the internal environment (Seth and Friston, 2016; Chanes and Barrett, 2016). Emotions, from this perspective, are not fixed responses to stimuli, but interoceptive predictions, i.e., anticipations of bodily states that serve adaptation and energy regulation (Barrett, 2017a, 2017b; Barrett et al., 2016) (Fig. 2).

Returning to the example of respiratory activity offers a valuable parallel between the predictive mind of contemporary neuroscience and TCM. Breathing slowly or deeply attenuates arousal not only because it reduces sympathetic activity and enhances vagal tone, but because it provides the mind-brain system with a coherent stream of interoceptive signals consistent with predictive models of "calmness" (Barrett et al., 2016). When internal models are rigid or dysfunctional, as in certain

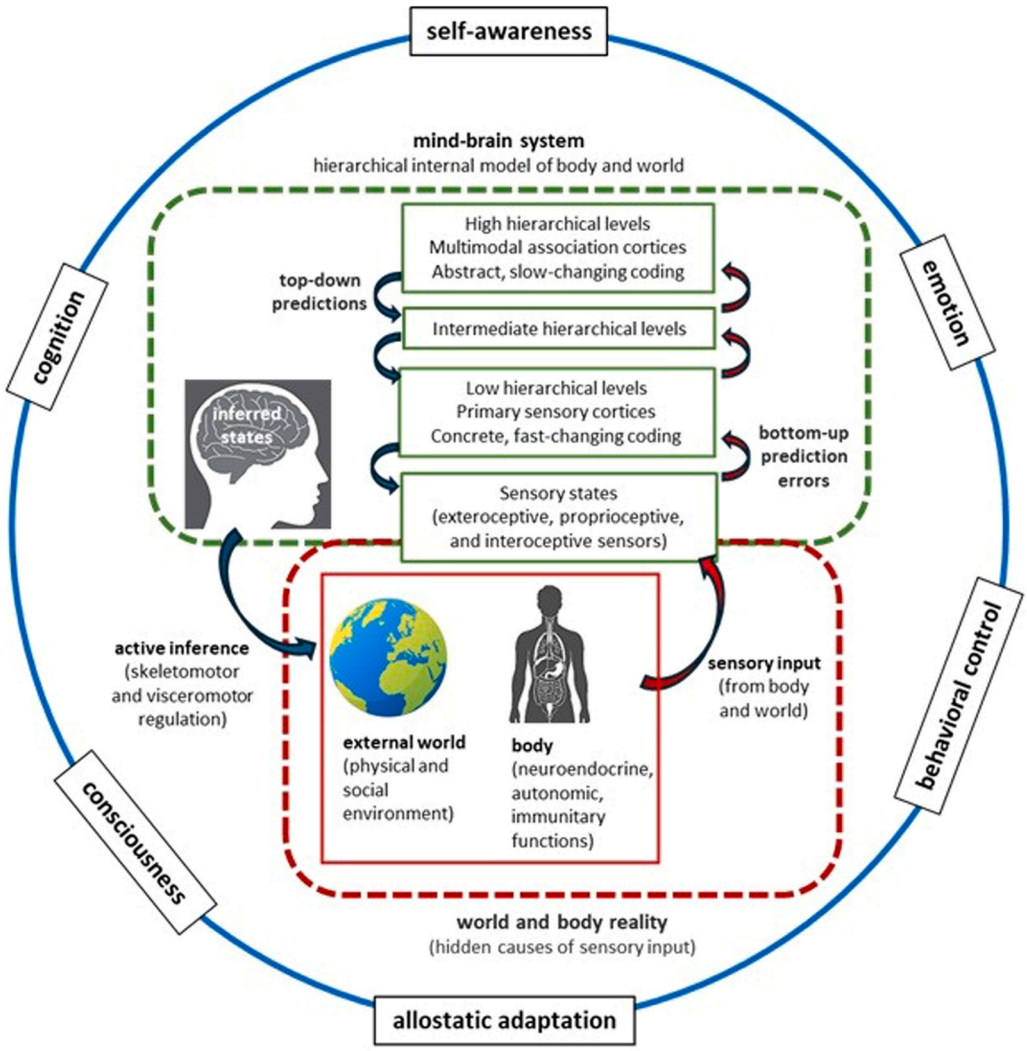

Fig. 2. The mind-body-world unity in predictive neuroscience. The mind-brain system maintains hierarchical generative models of the body and external environment (green dashed square), used to infer the hidden causes of sensory input related to bodily and worldly states: prediction signals propagate downward (blue curved arrows), while prediction errors ascend (red curved arrows). The real but hidden states of the body and world (red dashed square) influence the dynamics of sensory states at the joint border between the green and the red squares. Through continuous perception-action cycles (blue arrow for active inference; red arrow for incoming sensory signals from hidden reality), the system confirms or updates its models to better align with actual states arising from bodily and environmental interactions. Subjective experience, emotion, cognition, behavioral control, and allostatic regulation emerge from this continual loop. In this framework, health is defined by the system's capacity to maintain coherence between internal predictions and external sensory input.

affective disorders, the mind-brain system continues to generate inaccurate predictions that are not properly updated. This is the case in anxiety and depression, where subjective experience is shaped by distorted or overly stable bodily expectations (Paulus et al., 2019). In this context, slow and mindful breathing training can be understood as a tool for updating internal predictive models: voluntary modulation of respiration fosters a coherent pattern of internal sensory signals, helping to reduce interoceptive uncertainty and support more effective emotional regulation (Boyadzhieva and Kayhan, 2021). Thus, breathing is not only a fundamental physiological process, but also an active regulatory interface between consciousness, emotion, and body.

