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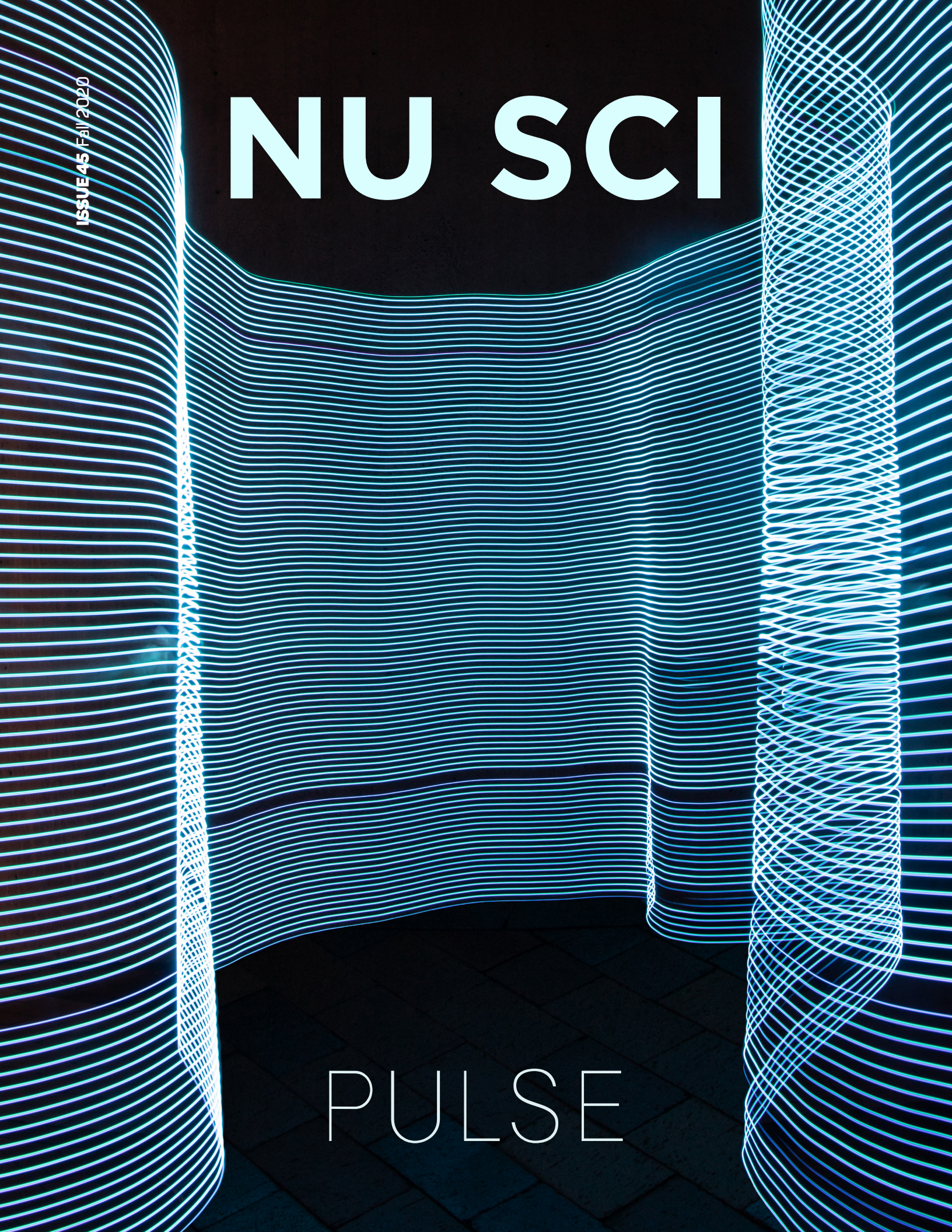

PULSE

Fall 2020

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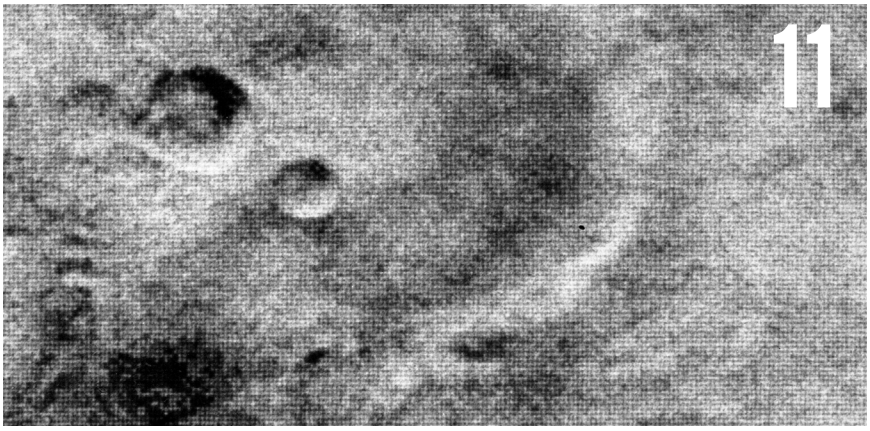

LETTER FROM THE EDITOR

Everything has a beginning; *we* start with a single heartbeat, a burst that becomes the rhythm that follows us through our lives. The melody of our heart is the soundtrack that crescendos at our most exhilarating moments and decrescendos at our most serene.

That's the duality of *Pulse*.

A ripple that can start life — like the possible microbes on Venus, the multitudes that originated from the Cambrian explosion, or the renewed one after a near-death experience. Yet those bursts carry momentum through forests and their cyclical fires, artificial hearts, and of course, real ones — no matter how heartbroken, anxiety-filled, or touch-starved. A discrete event that perpetuates its existence and eventually evolves into something so much more, with a natural desire to maintain continuity, to maintain being.

So what is a pulse but a will that simply persists in spite of resistance?

"Pulse" marks the beginning of our traditional publication cycle — our yearly, continuous attempt to bring life out of the words within our pages or, rather, to bring the life and energy around us into the words on our pages. Our writers have looked within themselves to the inner mechanisms of the heart and how it interacts with our health, our minds, and even with others. But they've looked beyond themselves too, looking at the flora and fauna, towards the deep expanses of space, and within the body of the ocean.

In looking to our club, I'd like to express how grateful I am for our hardworking editors, writers, designers, and photographers, as well as the web, marketing, and outreach teams. Despite being completely virtual this semester, they've exceeded expectations and are just as involved as ever. Even without a physical body or meeting, the pulse of NU Sci is still as vivacious as before.

"Pulse" is only the start, but I have no doubt that the same energy will continue to be expressed through the tireless curiosity and engagement of our devoted members.

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ANXIETY IN WOMEN AND ITS EFFECT ON HEART HEALTH

Pandemic version

BY KRISHNA DAVE, BIOCHEMISTRY, 2021
DESIGN BY HEATHER WELCH, ENVIRONMENTAL SCIENCE, 2020

Increased heart rate. Rapid breathing. Struggling to sleep. Feeling weak and tired. Sweating or trembling. These are the signs and symptoms of anxiety. One or more of these symptoms might be familiar to everyone because of the current pandemic. Anxiety disorder is real, and it has escalated quickly during the COVID-19 pandemic. Anxiety is characterized by the constant feeling of worry and stress, and it has physical repercussions such as increased blood pressure, which can affect cardiovascular health. According to the American Psychological Association, women are more likely to experience anxiety disorders than men; this was concluded pre-pandemic. During the pandemic, various research, surveys, and polls have shown that gender disparities have been emerging, along with the gap in the mental health system between men and women. A poll conducted by the Kaiser Family Foundation in March 2020 concluded that 49 percent of women felt that the coronavirus outbreak had severely disrupted their lifestyle compared to 40 percent of men.

> "49 percent of women felt that the coronavirus outbreak had severely disrupted their lifestyle compared to 40 percent of men."

COVID-19 has compelled many women to juggle familial responsibilities while working from home. In addition, access to reproductive healthcare resources has been seriously hindered during the pandemic, possibly increasing the onset of anxiety. The pandemic pushed countries into lockdown, and though it caused lots of general economic damage, sexual and reproductive health services were stripped away from women in particular. Women in affected areas have been unable to access contraception and have failed to get abortions, while maternal deaths have increased. A paper posted in the *Journal of the American Medical Association* states that physicians have also seen an increase in stress-induced cardiomyopathy, which is also known as broken heart syndrome. Cardiomyopathy could potentially be caused by the stress, isolation, and loneliness that people have experienced during the pandemic. Stress during the pandemic has been primarily caused and amplified by emotional trauma, lack of sleep, financial worry, and the death of a loved one. In the human body, the hormone cortisol is released in response to stress in order to protect the body. However, excessive cortisol production can lead to high levels of cholesterol, blood sugar, blood pressure, and triglycerides; all of which may lead to dangerous heart disease.

An experimental study performed with 92 women, published by *The Journal of Social Psychology*, concluded that workplace sexism fostered anxiety in women. This is a common problem around the world and may also take a toll on women's overall mental health. Anxiety disorders range from generalized anxiety disorder (GAD) to obsessive-compulsive disorder (OCD). The main differences between anxiety in men and women, as demonstrated by research, has been linked to genetic factors and female hormones. This research stresses the dire need for differential treatment between men and women. A study from *Current Cardiology Reports* stated that anxiety disorders likely increase the risk of cardiovascular disease (CVD), especially in women. Sample meta-analysis data showed that 16 percent of patients with CVD had an anxiety disorder. However, there are some limitations to the accuracy of such data because anxiety fluctuates over a period of time and is not consistently experienced by individuals. Another study showed the prevalence of anxiety disorders and their association with coronary heart disease. Experts concluded that, out of all the evaluated patients, 70.8 percent of the women with cardiac disease had a higher rate of diagnosed anxiety disorder compared to the men with cardiac disease. This research was conducted in 2007, however, the topic is still relevant today as the pandemic has potentially amplified and worsened anxiety disorders in women.

Unaddressed stress or burnout can lead to depression and trigger poor heart conditions. It is important to mitigate stress and burnout, yet there is a systemic lack of high-quality and accessible healthcare, especially in developing countries. One of the most prevalent self-care strategies is regular exercise, which has been proven to reduce depression and anxiety. There are also many mental health platforms, and psychological assistance and counselling resources are available. Crumbling economics, shattered businesses, record-breaking unemployment, losing loved ones are some of the visible repercussions of this pandemic. The less conspicuous, but not less imperative, factor is the emotional distress to which women have been subjected simply because of their gender.

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PHOTO BY PIXABAY

Dogs: A man's (health's) best friend

BY LILY WEBER, BIOLOGY & ENGLISH, 2023 DESIGN BY ETHAN WAPLE, DATA SCIENCE & BIOLOGY, 2023

Dogs are man's best friend — it's a common phrase used to describe the unique relationship that exists between humans and canines. It is a relationship so strong that it extends past households and into numerous other spheres of life such as law enforcement, military, and healthcare. Dogs have long served as faithful companions to their owners. Their loyalty, affection, and protective instincts are perhaps unmatched by any other pet. It's well known that dogs make great pets, and researchers are currently working on elucidating how owning them may actually lead to improvements in our overall health.

> "It's a known fact that dogs make great pets. What researchers are currently working on elucidating is how owning them may actually lead to improvements in our overall health."

In particular, correlations have been found between owning a dog and having improved heart health. For example, in 1999 Dr. Bruce Headey found that not only do dog owners make fewer doctor's office visits annually, they are also less likely overall to be on medication for heart issues. Far from mere correlation, there have also been studies that actually support a causal relationship between pet ownership and health. Dr. James Serpell, in 1991, conducted an experiment in which people who were not current pet owners were given a cat or dog. It was found that acquiring a pet substantially improved a person's health, psychological well-being, and in the case of dogs: exercise level. In 1992, Anderson et al. found that pet owners had significantly lower systolic blood pressure, plasma triglyceride levels, and plasma cholesterol levels — all metrics of heart health — than their non-pet owner counterparts. All in all, having a furry companion can be great for your cardiovascular health. In a time when cardiovascular disease is one of the major causes of death in the United States, dogs could potentially be a vastly underexplored way to supplement treatment.

