Timewarp: How your brain creates the fourth dimension

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Video: Wagon wheel illusion

THE MAN dangles on a cable hanging from an eight-storey-high tower. Suspended in a harness with his back to the ground, he sees only the face of the man above, who controls the winch that is lifting him to the top of the tower like a bundle of cargo. And then it happens. The cable suddenly unclips and he plummets towards the concrete below.

Panic sets in, but he's been given an assignment and so, fighting his fear of death, he stares at the instrument strapped to his wrist, before falling into the sweet embrace of a safety net. A team of scientists will spend weeks studying the results.

The experiment was extreme, certainly, but the neuroscientist behind the study, David Eagleman at Baylor College of Medicine in Houston, Texas, is no Dr Strangelove. When we look back at scary situations, they often seem to have occurred in slow motion. Eagleman wanted to know whether the brain's clock actually accelerates - making external events appear abnormally slow in comparison with the brain's workings - or whether the slo-mo is just an artifact of our memory.

It's just one of many mysteries concerning how we experience time that we are only now beginning to crack. "Time," says Eagleman, "is much weirder than we think it is."

By understanding the mechanisms of our brain's clock, Eagleman and others hope to learn ways of temporarily resetting its tick. This might improve our mental speed and reaction times. What's more, since time is crucial to our perception of causality, a faulty internal clock might also explain the delusions suffered by people with schizophrenia.

But first, the basics. Perhaps the most fundamental question neuroscientists are investigating is whether our perception of the world is continuous or a series of discrete snapshots like frames on a film strip. Understand this, and maybe we can explain how the healthy brain works out the chronological order of the myriad events bombarding our senses, and how this can become warped to alter our perception of time.

Spinning backwards

Some of the first hints that we may perceive the world through discrete "frames" arrived with studies of the well-known "wagon wheel illusion", in which the wheels of a forward-moving vehicle appear to slow down or even roll backwards. The illusion was first noted during the playback of old films, and it's due to the fact that the camera takes a sequence of snapshots of the wheel as it rotates. If the speed of rotation is right, it can look as if each spoke has rotated a small distance backwards with each frame, when the spokes have in fact moved forwards (see diagram, diagram).

This effect is not restricted to the movies: people also report experiencing it in real life. If these observations proved to be reproducible, it would suggest that the brain naturally slices our visual perception into a succession of snapshots.

So in 2006, Rufin VanRullen, a neuroscientist at the University of Toulouse in France, decided to recreate the illusion in his lab. Sure enough, when he spun a wheel at certain speeds, all subjects reported seeing it turn the "wrong" way. "The continuity of our perception is an illusion," he concludes.

The experiment even put a number on our visual frame rate - around 13 frames per second. But what within our brain sets this particular rate? When VanRullen measured his subjects' brain waves through electroencephalogram (EEG) electrodes on the scalp, he found a specific rhythm in the right inferior parietal lobe (RPL) - which is normally associated with our perception of visual location - that rises and falls at about the right frequency. It seemed plausible that as this 13-hertz wave oscillates, the RPL's receptivity to new visual information also shifts up and down, leading to something akin to discrete visual frames.

To test this hypothesis, VanRullen used transcranial magnetic stimulation - a non-invasive technique that can interfere with activity in specific areas of the brain - to disrupt the regular brain wave in the subjects' RPLs. That inhibited the periodic sampling of visual frames that is crucial for the wagon wheel illusion, reducing the probability of seeing the illusion by 30 per cent (*PLoS ONE*, vol 3, p e2911). The subjects could still see the regular motion of the wheels, however, probably because other regions of the brain, which don't operate at the necessary 13 hertz, took over some of the motion perception.

The case for discrete perception is far from closed, however. When Eagleman showed subjects a pair of overlapping patterns, both moving at the same rate, they often saw one pattern reverse independently of the other. "If you were taking frames of the world, then everything would have to reverse at the same time," says Eagleman.

VanRullen has an alternative explanation. The brain processes different objects within the visual field independently of one another, even if they overlap in space, he suggests. So the RPL may well be taking the "snapshots" of the two moving patterns at separate instances - and possibly at slightly different rates - making it plausible that the illusions could happen independently for each object.

This implies that there is not a single "film roll" in the brain, but many separate streams, each recording a separate piece of information. What's more, this way of dealing with incoming information may not apply solely to motion perception. Other brain processes, such as object or sound recognition, might also be processed as discrete packets.