At a more fundamental and phylogenetically older level, interoceptive predictions manifest as "affects", i.e., a core of vague, indistinct experiences that non-conceptually represent the momentary condition of the body, tracking the valence and intensity of internal physiological states and signaling the salience and quality of the organism's current relationship with the external environment. These predictions primarily serve "active inference" functions (that is, the active regulation of vital variables), but they also produce the phenomenal, pre-cognitive, pre-representational experience of "being a living embodied organism". This forms what can be considered as the primitive and deep core of conscious ipseity (Seth and Tsakiris, 2018): a raw and formless experience that nonetheless powerfully influences brain activity, reaching even the highest hierarchical structures of the neocortex, where the most abstract and multimodal representations are generated (Kleckner et al., 2017). This means that the representation of the body and the affective core, along with the visceromotor regulation of physiological functions, lie at the center of our mental life, underpinning not only emotions, but all our psycho-cognitive faculties. For this reason, the signals originating from and regulating the body are an integral part of our perceptual, ideational, and decision-making processes. Consider, for example, Antonio Damasio's somatic marker hypothesis (Bechara et al., 1996) and the extensive experimental evidence showing the influence of internal signals on exteroceptive perception, spontaneous thought, and the construction of bodily self-awareness (Azzalini et al., 2019). This also explains why energy deficits and psychomotor disturbances are often the primary manifestations of psychological distress.

Studies of functional and structural connectivity have revealed in the

human brain the presence of an intrinsic “interoceptive-allostatic system” (Kleckner et al., 2017). This is a broad network extending from higher cortical areas, such as the anterior cingulate cortex (ACC) and insula (regions associated with self-awareness, executive functions, and cognitive control of behavior) to subcortical structures like the amygdala, which project directly to the hypothalamus and brainstem nuclei, thus enabling predictive visceromotor control over the autonomic, neuroendocrine, and immune systems. This network operates as a distributed and hierarchical system: interoceptive regions, such as the posterior-dorsal insula and posterior somatosensory cortex, receive afferent inputs from the body and construct primary body maps, while the anterior insula and ACC formulate visceromotor predictions that guide adaptive behavior based on context and goals (Kleckner et al., 2017; Barrett, 2017a). Moreover, the interoceptive-allostatic network is tightly integrated with two higher-order intrinsic brain networks: the Default Mode Network, involved in generating the sense of self, episodic memory, mental simulation, and future projection; and the Salience Network, which detects relevant internal and external stimuli and selectively directs attention and cognitive resources (Kleckner et al., 2017; Barrett, 2017a, 2017b; Barrett et al., 2016). Both networks contribute to assigning adaptive meaning to bodily states and integrate them with emotional, motivational, and social factors. Psychological and social dimensions, often neglected in the classical homeostatic model, become central elements in allostatic regulation: viscerosensory representation and regulation of physiological systems, beyond governing the body, adaptively shape subjective experience, emotion, and social interaction.

In the ancient TCM model, where the human being is understood as a resonant mediator between Heaven and Earth, health follows the principle of *ganying* and depends on the harmony between cosmic and bodily rhythms. In the predictive neuroscience and allostasis paradigm, health emerges from the mind-brain system's ability to maintain dynamic coherence, an “informational resonance” between internal predictive models and sensory signals from the world and the body, ensuring continuous alignment between internal representation and reality. In both paradigms, human mind and experience are not conceived as isolated entities, but as emergent processes arising from the ongoing, dynamic interaction between psyche, body, and world, between the "inner" and the "outer".

5. Allostasis and the *Qi*: analogies between predictive neuroscience and TCM

The mind can be understood as a dynamic and embodied process, resulting from the continuous interaction between internal models, sensory signals, and corrective actions. This perspective marks a radical shift from classical dualist or computational conceptions, bringing neuroscience closer to an enactive view of mind and consciousness (Varela et al., 1991): experience, in this sense, is not something one “has” about the world, but something that “is constructed through doing and feeling”, arising from situated, embodied engagement by a living being continuously adapting to its environment.

This view of the mind finds resonance with TCM, which for millennia has regarded body, mind, and environment as interdependent aspects of a unified system. In Eastern classical texts, *Qi* is described as a dynamic and transformative flow, constantly adapting to changes in the external environment (seasons, climate, stress) and internal states (emotions, diet, activity). Its balance is governed by the interplay of *Yin* and *Yang*, representing complementary but opposing forces. When *Qi* flows freely, the organism is healthy; when it becomes blocked, scattered, or accumulates disharmoniously, physical symptoms and psychological disturbances emerge (Lee, 2018; Unschuld and Tessenow, 2011; Maciocia, 2007; Bottaccioli and Bottaccioli, 2024a, 2024b). Like *Qi* in TCM, allostasis describes a proactive and cyclical regulation process, aimed at maintaining physiological and psychological balance over time. The goal is not to react passively to perturbations but to anticipate future needs and mobilize resources before imbalance occurs.

