Interoception: How We Understand Our Body's Inner Sensations

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It's common to conceive of the brain as an organ designed to react to stimuli from the outside world. A heavy book falls off a table next to you, and your brain allows you to see, hear, and feel the impact. Watch a muted *video* of a book falling off a table, however, and your brain may still generate a version of these sensations — causing you to jump at the illusory slam of the book hitting the ground even though the signals we would normally process as sound or vibration are absent.

This is because our brains didn't evolve to react to the world around us, but rather to predict what's going to happen to us next, APS President Lisa Feldman Barrett of Northeastern University explains.

"Brains didn't evolve for rationality," said Barrett. "They did not evolve for you to think or to perceive the world accurately. They didn't even really evolve for you to see or hear or feel. Brains evolved to regulate a body so that it could move around the world efficiently."

The core task of a brain working in service to the body is allostasis: regulating the body's internal systems by anticipating needs and preparing to satisfy them before they arise. Interoception — your brain's representation of sensations from your own body — is the sensory consequence of this activity, Barrett says, and is central to everything from thought, to emotion, to decision making, and our sense of self.

"Your body is part of your mind, not in some gauzy mystical way, but in a very real biological way," she said during an Integrative Science Symposium at the 2019 International Convention of Psychological Science (ICPS) in Paris. "This means there is a piece of your body in every concept that you make, even in states that we think of as cold cognition."

To maintain allostasis, Barrett continued, the brain must continually construct concepts that guide the body by integrating scraps of sensory input with memories of similar experiences from the past. Creating this internal model of your body in the world allows the brain to infer the causes of the sense

data that it receives through the retina and other sensory organs.

“This predictive process is the way your brain navigates the world, guides your actions, and constructs your experiences,” she said.

Barrett’s work with functional MRI (fMRI) has also shed light on the role of the brain’s default mode network, which helps to initiate prediction signals, and the salience network, which helps to determine which unexpected sense data are important to learn in a given moment. Barrett’s research shows that both networks, working in concert, contribute to allostasis and its interoceptive consequences.

Ironically, Barrett notes, these regions’ limbic cortices, once derided as the brain’s reactively emotional “inner beast,” may be closely tied to the anticipatory processes that construct our perception of the world.

(Mis)Predictive Processes

Maintaining allostasis is a lot like managing a budget for the body, in which glucose, water, salt, and other biological compounds constitute the currency, Barrett says; as with any budget, it’s possible to run a metabolic deficit. When this happens, the brain will reduce spending on two “expensive” things: moving the body and learning new information. This can result in fatigue, confusion, and anhedonia and, in the long run, depression.

Allostatic disruption is just one of many factors that contribute to depression, Barrett notes. Appreciating the physical basis of symptoms can be helpful for people suffering with the disorder, who often feel that they can’t control their negative thoughts and feelings.

“Sometimes you feel wretched for a purely physical reason,” she said. “It’s not thoughts that are driving feelings, but feelings that are driving thoughts.”

Differences in the predictive processes supported by interoception can also contribute to psychopathology, says Martin Paulus of the University of California, San Diego. Healthy individuals, he explains, have a set of expectations about the state of the world that they update by observing and evaluating new evidence relative to past experiences.

A bicyclist, for example, may have a running model of where he can bike on the road that is based on how close cars generally come to the curb, which he would continuously update on the basis ofthe sounds of approaching cars and the distance at which he sees the vehicles pass him.

“It’s not that perception is a passive process,” Paulus said. “Perception is an active process based on what your prior experiences are.”

This process can go awry, however. A healthy individual might perceive an increase in heart rate when arriving at a party as an indicator of excitement, wrote Paulus and Murray Stein (University of California, San Diego) in *Brain Structure & Function*; someone with anxiety, however, may interpret that same interoceptive signal as predicting impending danger.

Paulus, Stein, and colleague Justin Feinstein (University of Tulsa) further investigated the basis of these interoceptive prediction schemas in Biological Psychiatry through an fMRI study of 26 participants, half of whom had high trait anxiety. The findings showed that participants in the two groups performed equally well in a series of tasks in which they had to choose between two options. Even when there was little chance of choosing incorrectly, however, highly anxious individuals demonstrated significantly more activity in the anterior cingulate, a region of the brain involved in differentiating between predictive and nonpredictive signals.

This suggests that individuals prone to anxiety may need to devote more processing resources to decision making in order to distinguish ordinary fluctuations in their physiological state from signals that predict potential harm, Paulus wrote.

Individuals experiencing this kind of interoceptive failure, including people with depression, he explained, will not shift to a more adaptive belief about the state of the world even in the face of evidence proving their current understanding is incorrect.

“You can often present this person with evidence that the anxiety is really irrational or has no basis, and yet there is a strong resistance to learning that new information,” he said.

Context rigidity, on the other hand, can lead individuals to inappropriately apply their past experiences to their understanding of an unrelated situation – for example, if a hiker who had a run-in with a bear on the trail began expecting bears around every corner on their daily commute.

Interoceptive signals can also lead us astray when our body’s signals conflict with our best interest, interfering with our intuitive decision-making abilities. To investigate this effect, Barnaby D. Dunn (Medical Research Council Cognition and Brain Sciences Unit, United Kingdom) and colleagues monitored the heart rates of 92 participants as they completed the Iowa gambling task. This measure of intuitive thinking hinges on individuals identifying that two of the four decks of cards available to them contain mostly profitable cards, while the other two decks are more likely to subtract from their final score. After completing this task, participants counted their heartbeats over several time intervals, which the researchers compared with actual electrocardiographic (EKG) measures of participants’ heart rates.