To investigate, VanRullen examined another neural function, called near-threshold luminance detection. He exposed his subjects to flashes of light barely bright enough to see, and found that the likelihood of them noticing the light depended on the phase of another wave in the front of the brain, which rises and falls about 7 times per second. It turned out that subjects were more likely to detect the flash when the wave was near its trough, and miss it when the wave was near its peak. The work was published in *The Journal of Neuroscience* earlier this year (vol 29, p 7869). "There's a succession of 'on' periods and 'off' periods of perception," VanRullen says. "Attention is collecting information through snapshots."

Perception is a sequence of 'on' and 'off' periods. We collect information through discrete snapshots

So it seems that each separate neural process that governs our perception might be recorded in its own stream of discrete frames. But how might all these streams fit together to give us a consistent picture of the world? Ernst Pöppel, a neuroscientist at the Ludwig Maximilian University in Munich, Germany, suggests all of the separate snapshots from the senses may feed into blocks of information in a higher processing stream. He calls these the "building blocks of consciousness" and reckons they underlie our perception of time (*Philosophical Transactions of the Royal Society B*, vol 364, p 1887).

It's an appealing idea, since patching together a chronological order of events hitting our senses is no mean feat. Sounds tend to be processed faster than images, so without some sort of grouping system we might, say, hear a vase smashing before we see it happen. Pöppel's building blocks of consciousness would neatly solve this problem: if two events fall into the same building block, they are perceived as simultaneous; if they fall into consecutive buildings blocks, they seem successive. "Perception cannot be continuous because of [the limits of] neural processing," says Pöppel. "A space of 30 to 50 milliseconds is necessary to bring together in one time-window the distributed activity in the neural system."

Slices of time

There's some evidence to suggest this might be what happens. In one experiment, Pöppel analyzed his volunteers' reaction times by measuring how quickly their eyes moved to follow a dot jumping across a computer screen. He found that their reactions seemed to follow a 30-millisecond cycle. If the dot moved any time within this cycle, it took until the end of the interval before the volunteers would react (*Naturwissenschaften*, vol 73, p 267). A similar cycle has since been observed when volunteers are asked to discern whether an auditory and a visual stimulus are simultaneous or consecutive - suggesting it may be at the root of Pöppel's building blocks of consciousness.

The brain's effort to maintain its timekeeping has implications for understanding some diseases. Schizophrenia, for example, could arise from an inability to coordinate information arriving from different parts of the brain (see "Delusions on demand"). A better knowledge of the way the brain integrates the discrete packets of information might provide further insights into this.

The question of discrete versus continuous perception is not the only challenge that time presents to neuroscientists. Many, including Eagleman, are concerned with the speed at which time seems to pass in different situations. Why do we feel that some, usually frightening, experiences last longer than others, even if objectively they occurred for the same number of seconds? Eagleman experienced this apparent slowing of time as an 8-year-old when he tumbled off a roof and broke his nose.

There are two possible explanations, he says. It could be a facet of the memory, or it could be that his brain's processing speed accelerated under the stress, making outside events appear to slow down in comparison. Decades later, he decided to replicate his experience under carefully controlled conditions.

After taking half a dozen members of his lab to a nearby amusement park and finding none of the rides scary enough, Eagleman found another outfit that offered a thrill ride known as a "suspended catch air device" which drops people from a 30-metre tower into a safety net below.

To measure the speed of his plucky volunteers' perceptions, Eagleman and his team designed a wrist-worn device they call a perceptual chronometer. An LED array on the face of the device displays a flickering single-digit number alternating with the negative of its image about 20 times per second. That would normally be too quick for a human to distinguish between the two images - you would just perceive all the elements of the LED array to be shining at once - but if their perceptual clocks of the terrified subjects accelerated even a little bit, Eagleman reasoned, the number would become visible.

The results were disappointing. As expected, the volunteers overestimated the time it took them to drop into the net: they thought the fall lasted for more than 3 seconds, rather than the actual time of 2.5 seconds. But they could not discern the flickering numeral, suggesting that their perceptions had not actually speeded up.