So why exactly do dogs so significantly improve human health? According to the Centers for Disease Control and Prevention, it may be due to increased opportunities to exercise, go outside, and socialize with other people. Dogs also help mental health by offering companionship in the face of loneliness and depression, an affliction with high rates particularly in nursing homes. Kramer et al in 2009 even found that 47.4 percent of nursing home residents had either major or minor depression or depressive symptoms. As concluded by Jongenelis et al in 2004, one of the leading causes of depression in older Americans, particularly in nursing homes, is a lack of social support and interaction. Dogs can help remedy this by providing a valuable source of social interaction to their owners.

A particularly moving example of this phenomenon at work is that of the formation of The Eden Alternative, a new philosophy for elder care discussed in surgeon Dr. Atul Gawande's book "Being Mortal." Hoping to revamp the nursing home he worked at, Dr. Bill Thomas brought in hundreds of animals, many dogs amongst them, for residents to choose and take care of. The results were staggering. Patients who hadn't spoken a word since he worked there were suddenly interested in taking the dogs for a walk outside. There was new life breathed into the facility, and it was the dogs who in part helped bring that life back. The success of Dr. Thomas's experiment led to his creation of The Eden Alternative as a philosophy for elder care.

As Dr. Thomas explained to Gawande, "the difference in death rates can be traced to the fundamental human need for a reason to live." These anecdotal findings were later supported by empirical research such as that of Bergman-Evans et al in 2004, which found decreased boredom, helplessness, and distress in elders who experienced The Eden Alternative. That may very well be the underlying principle of these stories. When caring for oneself is not sufficient motivation, caring for another living being can be. Regardless of the exact mechanisms, the empirical and anecdotal evidence are clear in their position that having a dog can help both your mental and physical well-being. As both human lifespans and diseases increase, and more and more shelter dogs are in need of families, it may be time to encourage the pairing together of man and his best friend once more. In particular, in the wake of the pandemic, interaction with other living beings has become all the more precious. In a time where social distancing and quarantine are the norm, it may be up to man's best friend to pick up the slack.

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PHOTOS BY RAWPIXEL

Health Humanities

From a heart behind medicine to a broader reconsideration of health

BY ASHLEY BROWN, BIOCHEMISTRY, 2024
DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

The medical field's reputation is characterized by its application of scientific advances with a more humane touch than other, purer sciences. Yet, as technology advances further by the day, ethical dilemmas arrive in droves — never escaping the debt incurred from an uneven stream of questions and answers. To address these mounting issues, the field of the Medical Humanities grew, particularly focused on creating more holistic physicians. More recently, there has been a call within the field to switch this name from "Medical Humanities" to "Health Humanities" as the field expands. This transition of rhetoric adds another layer of complexity for those interested in the field; regardless, the importance of this niche field is indispensable because of the tools it develops to address health as a whole and the injustices intertwined with it.

First, a brief history lesson about the field: there are several threads to the story of the Medical Humanities, and arguably the most foundational one details the initial separation of the natural sciences from the humanities and social sciences. Bruno Latour, a French philosopher pivotal in the study of science and technology, discusses this in his theory-based essay entitled "We Have Never Been Modern" in 1991. Latour dissects a book comparing two contemporaries: the English political philosopher Thomas Hobbes and the Irish chemist Robert Boyle. Truthfully, Hobbes also studied scientific phenomena, at the time called natural philosophy, while Boyle developed public opinions regarding political systems. However, the modern paradigm bucks against this, insisting on the separation of these two minds and thus on the continued separation of science and the humanities. The Heath Humanities, as a hybrid field, resists this simplistic division.

The transition from Medical to Health Humanities, on the other hand, is significantly more recent. This shift is centered on how the field is no longer limited to only instructing physicians to consider their patients more holistically in the context of an evolving medical field. This fixation on rhetoric largely represents a key element of the Health Humanities field itself: the humanities are an indispensable tool to guide science itself. Focusing on the "right word" is a perfect introduction to the heart of the Health Humanities.

The center for this debate largely comes down to a definition of health, a definition that sketches the outline for the Health Humanities. The Merriam-Webster Dictionary defines health as "the condition of being sound in body, mind, and spirit."

Then, in an article posted in *Academic Medicine* in 2017 discussing this topic, the authors also list "class, education, occupation, environment, race, and stigma," as "determinants" of health. These factors, as well as the focus on the rhetoric involved with them, branch outside of the comfort zone of science — and therein lies their importance.

What does the Health Humanities provide? Northeastern University's Professor Sari Altschuler, the director of the Health, Humanities, and Society minor, grants insight. Altschuler describes our Health Humanities curriculum as providing "a robust set of tools that people can use to answer questions ... that are not easily approached through more quantitative methods." This does not apply exclusively to pre-med students either but also to those interested in pathways of medicine such as nursing, research, and hospital administration.

> "This fixation on rhetoric largely represents a key element of the Health Humanities field itself: the humanities are an indispensable tool to guide science itself."

In actual application, the Health Humanities are critical in exposing structural inequalities. By placing science on a pedestal of untouchable detachment, it is difficult to hold it accountable; therefore, we need the humanities. One such example is the pulse oximeter. It measures oxygen levels in blood using light. However, a 2007 University of California, San Francisco study found that for those with darker skin, the actual oxygenation of the blood is lower than the pulse oximeter reads. This results in these already marginalized communities not only being denied necessary oxygen but if they do receive oxygen, their insurance may not cover it, claiming their oxygen levels are not low enough.

The Health Humanities is an increasingly relevant field, because of its contributions to medical practices, and more importantly to health and the structures surrounding it. This ties into Northeastern's career-preparation mindset, especially because we prepare students by, in Altschuler's words, "offering other sets of tools that give students an advantage when thinking about a career in healthcare."

For those who want to get more involved at Northeastern University, visit the Health, Humanity, and Society minor site.

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PHOTOS BY SHUTTTERSTOCK

THE TRUTH BEHIND YOUR RANDOM ACHES

BY EMILY TAN, DATA SCIENCE & BIOLOGY, 2024
DESIGN BY ETHAN WAPLE, DATA SCIENCE & BIOLOGY, 2023

Psychosomatic disorders are more simple than they sound. The word "psychosomatic" can be broken into two components: "psycho-," which means relating to the mind and "-somatic," relating to the body. In layman's terms, psychosomatic disorders occur when one's mental state manifests physical symptoms. Socrates first introduced a semblance of today's psychosomatic disorders 2500 years ago when he publicly criticized medicine's strictly organic approach to healing and its complete disregard of emotional and psychological circumstances. Now, the American Psychiatric Association defines psychosomatic disorders as "psychological factors affecting other medical conditions" with severities ranging from mild to extreme.

We've all likely heard of a psychosomatic disorder at some point in our lives, whether it be mild ones, such as stress-induced migraines, or more severe ones, like phantom limb syndrome. One of the more popular examples is gastric ulcers, or sores that develop on the lining of the esophagus, stomach, or small intestine. While they were incorrectly attributed to stress for centuries until the late-20th century, thanks to the work of Robin Warren and Barry Marshall in 1984, it is now common knowledge that these ulcers are caused by the bacteria *Helicobacter pylori*. During that year, perhaps in a moment of scientific genius, pure frustration, or maybe a combination of both, Marshall, a research pathologist, downed an infectious soup with a nefarious ingredient: the infamous *H. pylori*. He would not only go on to develop symptoms of gastritis and peptic ulcer disease, but he would also eventually go on to win a 2005 Nobel Prize in Physiology or Medicine with Warren for their contributions to medical research.

Though scientists now advocate for an allopathic, drug-based treatment for stomach ulcers to target *H. pylori*, recent studies have shown that there is some truth to the stress-induced gastric ulcer myth. A 2016 study consisting of 17,525 participants found a strong correlation between the degree of everyday life stress and development of gastric ulcers. In the lowest stress group, only approximately 0.4 percent of participants were diagnosed with peptic ulcers in comparison to an incidence rate of 1.2 percent in the highest stress group, after evaluating other factors such as age, gender, socioeconomic status, NSAID use, and tobacco use.

This may explain why there was a 21-year gap between the publication of Warren and Marshall's findings and their eventual Nobel Prize nomination and acceptance. A majority of the scientific community held steadfast in their belief of the physical manifestation of psychosocial ails, and they were not entirely wrong in doing so. In fact, in recent years, there has been a growing community of clinical researchers who advocate for a holistic treatment process that reviews both the patient's physical and mental health. Over the course of several decades, many researchers have offered varying explanations as to why this manifestation of physical symptoms in response to mental duress occurs. These include theories and concepts such as Hans Selye's general adaptation syndrome, which theorizes three stages in human response to prolonged stress: the alarm reaction, the stage of resistance, and the stage of exhaustion. Tissue catabolism or hypoglycemia are typical symptoms that arise during the alarm reaction, which is when the body first detects higher levels of stress hormones such as cortisol. These symptoms typically disappear during the stage of resistance but eventually return in the stage of exhaustion if stress is prolonged. Once the body is in the stage of exhaustion, even more hormones like catecholamines, which include norepinephrine and epinephrine, and opioids that have immune-suppressing properties, are detected. When the body's immune system functions are suppressed, pathogens are more likely to successfully infiltrate and infect it.

As the medical community moves closer to a holistic treatment protocol investigating both the physical and psychological duress of patients, research likewise is evolving to consider the disproportionate rates of psychosomatic afflictions in people from historically marginalized and disadvantaged backgrounds. Though there still is a long way to go in psychosomatic disorder research, Socrates would be proud that his revolutionary assertions 2500 years ago have taken root in modern society.

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Gamma band stimulation

A promising new treatment for Alzheimer's

BY DINA ZEMLYANKER, DATA SCIENCE & BIOCHEMISTRY, 2024

DESIGN BY VICTORIA PAJAK, BEHAVIORAL NEUROSCIENCE, 2021

Alzheimer's disease is a vicious illness most often characterized by drastic decline in cognitive function including memory loss and confusion — frequently causing severe emotional stress for the affected along with their family and friends. Fortunately, recent technology, called gamma band neural stimulation, has emerged, showing promise of having a significant impact on Alzheimer's. Although the direct causes and mechanisms by which Alzheimer's affects people are not fully known, there are several viable hypotheses that have been found to have merit. The common key pathological understanding between all of them is that extracellular deposits of amyloid-β (Aβ), and intracellular neurofibrillary tangles (NFT) of tau, which is a protein that helps create structures that transport nutrients in nerve cells, are the main markers and causes of visible symptoms. The most common hypothesis, the amyloid hypothesis, posits that mutations in genes coding for amyloid-β precursor protein (AβPP), a protein metabolized to breakdown products, and presenilin peptides, which form catalytic subunits in gamma secretases which also breakdown proteins, result in less efficient AβPP catabolism. This in turn leads to Aβ oligomer aggregation forming insoluble Aβ plaques. This causes synaptic damage and destructive inflammation, along with the phosphorylation of tau, which all lead to cognitive dysfunction and dementia.

> "Although the direct causes and mechanisms by which Alzheimer's affects people are not fully known, there are several viable hypotheses."

