The Neuroscience of Gut Feelings and Intuition: Gut-Brain Pathways Linking Interoception to Decision-Making

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Abstract

This review examines the key neural and gut pathways that underlie intuition and intuitive sensations, commonly referred to as "gut feelings," and their role in shaping decision-making. Intuition has long been debated as unscientific or unreliable, yet emerging evidence suggests it is grounded in measurable biological processes. The review synthesizes empirical and theoretical research across neuroscience, gastroenterology, and psychology to outline how interoceptive signals from the gut, transmitted via neural, hormonal, and immune pathways, are processed by cortical and subcortical regions and compared with predictions of bodily states generated by the brain. Through mechanisms such as predictive coding and the somatic marker hypothesis, these signals contribute to subconscious judgments that can bias or guide decisions before conscious reasoning occurs. Evidence indicates that gut-derived signals can be adaptive in uncertain or high-stakes contexts, but may also mislead when cues are irrelevant or biased. Despite advances, significant gaps remain regarding standardized definitions, measurement, and ecological validity of intuition research. By integrating multiple perspectives, this review contributes to a more comprehensive understanding of how gut–brain communication shapes intuitive decision-making and highlights future directions for refining models, addressing methodological challenges, and applying insights in clinical, organizational, and everyday settings.

Introduction

Over the past few decades, the gut-brain axis has emerged as an area of increased scientific interest (Mayer, 2011). Researchers are just beginning to understand the intricate communication system between the brain and the gastrointestinal (GI) tract, commonly referred to as the gut, and its diverse impacts on physiological and cognitive functions (Johns Hopkins Medicine, n.d.).

Studies show that more information passes between the gut and brain than any other system in the human body (Cleveland Clinic, 2023). Consistent evidence also links the gut to brain development, stress response, and mental health disorders (Cryan & Dinan, 2012). Some studies even suggest that irritation in the GI tract may send signals to the central nervous system (CNS) that trigger mood disturbances or disorders such as anxiety and depression (Johns Hopkins Medicine, 2024). This emerging understanding of the gut's involvement in both physical and emotional regulation provides new scientific insights on the long debated concept of intuition and gut feelings.

Intuition, often described as "knowing without knowing" is defined as subconscious hunches or insights constructed by the brain that arise without conscious reasoning. These thoughts can be perceived as physical sensations in the body or stomach, described as "intuitive bodily cues" or "gut feelings" (Neuroba, 2023). Although historically, many cultures recognized and valued intuition, its reality and reliability have been questioned, as many believe it is unscientific, false, and has no role in rational decision-making (Robson, 2022). However, extensive scientific research is now beginning to validate these consciously recognized sensations as real, biologically grounded experiences that subconsciously influence decision-making (Chen et al., 2020; Bechara et al., 1997).

In spite of this, significant gaps persist in defining, measuring, and understanding the role of intuition in decision-making. There is a lack of integration in existing research, as most focus on singular mechanisms involved in generating intuition, failing to capture the nuanced and multifaceted process.

Bridging these gaps is essential for gaining a more comprehensive understanding of intuitive sensations and their applications in various domains, particularly healthcare and decision-making. Validating the role of gut-feelings as a valuable diagnostic tool in clinical settings could potentially lead to earlier diagnosis and improved patient outcomes. Moreover, understanding the influence and impact of gut health on mental wellbeing and emotional regulation could provide a completely new perspective on mental disorders and treatment (Mayer, 2011).

This research seeks to narrow these critical knowledge gaps by bridging research highlighting **key neural and gut pathways that underlie intuitive sensations (i.e. gut feelings), and how they influence human decision-making.**

Background: The Gut-Brain Axis

The gut-brain axis is a bidirectional communication network in which multiple components of the gut and brain coordinate to regulate digestive, physiological, and cognitive processes. (Alzubide & Alhalafi, 2024). This system connects three primary constituents: the central nervous system (CNS), consisting of the brain and spinal cord; the enteric nervous system (ENS); and the gut microbiome (Carabotti et al., 2015). Sensory signals from the ENS and gut microbiome travel to the CNS, which in turn sends motor commands back to the gut. These interactions occur through multiple pathways including neural, hormonal, and immune signaling.