An interesting point of convergence in both models is that regulatory mechanisms rely on both innate programs and learned models constructed from experience-derived information. In the predictive mind paradigm, the mind-brain system builds internal models by recording over time the statistical regularities of organism-environment interactions, thus gradually becoming the neurophysiological realization of the causal structure of the world. Some regularities correspond to aspects of lived experience that have been inherited through phylogenetic evolution, such as stress responses, circadian rhythms, or sensitivity to biologically salient stimuli; other models, by contrast, are acquired through ontogenetic development, shaped by personal experience, social learning, and cultural practices. Similarly, in TCM, the concept of *Qi* encompasses both innate and acquired components: *Jing* (essence), transmitted by the parents and stored in the Kidneys, represents the hereditary foundation of vital energy, from which *Yuan Qi* originates, the primary force that fuels other forms of bodily energy; to this is added acquired *Qi*, derived from breathing and nutrition, i.e., the result of daily interaction with the environment. On the mental and cognitive level, TCM attributes to the function of *Yi*, associated with the Spleen, the role of processing, storing, and integrating experience (Lee, 2018; Unschuld and Tessenow, 2011; Maciocia, 2007; Bottaccioli and Bottaccioli, 2024a, 2024b). It is a faculty that registers interaction with the world and builds mental schemas and adaptive strategies, conceptually analogous to the function of internal models in the predictive mind framework. This parallel highlights how, in both paradigms, proactive, adaptive regulation emerges from a dynamic and continuous interplay between inherited programs and experiential learning.

Cyclicality and rhythmic adaptation are key concepts in both allostasis and TCM. In allostatic theory, the mind-brain system uses temporal models to anticipate metabolic demands and adjust behavior: day/night rhythms, seasonality, hormonal cycles. The brain predicts and prepares the organism for circadian and seasonal changes through anticipated shifts in hormone levels, neurotransmitters, and metabolic activity. Similarly, TCM holds that *Qi* follows natural rhythms: by day, it expands outward to protect the body; at night, it retreats inward for regeneration. In winter, it concentrates in deep organs; in spring, it expands to promote growth and openness (Lee, 2018; Unschuld and Tessenow, 2011; Maciocia, 2007; Bottaccioli and Bottaccioli, 2024a, 2024b). Both systems describe a form of predictive homeodynamics, attuned to temporal rhythms and environmental fluctuations.

Likewise, in both contemporary neuroscience and TCM, mental and emotional states are understood as dynamic, predictive, and circular processes that are deeply integrated with the organism's physiological regulation. In the predictive mind paradigm, cognitive and emotional states are not simply reactions to stimuli, but expectations and anticipations that guide sensory processing and proactively modulate bodily systems (Pezzulo et al., 2018; Seth and Friston, 2016). Within the allostatic framework, the mind is conceived as an anticipatory regulatory system that, through interoceptive predictions, modulates autonomic, immune, and endocrine functions, contributing to the maintenance of internal stability (Barrett, 2017a, 2017b; Sterling, 2012). Therefore, emotions and thoughts are not separate from physiology but represent functional components that actively participate in adaptation and self-regulation. A functional parallel emerges with TCM, which sees emotions as manifestations of *Qi* and active factors in the dynamic regulation of internal physiology. Emotions not only reflect the state of *Qi*, but also influence its movement, quality, and distribution (Kaptchuk, 2000). Emotional disharmony can disrupt the flow of *Qi* and lead to functional imbalances, whereas well-distributed *Qi* supports emotional and mental equilibrium. In TCM energetic physiology, for example, anger is linked to an unregulated ascent of Liver *Qi*; fear to its descent involving the Kidneys; sadness to its dispersion; obsessive thinking tends to stagnate the Spleen *Qi*, impairing the integration of experience (Lee, 2018; Unschuld and Tessenow, 2011). Importantly, TCM understands emotional patterns as lived, embodied experiences, accessed through

self-perception and somatic sensations, which serve as essential guides in diagnosing energetic imbalances and initiating healing. In this sense, *Qi* can be understood as the dynamic substrate of emotional and cognitive processes, whose imbalances manifest simultaneously on physical and psychological levels. Just as in the allostatic model, emotions in TCM are not reducible to psychic states; rather, they act as active agents and key processes in the ongoing regulation of the organism's internal state.

6. Beyond anatomy: function as a unifying principle in TCM and neuroscience

One of the most distinctive aspects of TCM is its functional conception of the organs: they are not primarily defined by anatomical structure, but by the physiological, psychic, and energetic activities they perform. The Heart, for example, is understood not only as a blood-pumping organ but also as the seat of the *Shen*, the mental and emotional consciousness; the Liver regulates not only the distribution of *Qi* and blood, but also emotions, initiative, and planning. Therefore, each *Zang-Fu* organ is less a fixed structural unit than a dynamic and relational function, defined by its participation in the organism's vital processes and its interaction with the environment: "Each internal organ is not simply an anatomical entity (though it is that too), but rather an energetic vortex that manifests in its different stages of aggregation across various aspects of life. Indeed, each organ is connected to a specific emotion, a tissue, a mental aspect, a color, a climate, a taste, a smell, and various other elements" (Maciocia, 2007). The term "energetic vortex", here understood not in a physical but in a functional metaphorical sense, expresses the idea that each organ is a node of interconnected vital processes, whose activity manifests across physiological, emotional, and mental levels. The organ exists insofar as it performs the function that defines it, i.e., a function determined by the specific *Qi* that animates it. This reflects primacy of function over structure as an explanatory principle of the organism (Maciocia, 2007; Bottaccioli and Bottaccioli, 2024b).

Such processual and relational view of function finds resonance in contemporary neuroscience, which has progressively moved away from a strictly localizationist conception, i.e., the idea that discrete mental functions (memory, attention, or emotion) are rigidly tied to specific neuroanatomical regions. Modern neuroimaging techniques show that cognitive and emotional functions emerge from the cooperative activity of widely distributed neural networks, whose configurations vary according to the context and the organism's state. Emotions, for instance, are not discrete entities with fixed neuroanatomical bases (e.g., fear in the amygdala), but rather mental states constructed by the brain through predictive models that integrate interoceptive signals, memory, language, and experiential context (Barrett, 2017a, 2017b). This integrative, constructionist view aligns with evidence that the same brain areas, such as the insula or the prefrontal cortex, participate in multiple functions: emotion, attention, perception, executive control. In other words, brain networks serving domain-general functions support different mental processes depending on the specific task demands and the dynamic configuration of neural activity across interconnected structures, reflecting the inherent flexibility of the mind-brain system (Pessoa, 2013). At the same time, a single function may be carried out by different neural circuits, highlighting the redundancy of representations in the nervous system.

