Days of Wonder

Even the most mundane features of an average Monday are anything but. Roger Highfield experiences time travel, invisibility and mysteries galore

CLAUS CHRISTENSEN/GETTY

Cosmic Voyager

6.45am I'm fast asleep, lying motionless in bed. Or am I? In reality, I am voyaging through the cosmos at a tremendous speed. My home world rotates once every 23 hours, 56 minutes and 4 seconds. At the equator – a circle with a circumference of about 40,000 kilometres – people are moving at a speed of 465 metres per second relative to the centre of our Earth. Lying in my bed in London, my relative speed is more like 280 metres per second, says Mark Lovell at the Institute for Computational Cosmology in Durham, UK.

I can go faster by taking a god-like view. Relative to the sun, I am travelling at 30 kilometres per second, while the solar system whirls around the heart of the Milky Way at a dizzying 210 kilometres per second.

Yet the Milky Way is moving too. My ultimate frame of reference is the echo of the big bang, the cosmic microwave background radiation. Relative to it, my bed is moving at a speed of 600 kilometres per second and I am hurtling towards the constellation Leo.

Time to rise

7.30am Like the majority of creatures on the planet, from algae to fungi and mammals, the cells in my body synchronise with the 24-hour rotation of the planet by an elaborate network of proteins called the circadian clock. The circadian clock of cyanobacteria is made up of three proteins, whereas most of the cells in the human body rely on about 20 proteins which turn on and off their production by acting on the genes that encode them.

Within these interconnected feedback loops, proteins precisely regulate their own production over a 24-hour cycle, says chrono-geneticist, Michael Hastings at the Medical Research Council's Laboratory of Molecular Biology in Cambridge, UK. Hastings says that it is possible to work out my "body time" by measuring the levels of a handful of these so-called clock proteins in a lab test. Proteins called Clock, Npas and Bmal boost gene expression, while others called Per and Cry dampen it down. Of course, it is much easier for me to check the time on my alarm clock.

Eyes wide open

7.35am Waking up can be the hardest part of the day and there's good reason for it. Biological clocks tick in every cell of my body but the master clock that orchestrates them sits in the suprachiasmatic nuclei (SCN) deep within my brain, near where my optic nerves cross. The SCN is made up of two tiny clusters of several thousand nerve cells and the molecular clocks that tick within them are set by external cues, such as mealtimes, light and darkness.

My body's morning wake-up signal is transmitted from my SCN to specialised nerves called perifornical orexin neurons. These prepare my body for the day ahead by organising a shot of blood-glucose from my liver, followed by a surge in stress hormones such as cortisol and aldosterone, explains Eric Fliers, a hormone and sleep specialist at the University of Amsterdam's Academic Medical Centre, the Netherlands. The orexin neurons also activate the sympathetic part of the autonomic nervous system, triggering increases in muscle tone, blood pressure and metabolism as I drag myself from horizontal to vertical.

That morning feeling

7.45am Understanding my body clock reveals why I would rather lie in at the start of the working week: the average circadian clock runs 10 to 20 minutes slower than a day. This is not an issue during the working week, but after a weekend of allowing my body clock to overrule my alarm clock, getting up for work at the usual time is equivalent to an early start of about an hour, says Andries Kalsbeek of the Netherlands Institute for Neuroscience in Amsterdam.

The implications go beyond simple grogginess. In 2008 Imre Janszky of Karolinska Institute and Rickhard Ljung of the Swedish National Board of Health and Welfare, both in Stockholm, found that more heart attacks occur on the first three days after the transition to daylight-saving time in spring, when people have to drag themselves out of bed an hour earlier (*The New England Journal of Medicine*, vol 359, p 1966).

After a quick shake, the Brazil nuts will be at the top of the jar

My head gets ahead

7.50am Relativity's effects on time are most pronounced near light speed or in the presence of crushing gravitational fields. Yet the pace of time even changes a little as soon as I get out of bed. Einstein's general theory of relativity says that time slows down as gravity strengthens. So clocks run a little slower on Earth's surface, where the planet's gravitational pull is greater, than in orbit.

In bed, of course, my head and feet are at the same height and consequently experience the same gravitational field. However, when I roll out of bed there is relative time travel between my head and my feet because Earth's pull differs.