Eagleman now attributes the apparent slowing of time to a trick of memory. An intense experience, with heightened fear or excitement, rivets our attention and evokes the firing of many neurons across the brain, he says, causing us to soak up more sensory details (*Philosophical Transactions of the Royal Society B*, vol 364, p 1841). Richer memories seem to last longer, he says, because you assume you would have needed more time to record so many details. "Your brain is on fire when you're dropping," he says. "You lay down denser memory. When you read it back out; you think ‘Gee that was taking a long time'."

That could explain many other temporal illusions too, such as the "oddball effect". When people see the same thing over and over (a picture of a dog flashed on a computer screen, say) and then suddenly see something different (Margaret Thatcher), the new thing seems to last longer, even if all the pictures are actually shown for the same duration. Functional magnetic resonance imaging has revealed that the brain shows a spike in activity when confronted with a surprising stimulus, suggesting that it causes a richer memory to be laid down - which, according to Eagleman's theory, explains why the experience seems longer-lasting.

In total, Eagleman's theory seems to explain a dozen or so similar illusions. Yet it can't rule out the possibility that in certain situations, some internal clock in the brain might really tick at a faster or slower rate, changing the perceived speed of events in the process.

Take the peculiar case of an individual known as BW. As BW drove his car one day, the trees and buildings by the road began to speed by, as if he were driving at 300 kilometres per hour. BW eased up on the accelerator, but the cityscape continued to whizz by. Unable to cope with the speed of the world around him, BW stopped his car by the roadside.

While BW perceived the world as having accelerated, in reality what had happened was that BW had slowed down. He walked and talked in slow motion: when his doctor asked him to count 60 seconds in his head, he took 280 seconds to do it. It turned out that he had a tumour in his brain's frontal cortex.

The case is not unique. Other people with damage in that area have reported similar symptoms. Though such drastically altered perception can clearly be debilitating, it might occasionally be advantageous to change the brain's internal clock. "Accelerating" the brain - the opposite of BW's experience - might help a footballer, say, or a soldier to view the world in slow motion when things get tight. The difficulty, however, is in finding a safe way to induce the phenomenon on demand.

Speeding up the brain

John Weardon, an experimental psychologist at Keele University in the UK, claims to have found a way. When Weardon exposed his subjects to 10 seconds of fast clicks (about 5 per second) and then asked them to estimate the duration of a burst of light or a sound, they believed that second stimulus lasted about 10 per cent longer than if they'd heard silence or white noise before the burst.

It looked as though their central pacemaker had accelerated but, again, the results might simply have been due to a distortion of memory. So Weardon's former student, Luke Jones at the University of Manchester, UK, decided to test the subjects' rate of mental processing during the experience. After exposing them to the clicks, he measured how quickly they could accomplish three different tasks: basic arithmetic, memorizing words or hitting a specific key on a computer keyboard.

The results, to be published in the *Quarterly Journal of Experimental Psychology*, showed that the clicks accelerated the subjects' performance in all three tasks by 10 to 20 per cent. It was as if the drumbeat of their brain's internal slave galley had sped up - compelling each neuron to row faster. White noise had no such effect. "Information processing in the brain is running in subjective time," says Weardon. "If you speed up people's subjective time, they really do seem to have more time to process things."

If you speed up someone's subjective time, they really do seem to be able to process more information

A 10 per cent improvement could make all the difference in plenty of real-world situations. By listening to click trains through headphones, cricket or baseball batters might improve their reaction times and scores. "It would be instantly banned by sporting authorities," Weardon reckons, but this sort of neural enhancement would be welcome in other quarters - allowing students to cram more work into less time, for example.

"It's a cool result," says Eagleman - but he wonders whether click trains may simply "perk the person up a bit, like a little shot of caffeine," rather than having anything to do with time. If that is the case, it may be little more than a close relative of the "Mozart effect". In 1993, researchers observed that students' performances improved if they listened to classical music before taking a test, but later studies showed that many sounds, including traffic noise or speech, can provide the same benefit. "It seems that any external auditory stimulus has this excitatory, or arousal effect," says Edward Roth, who teaches music therapy at Western Michigan University in Kalamazoo and has studied the Mozart effect.

Weardon and Jones, however, doubt that their observations arise from simple arousal. For one thing, white noise had no impact on their subjects' performance in mathematics or memory tests, nor on their time perception. Nor did the subjects show changes in heart rate, skin conductance or muscle tension associated with excitation. "We don't get any increase in autonomic arousal," says Jones.