This "many-to-many" relationship between structure and function, proposed by contemporary neuroscience, aligns with the logic of TCM, where each organ participates in multiple dimensions of human functioning (physiological, psychological, and relational). The Heart is not only circulation but also mental stability; the Spleen is not only digestion but also memory and concentration (*Yi*); the Kidneys, beyond reproduction and development, are the seat of willpower (*Zhi*). Though originating from different epistemological frameworks, the two traditions converge on a functional and systemic level: both conceive of the organism as a dynamic and complex network of interdependent processes, in which function is not an intrinsic property of an element, but emerges from the role it plays within the system.

7. Adaptation and imbalance: a dialog between allostasis, stress, and the theory of *Qi*

In the predictive mind-body system, prediction errors are typically resolved either by updating internal models or by adjusting behavior. However, when prediction errors persist or are insufficiently corrected, they may consolidate into maladaptive predictive models, contributing to the development and maintenance of pathological, often chronic, conditions. This occurs when adaptive mechanisms originally designed to maintain stability become rigid, inefficient, or overloaded, turning regulation itself into a source of dysfunction.

Stress provides a paradigmatic case for observing this process (Bottaccioli et al., 2019). In both allostatic models and TCM, stress is understood as a psychophysiological response to perceived threat or uncontrollability. Within the predictive mind framework, stress can be conceptualized as a response to predictive uncertainty, i.e., a condition in which the individual is unsure how to maintain a state compatible with allostatic needs or how to effectively pursue desired goals. Under such circumstances, the system must reallocate energetic resources to support the updating of internal models and predictions, with the aim of restoring adaptive control. In hierarchical models of "active inference", uncontrollability reflects the inability of higher-order levels of the neural hierarchy to adequately contextualize and modulate the activity of lower levels (Peters et al., 2017), with significant repercussions across the psycho-affective, behavioral, and visceromotor domains. In essence, stress arises when internal models become inaccurate or maladaptive and are no longer able to efficiently minimize uncertainty. At the neurobiological level, the activation of central neuromodulatory systems, particularly the noradrenergic system, increases the precision of prediction errors, thereby enhancing sensitivity to unexpected or novel stimuli and promoting model updating and learning flexibility. In parallel, the hypothalamus activates the sympathetic nervous system and the hypothalamic-pituitary-adrenal (HPA) axis, which coordinately regulate metabolic and physiological processes to provide the additional energy required by the brain-mind system to sustain the costs of learning. As part of this response, the HPA axis releases cortisol, which crosses the blood-brain barrier and binds to receptors in the hippocampus, amygdala, and cerebral cortex, thereby modulating synaptic plasticity and influencing learning processes (Peters et al., 2017).

While acute stress responses are often adaptive, problems arise when these responses fail to resolve predictive uncertainty. In such cases, neuroendocrine, cardiovascular, metabolic, and affective systems may remain chronically activated, leading to a progressive accumulation of "allostatic load". As defined by Bruce McEwen (McEwen, 1998; McEwen and Karatsoreos, 2022), allostatic load represents the physiological cost of sustained adaptation to stressors or dysfunctional contexts, with multisystemic consequences, including turbulent blood flow in coronary and cerebral arteries, hypertension, dyslipidemia, atherogenesis, cognitive impairment, and depressive symptoms. Chronic dysregulation can sustain a vicious cycle in which brain dysfunction and systemic disturbances mutually reinforce one another, progressively diminishing the individual's capacity to manage uncertainty and, over time, increasing the risk of developing pathological conditions. This process has been observed across a range of clinical conditions. In fibromyalgia and other forms of chronic pain, the brain may generate erroneous predictions about nociceptive input, triggering pain responses even in the absence of peripheral stimuli; these "false alarms" reinforce cycles of central sensitization, pain anticipation, and disability (Apkarian et al., 2009; Tabor and Burr, 2019). In depression, predictive models tend to overweight negative outcomes, leading to persistent pessimistic forecasting, reduced self-efficacy, and diminished sensitivity to positive signals (Huys et al., 2016; Kube et al., 2020). In anxiety disorders,

exaggerated predictions of threat generate stress responses that are disproportionate to actual risk (Paulus and Stein, 2006, 2010). Even metabolic disorders, such as insulin resistance in type 2 diabetes, can be interpreted through a predictive lens: a sustained mismatch between predicted and actual energy needs gradually disrupts metabolic regulation (Burdakov, 2019). Within this framework, pathology emerges not from isolated acute events, but from predictive and allostatic mechanisms that gradually become inefficient or pathological. Across conditions, chronic stress biases the predictive system toward rigidity, heightened sensitivity to uncertain or negative signals, and reduced adaptive flexibility, thereby amplifying allostatic load and promoting multisystem dysfunction. This body of evidence supports a mind-body-world unity, in which mental processes emerge from hierarchical and recursive interactions among neuroendocrine, cognitive, and visceromotor systems, grounded in bodily allostasis and continuously shaped by environmental contingencies.