As a result, we all have a slightly older head on a slightly younger body. Setnam Shemar at the UK's National Physical Laboratory in Teddington calculates that if I stand up for about 14 hours a day then, given my height of 1.87 metres, my head experiences an extra 10^{-12} seconds per day. So over a lifetime of 80 years, my head will have aged 300 nanoseconds more than my feet.

Nuts are nuts

8.15am Breakfast time and I reach for a new packet of muesli. Paradoxically, I find that the heavier nuts have congregated at the top of the packet. For decades, physicists have been debating gravity-defying nuts, partly because they seem a nifty way to create order from disorder and partly because industrial engineers always fret about the "unmixing" of grains or powders in factory processes.

Known as the Brazil nut problem, the puzzle seemed to be solved in 1987 when Anthony Rosato at the New Jersey Institute of Technology in Newark suggested that when a nut rose it created an opportunity for smaller oat flakes to infiltrate the gap. By contrast, several oat flakes would have to shift to make way for a nut to fall – a relatively unlikely event (*Physical Review Letters*, vol 58, p 1038).

So case closed? Not according to Sidney Nagel of the University of Chicago, who has long been fascinated by the physics of the humdrum, from the messy tendrils of honey to coffee rings. Nagel believes that shaking a box of muesli causes both oats and nuts to rise to the top of the packet. Further shaking leads to the oats sliding down the side of the packet, but because there isn't enough room for the larger nuts to do so, the Brazil nuts are marooned on top. Even Nagel is hesitant to claim the Brazil nut problem is solved. "Every time we think we have it all understood, something comes along to knock us out of our complacency," he warns.

HARRISON EASTWOOD/GETTY

Time commute

8.45am. My train to work is running late. As a neighbouring train moves off, I have the uncanny feeling that I am moving backwards. I don't think much about it – this is a well-known illusion of apparent motion, called vection – and begin to mull over the weekend's events. What is more surprising is that there is a link between the way I think and my apparent motion.

Neil Macrae and Lynden Miles at the University of Aberdeen, UK, probed the daydreams of undergraduates as they gazed at a screen where stars seemed to zoom either towards or away from them, corresponding to the experience of forward and backward vection, respectively.

They found that backward vection tends to make us think about events from the past, while forward vection prompts "future-oriented thinking". The team argues that the effects would be amplified with real movement, rather than simulated, and that this shows how the higher faculties of the brain are grounded in more primitive areas that deal with movement and the senses. As I move forward at last, I start to wonder: could this be why so many successful people like to drive fast cars?

To run or not to run?

9.30am As I stroll out of the subway station, it begins to rain. With no umbrella, and the *New Scientist* office a good few hundred metres away, I am faced with a dilemma: will I get less wet if I run to work instead of walking? This question has long vexed researchers.

Calculations published in 1995 by meteorologists at the University of Reading in the UK concluded that running is not worth the bother (*Weather*, vol 50, p 367). That view was challenged by two others caught in a downpour during a jog through the southern Appalachian forest near Asheville, North Carolina. Thomas Peterson and Trevor Wallis, who worked at the US National Climatic Data Center, decided that the original paper was wanting (*Weather*, vol 52, p 93). From their study they concluded that a runner would typically catch just 30 to 50 per cent of the water falling on a walker. The largest benefits are to be had when it is windy and the rain is heavy – exactly when people are most likely to run. I make a dash for cover.

Brain warp

9.45am As I slump, breathless, in my office I look up at the clock on my wall and, much to my surprise, it seems to take a little longer than a second for a single tick to pass. This delay is "real" in the sense that I am genuinely experiencing it. The phenomenon reveals how my brain edits my perception of time, says psychologist Kielan Yarrow of City University London.

During the time it takes my eyes to swivel and focus on the clock, the brain cuts off my vision so I am not distracted by movement blur. My brain then adds on the time taken to move the eyes to the next stable image so there is no gap in my conscious visual experience. But, rather than starting the perception when my eyes rest on the clock face, my brain extends my perception of what I see backwards in time by 50 milliseconds, to the moment before I started to move my eyes, so a second on the clock can seem fractionally longer.

This is far from being the only kind of mental time travel I experience in a normal day.

ROBERT VAN DER HILST/GETTY / SIGRID OLSSON/PLAINPICTURE

A watched kettle

10.45am. By mid-morning I am eager for a fix of the world's most popular drug, that insect neurotoxin popularly known as caffeine. And, yes, it really does take longer for the kettle to boil, if I watch it, due to the time-warping effects that attention has on the beat of a timer in my head.