Currently, the only pharmacologic treatments are acetylcholinerase inhibitors and N-methyl-D-aspartate receptor antagonists. Experts based the inhibitors on the cholinergic hypothesis, meaning that the medicine mimics the natural role of acetylcholine as a neurotransmitter in the brain. Unfortunately, these treatments can only slow the progression of the disease by around 30 percent and cannot prevent nor cure Alzheimer's. However, gamma band neural stimulation shows promise to significantly impact the disease. During sensory information processing and cognitive memory tasks, gamma activity increases in the brain. A reduction in gamma power occurs in people with Alzheimer's even before there is a visible accumulation of plaque or amyloid protein.

In an experiment done by Iaccarino et al, 40 hertz brain stimulation was shown to have significant positive effects. The levels of amyloid precursor protein (APP) intermediates (C-Terminal and N-Terminal fragments) were measured to examine the effects on the APP cleavage in the hippocampus of 5XFAD/PV-Cre mice that model Alzheimer's. APP determines brain amyloid concentration, and is the precursor to Aβ; the more cleavage of APP that occurs, the greater the brain amyloid concentration, a pathological marker of Alzheimer's. After the 40 Hz stimulation, there was a significant reduction in C-Terminal and N-Terminal fragments showing less cleavage of APP. Experts also concluded that the stimulation decreases endosomal processing of APP, as they documented a decrease in the markers for endosomes (early antisomnal antigen 1 and Ras-related protein).

The 40 Hz stimulation also caused changes in the state of microglia, which are brain and spine cells that act as immune defense for the central nervous system. Researchers observed that 35 percent of the upregulated genes, or genes expressed at higher rates due to the stimulation, had the highest expressions in microglia. Almost twice as many microglia were observed in the 40 Hz group compared to the control groups. In addition, microglia cell body diameter increased by 138.7 percent compared to random stimulation. Given that microglia act as the main defense for the brain, an increase in the amount and size of microglia suggests that the 40 Hz stimulation leads to a more effective brain defense system as well as decreased Aβ plaque accumulation.

Visual stimulation has also been shown by the same researchers to be an effective method of Aβ level reduction. After 3-month-old 5XFAD mice were exposed to 40Hz visual light stimulation using white lights, Aβ1-40 and Aβ1-42 levels were respectively reduced by 57.96 percent and 57.97 percent compared to the dark controls. The light stimulation traveled through the retina and optic nerve and resulted in increased gamma activity in the visual cortex, which led to the reduced Aβ levels.

Although there is still much more research to be done, especially regarding the effects of gamma stimulation on humans and not just mice, gamma stimulation has emerged as one of the first treatments with the potential to treat Alzheimer's effectively. Instead of just mildly ameliorating some of the symptoms, it may be able to treat already developed Alzheimer's and even stop the disease from progressing.

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BRIDGING THE BRAIN AND THE HEART

BY SHREYA NAKHAWA, CELL & MOLECULAR BIOLOGY, 2023

DESIGN BY YECHAN YANG, BIOLOGY & PSYCHOLOGY, 2022

Many of us have heard of or learned about the 11 systems that keep the human body functioning, such as the skeletal, muscular, nervous, and cardiovascular systems. Although these systems are made up of distinct tissues and cells, they are not as separate as one might believe. In particular, the nervous system is essential for controlling organ movements, such as those of the heart. The connection between the cardiac and the nervous systems is composed of a neural network that connects the two organs and makes decisions about cardiac function. This neural network might be damaged following brain or heart injury, affecting the functioning of both organs.

Neurons are ubiquitous in the human body, and the places in which they reside are not restricted to sensory locations. There is even a smaller network of neurons that exists within the heart. Achanta et. al. in 2020 created a model of these neurons residing within the heart of a rat. This network of neurons found within the heart is called the intracardiac nervous system (ICN).

Any neural network is made of many different neurons with different phenotypes and functions. Through the application of computational methods to analyze various attributes of these neurons, Achanta et. al. were able to identify different types of neural modulators or regulators in the ICN. The authors of this research paper claim that "determination of the deficits in the ICN that drive cardiovascular pathology can lead to new avenues of therapy not only for patients with heart failure but also with an eye toward preventative approaches, as the transition from health to disease is better understood from the perspective of the ICN." These neural modulators are important to our understanding of the cardiovascular system because their malfunctioning might result in a specific subset of heart diseases.

The neurons that reside within the heart are a part of the same neural network that bridges the heart and the brain. The different types of neurons create a hierarchy within the network, and Kember et al. theorized in 2013 that this hierarchy can control and regulate various cardiac functions. Although decisions about controlling heart rate come from higher up in the nervous system (the brain), ultimately these decisions are carried out by neurons surrounding the heart.

Building upon their theory that specific groups of neurons control cardiac function, Kember et al. also investigated the neural plasticity of neurons within this network — specifically, "the ability of a neural network to continuously modify the relationship between individual neurons to the effect of changing how heart rate is controlled by the network as a whole." Neural plasticity can be a potential factor in the neural network's decisions and how it controls cardiac function.

The researcher's suggested model of the neural network that composes the heart-brain bridge suggests that neurons don't act as one pulsating mass that controls the heart. Rather, neurons act individually and come to a consensus that allows the nervous system to interact with the cardiovascular system comprehensively, taking into account numerous variables that encompass cardiac function.

Like all bridges, this neural network that bridges the heart and the brain is prone to damage. Previous studies, such as Leto and Feola's in 2014, have linked cardiac dysfunction to cognitive dysfunction. One study in particular, conducted by Zou et al. in 2017, sheds light on which brain regions control and monitor specific cardiac processes. The brainstem, hippocampus, insular cortex, and prefrontal cortex are crucial brain regions that connect to the neural bridge between the heart and the brain. Injuries to these parts of the brain can negatively affect cardiac function. For example, injury to the prefrontal cortex of the brain might cause autonomic nerve damage, resulting in loss of heartbeat control via the autonomic nervous system.

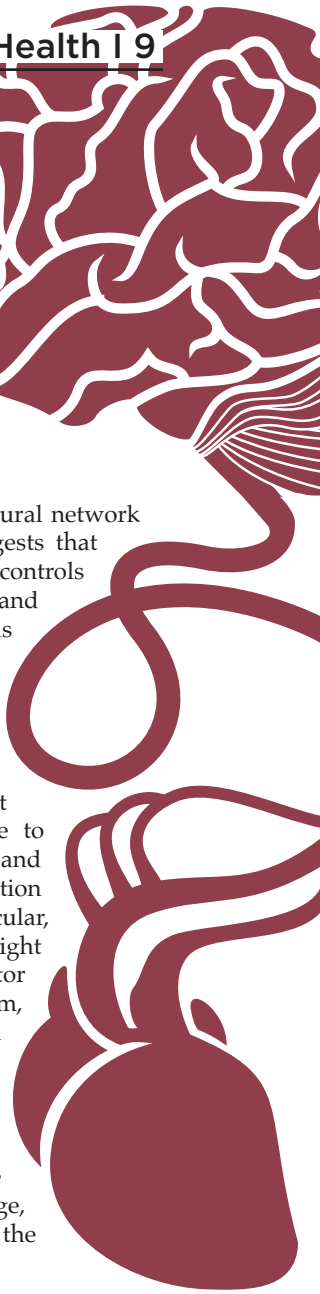

PHOTO BY SHUTTERSTOCK

Another region of the brain, the insular cortex, is also connected to the autonomic nervous system. Therefore, Zou et al. postulate that damage to this area of the brain will also result in severe consequences for the control of the cardiovascular system, including arrhythmia, disruption in blood pressure, injury to the myocardium (muscles of the heart), and breathing disorders during sleep.

The neural bridge between the brain and the heart is one that is constantly changing, monitoring, and impacting cardiac function. The interdependency of these two organs are highlighted by the association between cardiac and cognitive dysfunction. Although they are part of two completely different human body systems, they are bridged by a neural network that is crucial to maintaining cardiac function.

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BioMed Research International (2017). DOI: 10.1155/2017/5646348

Life on Venus

BY JOSEPH VALENTI, BIOLOGY & DATA SCIENCE, 2023
DESIGN BY EVAN DIAZ, ARCHITECTURE, 2025

Early in its discovery, it was thought that Venus may have a similar atmosphere to Earth's atmosphere for reasons such as the fact that it has observed clouds, but upon researching the environment of Venus, it became obvious that the climate was far from Earth's. The temperature on a normal day is around 400 degrees Celsius, or 752 degrees Fahrenheit, and its surface pressure is one hundred the times the pressure on Earth. Suffice to say that the prospect of life on such a hellish planet was thought to be pretty small. Despite this, recent studies have shown that, while its appearance seems unsuitable to life, there is data supporting the notion that, at one point, Venus was inhabitable and possibly had life of its own.

One study published by the American Astronomical Society proposed that Venus could have had a climate similar to Earth until relatively recently. Researchers noticed how Venus currently has the lowest orbital eccentricity in the solar system, meaning the variability in its orbit is particularly low compared to nearby planets, and they were able to determine, by comparing various models, that the eccentricity was likely affected by Jupiter's migrations within the solar system. Orbital eccentricity is important for evolution as it plays a large part in tidal energy and insolation flux, both of which contribute to maintaining stable heat, protecting against greenhouse effects, and prohibiting extreme water loss. This means that the migration of Jupiter within its orbit might have limited the orbital eccentricity of Venus, causing it to experience a rapid loss of water and enter a greenhouse state within its atmosphere. While this theory relies on some assumptions, such as implying there was water on Venus at one point without any evidence, it shows that the surface of Venus could have had a much more inhabitable terrain within the relative history of our solar system.

Despite its surface now being uninhabitable, researchers have found evidence that life may exist somewhere else on Venus — in the clouds. For nearly 40 years, a reading of phosphine gas within the clouds of Venus went largely unnoticed, as at the time, phosphorus-related gasses were largely ignored in the quest for finding life. But in September of 2020, a team of researchers from the University of California Riverside revealed in *Nature Astronomy* that they made the correlation between this 40-year-old reading and a possible sign of microbial alien life. While research following this discovery is still in its preliminary stages, the team has also found hints of other chemicals that predict signs of life such as oxygen, chlorine, and hydrogen peroxide.

> "I think many people are now revisiting the notion of Venus as a fully oxidizing environment."

To fully investigate this lead would take much more research, but the presence of these chemicals is not the only evidence as to why Venus's clouds are possible locations for life. Venus's lowest cloud has a climate in stark contrast to its surface, with temperatures of 60 degrees Celsius, or 140 degrees Fahrenheit, and 1 atmosphere of pressure, both of which are much more suitable to life. One study done by the University of Wisconsin published in *Astrobiology* in 2018 investigated the spectral signatures of Venus, reconfirming a great deal of what was already known about the planet but also denoting something new. In addition to studying its heavily sulfuric atmosphere, researchers noted that measured ultraviolet (UV) radiation resembles UV levels present when Archean Earth held photosynthetic life. This led to the conclusion that UV radiation absorption in their readings could very well be indicative of some sort of photosynthetic microorganism.

While the surface of Venus appears to be one of the most uninhabitable locations in the solar system, current research regarding its history and current atmosphere provides sufficient reasoning for further investigation into life on Venus. If given the same level of attention as Mars, perhaps it will become apparent that Earth was investigating the wrong neighbor for life.

Astrobiology (2018). DOI: 10.1089/ast.2017.1783
The Planetary Science Journal (2020). DOI: 10.3847/PSJ/abae63

PHOTOS BY PXFUEL AND RAWPIXEL

MASSIVE MARTIAN SAND WAVES

BY ISABELLE BRANDICOURT, ELECTRICAL ENGINEERING, 2024

DESIGN BY ASHLEY LUO, PHARMACEUTICAL SCIENCES, 2023

Less than 40 million miles away, Mars can be observed in the night sky by the naked eye, distinguishable by a reddish tinge to its pinprick of light. Data on Mars began to be collected almost as soon as space exploration itself began; the 1964 mission aboard NASA's Mariner 4 was the first successful flyby of Mars and captured 21 photos of the Red Planet. This mission, along with the following two successful ones, came back depicting a surface riddled with craters. For six years, Earth was under the impression that Mars' topography was nearly identical to the Moon's.