These phenomena parallel the conceptual framework of *Qi* dysregulation in ancient Eastern medicine. In TCM, health is seen as dependent on the harmonious flow of *Qi* across organs, emotions, and bodily systems, and chronic psycho-emotional stress is believed to disrupt this flow, leading to imbalances that, much like allostatic load in neuroscientific models, are understood as early indicators of dysfunction, often emerging before overt disease. A blockage in the flow of *Qi* (stagnation) is associated with symptoms such as emotional tension, frustration, chronic pain, musculoskeletal problems, and digestive disorders; this condition mirrors a maladaptive predictive model that fails to update in response to new experience, becoming self-reinforcing and reducing the system's adaptive flexibility. Depletion of *Qi* (deficiency) manifests as fatigue, exhaustion, anhedonia, and abulia, i.e., symptoms that closely overlap with clinical depression (Maciocia, 2007; Bottaccioli and Bottaccioli, 2024a); from a neuroscientific standpoint, this reflects a system chronically taxed by prolonged allostatic strain, which responds by conserving energy through diminished engagement, motivation, and behavioral activation. In contrast, *Qi* excess resembles a state of systemic hyperactivation, characteristic of conditions such as hypertension, chronic inflammation, or anxiety disorders; in these cases, the predictive system generates exaggerated responses to minor threats, resulting in sustained physiological arousal that, over time, leads to tissue damage, disrupted homeostasis, and compromised mental and physical health (Li et al., 2019; Liu et al., 2024).

In summary, in both the predictive mind framework and TCM, chronic illness emerges when adaptive regulatory mechanisms become persistently compromised: in predictive terms, unresolved uncertainty drives allostatic overload, generating chronic conditions in which adaptation turns into dysfunction; in TCM, disrupted *Qi* flow reflects, and often anticipates, illness as an expression of disturbed adaptation. Crucially, both models emphasize the importance of early intervention, targeting dysregulation before it crystallizes into disease: it is within this intermediate zone, between physiological adaptation and pathological breakdown, that healing becomes possible: not merely by correcting outcomes, but by restoring balance within the integrated mind-body-environment system.

8. The ecology of health: adaptation, allostatic load, and the medicine of Qi

In recent decades, growing concerns about climate change, urban pollution, and the rise in stress-related illnesses have inspired an interdisciplinary field of research that connects ecology, medicine, and social sciences. These disciplines integrate concepts such as the "exposome" (i.e., the sum of all environmental, chemical, biological, social, and behavioral factors capable of influencing individual health trajectories (Farinetti et al., 2025)), and "allostatic load" (which quantifies the physiological wear and tear resulting from chronic exposure to environmental and social stressors (Hoffman et al., 2024; Liang, 2024). Together, environmental and psychosocial exposure factors amplify allostatic load, accelerating biological aging and increasing the risk of disease (Guidi et al., 2021).

Recent studies have introduced the concept of the "bio-exposome", which centers on intracellular mechanisms underlying stress adaptation, yielding insights into chronic alterations in physiological allostasis that parallel the pathological fluctuations of *Qi* described in Eastern medicine models (Minnis et al., 2024). The concept of the bio-exposome is based on the idea of "adaptive calibration": individual biology, including genetics, epigenetics, immune responses, and stress responses, shapes and is shaped by the exposome in a dynamic process of mutual adaptation. This perspective encourages the adoption of a systemic and circular approach to understanding human development under conditions of adversity (Minnis et al., 2024). From a broader perspective, a compelling parallel emerges between the bio-exposome model and the energetic vision of TCM. In both cases, the human being is conceived as an open system, in constant reciprocal interaction with the environment. According to TCM, the human is not a dominant force but an integral part of a cosmic order, in which microcosm and macrocosm reflect one another. Health results from the dynamic balance between internal factors (*Jing*, *Qi*, *Shen*) and external influences (climate, emotions, relationships), within a continuous process of regulation and adaptation. Similarly, the concept of the bio-exposome describes the reciprocal adaptation between individual biology and environmental exposures, emphasizing that allostasis and health emerge from a complex network of interactions among genetic, epigenetic, immune, and psychosocial factors. In both models, health is the outcome of systemic regulatory capacity: for allostasis, this refers to the body's ability to maintain stability through change in the constant effort of adaptation; in the medicine of *Qi*, it involves preserving vital harmony in the energetic flow, adapting to external disturbances. As a result, illness is not a sudden event, but the outcome of a progressive breakdown in adaptive mechanisms, an imbalance between the internal system and the environment.

Under the influence of Taoist and Buddhist philosophy, TCM speaks of the need to preserve the "Three Treasures": *Shen*, *Qi*, and *Jing*, which are, ultimately, three forms of *Qi*. *Shen* represents the mental-spiritual aspect; *Qi* refers to the energy we can generate and fuel through our lifestyle behaviors (such as nutrition); *Jing* is the vital essence inherited from our parents, which can either be depleted or, conversely, preserved and nourished through healthy actions. Great emphasis is placed on self-regulation and behavioral practices in maintaining health: "Those who follow *Yin* and *Yang* will live; those who oppose them will perish. Those who follow maintain good order; those who resist bring about disorder. Going against the natural flow will create countercurrents, known as internal obstruction. This is why Sages do not wait for illness to manifest before treating it but address it before it arises; they do not wait for disorder to interfere with affairs, but act before it takes hold" (Unschuld and Tessenow, 2011). Numerous studies suggest that allostatic load is partially reversible, especially when addressed in its early stages. Interventions such as regular physical activity, proper diet, exposure to nature, microbiome regulation, social cohesion, relaxation techniques, and a supportive living environment can modulate neuroendocrine and immune systems, reduce allostatic load, and support the reversal of physiological effects of chronic stress (Chbeir and Carrión, 2023; Ghasemi et al., 2024). Medicine in the 21st century is thus called to integrate ancient holistic insights with contemporary scientific evidence, recognizing that health is not merely the absence of disease, but a dynamic and systemic balance between environment, body, mind, and vital energy. This is not only a clinical objective, but also an ethical and political one, as it is closely tied to quality of life and social cohesion (Najibi et al., 2025).