Warren Meck, a neuroscientist at Duke University in Durham, North Carolina, studies how this biological stopwatch measures intervals in the seconds to minutes range, which is crucial for all kinds of tasks, such as figuring out if I have enough time to cross a road safely or listening to music and timing the duration of my vowels and consonants as I speak (*Nature Reviews Neuroscience, vol* 6, p 755).

The level of nerve activity in my cortex oscillates and this rhythmic pattern of beats is picked up by the striatum, a region of the brain that is associated with reward. "The frequency of this 'beating' is governed by our level of anxiety and it is also influenced by the amount of attention that we pay to the clock," he says. So things we want to happen as quickly as possible seem to take forever because we're more concerned about them. ›

Faster coming home

1.30pm I encounter an additional form of time travel as I nip out to a press conference at an unfamiliar venue. The journey there seems to take significantly longer than my trip back to the office. Amitav Chakravarti at New York University has found that this effect is real. "The idea of how long a journey takes has to do with subjective feelings of when a journey is 'well under way' and when you are 'almost there'," he says.

On my outward journey I encounter familiar landmarks, such as shops, buildings, the subway station and so on, so I initially feel as if I am making less progress. Only when I leave the familiar, do I feel that the journey is well under way. And I don't feel that I'm almost there until I'm virtually at the venue.

The opposite is true on the journey home: as soon as I leave the venue, I feel that I am making progress. And this time, the appearance of familiar sights tells me that I'm almost home.

"Spin a hard-boiled egg fast enough and it will seem to defy gravity"

MATTHEW MAWSON/MILLENNIUM

Magic eggs

2pm I decide to enjoy a light lunch of boiled egg and toast. Well-cooked eggs give me a chance to impress onlookers with a gravity-defying trick. Spin a hard-boiled egg on its side and if you spin it fast enough, it will stand up and spin on its end (see video at bit.ly/hy7vzN).

It took two substantial papers by Keith Moffatt and Michal Branicki at the University of Cambridge and Yutaka Shimomura at Keio University in Yokohama, Japan, to show why (*Proceedings of the Royal Society A*, vol 460, p 3643 and vol 461, p 1753, respectively).

The secret is to work out how a spinning egg converts a frictional force that acts in the same horizontal plane as the table into a vertical force that lifts the egg. The answer lies with the Coriolis effect, which deflects objects moving in a rotating frame of reference. It's this effect that largely controls the circulation of Earth's atmosphere and oceans. In the same way, the Coriolis effect converts the frictional force into a turning force that lifts the egg to vertical.

The trick occurs only when the egg is hard-boiled because the energy you supply in spinning a raw egg is dissipated immediately by the sloshing fluid inside.

Still, the magic egg effect has not been completely cracked. We don't understand why it is so much harder to coax a soft-boiled egg to do the same trick. And theory fails to explain why a rapidly spinning egg makes tiny jumps during its relentless rise, though Shimomura speculates that they may be caused by imperfections on the surface where the egg spins.

Tumbling toast

2.10pm As I lift my buttered toast to my mouth, I drop it and, alas, it lands buttered-side down, just as Murphy's law predicts. Detailed calculations of the dynamics of tumbling toast made by Robert Matthews of Aston University in Birmingham, UK, have shown that this depressing tendency is no urban myth.

Neither does it have anything to do with the smear of butter, the weight of the toast or its aerodynamic properties. The critical factor is height alone – the toast sliding off a plate spins so slowly that only if it falls from heights above 3 metres does it have much chance of landing buttered-side up (*European Journal of Physics*, vol 16, p 172).

Matthews has confirmed his theory by having 1000 children push toast off plates more than 21,000 times in a mass experiment backed by the UK's Department of Education and a butter manufacturer.

It's not just Murphy's law at work, but the laws of physics too

LUBITZ + DORNER/PLAINPICTURE

It takes millennia for sunlight to reach us from the sun's interior

Ancient sunlight

3pm Even something as straightforward as a stroll in the sunshine after lunch is a thing of wonder. Everyone knows that it takes a little over 8 minutes for light to cover the distance from our local fusion reactor, the sun, to Earth.

But the real story of sunlight is even stranger. It actually takes many millennia for light to escape from the sun in the first place, according to Louise Harra at University College London's Mullard Space Science Laboratory.