So how else might the click trains alter time perception and information processing speeds? Edward Large, a neuroscientist at Florida Atlantic University at Boca Raton, has found that rhythmic sounds can entrain gamma brain waves, causing the beginning of each sound to be accompanied by a burst of several especially strong wave peaks. The click train may entrain other types of brain waves too - perhaps those that correspond to the discrete snapshots in our perceptions.

VanRullen and Jones agree that this may be the answer. "When you have faster oscillations, you have more snapshots per second," says VanRullen. "You may be more efficient at particular cognitive tasks, and because there are more snapshots in a given time, it may seem to last for longer."

If this theory is correct, the click train is literally resetting the brain's frame-capture rate. It's an intriguing possibility. Who hasn't wished for a little more time now and then? And you won't need to fall from an 8-story tower to get it.

By upsetting the brain's clock, you can recreate some of the delusions seen in schizophrenia

Delusions on demand

Schizophrenia has many symptoms: tormenting voices which emanate from windows or walls; delusions in which those affected lose the sensation of controlling their own bodies and thoughts; and occasional clumsiness or a jerky gait. Could all these problems stem from a faulty internal clock?

Schizophrenia certainly seems to affect people's perception of time. If someone with schizophrenia is shown a flash of light and a sound separated by 1/10th of a second, they typically have trouble discerning which came first. Such people also estimate the passing of time less accurately than most others. Now a flurry of studies has shown that if you upset the internal clocks of healthy people, you can create some of the symptoms and delusions associated with schizophrenia.

In one experiment, healthy volunteers learned to play a video game in which they had to steer a plane around obstacles. Once people became used to the game, the researchers modified it to insert a 0.2-second delay in the plane's response to volunteers moving the computer mouse. After the modification, the players' performance initially worsened; but in time their brains compensated for the delay, to the extent that they actually perceived the movement of the mouse and the movement of the aircraft to take place simultaneously.

But the subjects' strangest experience occurred then the experimenters removed the delay and set the timing back to normal. Suddenly, the players were perceiving the plane to be moving before they consciously steered it with the mouse (*Psychological Science*, vol 12, p 532). That's uncannily similar to how people with schizophrenia describe feelings that they are somehow being controlled by another being.

It's not the only experiment to demonstrate that these eerie feelings can arise from a faulty understanding of the timing of events. For example, we cannot normally tickle ourselves; somehow the intention to make the movement also suppresses the response. But when people were asked to brush the palm of their hand using a robotic probe that introduced a 200-millisecond delay between the intended movements and the actual movements, they felt the same sensation as they would if someone else were tickling them.

"That gets to a core issue in schizophrenia - the question of whether you are in control of your own body," says William Hetrick, who studies the brain's timekeeping and schizophrenia at Indiana University in Bloomington. "The ability to attribute actions to oneself versus others, to perceive one's own thoughts against thoughts generated from external sources, perhaps requires a tight coupling in time [within the brain]."

The idea could explain many of the experiences reported by people with schizophrenia. By muddling the order of thoughts and perceptions within your brain, for example, you might move your hand before you are conscious of the decision, making it feel as if someone else is controlling your movements. And when an advert appears on TV, your brain might picture the product before it consciously registers seeing it on screen - creating the disturbing illusion that your thoughts are being broadcast on television.

If poor time-processing really does underlie many psychotic delusions, it could point to a single culprit in the brain: the cerebellum. For decades, the cerebellum has been seen as a centre for timing the movement of muscles, but some neuroscientists now reckon that it might coordinate thoughts and the processing of sensory perceptions too.

That would fit with the neurological evidence. "During a broad range of mental tasks, people with schizophrenia have lower rates of cerebellar blood flow than healthy people do," says Nancy Andreasen, a schizophrenia researcher at the University of Iowa in Iowa City.

The idea has sparked plenty of interest. David Eagleman at Baylor College of Medicine in Houston, Texas, has studied people with schizophrenia using a video game similar to the aircraft game, which lets him manipulate delays between volunteers' actions and their outcomes.

When he alters time delays, people with schizophrenia find it more difficult to compensate than healthy controls. "Schizophrenic brains seem to be temporally inflexible," he says. "They don't recalibrate." Eagleman hopes such games might be useful in the future to measure the severity of schizophrenia, or patients' responses to treatment and drugs.

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