9. Allostasis and the medicine of *Qi*: toward an integrated mind-body paradigm of care

Both in predictive mind theories underpinning allostasis and in the concept of *Qi* in TCM, we find shared elements emphasizing the

importance of balance and adaptability for human health. Today, healthcare faces the growing burden of chronic illnesses and stress-related disorders. Combined treatment strategies could integrate pharmacological interventions with practices aimed at enhancing *Qi*, such as acupuncture, Tai Chi, Qigong, meditation techniques, and herbal medicine, all approaches whose effectiveness in reducing allostatic load is now supported by compelling empirical evidence (Wayne et al., 2025; Minelli et al., 2025). Today, advances in neuroimaging and molecular biology offer new opportunities to explore the neurophysiological and epigenetic correlates of such practices (Jinich-Diamant et al., 2025; Buric et al., 2017; Venditti et al., 2020), providing an empirical foundation for understanding how they can modulate brain circuits and gene expression.

9.1. Meditation and mind-body practices

In recent years, neuroscience research has shown that meditation and mind-body practices induce brain structural changes (Fox et al., 2014; Laneri et al., 2016) and measurable effects on the activity and functional connectivity of brain regions crucial for allostatic regulation and affective processing. Neuroimaging studies have shown that various types of mindfulness training can modulate the activity in the ACC and the anterior insula, brain areas involved in interoceptive monitoring, bodily awareness, and emotional regulation (Haase et al., 2016; Farb et al., 2023). A meta-analysis by Marusak et al. (2018). found that meditative practice strengthens communication between the ACC and the insula, supporting more effective integration of bodily perception and cognitive control. These neural adaptations are accompanied by modulation of connectivity between the ACC and the amygdala, possibly indicating enhanced cortical control over limbic circuits, reduced stress reactivity, and more stable emotional regulation. In long-term meditators, meditative experience is associated with an increase in gray matter volume in the rostral portion of the ACC and a stable increase in functional connectivity with the bilateral insula, especially during meditative states (Fox et al., 2014; Perez-Diaz et al., 2024). These structural and functional changes appear to reflect lasting neuroplastic adaptations that support refined attentional control, improved interoceptive integration, and more conscious regulation of emotional responses.

Parallel research in the field of molecular biology has shown that mind-body practices (e.g. mindfulness, meditation, yoga, and Tai Chi) produce measurable epigenetic modifications, influencing major physiological adaptation systems (Jinich-Diamant et al., 2025; Buric et al., 2017; Venditti et al., 2020). Several studies (Buric et al., 2017; Venditti et al., 2020; Yang et al., 2021; Kripalani et al., 2022; Venditti, 2025) consistently demonstrate that these practices modulate the activity of genes involved in inflammatory responses, metabolic processes, and the regulation of the HPA axis governing the stress response. A down-regulation of pro-inflammatory genes such as *NF-κB* and *COX2* has been observed, associated with reduced cytokine release and decreased chronic immune system activation (Kripalani et al., 2022; Venditti, 2025). Contemplative practices also contribute to stabilizing HPA axis activity by reducing cortisol production and normalizing the gene expression of glucocorticoid receptors (Venditti, 2025). These effects are further mediated by the coordinated modulation of several enzymes (histone deacetylases and acetyltransferases, and DNA methyltransferases) that regulate chromatin structure and, through complex epigenomic remodeling mechanisms, influence neuronal plasticity and the stability of brain circuits involved in emotional regulation and stress management (Venditti et al., 2020; Kripalani et al., 2022; Venditti, 2025). Overall, this evidence outlines a process of integrated epigenetic regulation in which mind and body are connected in an adaptive bio-regulatory loop: through the modulation of neural activity and gene expression, the mind-brain system optimizes inflammation, metabolism, and stress-response mechanisms, promoting psychobiological resilience and supporting allostasis and adaptation.

These findings are also significant in understanding and treating chronic pain, which can be viewed as the expression of a potentially reversible epigenetic dysregulation. In fact, alterations in DNA methylation and histone acetylation in genes regulating inflammation and endocrine responses contribute to sustaining hyperactivity in nociceptive circuits and diminishing the effectiveness of central pain inhibition mechanisms, particularly in the amygdala and prefrontal cortex (Collier et al., 2025). In this light, mind-body practices such as mindfulness and mindfulness-based cognitive therapy may promote adaptive epigenetic remodeling by reducing the expression of pro-inflammatory genes, enhancing neuroprotective and antinociceptive gene expression, and normalizing HPA axis activity and cortisol levels. These processes may represent a neuro-epigenetic reorganization of pain circuits, marked by reduced limbic hyperreactivity and a recalibration of central nociceptive processing, promoting a more stable and adaptive modulation of pain through enhanced cortical control and diminished emotional reactivity to painful stimuli.