The ENS is the gut's nervous system, comprising of approximately 500 million neurons that line the GI tract, making it the most complex neural network outside the brain (Cleveland Clinic, 2023). It manages digestion, nutrient absorption, and other gut-related functions, while also acting as a sensory organ that consistently monitors the body's internal environment and relays this information to the CNS. These signals influence a range of functions, including mood, sleep, cognition and shaping intuitive judgements (Alzubide & Alhalafi, 2024).

The ENS works closely with the gut microbiome, a diverse community of trillions of microorganisms, including bacteria, fungi, archaea, and viruses, concentrated mainly in the large intestine (Gerrie, 2023). These microbes aid digestion, facilitate nutrient absorption, regulate immune responses, and contribute to hormone production. Recent research indicates that the gut microbiome also plays a vital role in regulating normal CNS function (Sharon et al., 2016). Certain bacterial species from the gut microbiome produce signaling molecules similar to those used by the ENS to transmit information to the CNS or influence local gut processes, indirectly affecting brain function (NeuroLaunch Editorial Team, 2024).

Together, the ENS and gut microbiome process interoceptive information from the body's multiple internal organs, and transmit it to the CNS, which sends motor signals in response. These interactions are hypothesized to form the psychological basis of intuitive sensations and judgements (Seth, 2013).

Methodology

This literature review was conducted using databases including Google Scholar, PubMed, ScienceDirect, and ResearchGate. Keywords such as “gut feelings,” “gut-brain axis,” “intuition,” “predictive coding,” and “decision-making” were used to identify relevant studies. Both empirical and theoretical papers were included. No restrictions were placed on publication date or study design, as the aim was to capture a broad range of findings. Articles were organized thematically and selected based on their relevance on neural pathways, gut physiology, and models of intuition. Only articles published in English were used, while conference abstracts, animal studies, and non-academic sources were excluded. In total, approximately 55 sources were reviewed, with 40 forming the core of this analysis. This review emphasizes both converging evidence and gaps across disciplines, with a main focus on building a conceptual framework that summarizes, connects, and analyzes key ideas.

Processing Sensory Information within the Gut

Current research identifies three primary mechanisms through which sensory information is encoded within the gut: **primary afferent neurons, enteroendocrine cells (EECs),** and **immune cells** (Mayer, 2011). Each detects distinct classes of stimuli and uses either neural, hormonal, or immune signaling to transmit information to the CNS, collectively forming a critical component of the gut-brain axis.

While primary afferent neurons are often emphasized as the primary source of gut-derived intuitive sensations, the indirect contributions of EECs and immune cells is often overlooked. This conceptual ambiguity may reflect methodology biases, since neuron signaling is easier to measure compared to hormonal or immune effects (Chen et al., 2020). Understanding these synergies is essential for accurately interpreting how visceral signals shape cognition and decision-making through intuition.

An integral part of the ENS, **primary afferent neurons** detect mechanical, chemical, and thermal stimuli from across the body (ScienceDirect, n.d.). Specialized membrane-bound receptors convert these stimuli into changes in the neuron's electrical potential, a process known as **sensory transduction**. If this change in potential reaches a certain threshold, an action potential is generated, triggering neurotransmitter release. Neurotransmitters are neural signaling molecules that relay sensory information to the brain primarily via the vagus nerve, enabling real-time representation of the body's internal state, a fundamental component in generating intuitive judgements.

Enteroendocrine cells (EECs) act as chemosensory transducers, detecting content within the gut microbiome such as nutrients, toxins, and microbial metabolites (Sanchez et al., 2022). When these substances interact with specialized receptors on the cell surface, they trigger internal processes that cause the cell to release peptide hormones through **exocytosis**. These signaling hormones enter surrounding tissue or bloodstream and influence brain regions involved in appetite regulation, reward processing, and emotional state (Furness et al., 2014). With exception, a subset of EECs known as neuropods can release neurotransmitters, similar to those used by primary afferent neurons (Kaelberer et al., 2020). Research highlights that while EECs play a crucial role in contributing to our sense of wellbeing and influence physical gut-feeling, their direct impact on intuition is limited (Mayer, 2011).

