GOOD VIBRATIONS

By deconstructing the brain's decision-making process, can neuroscientists unravel the secrets of happiness?

By Alex Hutchinson
Photographs by Ziv Koren

Déborah Marciano's path as a cognitive neuroscientist started with a surprise. She was analyzing the data from her very first PhD study, which used electrodes placed on the scalp to explore how regret is encoded in the brain, and saw a pattern emerge in the results. But it was precisely the opposite of what she'd expected.

Research has shown that after choosing between two options, people typically feel worse when they realize that the alternative, unchosen possibility yielded a better result than the one they selected. Think of those TV shows in which a contestant has to decide which door to open to reveal a prize. Getting a thousand dollars feels great, but less so if you learn you could have won a million dollars.

To find the neural correlates of regret, Marciano set up an experiment very similar to these shows: she asked subjects to choose between two boxes displayed on a screen. Each contained either a monetary reward or a loss. After subjects decided, they saw the unchosen outcome and then their own. "We found that people care about the alternative outcome, but not as we predicted," says Marciano. "From looking at their brainwaves, it seemed that for certain outcomes, subjects were *happier* following a good alternative, not less happy. But why?" She reran the analysis and eventually reran the whole experiment, measuring brain activity for hours at a time in 40 volunteers. But the results didn't change.

It turned out to be a lucky break. Marciano had stumbled upon what's now known as the alternative omen effect, a striking example of how our subjective experience of a given outcome is shaped by its context. Untangling how our brains make sense of what-ifs and could-have-beens remains a puzzling challenge for neuroscientists — and an important one: "I think that understanding what shapes our subjective experiences can help us make objectively better decisions," she says, "and also decisions that will make us happier."

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Marciano was born and raised in Paris and planned to move to Israel after high school, but her parents wouldn't let her go until she'd finished a university degree, so she was left scrambling at the last minute to find a program that would let her in. She'd imagined being a doctor but ended up in a selective and highly unusual double major at the Sorbonne, combining law and economics. Grappling with topics such as utility and satisfaction, and how to incentivize people to do the right thing, she saw a common thread: the question of how people make decisions in the messy real world.

After graduating, she headed to the Hebrew University of Jerusalem, where she studied psychobiology and enrolled in the university's unique interdisciplinary honours program in the humanities. By this point, she'd decided to become a cognitive neuroscientist. Marciano stayed at the Hebrew University for her master's and PhD, supported by an Azrieli Graduate

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Studies Fellowship from 2015 to 2017, while also completing a program at the Federmann Center for the Study of Rationality, where most of her classmates were philosophers and economists. Despite the seemingly meandering path for a would-be brain scientist, it all led her back to decision-making.

"I think in research it's really an advantage to have all of these backgrounds, because you think of the big questions," she says. "It helps you make connections between all these different fields. You have them in the back of your head, and you just can't help but connect the dots."

The alternative omen effect is a reflection of our angst about the road not taken. Marciano found out in her experiment that when participants were shown the outcome of the unchosen option, they formed biased expectations: "When the box they *didn't* choose turned out to contain a prize, subjects became more pessimistic about the chances that their box would contain a prize. They expected to lose." Even when the experiment was set up to make it clear that there was no correlation between the two options, and that the number of prizes in the game was not limited, the effect persisted. It was as if, she and her colleagues concluded, we intuitively assume that there's a limited amount of luck in the world.

Marciano is still interpreting the implications of a belief in limited luck — whether it's limited in time or space, what it means for how we make decisions, and so on. But the results also carried a broader message: how we perceive a given set of outcomes depends on how they're presented to us. Change the context and you change our response. In this case, some irrelevant information about the other option changed people's expectations and, in turn, their subjective experiences. And that led her to consider another gambling riddle, the near-miss effect, in her postdoctoral research.

In 2019, Marciano moved to the University of California, Berkeley to work with Robert Knight, a world-leading neuroscientist, and Ming Hsu, a neuro-economist based in Berkeley's business school.

Marciano quickly made a positive impression, displaying "that rare combination of theoretical brilliance, empirical skills, productivity and motivation that highlight future scientific leaders," Knight says. She is also committed to building diversity in science, he adds: during the COVID-19 pandemic, she successfully lobbied for enhanced childcare funding for postdoctoral researchers and co-authored a paper on gender bias in academia.

To track how the expectations of people change over time, Marciano uses neuroscience techniques that can capture rapid changes in brain activity, such as electroencephalography (EEG) and intracranial EEG.

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The near-miss effect sits comfortably at the intersection of Knight's and Hsu's interests. Consider a slot machine where you have to match two symbols to win. "In theory, there are just two types of feedback: you win or you lose," Marciano explains. "But that's not the way it feels, right?" If the first spin stops at a lemon, and the second spin appears to be slowing to another lemon but then stops one agonizing click short, you'll feel something different compared to a "full miss." Gambling research has found that compared to losing decisively, *almost* winning makes people more unhappy, but also more likely to take another spin — a fact that explains why, in many jurisdictions, casinos are expressly forbidden to program their slot machines to deliver an excessive number of near-misses.