Overall, the researchers wrote in *Psychological Science*, participants with more accurate interoception were more likely to make decisions that aligned with their cardiac activity — that is, to choose a deck in response to an increase in heart rate. If their heart rates increased in anticipation of choosing the wrong decks, however, this could lead individuals to score worse than those who had less awareness of their body’s activity.

Paulus’s ongoing Tulsa 1000 longitudinal study is focused on identifying how these kinds of predictive failure modes contribute to various psychopathologies involving substance use and eating behavior. One aspect of the study puts cardiac interoception on center stage, tasking participants with counting their heartbeats to assess their awareness of their own bodies.

“What I would like to do is see whether we can build, in a literal sense, the EKG of the psychiatrist,” Paulus said.

In addition to supporting more precise diagnoses, this could enable practitioners to communicate how failures in the predictive processes that draw on interoception may contribute to psychopathology on an individual basis, he concluded.

Listen to Your Heart

In the absence of input from the outside world, the brain might generate its own spontaneous activity, but it's also possible that such activity reflects the brain processing visceral input from our internal organs, said Catherine Tallon-Baudry, who studies cognitive neuroscience at École Normale Supérieure in France. The heart and the gastrointestinal tract both generate their own electrical activity (this is what allows a donor heart kept in cold-storage to continue beating on its own) and, during fetal development, these organs begin contracting before the brain becomes fully active. This suggests that the brain develops in response to these organs.

"We tend to think that the brain is sitting on top of the pyramid, and it's controlling the body in general — actually, it's probably the other way around," Tallon-Baudry said.

One indication of this is the way in which information is relayed to and from the brain through the body's sensory pathways: 80% of fibers in the vagus nerve ascend from organs such as the stomach and the heart to the brain, while just 20% descend in the reverse direction.

This sensory interplay may be about more than just allostatic regulation, however — Tallon-Baudry's research suggests that it may also support first-person perspective taking, a foundational building block for our sense of self.

To be conscious, you need to have a subject of consciousness, she explains, and interoception of signals from our organs may help our brains unite incoming information — including sight, body placement, and cognitive categories — into a singular point of view.

Discussions of consciousness can easily veer into philosophical territory, Tallon-Baudry said, but her work focuses mainly on the mechanical aspects of this phenomenon.

"We know there is a lot of unconscious information processing in the brain, so having first-person perspective is not necessarily a default mode. We need a mechanism to account for it," she said.

In a *Journal of Neuroscience* study probing the link between the heart and first-person perspective, Tallon-Baudry and colleagues Mariana Babo-Rebelo and Craig G. Richter (École Normale Supérieure) monitored 16 individuals' heart and brain activity using magnetoencephalography (MEG) as their minds wandered. The participants were periodically interrupted by a visual stimulus, at which point they reported the content of their thoughts. During thoughts that participants later reported being about themselves, individuals demonstrated a greater neural response to their own heartbeat in the default mode network than during thoughts about someone or something else.

"How the brain responds to heartbeats distinguishes between self and other," Tallon-Baudry said.

One application of this and other findings related to visceral inputs, she noted, is to aid in the difficult

task of assessing patients in unresponsive states, such as those emerging from comas. Monitoring the brain's response to heart rate can reveal transient signs of consciousness in these patients, Tallon-Baudry explained, which can have serious consequences for end-of-life decisions.

Feeling Is Seeing Is Believing

Interoception of input from our hearts can also influence our visual perceptions, said APS Fellow Manos Tsakiris (Royal Holloway University of London, United Kingdom) — whether what we're seeing is there or not.

Faulty predictive coding can contribute to a range of phenomena, he notes. In the United States, for example, Black individuals are more than twice as likely as Whites to be unarmed when killed during encounters with police, who sometimes report misidentifying objects such as phones as guns and other weapons.

This racial bias has also been demonstrated in the lab, where White participants engaged in weapons identification and first-person shooter tasks are more likely to report seeing a gun or to fire their digital weapon in response to images of Black individuals.

In a similar Nature Communications study of 30 White participants, Tsakiris and colleagues monitored individuals' cardiac cycles using EKG during a weapon-identification task. The researchers found that individuals were more likely to identify a non-threatening object as a gun when it followed an image of a Black individual presented during cardiac systole, when blood is ejected from the heart, than during cardiac diastole, or between heartbeats.

This suggests that ongoing heart activity — and cardiac systole in particular, which is thought to enhance perception of fear-inducing stimuli — can influence the expression of bias, Tsakiris and colleagues Ruben T. Azevedo (University of Kent, United Kingdom), Sarah N. Garfinkel (University of Sussex, UK), and Hugo D. Critchley (Brighton and Sussex Medical School) wrote.

"Rather than saying seeing is believing, we should think more about believing is seeing," Tsakiris said. "The kinds of prior beliefs and experiences that you have dominate perception."

Our body's response to images can also shape the way we see our sociopolitical world, which, at times, can make it difficult to separate fact from fiction, he says. In his ongoing research, he has found that heart acceleration in response to photojournalistic images of human suffering is correlated with judging that image to be real, rather than staged or edited. Individuals who have difficulty labeling their own emotions, on the other hand, are more likely to dismiss such images as faked.

One factor that doesn't appear to play a role in these studies, Tsakiris notes, is political orientation: Both conservatives and liberals were found to use arousal as an index of realness, though the link between arousal and perceived realness was stronger in older participants.

"Images from paintings to icons to photojournalism and beyond have always been very powerful cultural agents that shape culture and the ways we experience social and political events, especially when these are happening remotely," Tsakiris said.

These images are often thought of as “truthful witnesses of reality,” he continued, but at the same time, they reflect our beliefs. It’s this illusion of authenticity, supported by the interoceptive properties that construct our realities, that can make these and other perceptions so powerful. œ

References and Further Reading

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