The outward flow of photons from the core to the surface of the sun around 700,000 kilometres away would take less than 3 seconds if the path was clear. However, the flow is continually blocked by collisions because the sun is extremely dense near its heart. The photons travel only a fraction of a centimetre between collisions, slowing them tremendously. "Overall it takes 170,000 years to get through the interior," says Harra.

Sunset in my head

5.30pm The world has turned since I got out of bed. Now it's dusk and the inhibitory proteins in my circadian clock, notably Per and Cry, have reached their peak. These proteins turn down the production of Clock, Npas and Bmal which are so active during the day and prepare my body for the passing of another full rotation of the Earth. Deep in my brain, the SCN takes this body-clock information and passes it to the pineal gland, which secretes melatonin. The hormone tells the cells and organs of my body that it is night. I begin to feel tired.

Walking on a cloud

6.30pm I cross the road on the way back to the subway and ponder why the ground feels so solid when I know that matter is actually 99.9999999999999 per cent empty space. The positively charged nucleus of an atom, where almost all of its mass resides, has a radius of 10^{-15} metres, while the entire atom is 10^{-10} metres across. Peter Coveney of University College London explains that the "empty space" in atoms, while empty of mass, carries the negative electrical charge of the point-like electrons within each atom. The negative electric charge on the outside of the atoms in the road exerts a repulsive force on the negative charge of the atoms in the soles of my shoe. "That you don't fall through the ground is testimony to the incredible strength of intermolecular forces," says Coveney.

Cosmic snack

8pm I have a bowl of soup for a snack and it is striking how the croutons tend to clump together, making it much easier to eat them. Dubbed the Cheerios effect, this phenomenon applies to anything that floats, including bubbles on beer and the eponymous cereal. A review of explanations for the effect came in 2005 from Dominic Vella, now at the University of Oxford, and Lakshminarayanan Mahadevan of Harvard University. Mahadevan enjoys applying mathematics to everyday life, from equations to describe the cut of a suit to what happens as paint dries (*American Journal of Physics*, vol 73, p 817)

It turns out that croutons, like Cheerios, disrupt the cohesive forces between molecules on the surface of the liquid. In the case of Cheerios, the Os create tiny depressions in the milk's surface which cause them to drift towards each other. They also tend to clump against the edges of a clean bowl because the milk molecules are more strongly attracted to the molecules on the bowl's surface than they are to other milk molecules. This extra attraction pulls the Cheerios to the side of the bowl.

My snack is telling me that pockets of additional attraction can emerge even when the forces between particles are the same in all directions, "something which is not obvious to everybody", says Arshad Kudrolli of Clark University in Worcester, Massachusetts. Galaxies cluster by an analogous mechanism, through the action of gravity. It is humbling to think that the cosmos is a little like my bowl of soup.

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My sick sink

Even without the dirty dishes, it is filthier than a freshly flushed toilet

GREGOR SCHUSTER/GETTY

8.20pm I wipe my soup bowl clean and shudder as I recall a study that showed that about 100 million bacteria lurk in a typical dishcloth. Many are rod-shaped bacteria that originate from faeces. In fact there are more faecal bacteria, such as *Escherichia coli* and *Klebsiella*, in my kitchen sink than in the toilet bowl after I flush it. "That's probably why dogs drink out of the toilet," jokes Chuck Gerba at the University of Arizona in Tucson (*Journal of Applied Microbiology,* vol 85, p 819).

The culprit is mostly bacteria originating from raw meat. "These bacteria enter via the food supply and then multiply in the wet and moist environment in the kitchen," says Gerba. My sink carries the ultimate domestic biological weapons. "The object in the house with the most faecal bacteria and total bacteria is the kitchen sponge or dishcloth."

Gerba advises me to make liberal use of bleach.

Invisible howlers

8.40pm As I settle to watch a DVD of *Apocalypse Now*, I remember an old friend telling me that Francis Ford Coppola's masterpiece on the Vietnam war actually contains more continuity errors than any other movie he could think of. I still struggle to spot any of these howlers at all. Why?

This is a prime example of "change blindness", according to Dan Simons of the University of Illinois at Urbana-Champaign and co-author of *The Invisible Gorilla* (Harper Collins, 2010). "Many people are convinced they regularly notice such errors," he says, but in reality, we actually notice very few of them.