Immune cells within the gut comprise an estimated 70-80% of the body's total immune population. They monitor our microbial environment to maintain homeostasis and ensure a balance between beneficial and harmful microbes (Wiertsema et al., 2021). Pattern recognition receptors (PRRs) on these cells detect microbial-associated molecular patterns (MAMPs), which initiate immune activation resulting in the secretion of cytokines (Zheng et al., 2020). These signaling proteins regulate inflammation, coordinate immune responses, and influence neural activity. Cytokines can alter mood and cognition both indirectly, via systemic inflammation, and directly, by signaling to the CNS through the bloodstream or in some cases, via vagal pathways. It remains unclear whether cytokine signaling should be considered a part of forming intuition, or whether it primarily alters mood states that indirectly bias decisions as evidence for either side is limited (Khalsa et al., 2017).

Together, these three sensory systems of the gut generate the interoceptive dataset from which higher-order processes, including intuitive gut feelings, are constructed. **Table 1** summarizes the roles and communication methods of all 3 sensors below.

Table 1. Focal mechanisms in processing various stimuli within the gut and body, and communication methods used to send information to the CNS

Sensor Type	**Type of Stimuli being Processed**	**Main Signaling Molecule**	**CNS Communication Pathway**

Primary Afferent Neurons	Mechanical, thermal, chemical, and other stimuli in the body	Neurotransmitters	Vagus Nerve
Enteroendocrine cells (EECs)	Nutrients, toxins, and microbial molecules in the gut microbiome	Mainly hormones. Neuropods produce neurotransmitters	Hormones use the bloodstream, neurotransmitters use the vagus nerve
Immune Cells	Microbial stimuli and other changes within the GI tract	Cytokines	Bloodstream. Can occasionally use the vagus nerve

Communicating Sensory Signals to the CNS

After sensory information has been processed into neurotransmitters, hormones, or cytokines, the ENS transmits this data to the brain via two principal pathways; the **vagus nerve** and the **bloodstream** (Berthoud & Neuhuber, 2000; Furness et al., 2014).

The **vagus nerve** is the longest cranial nerve, and it forms the fastest and most direct pathway connecting the CNS and ENS (Gerrie, 2023). It transmits gut-derived information primarily through neurotransmitters produced by primary afferent neurons, neuropods, and certain gut microbiota. Approximately 80-90% of vagal fibers are **afferent**, carrying sensory information from the gut to the brain, while the remaining 10-20% are **efferent**, delivering motor commands in the opposite direction (Berthoud & Neuhuber, 2000). Neurotransmitters activate vagal afferent neurons by binding to specialized receptors on their nerve endings, generating an electrical impulse. This impulse travels to the **nucleus tractus solitarius** (NTS), where information is relayed to higher brain regions for interpretation. Different neurotransmitters activate specific receptor subtypes, producing distinct patterns of electrical activity that determine the type of message the brain receives (Bear et al., 2016). Despite the complexity of this process, it occurs within a few milliseconds, often preceding conscious awareness (Critchley & Harrison, 2013).

The **bloodstream** pathway is slower, but systematic and longer-lasting (Furness et al., 2014). Hormones released by EECs are secreted into the gut's capillaries and circulate systemically (Sanchez et al., 2022). Many act on brain regions where the blood-brain barrier (BBB) is more permeable, allowing them to bind to receptors in the brain involved in regulating mood, appetite, and energy balance. Cytokines follow similar principles, influencing the brain either indirectly by triggering the release of secondary messengers, or directly when they gain access to brain tissue. Certain cytokines can also signal through the vagus nerve in a manner comparable to neurotransmitters (Zheng et al., 2020; Salvo-Romero et al., 2020).

Neural Processing of Sensory Information

The **nucleus tractus solitarius** (NTS) serves as the primary relay and integration center for gut-derived signals that contribute to intuition (Hwang & Oh, 2025). Located in the brainstem, the NTS receives visceral sensory input from across the body via the vagus nerve and other afferent pathways (Berthoud, 2018). Within this structure, incoming information is integrated, filtered, and decoded to determine which signals require attention and are salient enough to be transmitted to higher brain regions. From there, the NTS forwards selected data to regions involved in emotion, interoception, and decision-making (Hwang & Oh, 2025).

Multiple cortical and subcortical regions operate in coordination to transform visceral inputs into the subjective experience of intuition (Critchley & Harrison, 2013). **Table 2** summarizes the principal brain areas implicated in this process and their respective contributions to the generation of intuitive sensations.