Enter Mariner 9. This 1971 mission was wildly successful, capturing over 7,000 images of Mars from orbit over the span of nearly a year. Revealing dormant volcanic peaks, dust storms, and massive valleys, this new data introduced a new depth to all previous assumptions about Mars. In the following years, multiple spacecraft were set on course to Mars from all over the world, including the U.S., the Soviet Union (then Russia in later years), and Japan. Faith in Mars exploration efforts was low following an overwhelming number of mechanical failures and denial of the possibility of Martian life. Things started to look up in the early 2000s, when evidence of ancient water rejuvenated excitement in this neighboring planet. Perhaps if life can sustain itself then there is potential for colonization. Hundreds of spacecraft have since orbited and even touched down on Mars, some dying there and some returning — all relaying an impressive amount of data back to researchers on Earth. 2012 brought the amazing find of methane and other organic compounds on the surface, reinforcing hypotheses supporting Martian life. Only by fully examining and understanding Martian conditions will humans perhaps one day be able to populate the Red Planet.

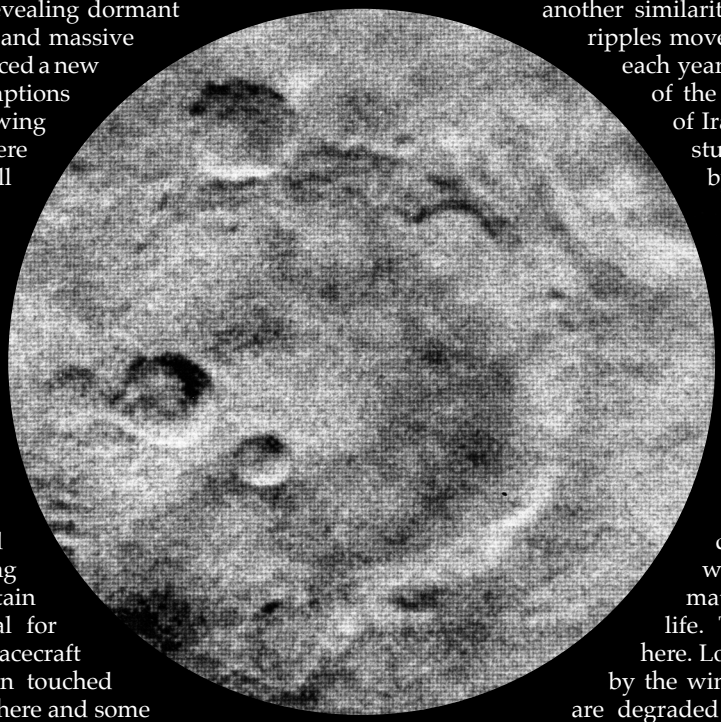


PHOTO BY NASA/JPL

One such condition is the massive mounds of desert sand on the planet's surface. While evidence supports the existence of centuries-past water sources, the climate is currently as dry as a bone. Images from several missions depict flowing wave patterns in the sand continuing for miles and miles. Classified as "megaripples," these fluctuations can be modelled by similar dune structures on Earth. After further analysis, rovers confirmed they are composed of ultra-fine particles at their base and topped with heavier, bigger particles. While on Earth, dunes are pushed by wind, the thin atmosphere of Mars means its winds were thought to be too weak to cause this effect. This weather data, the physical makeup of the sand layers, and observations spanning several years led scientists to believe that these Martian structures were stagnant and immobile memories of unimaginably intense windstorms from centuries past. As new data is constantly discovered, this theory has been challenged and overturned. An Italian study conducted over a much longer period of time, closer to a decade, found evidence of megaripple movement. Proving another similarity to Earth, these Martian ripples move at around 10 centimeters each year, which is close to the rate of the ripples in the Lut Desert of Iran. The researchers of that study hope to move forward by mapping wind intensity across the entire planet, locating both higher and lower than expected intensities.

But what does this mean for Mars exploration? An extensive study from 2017, "Habitability on Early Mars and the Search for Biosignatures with the ExoMars Rover," discusses the impacts of wind on locating organic material to use as proof of life. The timing is everything here. Loose organics being carried by the winds for any extended time are degraded by exposure to ionizing ultraviolet radiation, chemical harm, and general wear and tear. However, since all viable matter has to be protected underground, the sand shifts are essential in uncovering sites for rovers to drill into and collect samples of protected rock. Therefore, knowing that the wind exists, and hopefully in the future mapping its average intensity across the whole planet, will allow researchers to locate potential havens for gathering biological samples. Depending on the results of these future studies, we will have more insight into how life could be sustained on the red planet and what humans might need to one day survive there ourselves.

Astrobiology (2017). DOI: 10.1089%2Fast.2016.1533
Journal of Geophysical Research: Planets (2020). DOI: 10.1029/2020JE006446

Series of summer breakthroughs in solar physics could make predicting dangerous solar flares a reality

BY NOAH HAGGERTY, APPLIED PHYSICS, 2024
DESIGN BY CARINA HALCOMB, EXPERIENCE DESIGN, 2024

Over the summer, two independent collaborations of solar physicists published breakthrough papers within months of each other, furthering our understanding of the mechanics of solar flares and how to predict them. With just four years until peak activity in the sun's 11-year solar cycle, the ability to predict potentially dangerous solar flares is more crucial than ever.

High energy solar flares and massive ejections of solar material in the form of CMEs (coronal mass ejections) can pose a significant threat to Earth — disrupting satellites, bombarding astronauts with dangerous levels of radiation, and, in worst cases, blowing out ground transformers and crippling electric grids. While CMEs travel considerably slower than light, allowing for a short warning period of about two days, solar flares travel at the speed of light, leaving Earth quite literally in the dark until they strike. With society's growing reliance on electronics and modern technology, predicting these solar events to provide a warning period and enact preventive measures could potentially prevent billions of dollars in damages and save lives.

"With society's growing reliance on electronics and modern technology, predicting these solar events to provide a warning period and enact preventive measures could potentially prevent billions of dollars in damages and save lives."

But solar physics has been stalling. Empirical methods of predicting flares have fallen short of reliable and practical. To make matters worse, two decades after the discovery of "sunquakes" that ripple across the solar surface in response to solar flares, further complicating flare mechanics, scientists had made little progress in understanding how the two fundamentally relate — until now.

In May, an international collaboration of scientists from the United States, Colombia, and Australia published two papers announcing a breakthrough in understanding how solar flares and their accompanying sunquakes interact. The group focused on an odd M-class flare, the second-highest energy classification, which seemed to have an uncharacteristically abrupt eruption. This suddenness helped the team view the flare and its ripples with unprecedented clarity. Through a new mathematical model, the group determined that the source of the sunquake was much deeper into the sun's surface than predicted. This led to their revolutionary hypothesis that the solar flare had not caused the sunquake ripple but that it had acted as a trigger for an energy release deeper in the sun. The scientists are optimistic about the potential implications of this discovery for the future of the field and solar flare prediction. Martínez Oliveros, a leading scientist on the papers, predicts, "We may even forecast some details about how large an active region is about to appear and what type — even, possibly, what kinds of flares — it might produce. This is a long shot, but well worth looking into."

Not only two months later did another breakthrough shock the solar physics community — and even caught the attention of NASA. At the end of July, a team of Japanese physicists announced they had created a new model, dubbed "Kappa-Scheme," for predicting X-class solar flares, the highest energy class and most dangerous to Earth. Unlike past empirical models, Kappa-Scheme is physics-based, meaning it models the magnetic fluid mechanics of the sun to make its predictions as opposed to relying on statistical analysis. When the team tested this new model on data from the past solar cycle, with the exception of one flare in 2014, it successfully predicted the time, solar location, and general intensity of every single X-class flare in the cycle over 20 hours before each happened. While it also threw a handful of false warnings, a model of this accuracy has never been created before.

These breakthroughs set the stage for a possible positive feedback loop in solar physics in which new understandings of flare mechanics drive more accurate physics-based prediction models, which in turn create incentives for government investment in new solar research and instrumentation to collect data. Both studies published over the summer utilized data from NASA's Solar Dynamics Observatory satellite, and the Japanese team also pulled data from the National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellites (NOAA GOES) constellation.

NASA and NOAA work in collaboration to warn "electric companies, spacecraft operators and airline pilots before a CME comes to Earth so that these groups can take proper precautions." These precautions usually include shutting down satellite systems and throttling electrical grids to handle incoming surges. With the implementation of these new scientific breakthroughs into current warning systems, the agencies could soon provide a warning period for solar flares, and an additional day cushion for CME warnings. These warnings will help mitigate one of modern technology's greatest vulnerabilities and create an extra level of assurance for the safety of everyone on Earth.

Science (2020). DOI: 10.1126/science.aaz2511
The Astrophysical Journal Letters (2020). DOI: 10.3847/2041-8213/ab9173
The Astrophysical Journal Letters (2020). DOI: 10.3847/2041-8213/abad2a

PHOTO BY JUSTIN DICKEY VIA UNSPLASH

Pulsars:
The lighthouses of the universe

BY LUKE MARTIN, PHYSICS, 2024
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

Even among the myriad of mysterious, awe-inspiring objects in our universe, pulsars deserve special recognition. As one of the densest objects and most powerful magnets known to man, the pulsar is one of nature's most extreme creations. The husks of dead stars — the fastest of which can spin over 700 times per second, pulsars emit concentrated beams of electromagnetic radiation, which from our vantage on Earth, appear to pulse at regular intervals.

Pulsars are a rapidly-spinning variant of neutron stars — the cores of supernovae not quite massive enough to become black holes. Their rotational periods range from 1 millisecond to 15 seconds, with most falling between 0.3 and 3 seconds. They are typically around 1.5 solar masses, with radii close to 10 kilometers, making them the densest objects in the universe after black holes. If the sun were made of neutron star material, it would weigh almost 250 times the rest of the galaxy combined!

> "When the magnetic field is not aligned with the axis of rotation, the magnetic poles whip around the star like the beam of light from a lighthouse."

Neutron stars are formed by the collapse of massive stars, typically those of eight solar masses or more. At the end of their life, these massive stars explode outwards in a supernova. The leftover core rapidly shrinks, with the extreme conditions crushing protons and electrons together into neutrons (hence the name "neutron star"). Angular momentum is conserved in this process, but the extreme decrease in diameter from millions of kilometers to between 20 and 24 km makes rotational speed increase dramatically. When the spin is fast enough and the magnetic field strong enough, neutron stars radiate as pulsars.

> "If the Sun were made of neutron star material, it would weigh almost 250 times the rest of the galaxy combined!"

The magnetic field surrounding the strongest pulsars can exceed 1013 gauss — over 10 trillion times that of Earth's. Charged particles are accelerated along the magnetic poles to relativistic speeds, generating electromagnetic radiation in the form of radio waves, X-rays, or gamma rays. When the magnetic field is not aligned with the axis of rotation, the magnetic poles whip around the star like the beam of light from a lighthouse. To an observer on Earth, the emissions appear as brief pulses of radiation, from which pulsars get their names.

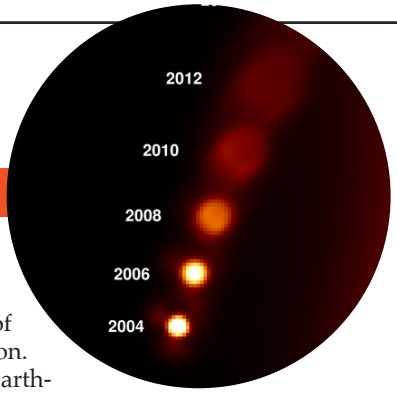
From confirming predictions of General Relativity to being the most accurate natural clocks in the universe, pulsars have proven to be incredibly valuable to astronomers. Their continued discovery and research will no doubt create both questions and answers that help to unveil the hidden nature of our universe.