According to the predictive processing model, perception arises from the interaction between top-down mental expectations and bottom-up bodily signals. The brain does not passively receive information but constantly predicts and updates its internal representations based on the prediction error between what it expects (its internal models) and what it perceives. When the mind-brain anticipates relaxation or relief, it interprets nociceptive input in line with that expectation, generating a real experience of pain attenuation (Atlas, 2021). Factors such as trust, empathy, and the quality of the therapeutic context reduce prediction error and enhance clinical outcomes, providing a neuroscientific foundation for the role of ritual and the therapeutic relationship. Treatment expectations and therapeutic alliance are closely linked to pain reduction and to the predictive strength of analgesic responses over time (Atlas, 2021). Furthermore, the clinical context and the patient-therapist relationship modulate pain perception by shaping expectations, emotional tone, and social support, all of which influence the brain's encoding of sensory input (Kang et al., 2025). From the perspective of predictive processing, mindfulness can be understood as a form of "prediction training", that helps to refine the inferential mechanisms of the mind-brain system, allowing it to anticipate and interpret bodily and mental experiences with greater accuracy. During practice, the mind-brain system learns to reduce the weight of automatic and reactive expectations (i.e., defensive predictions based on learned patterns of stress or pain responses that anticipate threat regardless of actual stimuli) and to improve the precision with which interoceptive signals are processed (Farb et al., 2013, 2015). Recent studies have proposed that meditative training may induce a shift from "active inference" (prediction errors are minimized by acting upon the world) to "passive perceptual inference" (prior knowledge is revised considering current evidence), by modulating the "precision-weighting" between higher-order cognitive models and low-level sensory inputs (Lutz et al., 2019; Pagnoni, 2019). In focused attention meditative practices, attention remains fixed on a chosen object (breath, sensations, or sounds) while monitoring and disengaging from distractions. This process enhances the precision of attended sensory streams (interoceptive, proprioceptive, or exteroceptive) while down-weighting abstract cognitive activity such as mind-wandering (thoughts, memories, future planning), which depends on "high-level models" constructed in higher-order cortical areas (Lutz et al., 2019; Pagnoni, 2019). By remaining still and non-judgmental, practitioners can observe habitual stimulus-response patterns (e.g., a distressing thought triggering a slumped posture, tight chest, or shallow breathing) without reinforcing them; through this distanced observation, one learns to remain non-reactive (Lutz et al., 2019; Pagnoni, 2019), thus reducing the salience of spontaneous thoughts and discouraging maladaptive reinforcement, such as rumination. Overall, meditation "nudges" the predictive mind in the direction of perception (changing the model to better match the world) rather than action (changing the world to better match the model). In sum, meditation can be understood as a neuroplastic learning process that helps rebalance the mind-brain system by

enhancing the alignment between top-down predictive signals and bottom-up sensory input. This recalibration fosters the harmonious integration of emotional, cognitive, and physiological domains, thereby supporting psychological well-being and resilience, and it may help explain the observed psychotherapeutic effects of meditation in addressing depressive relapse, anxiety, chronic pain, and addictive behaviors (Barrett and Chang, 2016; Cheng et al., 2022; Priddy et al., 2018).

9.2. Acupuncture

Similarly, acupuncture can be interpreted as a bridge between the concept of *Qi* and the predictive mind model. Numerous neuroimaging studies have shown that acupuncture modulates the activity of brain structures involved in the processing and integration of pain signals, including the insula, the ACC, and the medial prefrontal cortex. These are also key structures of the Salience Network and the Default Mode Network, the major intrinsic brain networks responsible for the continuous comparison between top-down expectations/predictions (internal models) and bottom-up bodily inputs (Fang et al., 2009; Kong et al., 2009). Acupuncture can be understood as an intervention that reshapes the predictive processes of the mind-brain system by reducing the mismatch between internal models and actual sensory input, thus minimizing prediction error. In chronic pain disorders, such errors are supposed to drive hyperactivity in interoceptive and limbic networks of the "pain matrix", which are involved in interpreting bodily signals as painful or threatening. By correcting predictive distortion, acupuncture may help re-establish functional coherence between cortical areas involved in sensory, cognitive, and emotional integration and bodily awareness (prefrontal cortex, ACC, insula) and subcortical structures directly involved in autonomic and visceral regulation (such as the hypothalamus, brainstem, and periaqueductal gray). This reorganization supports a more proportionate and adaptive physiological response to real bodily states and promotes a dynamic realignment between cognitive, emotional, and somatic representations, resulting in a more integrated and stable modulation of nociceptive experience. A study by Napadow et al. (2009). demonstrated that stimulation of specific points, such as ST36 (*Zusanli*), coordinately modulates the autonomic nervous system and the brain networks involved in interoceptive awareness and allostatic regulation. During manual needle stimulation, an increase in heart rate variability and greater coherence in autonomic oscillations are observed, i.e., a dynamic synchronization among heart rate, breathing, and vasomotor activity. This condition is thought to reflect an optimal autonomic state, dominated by parasympathetic (vagal) tone, indicative of more efficient integration between mental, neural, and bodily processes. In parallel, fMRI imaging shows increased functional connectivity between the anterior insula, ACC, and medial prefrontal cortex, regions implicated in integrating bodily sensations and emotional states, as well as in predictive mechanisms that update internal models of bodily states based on actual sensory information. This reorganization of connectivity suggests that acupuncture does not act solely on peripheral sensory circuits; it rather reshapes central dynamics of interoceptive and affective integration, supporting a more coherent, adaptive bodily perception less influenced by anticipatory distortions related to pain. Within the predictive brain framework, the coherence of autonomic oscillations represents a physiological marker of reduced interoceptive prediction error: the brain learns to predict and interpret bodily states more accurately, minimizing the discrepancy between internal expectations and actual physiological signals. In this sense, the "coherence" described by Napadow et al. (2009). is an objective sign of mind-body harmonization, a dynamic balance in which parasympathetic modulation, interoceptive awareness, and perceptual stability emerge as expressions of a mind-brain system that has reduced its prediction error and restored functional synchrony between brain, body, and emotional states. Supporting this interpretation, Langevin and Wayne (2018) proposed that the mechanotransduction of connective tissues triggered by needle insertion constitutes an interoceptive signal capable of modifying the precision of bodily predictive models, thereby improving somatic self-perception and homeostatic regulation.