Table 2. Principal brain regions involved in processing gut-derived signals and their contributions in generating intuitive responses.

Brain Region	**Role in processing Gut Signals**
Insular Cortex (specifically the Anterior Insula)	● Functions as a primary cortical hub for integrating interoceptive signals relayed from the NTS, contributing to conscious awareness of bodily states (Craig, 2009; Critchley & Harrison, 2013).
Somatosensory contrex	● Encodes spatial and quantitative details of sensory signals (e.g., pressure, temperature, tension) and maps the sensation by specifying the origin and physical properties (Khalsa et al., 2018).
Amygdala	● Key region in emotional processing and decision-making (Bechara et al., 1999)

	● Assigns emotional salience to interoceptive signals (e.g. threat, reward, fear) and links them to emotionally relevant memories stored here and in the hippocampus (Critchley & Harrison, 2013).
Anterior cingulate cortex (ACC)	● Monitors the emotional salience of interoceptive input, detects inconsistencies in bodily signals, and evaluates risk vs comfort in decision contexts (Medford & Critchley, 2010).
Ventromedial prefrontal cortex (vmPFC)	● One of the most crucial components in intuitive decision making as demonstrated by Bechara et al (1999). ● Integrates interoceptive and emotional data from previous regions with stored memories of past experiences to weigh value, anticipate consequences, and guide decision making, ultimately shaping intuitive judgement (Bechara, Damasio, & Damasio, 2000).

These regions form an interconnected network that allows for dynamic processing of visceral information. Signals from the NTS likely reach multiple regions simultaneously through parallel pathways, with ongoing back-and-forth communication ensuring that bodily cues are continually re-evaluated in the context of emotional state, memory, and environmental demands (Loewy & Spyer, 1990). Notably, evidence across studies lack consensus on whether gut feelings are consciously constructed in cortical or subcortical areas, suggesting that these networks can adapt their interactions and structure based on current circumstances.

Integrating Bottom-up and Top-down Information to Construct Intuition

The brain constructs intuition by integrating two primary streams of information: bottom-up sensory input from the gut as outlined in earlier sections, and top-down predictions generated from prior experiences (Seth, 2013). Together, these processes create a mental model of the world, shaping intuitive thoughts and sensations.

Contemporary models describe the brain as a prediction machine that continuously generates expectations about incoming sensory data and updates them when prediction errors occur (Michel, 2023). It predicts interoceptive information based on patterns between past experiences and the current context. After visceral information is received from the gut, and processed by higher brain regions as discussed above, the brain compares the predicted and actual internal state of the body, all processed below conscious awareness. These predictions build the foundation for intuitive thoughts. When current bodily signals resemble those previously associated with risk or comfort, the brain predicts a similar outcome, which manifests as the subjective experience of intuition.

This process is explained by predictive coding, a theory proposing that the brain actively anticipates sensory input using pattern recognition rather than passively registering it (Seth, 2013). The brain constantly compares its predictions with actual sensory input and attempts to minimize the difference, or "prediction error". This can be achieved by updating predictions to match sensory signals or, as some versions of the theory suggest, by altering the body’s interoceptive state to match predictions.

The brain does this by sending efferent motor signals through autonomic pathways to various organs, including the ENS (Seth, 2013). A region in the brain called the **basal ganglia** helps determine what autonomic responses should be initiated, such as lowering heart rate, relaxing muscles, adjusting posture, or modulating gut activity (Loewy & Spyer, 1990).

Top-down predictions are thought to have likely evolved to enhance survival efficiency (Seth, 2013). By anticipating sensory input based on past patterns, the brain can rapidly respond to potential threats or opportunities without waiting for full sensory confirmation. This predictive capacity conserves cognitive resources, enables faster reactions, and can bias attention toward stimuli most relevant to survival.

When original bodily signals from the gut align with brain predictions, the resulting physical sensations are tied to intuition. When they differ, bodily signals generated by the brain to minimize prediction error can manifest as gut feelings. These sensations reinforce intuitive thoughts constructed by the brain by being more physical, conscious, and tangible (Chen et al., 2020).

How Gut Feelings Influence Decision-Making

Multiple studies, including Bechara & Damasio (2005) have shown that intuition can have a strong influence on decision-making by rapidly biasing choices, often operating before conscious reasoning takes place.