Science (2004). DOI: 10.1126/science.1090720
Physics Reports (1991). DOI: 10.1016/0370-1573(91)90064-S
Journal of Physics: Conference Series (2017). DOI: 10.1088/1742-6596/932/1/012002

The phantom planet

How one of the first directly imaged exoplanets turned out to be dust

BY SHARMILA KUTHUNUR, JOURNALISM, 2022
DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022



Proceedings of the National Academy of Sciences (2020). DOI: 10.1073/pnas.1912506117
PHOTO BY NASA

In 2008, news was abuzz with the detection of a massive exoplanet just 25 light years away from Earth, practically in our cosmic backyard. While the features of neither the exoplanet, Fomalhaut b, nor its star, Fomalhaut, were extraordinary, this discovery was notable for two things that unfolded in its wake.

First, it proved that Fomalhaut b really did exist — a possibility that had only been theorized since the early 1980s. Second, perhaps more importantly, the discovery was proof to the scientific community that exoplanets could be detected by direct imaging. Until then, discovery efforts had either utilized transits or measured the suspected planet's gravitational interaction with nearby objects. These methods work only when the exoplanets are huge enough to either be seen against the backdrop of their host stars, or to cause noticeable disruptions in the surrounding space.

Another method brought to light by the success of Fomalhaut b's discovery, required telescopes to use a coronagraph to block Fomalhaut's light, thus creating an artificial eclipse. The subsequent dimming made it possible to detect Fomalhaut b, which would have otherwise been engulfed in its star's brightness.

The discovery was confirmed by two other independent studies, and cited by many more. Fomalhaut b was also among the winners of NameExoWorlds in 2015, an unprecedented contest conducted by the International Astronomical Union, after which it was crowned 'Dagon.' As with any exoplanet discovery, researchers began to theorize how Dagon came to be.

Two theories persisted, one that claimed Dagon to have formed near Fomalhaut and pushed outwards to its current location, and another that theorized that Dagon formed in its current position. One of the tasks of the much-awaited James Webb Space Telescope was to decipher Dagon's features in detail. Dagon checked all boxes in terms of position, brightness, and orbit. Dagon's behavior was exactly what astronomers expected. There was only one problem: The exoplanet did not exist.

Fomalhaut's system is only 200 million years old, hinting that the planets are still cooling, during which they release tremendous amounts of heat as infrared radiation. However, none of the Earth-based telescopes detected the planet in infrared wavelengths. This puzzle was further deepened by observations that Dagon was fading, disintegrating, and expanding.

Latest research, published on April 20, 2020 in the *Proceedings of the National Academy of Sciences* (PNAS), outlines Dagon's atypical behavior; it concludes that Dagon is actually a dispersing cloud of dust that has been reflecting its star's light in such a way as to produce the illusion of an exoplanet.

"Fomalhaut b represents a phase in planetary system evolution that we had never imaged before, so it is now a benchmark in a new direction," George Rieke, a professor at the University of Arizona and co-author of the 2020 *PNAS* study, told *NU Sci*.

Rieke emphasizes that Dagon's 2008 discovery was of high quality and completely accurate considering the information known at the time. Back then, there was no reason to doubt the nature of the exoplanet. Move over, given the thorough vetting process that new discoveries go through before being announced to the public, instances like these are extremely rare.

"You are not allowed to call the newspapers just because you found a faint object near a bright star — you have to wait patiently for a year or two," explained Rieke.

The events that unfolded since the discovery: additional research and monitoring to detect changes in Dagon's behavior have updated our knowledge about the Fomalhaut system. At its core, this is how science works. With ongoing research, old knowledge evolves with fresh insights, and on the whole science keeps moving forward.

"If we did not evolve in our understanding and change our interpretations, science would be a very boring enterprise," says Rieke.

Early 1980s — Debris ring discovered around Fomalhaut.

2005 — Astronomer Paul Kalas theorized that the debris ring was gravitationally modified by a planet. Shortlisted candidates included Fomalhaut b.

2006 — Fomalhaut b reduced to half its original brightness. Infrared observations could not detect it.

2008 — Experts obtained the first image of the exoplanet Fomalhaut b.

2015 — Fomalhaut b was one of the first exoplanets given an official name in the NameExoWorlds contest.

2020 — Peer-reviewed literature concluded that Fomalhaut b is in fact a dispersing cloud of dust.

Pulsating jellyfish

The most efficient swimmers in the ocean further enhanced with microelectronics

BY CAILEY DENONCOURT, BIOENGINEERING, 2022
DESIGN BY HEATHER WELCH, ENVIRONMENTAL SCIENCE, 2020

For an animal missing both a heart and a brain, jellyfish are beautifully mystifying to watch as they glide through the water. As very simple creatures and extremely slow swimmers, jellyfish have been overlooked by many researchers when in fact the way in which they pulsate their bell to move is quite complex and efficient.

It was not until 2013 when Dr. Brad J. Gemmell and his research team at the Marine Biological Laboratory investigated the mechanics behind jellyfish propulsion through a unique form of passive energy recapture. For their study, Aurelia aurita, or moon jellyfish, known for their translucent, moon-shaped bell and short tentacles, were observed using computational fluid dynamics and pressure estimations through velocity measurements.

> "The unique method of passive energy recapture used by jellyfish could further be studied and eventually implemented into biomimicry applications."

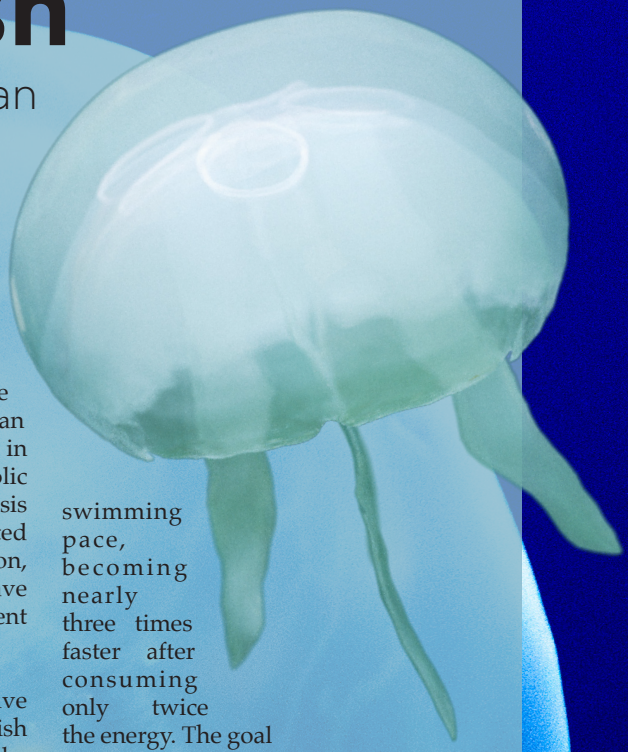
When the jellyfish contract their bell, they form two vortices. A high-pressure vortex forms underneath while a low-pressure vortex forms on the outer edges. As the bell bends, the high-pressure vortex propels the jellyfish forward. This causes the low-pressure vortex to roll beneath the bell, after which the water floods into this low-pressure area, resulting in a secondary push, again propelling the jellyfish forward. This second boost requires zero extra energy since no muscle contraction is required, allowing the jellyfish to move 80 percent farther without any energy expense.

However, jellyfish are about 90 percent water and swim at a much slower rate compared to their fish counterparts. In order to accurately compare the energy expenditure between other aquatic creatures, Gemmell used the cost of transport analysis rather than the currently accepted calculation in order to account for net metabolic energy demand. Using this analysis method, moon jellyfish are calculated as 3.5 times more efficient than salmon, which was previously thought to have been the most powerful and efficient aquatic animal.

The unique method of passive energy recapture used by jellyfish could further be studied and eventually implemented into biomimicry applications, including the design of ocean machines like autonomous underwater vehicles. By applying this jellyfish trick, the length of a possible deep sea expedition could increase by reducing energy consumption.

But more so, researchers at the California Institute of Technology and Stanford University used microelectronics to even further the efficiency of jellyfish. In a paper published at the beginning of 2020, moon jellyfish were given eight pacemakers placed along the nerve clusters on their bell in order to increase the frequency of bell contractions, which would hypothetically correlate to an increase in the swimming speed of the jellyfish.

They found that at a frequency of around 0.5 to 0.62 hertz, the swimming speed of the jellyfish was about 2.8 times greater than without the microelectronic attachment. Not only were the jellyfish able to swim faster but they were also more efficient than their usual swimming pace, becoming nearly three times faster after consuming only twice the energy. The goal of this study was to evaluate the possible energy savings for using jellyfish as a mode to discover more about the ocean. Current robots being deployed into the ocean for research purposes use up to 1,000 times more power than the jellyfish with the microelectronic attached. Natural jellyfish live in a wide variety of environments with a range of temperatures, salinity and oxygen levels, and other conditions that could be mapped out with the help of bionic ones.



With no harm coming to the jellyfish through the attachment of the microelectronics, the most efficient creatures in the ocean can be further powered for even higher efficiency. Although there still remains further developmental improvements and ethical questions in using and controlling jellyfish for research purposes, the possible implications could allow humans to explore the 90 percent of the ocean that still remains a mystery to this day. All in all, jellyfish are some of the coolest creatures in the ocean, and that's a no brainer.

Science Advances (2020). DOI: 10.1126/sciadv.aaz3194
PNAS (2013). DOI: 10.1073/pnas.1306983110

PHOTOS BY SHUTTERSTOCK AND WIKIPEDIA

Whistles underwater

ARTICLE AND DESIGN BY RACHEL LINES,
BEHAVIORAL NEUROSCIENCE, 2023

How humans are changing dolphin communication

Dolphins are generally regarded as one of the most intelligent species of mammals, even demonstrating the ability to learn and follow verbal cues and gestures from human trainers while in captivity. In the wild, dolphins use sound signals to navigate, hunt, and communicate with other creatures, including individuals of their own species and of other dolphin species. Dolphin sounds can be broken down into three distinct categories: clicks, burst pulsed sounds, and whistles — a specific type of call with distinct communication purposes. In fact, each dolphin has a signature whistle, which they use to identify themselves and address others, and this call has complex uses in social contexts. Therefore, there are concerns about the effects of human-produced noise on these whistles and resulting behavioral changes in dolphins.

One of the most significant calls produced by dolphins is the signature whistle. Through the analysis of 50 years of signature whistle research, researchers from the University of St Andrews and the Woods Hole Oceanographic Institute defined the call as "a learned, individually distinctive whistle type in a dolphin's repertoire that broadcasts the identity of its owner." These calls develop as early as the first three months of life, and are influenced by experience. Dolphins base their signature whistle on sounds they hear, such as their mother's whistle or whistles from their own population. Unlike vocal learning in other species that copy a model, dolphins use their experience to create a signature whistle that avoids closely matching signals they have previously heard. Once the signal has crystallized, or been defined by an individual, there are very few factors that can change the call. The sound becomes a permanent identifier for the dolphin.

Signature whistles are used for several purposes in dolphin communication. Typically produced only when animals are out of visual range, these calls identify the producer to nearby animals. Dolphins are also skilled in vocal copying and use this ability to address other animals. For example, dolphins will copy a signature whistle of another individual and call out using this signal in an attempt to address that individual. Dolphins also repeat whistles to confirm that they received an original signal. In other contexts, whistles can convey stress levels based on rates of sound production. They can also convey the recognition of other animals that they passed by at sea or the reunion of a mother and her calf.

