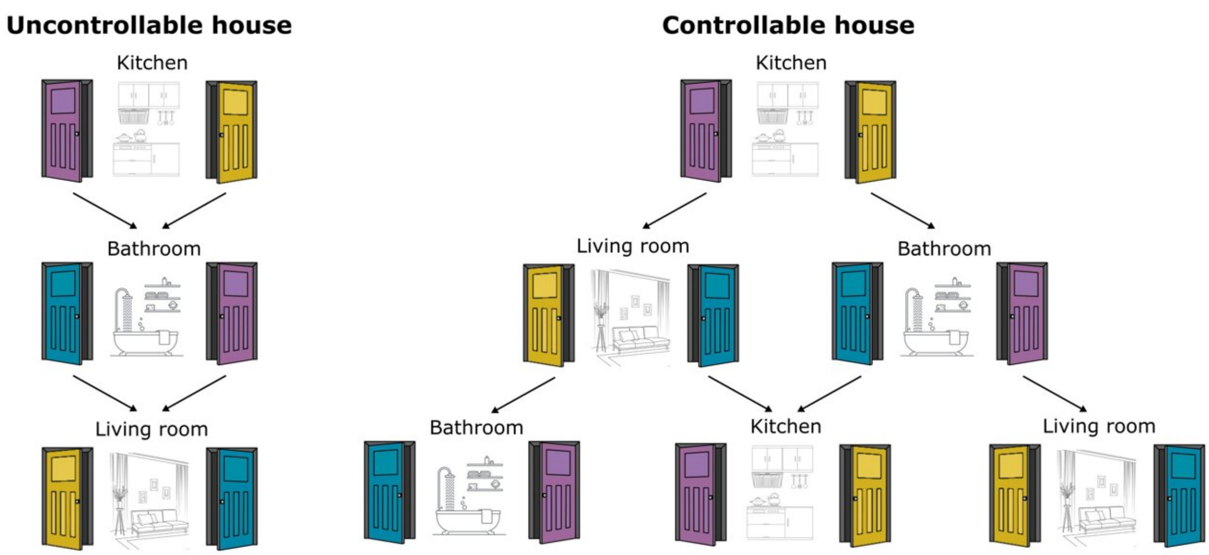
Medical Xpress

How does the brain know whether our actions actually make a difference?

March 10 2022



In "controllable houses", the door's color determines which room it leads to. In contrast, in "uncontrollable houses" the sequence of rooms is fixed, making your choices meaningless. Credit: Romain Ligneul

Determining whether we have control over a situation is not just a matter of trial and error. Our ability to do so is strongly influenced by internal factors, most prominently by our mental state. High levels of stress, anxiety and depression impair people's sense of controllability, often causing them to believe that their actions don't matter, even when they do.

Scientists have been investigating how this complex cognitive process works for decades. However, due to conceptual and methodological confounds, progress has been slow. In a new study, published today (March 10th) in the journal *Nature Human Behaviour*, researchers from the Champalimaud Foundation in Portugal and the Donders Institute for Brain, Cognition and Behaviour in the Netherlands, present a breakthrough in the field.

"The mechanism we have discovered hasn't been considered before, but we have gathered ample evidence—from behavior to neural activity—to strongly suggest that this is indeed how the brain calculates controllability," said the study's lead author, Romain Ligneul, a postdoctoral researcher at the Champalimaud Foundation.

Are you in control?

To determine how the brain estimates controllability, the team first had to design the right experiment. But how can a person's subjective sense of control be measured objectively?

"To give an intuitive idea of how our task works, I like to use a metaphor," said Ligneul. "Imagine that you are walking around a virtual-reality house where every room has two doors that sometimes change color."

The team designed different houses that look identical, but have one key difference: they can either be controllable or not. In "controllable houses," the door's color determines which room it leads to. Once you have learned the correct associations between door-color and rooms, you can choose where to go next. In contrast, in "uncontrollable houses," the sequence of rooms is fixed. So, for example, if you are in the kitchen, either door would take you to the bathroom, making your choices meaningless.

"Since the houses look alike, we can switch participants between controllable and uncontrollable houses without their knowledge," said Ligneul. "Then, we let them explore the house a little bit before we ask: 'which room lies behind either of the two doors in front of you?'"

When the question pops up, you might not have fully grasped what's going on yet. Especially since once in a while, the algorithm would confuse the subjects by changing the door-room associations. Still, your answer will reveal what your intuition tells you. If you feel you don't have control, you would say that both doors lead to the same room. However, if you feel like your choices matter, you would specify a different room for each door.

The actor versus the spectator

With this clever experimental design, the team has uncovered a new mechanism that explains how the brain estimates controllability. "We found that there are two learning processes that occur in parallel: the actor and the spectator. The brain continuously monitors and compares these two processes to determine which is better at making predictions," explained Zachary Mainen, a principal investigator at Champalimaud Foundation and co-author of the study.

"A game of tennis is a good example of how the systems operate," added Ligneul. "The actor system would be dominant when it's your turn to serve, because your brain needs to calculate which actions would generate the best trajectory. However, if you are in the return position, then there's nothing you can do to determine where the ball will land. So in that case, your brain would opt for the spectator system so that you'll be ready when the ball comes your way."

A stress test

The team's novel learning model gained further support when they added stress to the equation. "Similarly to anxiety and depression, exposure to uncontrollable stressors is known to lead to illusions of lack of control," said Ligneul. "We, therefore, reasoned that if our model was indeed correct, then exposing participants to such stressors before the task should tilt the scales towards the spectator system."

The stress test confirmed their hypothesis. Participants that received a series of uncontrollable mild electric shocks tended to adopt the spectator's position. And the higher their general stress level was to begin with, the more effective the manipulation was. On the other hand, even though they effectively received the same number of shocks, participants who could take action to avoid the shocks were better at implementing the actor model.

Why would these early experiences influence people's perception of controllability later on? According to Ligneul, there are two hypotheses. The first is that high-stress levels may trigger emotional processes that impair performance in cognitive tasks. The other, which he finds more likely, is that they are actually just being rational. "Their experience has taught them that the world is uncontrollable. So when they approach a new situation, this prior assumption guides their predictions and decision-making process," he suggested.

A novel brain circuit

In the final part of the study, the scientists investigated the neural basis of this mechanism. This time, participants performed the task inside an MRI scanner that collected images of their brain activity in real-time. Using this approach, the team pinned down several key brain areas.

"We found certain brain structures that encode signals relating to the actor learning process and others that encode both processes. This means that the brain can compare these different sources at any given moment to estimate controllability," explained Lignuel.

Is it surprising that the same brain area would represent both processes? "Not at all," Ligneul answered. "Since the two processes need to be compared continuously, colocalization would help ensure that the comparison can happen quickly."

Development, depression & control

Armed with this series of insights, the team plans a series of follow-up studies. "Our findings have broad implications in diverse fields," said Ligneul. "We are excited to investigate how this mechanism evolves with age and how various factors, such as growing up in a stressful environment, affect it. Also, we are looking forward to exploring this mechanism within the context of mental disorders. We believe that this approach will shed light on why depression leads to illusions of lack of control, and how psychiatric drugs work, which are wide-open questions," he concluded.

More information: Romain Ligneul, Stress-sensitive inference of task controllability, *Nature Human Behaviour* (2022). DOI: 10.1038/s41562-022-01306-w.
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