The **somatic marker hypothesis** (SMH), proposed by Antonio Damasio, suggests that emotional processes, particularly those expressed as bodily states known as somatic markers, play a pivotal role in shaping decisions (Bechara et al., 1997). Emotional experiences, whether conscious or unconscious, are linked to measurable physiological changes, such as alterations in heart rate, respiration, or muscle tension. These markers function as biasing signals, attaching positive or negative emotional associations to available options. By weighing potential outcomes for affective value, somatic markers can guide decisions toward perceived rewards or away from potential risks.

Additional neural and psychophysiological studies show that visceral signals such as cardiac and gastrointestinal arousal, hormonal cues, and immune markers, all communicated through the gut-brain axis, are represented in interoceptive brain regions that can influence value computations and action selection. Evidence from the early Iowa Gambling Task work and later experiments therefore support the SMH and the idea that gut feelings can be actively generated by the brain in order to confirm expected outcomes.

The Iowa Gambling Task (IGT) has been widely used to investigate the SMH (Bechara et al., 1994). In this task, participants select from several decks of cards, some of which provide small, consistent gains that yield a net profit over time, while others offer large, immediate rewards but result in greater long-term losses. Anticipatory bodily responses, such as increased skin conductance when reaching for disadvantageous decks, often occurred before the participant consciously identified which decks are more favourable (Bechara et al., 1994). Individuals with greater awareness of these cues tended to favor the advantageous decks, avoiding riskier options

(Alkozei et al., 2018). In contrast, participants with damage to the ventromedial prefrontal cortex (vmPFC) generated smaller signals and performed more poorly (Bechara et al., 1994, 1999, 2000, as cited in Miranda, 2025). Although the task did not explore gut feelings specifically, its findings demonstrate that bodily signals can indicate safe versus risky options before conscious awareness guides decision-making. While the IGT remains a cornerstone in studying intuition, its ecological validity is limited. Real-world decisions rarely resemble card games, raising the question of whether laboratory tasks accurately capture intuitive decision-making.

Subsequent studies have produced similar results. For example, Dunn et al., (2010) found that individuals who could more accurately perceive their heartbeats often made faster and more confident decisions in ambiguous situations. Sugawara (2020) demonstrated that training people to enhance their interoceptive awareness can even lead to better decision outcomes in certain tasks.

However, the evidence is not indisputable. Some studies argue that participants of the IGT may consciously learn the deck contingencies, suggesting that improved performance might reflect explicit reasoning rather than intuitive signals (Bechara et al., 1997; Simonovic et al., 2019). However, critics don’t fully account for the anticipatory bodily cues that precede conscious awareness. Therefore, the IGT may reflect a hybrid process where intuition and explicit reasoning interact. Moreover, predictive coding models highlight that somatic markers can occasionally represent false positives, where the body signals threat or reward inaccurately, hindering decision-making (Bechara & Damasio, 2005). These findings highlight the need to consider both intuitive and deliberate processes when evaluating decisions.

Discussion

Fairbank (2025) and Kaufman (2021) highlight how intuitive bodily cues can be particularly valuable when time or information is limited, or in contexts where conscious analysis is difficult, such as in social interactions that involve reading subtle, unspoken signals. They can provide speed and accuracy advantage in high-stakes contexts such as medical diagnosis, sports performance, or emergency response. Trvernymd (2023) goes further to suggest that intuition may even outperform deliberate reasoning in these scenarios, especially when the brain has accurately learned and encoded relevant patterns.

Yet, reliance on gut feelings also carries disadvantages. Both Fairbank (2025) and Robson (2022) emphasize that in situations where bodily cues are irrelevant, misleading, or are shaped by biased experiences, they can impair judgment. Furthermore, in situations requiring complex reasoning and sustained cognitive control, relying solely on intuitive sensations can lead to poor choices. Studies like Bechara & Damasio (2005) also show that bodily cues can produce false positives and are often unreliable in uncertain or complex situations.