The mechanism behind this curious effect, however, is not clear. "When I first read about the near-miss effect, I immediately wondered whether this was about expectations again," says Marciano. "At a slot machine, the most exciting part of the game is the spinning part. This is what we are attracted to. It's not that we close our eyes and just wait for the game to finish. Something is happening during this spinning, and especially during the deceleration. We're forming expectations, I think, and these expectations change the way we feel about losing."

Gambling researchers have been studying the near-miss effect for decades in the hope of understanding pathological gambling and addictions. But Marciano's interest goes beyond gambling. "I use biases in general, and the near-miss effect in particular, as a window into something bigger and more general," she says. "These experiences help us understand how the brain processes reward. The alternative omen and near-miss effects are very specific situations in which our surprising behaviour gives us a hint about the processes going on in the black box of our mind."

The near-miss effect also made her think about expectations in a new way. Reward expectations play a very important role in cognition, impacting faculties such as memory, learning, motivation and satisfaction, but they have traditionally been studied as static. "In many real-life situations, however, expectations are not fixed," says Marciano. "They evolve as situations unfold, sometimes within seconds. Consider a football game. You don't sit through the game thinking, 'My team has a 30 per cent chance of winning.' Your expectations vary as the game evolves and goals are scored. Same goes for a car accident, or a date. Given the central role of expectations in cognition, we felt it would be important to study the dynamics of expectations. We were wondering how we could capture these dynamic expectations, and if and how they shape our subjective experience."

Slot machines provide Marciano with a real-time way to observe dynamic expectations and develop a deeper understand of how they relate to subjective experience. Plus, because slot machines are used frequently in gambling research, there are already validated research paradigms. To track changes in expectations, Marciano uses neuroscience techniques that can capture rapid changes in brain activity: electroencephalography (EEG) and intracranial EEG.

Knight's research group works with patients who are about to undergo surgery for epilepsy. They've had electrodes implanted in their brains to figure out where the seizures are starting, but often have to wait for a week or so before the surgeons are sure they've identified the right spot. While they wait, many patients agree to take part in neuroscience experiments. The intracranial — inside-the-brain —

electrodes provide high-resolution measurements of brain activity that are impossible with conventional imaging techniques, Knight explains. With a network of collaborating surgeons across the United States and around the world, his research team always has someone ready to hop on a plane whenever one of these patients is available and willing to participate. This tool gives Marciano the ability to observe how subjects' brain activity changes on a moment-by-moment basis.

One day last fall, Marciano received data from an epilepsy patient in Oslo who had played a series of virtual slot machine games the previous day. Activity in the patient's orbitofrontal cortex, an area that integrates information about potential rewards from other parts of the brain, "beautifully tracked" their changing expectations as the slot machine spun: a gradually swelling crescendo of hope followed by a sudden crash, in the case of near misses.

The anterior cingulate cortex, meanwhile, keeps track of prediction error: the gap between what you thought was going to happen and what actually happened. The interaction between these two brain regions — between expectation and prediction error — as the wheels spin may be what gives us the mistaken impression that we'll win if we drop just one more quarter into the machine, Marciano suspects. But nailing down the role of other brain regions will take time and luck: the data she gets depends in part on where her volunteers' seizures originate, which determines where the electrodes are placed. In the meantime, a series of EEG and behavioural experiments have confirmed her predictions: our expectations can change within hundreds of milliseconds. This "rollercoaster of expectations," the ups and downs, predicts happiness ratings following gains and losses on the slot machine. Future studies with lesion and Parkinson's patients (who often develop problematic gambling habits once medicated) will help her understand the neurobiological mechanisms at play during expectation formation.

Daniel Kahneman, the Nobel Prize–winning psychologist who helped pioneer the study of cognitive biases, was famously skeptical of our ability to overcome them. Knowing that you're prone to certain patterns of thought doesn't necessarily enable you to avoid them, he argued. Will learning about the near-miss effect help anyone walk away from a slot machine rather than dump more money into it? Or to navigate other situations where near misses influence our responses, from picking stocks to driving in traffic?

To Marciano, this framing of the question is too narrow. To her, there's no doubt that understanding seemingly irrational responses like the alternative omen and near-miss effects can be used to alter behaviour. "I think the casino industry understands this very well," she says, "and they exploit it." But there are also broader benefits to understanding the mechanism behind biases. "The near-miss effect was just the starting point that led us to ask how we form expectations from moment to moment," she says, "and how these expectations relate to outcome evaluation in healthy cognition and in disorders such as depression."

Moreover, after years of studying decision-making from the perspective of economists, philosophers and psychologists as well as brain scientists, Marciano doesn't believe we should aspire to a robotic rationality that makes every decision on the basis of its predicted utility. The changes taking place in our brains as a spinning slot machine wheel slows to a halt reflect a much larger truth about how our subjective experiences depend as much on the journey as the destination. "I think we're now understanding that happiness is not just 'Did I win?' or 'Did I lose?'" she says. "It's also, 'Was I surprised along the way? Did my hopes go up or down?' Just like with a rollercoaster, focusing on the start and the end doesn't tell you much about the experience. Looking at the turns and loops is a whole other story." ▲●■