Whistles, and especially signature whistles, have a crucial role in dolphin communication and social abilities. For this reason, researchers have begun to look into the impact of human activity on these signaling mechanisms. The presence of boats is known to have an influence on dolphin behavior, including vertical and horizontal patterns of avoidance from boats that increase dive duration. These altered behaviors can affect hunting and social interactions for dolphins. Researchers at the Blue World Institute of Marine Research and Conservation examined the frequencies produced by recreational boats and found that they fell within the same range as dolphin signals, particularly whistles.

To avoid the masking of their calls, dolphins have altered their signals in noisy oceanic environments dominated by recreational boat noise. These signal variations include changes in whistle frequency modulation, increased emission rates and durations of calls, and changes in call structure. Another reason that dolphins may be changing their calls is the disruption of a behavior. When a recreational boat — or another source that alters sea ambient noise — appears, dolphins may change their task and type of communication. For example, dolphins engage in intense communication with group members to increase hunting success. Noisy conditions would require higher energy requirements to produce unmasked sounds and could cause increased stress in response to decreased food intake.

The alterations to dolphin communication caused by human-produced noise is very concerning, especially considering the importance of whistles in their communication, from hunting signals to greetings and recognition. The increased sea ambient noise in coastal areas is frequently related to human recreational activities, and dolphins tend to avoid areas with this increased noise. Therefore, it is crucial to understand the frequencies of noise pollution that recreational boats produce and encourage education about the effects of recreational activities on marine animal behavior. Many people enjoy learning about these species at aquariums and other animal experience parks, and this fascination can be applied to help preserve the natural behaviors of these captivating oceanic species.

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Marine Pollution Bulletin (2016). DOI: 10.1016/j.marpolbul.2016.02.030
Acta astronautica (2014). DOI: 10.1016/j.actaastro.2014.07.003

PHOTO BY PIXABAY

Fire is a blessing and a curse (and a result of climate change)

BY YAEL LISSACK, BIOENGINEERING & ETHICS, 2021
DESIGN AND PHOTO BY SAM KLEIN, DESIGN, 2022

For most people, fire is synonymous with destruction and death. After the recent apocalyptic-looking orange skies in northern California made national news, this association has only been strengthened. Because of California's rampant wildfires, thousands of people and countless animals have been displaced, more than a thousand homes have been destroyed, and five people have tragically died. Notably, two of the most recent fires have even made the list of the state's largest in history. Despite their catastrophic effects on humanity, natural forest fires do occur and even have some benefits to ecosystems. According to the Center for Climate and Energy Solutions, the annual number of large fires in the western United States has nearly doubled between 1984 and 2015, mirroring increases in temperature and dryness due to climate change. *Scientific American* links less dependable precipitation, hotter temperatures, drier soil, snowpack that melts sooner, and salvage logging to increased risks of large blazes. Furthermore, recent USDA Forest Service projections show that a 1 degree Celsius average increase in global temperature could increase the annual mean area burned by up to 600 percent in some regions of the U.S.—and according to the National Oceanic and Atmospheric Administration, this could easily happen within the next 30 years.

> "1 degree Celsius average increase in global temperature could increase the median area burned by fires per year by up to 600 percent."

While it may seem counterintuitive, forest fires have been a force of ecological balance for thousands of years. Most ecosystems benefit from periodic fires—many plants and animals have even evolved to depend on them. Naturally, matter such as dead or decaying plants builds up on the forest floor over time; this results in anaerobic, sunlight-deficient conditions that can choke out small plants and new growth, kill oxygen-dependent species in the soil, and prevent nutrients from being accessed by plant roots. A natural fire can clear that layer of decay and release trapped nutrients back into the ecosystem. Once the nutrient-rich burnt material has settled, it becomes the optimal medium for new plant growth. Roots can then access these nutrients more quickly than if the material had decayed over time. Moreover, invasive plants are less likely to recover in this environment, allowing native plants to rebuild the forest with greater biodiversity.

Many plants have evolved over time to take advantage of this cycle. For example, numerous species of pine trees that are indigenous to environments where hot, fast moving fires occur frequently have evolved to have thick, tough "serotinous" cones that are tightly closed with strong resin and can hang on the trees for years. Only when a large fire engulfs the tree are the seeds released, as the resin melts from the cone. The bed of nutrient-dense ash left over from the blaze is the perfect nursery for pine seeds to germinate and repopulate the forest. This isn't new information either. Members of the Karuk, Yurok, and Mono Native American Tribes, as well as countless other indigenous peoples in the U.S., have been performing ceremonial burnings for thousands of years—that is, until the U.S. government banned the practice.

Though there are benefits to natural blazes, more than 80 percent of wildfires in the U.S. are caused by people and are harder to control than ever before because of an increase in droughts, higher temperatures, drier air, and stronger winds. As temperatures continue to rise as NASA projects, this disturbing trend will only worsen. Other practices such as salvage logging can also contribute to the increase in fire severity. Salvage logging is a method of removing burnt trees from post-fire landscapes, often by companies to squeeze any remaining profit from the left-over timber. This practice removes precious nutrient resources from the remaining biosphere and makes the land even more vulnerable to future fires. As the risk of forest fires grows with rising temperatures, the responsibility falls on us to protect our landscapes. Like any destructive force, recovery plans with active forest management must be put in place before a devastating fire hits to minimize habitat damage and reduce excessive erosion. Fire-resistant design features and materials should be the standard for buildings in fire-prone areas. Additionally, individuals should take care to fully extinguish any personal fires while camping or outside.

While Smokey the Bear is right that "Only YOU can prevent forest fires," climate change is indeed accelerating their occurrence faster than the gender-reveal-parties-gone-wrong that ignite them. It is up to us to be responsible outdoorsmen—which means more than just extinguishing campfires; it must also include fighting to reduce our contributions to global climate change.

THE HEARTBEAT OF THE OCEAN IS SLOWING

BY ISABEL KAIN, PHYSICS, 2021
DESIGN AND PHOTO BY SAM KLEIN, DESIGN, 2022

We intuitively know that the ocean is constantly moving: the tides ebb and flow, waves swell and crash, plane wreckage moves mysteriously across latitudes to be beached on the other side of the world. But what makes the ocean move? The steady heartbeat of the ocean is its global-scale currents.

Ocean circulation is the global-scale movement of water, driven by separate processes on two scales: surface currents in shallow water, and deep currents along the bottom layers of the ocean. Surface currents are driven by energy exchange between shallow ocean water and the wind. The shear stress of air blowing along the surface of the water imparts momentum from the wind to the water, initiating a drift current in the shallow surface layer. This wind also deforms the shape of the surface, creating choppy waves, which in turn changes the grip the wind has on that sea surface. Over time, circulating winds and the rotation of the Earth can combine to create gyres, swirling vortices of water thousands of kilometers in diameter. And sometimes, water isn't the only thing swept along: the Great Pacific Garbage Patch is an example of a man-made gyre, a massive wasteland of floating garbage kept together by the swirling of surface currents.

Deep water beyond the reach of air-sea interactions is pumped by thermohaline circulation, driven by differences in the heat and salinity of units of water. The ocean is stratified into layers with slightly different compositions, temperatures, and densities. Warm, fresh water rises slowly towards the surface, and cool, salty water sinks towards the ocean floor, buoyed or sunk by its relative density to the surrounding water. This sinking displaces water at the bottom of the ocean, instigating a creeping conveyor belt of water transport. This process transports 1015 watts of heat from the tropics to the polar latitudes, which accounts for about one-quarter of the total heat transport of the atmosphere and oceans combined. Reaching every ocean basin across the globe, this process merges the Earth's oceans into a connected global system, facilitating the global transport of energy, nutrients, and living creatures. This circulation progresses at a snail's pace, typically moving at only 0.4 inches per second, and cycles the deep, dense water at the bottom of the world's oceans approximately every 600 years.

> "The steady heartbeat of the ocean is its global-scale currents."

This ocean heartbeat allows ocean life to flourish as well. As deep water is pulled to the surface by upwelling events, nutrient-rich water is flushed upwards through the water column. Phytoplankton, primary producers and the foundation of the oceanic food web, bloom around these nutrient flows and kickstart a zone of extremely rich biological activity. These upwelling events become biotic magnets for all levels of the food chain, and humans are no exception: approximately one-quarter of the global marine fish catch comes from upwelling zones, which account for only 5 percent of the total ocean.

As we have increasingly discovered in the 21st century, human actions can have cascading effects on delicate, crucial natural processes. Rising atmospheric CO_2 and the resulting warming of Earth's oceans have wreaked havoc on marine systems and could potentially interrupt ocean circulation. A weakening—or even total arrest—of global ocean circulation could spell disaster for huge swaths of the Earth's ecosystems. As deep water ceases to be cycled to the surface, it will become depleted of oxygen, choking all marine life—which is the projected cause of many mass extinction events throughout geologic time. Ceasing upwelling events would cause a collapse in the plankton population, which would in turn kneecap the rest of the marine food chain. The weather in northern and western Europe would turn cold and unpredictable, as the stabilizing effect of Atlantic thermohaline circulation dissipates, and storms and floods in many regions of the world will increase in frequency and intensity. Already, the Atlantic meridional overturning circulation, the largest thermohaline circulation pattern, has shown evidence of 15 – 20 percent weakening over the past 200 years, with scientists speculating that human impact is accelerating this process, causing a devastating 13 centimeters of sea level rise.

The movement of Earth systems can seem immoveable, and humans have been wont to take them for granted. But we've begun to learn that our choices create untold environmental impact and can disrupt cycles which have continued for millennia. The effects of changing circulation patterns will not be kind to us, and we will soon find out what happens to us when the ocean's pulse quiets.

Geophysical Research Letters (2013). DOI: 10.1002/2013GL057992
Encyclopedia of Ocean Sciences (2001). DOI: 10.1006/rwos.2001.0111

THE LIVING BOMB AND ITS AFTERMATH

Radiation of life during the Cambrian explosion

BY JOHN DROHAN, DATA SCIENCE & BIOCHEMISTRY, 2023

DESIGN BY SOPHIA HITT, BIOLOGY, 2023

Life on Earth today is fantastically diverse, as even within just the animal kingdom more than 1 million species have been discovered. They all have their own role in the ecosystem, defined as their niche. While organisms have always had their own niches in the environment, prior to the geological time period known as the Cambrian, the biodiversity of species was extremely limited. This means that the ecosystems of the Ediacaran period, the period before the Cambrian, were simple with many fewer niches being filled. After the Ediacaran period, there was a radiation of species that occurred, which became known as the Cambrian explosion, and it shaped life on Earth today.

Life in the Ediacaran period has been described as almost alien to the life seen on Earth today. Still contained within the ocean, animals in the Ediacaran were primarily soft-bodied seafloor creatures that resembled fronds or ribbons. These animals existed alongside sponges and unicellular organisms for nearly 80 million years, until life on Earth took an abrupt and explosive turn. Suddenly, animals began to develop an entirely different anatomy that appeared similar to species living on Earth today. These new Cambrian developments marked the extinction of many species that failed to adapt, bringing about the end of the Ediacaran period. In fact, since the Cambrian explosion, there has been almost no major anatomical reorganizations of animal species.

The distinct differences between Ediacaran and Cambrian life are characterized by alterations in the animals' behaviors and biology. Biomineralization, or the use of minerals in the environment to form a shell or skeleton, led to development of hard-bodied organisms with a distinct advantage over Ediacaran life. This adaptation, along with the development of environmental manipulation such as burrowing, most likely led to the appearance of macroscopic predation in the Cambrian period. Microbes on the seafloor were the only prey of predators living in the Ediacaran period, but now in the Cambrian world, any unprotected organism was at risk. Many Ediacaran species were unable to adapt to macroscopic predation, and their populations were decimated; others evolved and thrived, starting the predator-prey race for survival. In taxonomy, or the science of classifying living things, organisms are separated into kingdoms which can be broken down into separate phyla. Between 20 and 35 major phyla of the animal kingdom that are living today can be traced back to the Cambrian explosion. This is remarkable because the entire kingdom of Animalia contains only 36 known major phyla and the Cambrian explosion spanned less than 25 million years, which is extremely short in geologic time.