Despite growing scientific interest in the gut–brain axis, research specific to intuition and gut feelings remains limited. The majority of studies analyzed focused on individual mechanisms or theories, such as predictive coding, the SMH, or the axis itself, rather than integrating these processes to understand intuition as a whole. This highlights a key limitation in the field, but also underscores a strength of this review. By synthesizing multiple concepts, it provides a more comprehensive perspective on intuitive processes. Additionally, much of existing research relies heavily on artificial tasks such as the IGT, limiting ecological validity. To address this, future studies should examine intuition in real-world decision-making contexts, such as medical practice, crisis response, or business negotiations to provide richer insights than laboratory tasks alone. Similarly, the absence of standardized methods for defining and measuring gut feelings makes comparisons across studies difficult, highlighting the need for consistent frameworks and measurement tools. Expanding research to integrate neural, immune, hormonal, and contextual influences may offer new insights to enhance practical applications in healthcare, education, and other fields where rapid, accurate decisions are critical. By bridging and expanding laboratory and real-world contexts, future work can deepen our understanding of intuition as a dynamic, embodied process with significant implications for both science and practice.

Limitations

This review is also shaped by certain limitations in scope and process. First, the analysis was restricted to English-language sources, which may have excluded relevant findings published in other languages and limited the diversity of perspectives considered. Second, as a literature-based review, it does not provide new empirical data to directly test or validate the theories discussed, making the findings more conceptual than experimental. Finally, the project was conducted within a narrow timeframe of 2 months, limiting the extent to which we could fully explore the range of interdisciplinary research available.

Conclusion

In conclusion, this review highlights intuition as a biologically grounded, subconscious process shaped by gut-brain interactions. Through predictive coding, the brain continuously generates expectations about the body's internal state. These predictions are compared with actual interoceptive input from the gut transmitted through neural, hormonal, and immune signaling. Cortical and subcortical regions then identify patterns between current predictions and past experiences to anticipate future outcomes and guide decisions accordingly. Physical gut sensations may arise from both sensory input or brain-driven adjustments to minimize prediction errors, thereby reinforcing intuitive judgements. Collectively, these insights demonstrate the adaptive and influential role of intuition in decision-making, particularly in unfamiliar situations, while also analyzing the underlying neural and gut pathways. By synthesizing these findings, this review contributes to a deeper understanding of how gut-brain communication and cognitive processes can create subconscious responses that influence human behaviour and decision-making. Future research should refine these models, address methodological limitations, and explore practical applications in clinical, organizational, and everyday contexts.

References

Alzubide, S., & Alhalafi, M. (2024). The Gut Brain Connection. *Journal of Behavioral and Brain Science*, *14*(03), 103–117. https://doi.org/10.4236/jbbs.2024.143008

APA PsycNet. (n.d.). https://psycnet.apa.org/record/2005-09544-006

Bear, M. F., Connors, B. W., & Paradiso, M. A. (2016). *Neuroscience: Exploring the brain* (4th ed.). Wolters Kluwer.

Bechara, A. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex*, *10*(3), 295–307. https://doi.org/10.1093/cercor/10.3.295

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*(1–3), 7–15. https://doi.org/10.1016/0010-0277(94)90018-3

Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to Decision-Making. *Journal of Neuroscience*, *19*(13), 5473–5481. https://doi.org/10.1523/jneurosci.19-13-05473.1999

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, *275*(5304), 1293–1295. https://doi.org/10.1126/science.275.5304.1293

Berthoud, H., & Neuhuber, W. L. (2000). Functional and chemical anatomy of the afferent vagal system. *Autonomic Neuroscience*, *85*(1–3), 1–17. https://doi.org/10.1016/s1566-0702(00)00215-0

Carabotti, M., Scirocco, A., Maselli, M. A., & Severi, C. (2015, June 1). *The gut-brain axis: interactions between enteric microbiota, central and enteric nervous systems*. https://pmc.ncbi.nlm.nih.gov/articles/PMC4367209/

Chen, W. G., Schloesser, D., Arensdorf, A. M., Simmons, J. M., Cui, C., Valentino, R., Gnadt, J. W., Nielsen, L., St Hillaire-Clarke, C., Spruance, V., Horowitz, T. S., Vallejo, Y. F., & Langevin, H. M. (2020). The Emerging Science of Interoception: Sensing, Integrating, Interpreting, and Regulating Signals within the Self. *Trends in Neurosciences*, *44*(1), 3–16. https://doi.org/10.1016/j.tins.2020.10.007