In sum, the healing effects of acupuncture are thought to operate by modulating allostatic circuits, reducing interoceptive prediction error, and promoting realignment between body and mind through the interplay of somatic stimulation and perceptual learning. Furthermore, the predictive model also explains individual differences in the response to acupuncture: each patient possesses a unique internal model of the body and of pain, shaped by experience, culture, and interoceptive sensitivity (Atlas, 2021; Kang et al., 2025). The mind-brain system exhibits inter-individual variability in the capacity to update predictive models; in some, it demonstrates greater adaptive flexibility to bodily and contextual signals, while in others it reveals inferential rigidity, which can influence treatment response.

10. Conclusions

Neuroscientific models of the predictive brain underlying allostasis and the principles of TCM converge on the idea that the mind emerges from bodily regulation, and that mental and physical health are inseparable. TCM anticipates, in symbolic and energetic terms, what neuroscience is now exploring in functional and computational language: the idea that sensing, thinking, and acting are integrated expressions of a continuous biological process of regulation, adaptation, and meaning-making. As Varela wrote: "The mind is not a ghost in the machine, but the way life knows and regulates itself". Eastern philosophy and TCM have always emphasized the deep connection between the body and *Qi*, whose harmony is essential to individual well-being. In a completely different, but functionally convergent, epistemological context, contemporary neuroscience identifies a similar regulatory principle in interoceptive active inference: the predictions that the brain formulates to regulate bodily states and energy balance. According to this perspective, subjective experience is deeply rooted in bodily signals: the "self" is not a metaphysical entity, but a predictive model of the body, constructed by the brain to maintain allostatic equilibrium (Seth, 2021). Similarly, TCM sees consciousness (*Shen*) as an expression of the Heart in harmony with the other organs. Both models, neuroscientific and Eastern, move beyond the mind-body dualism, proposing instead a personal identity conceived as a dynamic and relational process involving psyche, body, and world. Table 1 presents a synoptic overview of the main functional analogies between TCM and contemporary neuroscience.

The implications of this convergence are profound. On a philosophical level, they promote overcoming mind-body dualism to see the mind as an emergent property of life organized in dynamic harmony with its environment. On a clinical level, this perspective suggests that healing should be understood as a process of predictive realignment among brain, body, and environment, through which the mind-brain-world unity restores functional coherence across cognitive, affective, and somatic dimensions. This underscores the need for an integrated model of medicine that treats biological, psychological, and social factors as interdependent components of a single and unitary adaptive system. In a society marked by new forms of stress, isolation, and disconnection, rediscovering an ecology of health, which includes the mind, the body, the environment, and therapeutic relationship, is not just a scientific option but an ethical and political choice. In this light, the ancient principle of the *Neijing* that "the Sage treats what is not yet illness" resonates today as a call to develop a medicine of prevention, balance, and awareness, fostering a more person-centered clinical practice (Bottaccioli and Bottaccioli, 2024a, 2024b; Minelli et al., 2025).

CRediT authorship contribution statement

Andrea Minelli: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Table 1
Functional convergences between traditional Chinese medicine and the predictive neuroscience model underlying allostasis.

	Traditional Chinese medicine (TCM)	Neuroscience of allostasis / predictive mind-brain system
Health Model	Dynamic harmony among the flow of *Qi*, internal organs, emotions, and the environment.	Allostatic adaptation as dynamic balance between internal predictive models and bodily/environmental signals.
Conception of mind and self	*Shen* (mind/consciousness) is seen as a vital, embodied function of the Heart, rooted in the organism's physiological rhythms and dynamically related to the other *Zang-Fu*; it depends on the harmonious interaction among the *Zang-Fu* organs and the unobstructed circulation of *Qi* and Blood.	The self is understood as an embodied mind, shaped by the brain through interoceptive predictive models that anticipate and modulate bodily states; consciousness reflects the mind-brain system's ability to maintain coherence between predicted and sensed internal states, ensuring efficient allostatic adaptation.
Function vs Structure	Each organ (*Zang-Fu*) has psychic, somatic, energetic, and relational functions; primacy of function over structure as an explanatory principle of the organism.	Psychic and behavioral functions emerge from the activity of distributed neural networks, following a "many-to-many" mapping between neural circuits and functional domains.
Regulatory model	*Qi* is rhythmically regulated through cyclical transformations governed by *Yin-Yang* dynamics and the Five Phases, in harmony with the environment and diurnal/seasonal cycles.	Active inference and allostasis operate through predictive and adaptive mechanisms that proactively regulate bodily systems in accordance with circadian, ultradian, and seasonal cycles, aligning internal states with environmental dynamics.
Emotions and physiology	Emotions influence the flow of *Qi* and are linked to organ function (e.g., anger is related to Liver).	Emotions as interoceptive predictions: neural processes that anticipate and modulate bodily states and energy regulation.
Pathological process	Psychophysical dysfunction arises from blockage, deficiency, or excess of *Qi*.	Persistent misalignment between predictions and sensory signals results in allostatic load and dysfunction.
Illness and stress	Illness as *Qi* imbalance caused by environmental, emotional, or behavioral factors.	Allostatic load results from inefficient or prolonged anticipatory processes, leading to systemic, multisystem dysregulation.
Prevention and healing	*The Sage treats before illness manifests* (*Neijing*): attunement to body and environment, balancing internal and external demands.	Early intervention models to correct anomalies in predictive processing before allostatic load consolidates into pathological conditions.
Therapeutic techniques	Meditative practices, acupuncture, qigong, and breath or emotion regulation contribute to the harmonization of *Qi*.	Mind-body practices such as mindfulness and breathing techniques support the modulation of the interoceptive–allostatic network and influence epigenetic processes.

Declaration of Competing Interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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