The major components of evolution, adaptation and mutation, were the driving forces of the diversification that occurred during the Cambrian explosion. Before this time, life on Earth was simple and uniform, but macroscopic predation allowed for only animals with advantageous traits to survive. This evolutionary pressure created a deeply complex food web from a series of speciation events. Each speciation event led to an abundance of new species from a common ancestor, filling a role in an ecosystem that still persists to this day. Researchers still haven't agreed on a concrete explanation, but there are many theories that speculate what could have happened to push life on Earth toward rapid diversification during the Cambrian explosion. One popular theory, known as biotic replacement, suggests that it could have been a series of microevolutions that pressured certain species into extinction. Another theory, referred to as the catastrophe, argues that there may have been a major event that disrupted life on Earth. As species repopulated, the species that held the traits necessary for rapid diversification were simply better equipped to survive. The development and spread of these traits allowed species to occupy specific niches in the environment; without them, the speciation events would have been stagnated.

Continuing to study the underlying mechanisms of the Cambrian explosion today helps scientists to better understand the evolution of life on Earth. The Ediacaran species diversified during the Cambrian explosion into the animal phyla we recognize today, but what about the species that failed to survive? What branches of life have yet to be uncovered, and what secrets do they hold about the hidden ancestry of all animals on Earth?

Trends in Ecology and Evolution (2018). DOI: 10.1016/j.tree.2018.06.003

Fessenden's oscillator is all the range

An early foundation of sonar

BY JESSICA HEALEY, MECHANICAL ENGINEERING, 2024

DESIGN BY VICTORIA PAJAK, BEHAVIORAL NEUROSCIENCE, 2021

Despite constant navigation on its waters, many aspects of the ocean remain mysterious. Ships have been facing the ocean's hidden surfaces and unpredictable storms for most of history. By releasing sound waves, and measuring the time it takes for them to return, Sound Navigation and Ranging (sonar) aids with travel, navigation, and detection. In the early 1900s, a stubborn Canadian-born inventor created the first successful echo-ranging device — the Fessenden oscillator.

Reginald Fessenden created hundreds of patents throughout his life. He heavily studied radio waves, a kind of electromagnetic radiation. He eventually turned to their transmission through water, which led to the invention of the Fessenden oscillator. Before Fessenden's invention, the tragedy of the RMS Titanic opened many eyes to the dangers lurking under the surface of the ocean. Organizations, such as the Submarine Signal Company (SSC), aimed to create a device that would prevent another disaster. It was the SSC, right here in Boston, that asked for Fessenden's help with the receiver of its submarine bell system. He was not impressed by the product and wanted to create his own transmitter. When SSC executive Harold Fay denied his request, Fessenden invented a receiver and a transmitter through a loophole in his orders.

The Fessenden oscillator was the first modern transducer used in sonar, and its design was similar to a microphone. It consisted of a steel cylinder with an inner copper tube that vibrated with an alternating current. In 1914, the oscillator sent and received morse code in Boston Harbor. Fessenden and SSC engineers also successfully tested it against an iceberg in Canada that same year. However, World War I broke out soon after, and the SSC focused on using the device for underwater signaling, not echo-ranging. This was not Fessenden's intention, as he created the device to prevent situations like the RMS Titanic. He tried to sell the device's ranging potential to the British Royal Navy and fell out of favor with the SSC. It was not until 1923 that the SSC sold the product as an echo-ranging device. Prior to 1923, the device was otherwise used as a telegraphy system. Fessenden's invention was the earliest practical form of ship sonar, and part of its technology, along with the ideas behind it, are still used by modern ships. His strong-willed ambition, while causing conflicts in the early 1900s, continues to benefit society more than a century later.

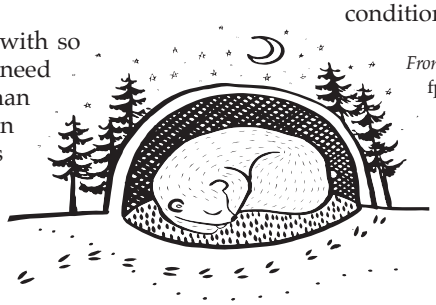
Low-resource survival: How hibernating animals conserve energy

BY AUDREY GALLIER, COMPUTER SCIENCE, 2023

As fall descends on the Northern Hemisphere, bears and chipmunks begin to hoard food and build fat stores in preparation for winter. Hibernation occurs in hundreds of known species, including mammals, reptiles, amphibians, and even one species of bird — the common poorwill. While animals hibernate, their metabolism slows dramatically: they become hypothermic, their heart rate drops to as low as 1 percent of the original, and some animals do not eat or drink for months. We are still uncovering the details of hibernation, and current research on this fascinating process may soon have medical benefits.

Hibernation is commonly thought of as a winter necessity, but it can be more accurately described as a resource-preserving mechanism. Animals hibernate when they lack sufficient resources to maintain normal metabolism. These environmental circumstances can occur under severe weather conditions or when predators restrict access to food and water. For example, the Malagasy lemur of the tropics hibernates during the region's dry season. The low-metabolism state is not sleep, but a more extreme state called torpor.

How do hibernators manage to survive with so little fuel and oxygen? These species need to avoid using more ATP (energy) than they can produce, so they cut down on high-energy cellular processes such as transcription and translation. Epigenetic mechanisms, like DNA methylation, and cellular factors, like ribosome dissociation, globally repress these high-energy processes. Simultaneously, genes for hibernation-specific mechanisms, such as burning fat and protecting cells with antioxidants, are upregulated.



As gene regulation and editing technologies are being explored in medicine, the genetic basis of hibernation is promising for medical applications. But controlling gene regulation may not be necessary in order to reap the medical benefits of hibernation. In 2018, Changhong Ren et al. conducted an experiment on mice to determine whether depriving them of oxygen would create a hibernation-like state. The rodents' oxygen consumption dropped by 80 percent, and their body temperature decreased by 8 degrees Celsius. Additionally, they suffered less neuron damage when blood flow to the brain decreased. This evidence suggests that hypoxia treatment for stroke patients may promote recovery. Other potential medical applications of hibernation findings include muscle loss, heart problems, and weight loss. If we develop hibernation-like treatment further, this mechanism that helps animals survive extreme conditions could save human lives.

Frontiers in Physiology (2020). DOI: 10.3389/fphys.2020.00436

Aging and Disease (2018). DOI: 10.14336/AD.2018.0702

The International Journal of Developmental Biology (2009). DOI: 10.1387/ijdb.082643pm

PHOTOS BY SHUTTERSTOCK AND THE NOAA PHOTO LIBRARY

Reflecting earth's rotation around the celestial pole, stars light up the sky over the Anza-Borrego desert in Southern California.

PHOTO BY MUHAMMAD ELARBI, COMPUTER SCIENCE, 2022

Music, math, and the mind

Why do we perceive musical chords as good or bad?

BY CARA PESCIOTTA, PHYSICS, 2022

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

A symphony resounds, stirring feelings of peace and fear, sadness and joy, all in one piece and all without words. This absence of words in a classical symphony, or any instrumental piece, leaves just musical properties as the cause of an emotional response. Intuitively, most would say that fast tempos and loud dynamics create energy or anxiety while slow and soft songs bring about peace or sadness. This can be explained by differences in neural activation and stimuli that correlate to our natural body rhythms. Intuition is less obvious, though, when considering the melodies and harmonies — why do certain chords give a sense of pleasure, while others leave a bitter taste?

Musicians actually have a name for these visceral reactions felt in response to different chords. Consonant notes are those that create pleasure or stability, while dissonant notes create unease or instability. Both of these have their place in music, as oftentimes a song's chord progression will include a dissonant chord before a consonant one. This is called resolution, when a perceived unstable chord transitions to a stable one. Including both of these in music is part of what makes a piece compelling and enhances its emotional value.

For centuries, musicians and scientists have wondered what gives certain chords these characteristics. The ancient Greeks suggested a mathematical relationship between string length in instruments where the produced frequencies exist in whole number ratios; more recent hypotheses propose that beating, when a chord produces an unpleasant wobbling sound, is what makes a chord dissonant. It was not until 2010 that these variables were separated to study what makes consonance and dissonance present in music notes.

A University of Minnesota study by Dr. Josh H. McDermott had students compare their preferences for chords, mixing combinations of harmonics and beating. The students reacted positively to harmonic chords, meaning the frequencies of notes in the chord are multiples of a common fundamental frequency. A fundamental frequency of 440 hertz (Hz), the note A4 for example, would be played along with integer multiples 880 Hz and 1320 Hz to create a harmonic. This is evidence in favor of the Greeks' hypothesis, where a mathematical relationship, harmonics, creates consonance.

The beating hypothesis was largely debunked; the evidence linking beating and dissonance was weak and inconsistent when compared to that of inharmonic chords. A follow-up study by the same scientist confirmed that beating is not related to dissonance, however it is still disliked by many and merits future study as to why.

While this research strongly suggests harmonics can explain preference for certain musical sounds, there is a confounding variable that may be contributing to the mathematical result. The study unexpectedly found that "harmonicity measures were positively correlated with musical experience" as well as "the strength of consonance preferences." This indicates that there is a learnt component to preferring harmonic frequencies, likely also corresponding to cultural practices.

The University of Minnesota study, polling college students in the United States, draws on participants with heavy Western influence in their understanding of music and what is considered "good." Western music values harmonics, and many of the students with musical backgrounds, even those without, were likely taught to value them as well. It is expected that conclusions would be different across different cultures considering there are a number of chords considered dissonant in Western music that are widely used elsewhere.

> "Consonant notes are those that create pleasure or stability, while dissonant notes create unease or instability."

There are a number of other possible explanations that, whether or not they incorporate consonance and dissonance, require future study to better understand music in the brain. In relation to beating, it is thought that the nature of how the phenomenon is created irritates nerve fibers in the ear, which results in a dislike of the sound. There are also theories about a human propensity for predictions and expectations that suggest a sound is good when it meets expectations and bad when it does not.

Despite music being a driving force across countries and centuries, there is still much to learn about why notes carry the weight that they do. It is remarkable that a sound — consonant, dissonant, beating, or plain — can evoke such profound feelings. It is important to continue this research, as we are just beginning to understand how physics and biology interact to produce centuries-old symphonies that still shake us today.

Frontiers in Psychology (2018). DOI: 10.3389/fpsyg.2018.02118
Current Biology (2010). DOI: 10.1016/j.cub.2010.04.019

PHOTO BY SHUTTERSTOCK

Another one lights the dust
Echo mapping the universe

BY ANNABELLE MATHERS, CIVIL ENGINEERING, 2022

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Black holes are known as eradicators of light and matter, earning a mysterious and destructive reputation. However, these space oddities have behaviors, albeit occasionally baffling, that may help construct the conceptual building blocks of scientific phenomena all across the universe. As is common in the world of science, one discovery can cause ripple effects across previous interpretations and methods. One such discovery lies in the development of echo mapping, a light-based technique that, furthered by the behavior of black holes, potentially plays a role in mapping the rest of the universe. More specifically, echo mapping locates bodies in space and, by extension, measures the space between them using chain reactions of light, matter, and thermal energy.