Craig, A. D. (2008). How do you feel — now? The anterior insula and human awareness. *Nature Reviews. Neuroscience*, *10*(1), 59–70. https://doi.org/10.1038/nrn2555

Critchley, H. D., & Harrison, N. A. (2013). Visceral influences on brain and behavior. *Neuron*, *77*(4), 624–638. https://doi.org/10.1016/j.neuron.2013.02.008

Cryan, J. F., & Dinan, T. G. (2012). Mind-altering microorganisms: the impact of the gut microbiota on brain and behaviour. *Nature Reviews. Neuroscience*, *13*(10), 701–712. https://doi.org/10.1038/nrn3346

De-Wit, L., Machilsen, B., & Putzeys, T. (2010). Predictive coding and the neural response to predictable stimuli. *Journal of Neuroscience*, *30*(26), 8702–8703. https://doi.org/10.1523/jneurosci.2248-10.2010

Dunn, B. D., Galton, H. C., Morgan, R., Evans, D., Oliver, C., Meyer, M., Cusack, R., Lawrence, A. D., & Dalgleish, T. (2010a). Listening to your heart. *Psychological Science*, *21*(12), 1835–1844. https://doi.org/10.1177/0956797610389191

Dunn, B. D., Galton, H. C., Morgan, R., Evans, D., Oliver, C., Meyer, M., Cusack, R., Lawrence, A. D., & Dalgleish, T. (2010b). Listening to your heart. *Psychological Science*, *21*(12), 1835–1844. https://doi.org/10.1177/0956797610389191

Fairbank, R. (2025, April 15). Can you trust your gut? The pros (and cons) of intuition—according to science. *Health*. https://www.nationalgeographic.com/health/article/intuition-benefits-limitations-science

Furness, J. B., Callaghan, B. P., Rivera, L. R., & Cho, H. (2014). The enteric nervous system and gastrointestinal innervation: integrated local and central control. *Advances in Experimental Medicine and Biology*, 39–71. https://doi.org/10.1007/978-1-4939-0897-4_3

Hwang, Y. K., & Oh, J. S. (2025). Interaction of the vagus nerve and serotonin in the Gut–Brain axis. *International Journal of Molecular Sciences*, *26*(3), 1160. https://doi.org/10.3390/ijms26031160

Kaelberer, M. M., Rupprecht, L. E., Liu, W. W., Weng, P., & Bohórquez, D. V. (2020). Neuropod Cells: The Emerging Biology of Gut-Brain Sensory Transduction. *Annual Review of Neuroscience*, *43*(1), 337–353. https://doi.org/10.1146/annurev-neuro-091619-022657

Kaufman, R. (2021, May 3). Trust your Gut—If you're aware of your heartbeat. *Science*. https://www.nationalgeographic.com/science/article/110110-hearts-heartbeats-gut-instincts-cards-choices-science

Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., Feusner, J. D., Garfinkel, S. N., Lane, R. D., Mehling, W. E., Meuret, A. E., Nemeroff, C. B., Oppenheimer, S., Petzschner, F. H., Pollatos, O., Rhudy, J. L., Schramm, L. P., Simmons, W. K., Stein, M. B., . . . Zucker, N. (2017). Interoception and Mental Health: a Roadmap. *Biological Psychiatry Cognitive Neuroscience and Neuroimaging*, *3*(6), 501–513. https://doi.org/10.1016/j.bpsc.2017.12.004

Lewis, R., MD. (2023, November 28). Predictive processing theories are unlocking deep mysteries in neuroscience. *Psychology Today*. https://www.psychologytoday.com/ca/blog/finding-purpose/202311/the-predictive-brain-and-the-hard-problem-of-consciousness

Loewy, A. D., & Spyer, K. M. (1990). *Central regulation of autonomic functions.* Oxford University Press.