Simons has gathered some remarkable evidence to show that it is possible to look at something without seeing it. In one experiment he carried out with Daniel Levin of Vanderbilt University in Nashville, Tennessee, a stranger asked people walking across a college campus for directions. During the resulting conversation, two men carrying a wooden door passed between the stranger and the subjects. Half of those tested failed to notice that as the door passed, the stranger had been replaced with a man wearing different clothes and of a different height and build.

My change blindness occurs because it is not possible to perceive and remember all of the details of the world around me. Many howlers in films are continuity errors where items in one scene disappear, move or change colour in subsequent scenes. In the case of *Apocalypse Now*, perhaps my limited visual memory did not retain enough details between scenes to reveal the howlers, never recorded them in the first place, or simply did not compare them.

Censored reading

11.20pm Before I go to bed, I pick up an old issue of *New Scientist* to help research this feature. I think that both of my eyes focus on one part of the text but, in fact, my right and left eyes often focus on different parts of words, according to psychologist Simon Liversedge at the University of Southampton, UK, who has performed sophisticated eye-tracking studies. And although I think that my eyes are moving smoothly across the text, that is an illusion, he says: "When you read, you make a series of fixations interspersed with fast movements of the eyes called saccades."

During a saccade my eyeballs swivel by between 2 and 5 degrees, over an interval of 30 to 50 milliseconds. The fixations that I use to read take up to 250 milliseconds (*Psychological Bulletin*, vol 134, p 742).

My brain suppresses the confusing blur of words during a saccade, only collecting visual information at the start and end. It then integrates these snapshots to provide me with the sensation of a "smooth flow" of words and delivers them to my language-processing system, via the visual cortex at the back of my head.

NORDIC PHOTOS/SUPERSTOCK

Behind the newspaper, my eyeballs swivel several degrees

Invisible nose

11.40pm Editing my vision is not the only way my brain tricks me during my bedtime reading. Even though I have two eyes, and so two views of the page, I only perceive one world. To achieve this Cyclopean view, my visual system must coordinate the input of the two eyeballs precisely and systematically and then process it, says Mark Changizi, director of human cognition at the 2AI Labs in Boise, Idaho, and author of the *Vision Revolution* (Ben Bella, 2009).

This is easy for me to investigate. I shut one eye and see that my nose alone takes up a considerable portion of my view. When I re-open that eye, it becomes obvious that my nose is actually transparent – I can gaze through it to the world beyond. In fact, says Changizi, I am seeing the future too. From the time light hits my eye, it takes one-tenth of a second for the brain to perceive it. “Your brain actually generates a perception of what the world will look like in a tenth of a second. You don’t see reality but a construct, one which evolved to help you to survive.”

"Even though I’m lying motionless, I’m hurtling at great speed through the cosmos"

Molecular machines

11.45pm While I sit in bed and stir my bedtime cocoa, armies of microscopic machines in my body go marching. The machines are a family of protein motors called myosins that turn chemical energy into motion. Inside my nerves, for example, myosin V walks around on two “legs” along tracks called actin filaments, though their 74-nanometre stride is less than a 10-millionth of my own.

In my muscles, myosin II forms filaments of around 300 molecules which also walk, like a millipede, along the actin filaments to make my muscles contract. Each myosin molecule can develop a force of a couple of piconewtons this way, according to Robert Cross at the University of Warwick in the UK. “Lifting a 40-gram spoon means that in your arm an additional two million million myosin molecules are working as a team,” he says. Many more molecular machines take part in the serious business of keeping me alive, to open and close my eyelids, dilate my irises, help me to hear by sensing the motion of hair cells in my inner ear and, as I yawn, squeeze air out of my alveoli to move my vocal chords to generate a satisfied sigh.

Mysterious yawn

11.55pm As I stretch and yawn before I succumb to sleep, I remember that there are plenty of ideas around to explain why I yawn. They include brain cooling, improving attention by helping us draw in more oxygen, synchronising our mood with others. Another suggestion is that baring teeth during a yawn evolved as a way of protection from predators intent on ambushing a drowsy foe. There are many more.

No one is sure which explanation, or combination of explanations, is the right one. I close my eyes, satisfied that deeper understanding does not diminish life, but instead amplifies my sense of awe. ■

Roger Highfield is the editor of *New Scientist*