How our brain perceives time

"If you are standing on hot coals, a second feels like an eternity," Albert Einstein notes to President Franklin Roosevelt in the recent National Geographic Channel miniseries *Genius*. "But when you are in bed with a beautiful woman, an hour passes in a split second. That is relativity."

It's sexed up slightly from a more commonly quoted Einstein saying, but the idea is the same. Relativity theory describes how speed and gravity affect the passage of time. Near a black hole, for instance, Einstein's General Relativity theory predicts that time would pass faster for a space traveler than for those left behind on Earth. That's the basis of the 2014 hit movie *Interstellar*, about a man who ends up biologically the same age as his grandchildren, after a space mission that for him, and for all clocks and other devices aboard his ship, had taken only a few years. It wasn't a mental phenomenon akin to analogy that Einstein gave to FDR. The protagonist of *Interstellar* really did move faster through time than everyone else, a reality that is supported by experiments with atomic clocks, and by the Einstein field equations that comprise General Relativity.

But the brain's ability to perceive the passage of time differently at different moments is actually another kind of relativity –neurorelativity. It's a very new field, having emerged only over the past few years, but with his hot coal analogy Einstein unwittingly predicted it.

The brain has its own time dilation

Speaking with world leaders, celebrities, and the public, Einstein could not always speak in the language of math. He had to summarize, capturing the attention of his audiences with an opening hook that related his fundamental discoveries about the fabric of space-time to everyday experiences. The hot coal analogy is just one example, but in using it, perhaps unwittingly, Einstein predicted one direction that neuroscience is taking in our era, the elucidation of timing mechanisms within the brain, and the relation of such mechanisms to internal perception of time. Highlighted in a new book, *Your Brain is a Time Machine*, by UCLA behavioral neuroscience professor Dean Buonomano, internal time perception runs the gamut subjective feelings like how fast your day seems to be running, to very measurable things, like how the timing of speech affects your understanding of it. As an example of the latter, Buonomano notes how the following sentence has two different meanings, depending on the length of pause between the last two words:

"They gave her cat-food"

"They gave her cat food."

One of Buonomano's central points is that time perception is complex, involving disperse areas of the brain. There is a timing area –the suprachiasmatic nucleus (SCN) in the hypothalamus– that responds to the light-dark cycle in the course of the day, affecting your sleep. But the SCN doesn't tell you how many days and nights have gone passed, nor does it account for why your two days at Disneyland seemed to fly by much faster than your two hours at the dentist. The bulk of research shows that those differences, and hearing the difference between feeding a cat any food, and being fed cat-food, depend on multiple brain areas at once.

That's on the sensation end of things, but when it comes to saying the lines about the cat, we're in the realm of the brain's motor system. This aspect of neurorelativity research brings us to a specific part of the brain, the cerebellum. This area of what's called the hindbrain (the lower region of the brain) has been known for well over 150 years for it's role in motor control and coordination, but has been recognized increasingly over the past few decades for perceptual roles as well. One of these is time perception, which makes sense since that's what is needed to support motor coordination.

Insight from genetic disorders

The mechanisms by which the cerebellum can affect perception are by no means in sight. But brain pathways carrying information on senses such as vision, hearing, touch, pain, proprioception, self-motion perception all connect one way or another with the cerebellum. In the case of timing, there are cerebellar deficits that provide enormous insight, many of those deficits having significant genetic components.

Damage to the cerebellum, and also cerebellar deficits resulting from genetic disorders, manifest most notoriously with ataxia, the loss of control of movement. But ataxia often is accompanied by other deficits, many of which stem from problems related to timing. Of course, all movement is inherently related to time. In fact, we define movement as a change in position over time. A violinist playing a complex piece of music, a gymnast releasing and re-catching a bar, writing with a pencil, or following an object with one's eyes –all of these tasks require the central nervous system to make very precise time calculations, and use those calculations to modulate commands sent to muscles. So it should be no surprise that cerebellar disorders manifest involving the calculation of time in relation to factors such as distance, force, direction of movement.

But what about the perception of time itself? It turns out that cerebellar disorders also may include dyschronometria –impairment of the usual ability to estimate how much time has passed. If given something entertaining to do, you might lose track of time, as in Einstein's analogy, thinking that only a few minutes have passed by instead of an hour. You might then return to work late from lunch or miss your flight, but the miscalculation would be temporary and limited. If everything is working normally, you would not show up at your sister's wedding reception one week late after spacing out hearing music, watching a show, or indulging in pleasures of the flesh.

Why we lose track of time, and why time seems to drag out, during certain mental states is something that neurorelativity studies have yet to sort out, but it's clear that once out of that temporary state the brain snaps into action. And so, you rush through your showering and grooming in order to catch up, as you are back in the time frame of the rest of the world. With dyschronometria though, a person doesn't perceive the passage of time in synch at all with everybody else. A minute to the outside world, and on your watch, could feel like a week inside your mind, or the other way around, with no hot coals, no travel near the speed of light, and no black holes to make that happen. So it's really like a kind of internal time dilation.

There are hereditary forms of cerebellar ataxia, both with autosomal and sex-linked inheritance, and an emerging list of associated genes. In many cases, dyschronometria is a part of the clinical picture, and it also can happen as a result of lesions, for instance with trauma.There is no way to check yet, but we might speculate that brains in non-humans might be optimized differently for time perception compared with our own. Considering a long-lived giant tortoise, like Charles Darwin’s pet Harriet who lived until the year 2006, it’s reasonable to hypothesize that the passage of time might not feel the same within the mind of such as creature as it does within a human mind. In her final years, did Harriet recall some event from Victorian times as if it had happened just yesterday? That’s anyone’s guess, but either way getting a grip on the biology underlying how the brain relates to time of the outside world might advance the human experience in ways that that we can only begin to imagine.

David Warmflash is an astrobiologist, physician and science writer. Follow @CosmicEvolution to read what he is saying on Twitter.