Mayer, E. A. (2011). Gut feelings: the emerging biology of gut–brain communication. *Nature Reviews. Neuroscience*, *12*(8), 453–466. https://doi.org/10.1038/nrn3071

Medford, N., & Critchley, H. D. (2010). Conjoint activity of anterior insular and anterior cingulate cortex: awareness and response. *Brain Structure and Function*, *214*(5–6), 535–549. https://doi.org/10.1007/s00429-010-0265-x

Miranda, A., Duschek, S., & Mata, J. L. (2025). The linkage between decision-making and bodily states: an investigation using an emotional startle reflex paradigm and the Iowa Gambling task. *Psychological Research*, *89*(2). https://doi.org/10.1007/s00426-025-02114-3

Neuroba. (2025, April 18). The Neuroscience of Intuition: How do we know without knowing? | Neuroba. *Neuroba*. https://www.neuroba.com/post/the-neuroscience-of-intuition-how-do-we-know-without-knowing-neuroba

NeuroLaunch.com. (2024, September 30). *Gut intelligence: the hidden power of your second brain*. https://neurolaunch.com/gut-intelligence/

Professional, C. C. M. (2025, June 2). *The Gut-Brain connection*. Cleveland Clinic. https://my.clevelandclinic.org/health/body/the-gut-brain-connection

Protogerou, C., & Hagger, M. S. (2019). A case for a study quality appraisal in survey studies in Psychology. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.02788

Robson, D. (2022, April 5). *Intuition: When is it right to trust your gut instincts?* https://www.bbc.com/worklife/article/20220401-intuition-when-is-it-right-to-trust-your-gut-instincts

Royal Holloway, University of London. (2023, June 20). How signals from the heart shape our gut feeling on whether to trust our own judgment or someone else's. *Medical Express*. https://medicalxpress.com/news/2023-06-heart-gut-judgment.html

Salvo-Romero, E., Stokes, P., & Gareau, M. G. (2020). Microbiota-immune interactions: from gut to brain. *LymphoSign Journal*, *7*(1), 1–23. https://doi.org/10.14785/lymphosign-2019-0018

Sanchez, J. G., Enriquez, J. R., & Wells, J. M. (2022). Enteroendocrine cell differentiation and function in the intestine. *Current Opinion in Endocrinology Diabetes and Obesity*, *29*(2), 169–176. https://doi.org/10.1097/med.0000000000000709

ScienceDirect. (n.d.). *Afferent neuron.* ScienceDirect Topics. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/afferent-neuron

Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in Cognitive Sciences*, *17*(11), 565–573. https://doi.org/10.1016/j.tics.2013.09.007

Sharon, G., Sampson, T. R., Geschwind, D. H., & Mazmanian, S. K. (2016). The central nervous system and the gut microbiome. *Cell*, *167*(4), 915–932. https://doi.org/10.1016/j.cell.2016.10.027

Simonovic, B., Stupple, E., Gale, M., & Sheffield, D. (2019). Sweating the small stuff: A meta-analysis of skin conductance on the Iowa gambling task. *Cognitive Affective & Behavioral Neuroscience*, *19*(5), 1097–1112. https://doi.org/10.3758/s13415-019-00744-w

Sugawara, A., Terasawa, Y., Katsunuma, R., & Sekiguchi, A. (2020). Effects of interoceptive training on decision making, anxiety, and somatic symptoms. *BioPsychoSocial Medicine*, *14*(1). https://doi.org/10.1186/s13030-020-00179-7

The Brain-Gut connection. (2024, June 20). Johns Hopkins Medicine. https://www.hopkinsmedicine.org/health/wellness-and-prevention/the-brain-gut-connection

Ubc, A. (2024, January 8). Our second brain: More than a gut feeling. *UBC Magazine*. https://magazine.alumni.ubc.ca/2023/spring-2023/health-science/our-second-brain-more-gut-feeling

Verny, T. (2023, August 19). *Intuition: what it is, how it works — Dr. Thomas R. Verny, M.D.* Dr. Thomas R. Verny, M.D. https://www.trvernymd.com/blog/intuition-what-it-is-how-it-works

Wiertsema, S. P., Van Bergenhenegouwen, J., Garssen, J., & Knippels, L. M. J. (2021). The Interplay between the Gut Microbiome and the Immune System in the Context of Infectious Diseases throughout Life and the Role of Nutrition in Optimizing Treatment Strategies. *Nutrients*, *13*(3), 886. https://doi.org/10.3390/nu13030886

Zheng, D., Liwinski, T., & Elinav, E. (2020). Interaction between microbiota and immunity in health and disease. *Cell Research*, *30*(6), 492–506. https://doi.org/10.1038/s41422-020-0332-7