The properties of light, with respect to time and distance, ensure that experts can apply physical behaviors observed within the structure of black holes to the structure of light-producing galaxies as a whole. Using improved telescopic sensors and years of imaging, experts recently reinforced the idea that black holes indirectly emit a characteristic light from a chain reaction starting in their inner regions. Light does not originate from within the black hole itself but rather from nearby superheated atoms that form a plasma disk around the black hole. This accretion disk may burn brightly enough to produce visible light, which then travels outwards through subsequent layers of cooler plasma disks. Each layer encircles one another and exhibits the echoes of the previous layer's light emission. Finally, as the light continues outwards, it reaches the inner surface of a cloud of dust, which encircles the entire system. This cloud of dust, known as a torus, absorbs the light, which is then transferred to heating dust particles that emit new infrared light.

Scientists observe both the visible and infrared light from the plasma disks and cloud of dust respectively. It is the locations where these emissions occur that determine the dimensions of the black hole, a technique that eventually enables the mapping of any luminous entity involved. Typically, the torus exists relatively far from the plasma disks (potentially trillions of miles away). This is thanks to high heat energy, radiated by the plasma, preventing dust formation until temperatures decrease to at most 2,200 degrees Fahrenheit. Thus, the more energy in the plasma, the farther away the torus begins. By measuring the time between flashes of visible and infrared light, scientists determine the distance between the outermost plasma and innermost dust (using constant speed of light). Knowing the relationship between distance and (the decrease of) heat energy, scientists can find the original energy of the plasma disks, which is directly proportional to their luminosity. These echoes of light between plasma and dust allude to the more scientific term for this process, dust reverberation mapping.

Scientists observe this process from Earth, and consequently employ techniques to relate what they witness to what actually occurs in distant galaxies. The basis for comparative light measurement, as followed by some scientists, relies on differentiating this true luminosity of a body from its apparent brightness to observers on Earth. The difference between those levels of light indicates the conditions and distance from where the light first traveled. Here, telescopes use echoes of brightness seen on Earth to calculate original luminosity, with which scientists reverse-calculate the distances between celestial bodies and components. Once again, calculations may consider the speed of light, interaction with dust particles, and surrounding temperatures when evaluating light associated with mapping black holes.

> "However, these space oddities have behaviors, albeit occasionally baffling, that may help construct the conceptual building blocks of scientific phenomena all across the universe."

The aforementioned relationships between distance and echoes of light and energy are not entirely new, but, with refinement of technology and insight, mapping black holes continues to gain support as a future way to map galaxies (for which black holes are the center or component) relative to Earth. By creating reference points for massively complex and disparate galaxies, experts may improve their understanding of the deeper expanses of the universe. Light measurements, in the context of time and distance, can also improve estimation of the time and manner in which an entity formed. However, there is skepticism toward the accuracy of current technology and methods. For example, the exact behavior of the torus, and the need for long-term data for light traveling across larger black holes, requires further investigation. Nonetheless, these luminous black holes remain the candle in the wind for the pursuit of echo mapping and for the efforts to ensure that the chance to perceive the far reaches of the universe comfortably from Earth is more than dust in the wind.

Nature Astronomy (2020). DOI: 10.1038/s41550-019-1002-x
The Astrophysics Journal (2020). DOI: 10.3847/1538-4357/aba59b

PHOTOS BY SHUTTERSTOCK

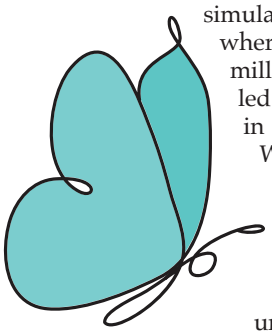
A method to madness

The mathematical basis for the butterfly effect

BY NETHRA IYER, CHEMICAL ENGINEERING, 2024
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

In the blockbuster hit "Jurassic Park," fan-favorite Jeff Goldblum stars as the eccentric Ian Malcolm. As a critic of the magnificent park, Malcolm often claims that nature is best in its most primal form, untouched, as even small artificial changes can have dire consequences. This notion is known as the butterfly effect, a small piece of a branch of mathematics known as chaos theory. The butterfly effect essentially proves that if a butterfly flaps its wings in one part of the world, it will ultimately cause a tornado elsewhere.

The butterfly effect was not coined until about 50 years ago, when MIT professor Edward Lorenz decided to truncate and round one of his variables in a weather simulation. This small change, where he rounded from millionths to thousandths, led to an unexpected result in his weather simulation. With this knowledge, Lorenz concluded in his paper "Deterministic Nonperiodic Flow" that not only do small changes in nature have unpredictable effects, but also that it is impossible to predict the future. This is where the idea of chaos theory was born, paving the way for more research on the forces and laws that make up the Earth, all the while breaking the rules of classical physics.



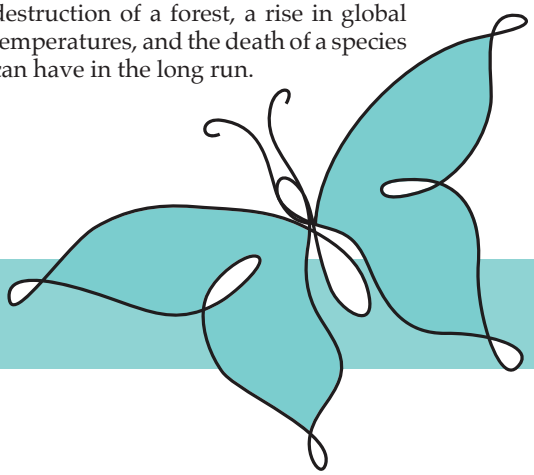
In this paper, Lorenz focused on breaking down the idea of chaos theory and the butterfly effect through the logic of mathematics. Lorenz's idea was to show that in imperfect systems, such as the atmosphere, "such procedures involve replacing the continuous variables by a new finite set of functions of time." This means that variables will constantly need to be changed, mirroring the actual world and universe. He concluded that in nonperiodic, or chaotic, scenarios, it would take an incredible number of computations to logically map out what the universe can do in seconds. So while a butterfly's flapping wings will cause a tornado, it is not humanly possible to figure out when, where, or how.

Lorenz's work broke down much of Pierre Laplace's idea of an orderly universe where all possibilities lead to unique, single outcomes. Laplace's work "A Philosophical Essay on Probabilities" states that "we ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow." Laplace essentially explains that the universe is a result of cause and effect; what happened in the past created the present, and if humans are able to map out what happens in the present, they can easily predict the future. Laplace describes the universe as very straightforward, methodical, and periodic. However, Lorenz counters this by explaining that "prediction of the sufficiently distant future is impossible by any method, unless the present conditions are known exactly." This, as aforementioned, is not humanly possible because of the sheer number of variables and calculations. Laplace's work does not account for the idea that all butterflies do not act the same way: they each have their own number of flaps at different points in time.

> "Based on Lorenz's work, if a single butterfly's wing flapping can cause a tornado, it is horrifying to imagine what the destruction of a forest, a rise in global temperatures, and the death of a species can have in the long run."

Moreover, Lorenz's work proves what Ian Malcom said in "Jurassic Park": nature is best at its most primal form. Nature is stable when chaotic. One of Lorenz's findings is that "all solutions, and in particular the periodic solutions, are found to be unstable." This proves that a perfect system cannot exist in nature because it is unstable; imperfection is what is best. Trying to change the flap of a butterfly's wings in order to prevent a natural disaster will paradoxically bring about more disasters.

Lorenz's findings of the butterfly effect led to more than just a deeper involvement in chaos theory. They proved that nature should remain untouched, and disturbing the "peace" of chaos will only cause harm. This is vital, as humans have been changing nature in major ways such as the Industrial Revolution, poaching and hunting, and now, increasing greenhouse gas emissions. Based on Lorenz's work, if a single butterfly's wing flapping can cause a tornado, it is horrifying to imagine what the destruction of a forest, a rise in global temperatures, and the death of a species can have in the long run.



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PHOTOS BY SHUTTERSTOCK

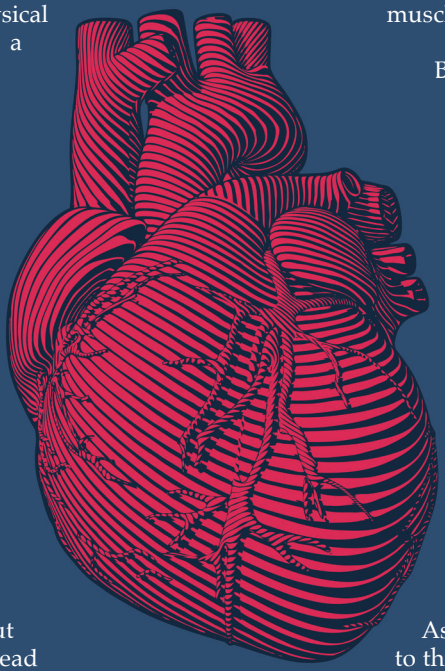
IS A "BROKEN HEART" JUST A SAYING?

BY DHRITI AIYLAM, BEHAVIORAL NEUROSCIENCE & ENGLISH, 2023

DESIGN BY SOPHIA HITT, BIOLOGY 2023

Heartbreak often brings to mind cartoon hearts dramatically shattering into pieces Looney-Tunes-style, or eating a giant tub of ice cream and crying over romantic comedies. In reality, though, according to the American Heart Association (AHA), there is such a thing as a literal broken heart, which raises the question — is it actually possible to die of a broken heart?

Broken heart syndrome is a condition that sets in after an extreme emotional or physical stressor. Such stressors are diverse — a serious illness, the unexpected loss of a loved one, financial loss, a sudden drop in blood pressure — including even positive shocks such as a surprise party or winning the lottery. Broken heart syndrome involves the ballooning of the midsection and lower part of the left ventricle (known as the apex). Interestingly, during systole (contraction), the bulging ventricle looks like a *tako-tsubo* (a round-bottom, narrow-necked ceramic pot used by Japanese fishermen to trap octopuses), which is why in 1990, a Japanese physician coined the term *takotsubo cardiomyopathy* for the condition. However, since the left ventricle is the chamber responsible for pumping oxygenated blood throughout the entire body, such dysfunction can lead to poor circulation and severe, short-term muscle failure.



But why would stressful events lead to heart abnormalities? It's no secret that after adverse experiences, the likelihood of anxiety disorders and depression is much higher — one of many established ties between mental health and heart health. One study presented at the AHA Science Convention clearly shows this. Involving 78 volunteers who had recently lost a spouse or child (and who also scored higher on anxiety and depression tests), the bereaved had an average of 75 beats per minute (five beats more than the controls) and double the episodes of tachycardia (rapid heartbeats) within two weeks of the tragedy. Although experts aren't sure of the exact cause, the prevailing theory is that surging stress hormones, such as adrenaline, are able to "stun" or freeze the heart, which could cause changes in either heart muscle cells, coronary blood vessels, or both that prevent normal contraction of the left ventricle. In rare cases, certain drugs can be the cause of the stress hormone surges that induce broken heart syndrome, including epinephrine (used to treat severe allergic reactions and asthma attacks), duloxetine (a depression treatment, or a medication administered to treat nerve problems in people suffering from diabetes), levothyroxine (a drug given to people who have thyroid gland problems), and stimulants such as methamphetamine or cocaine. Another possible cause is a difference in the heart muscle structure itself.

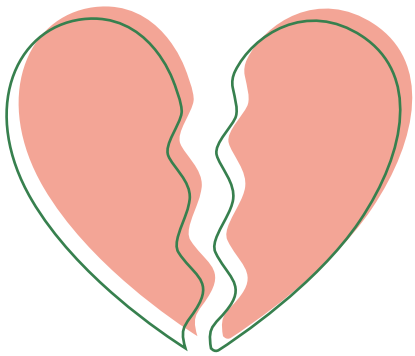
Broken heart syndrome is frequently misdiagnosed as a heart attack, and for good reason — the two primary symptoms, chest pain (angina) and shortness of breath, are shared by both. In order to determine which one of the two it is, clinicians will do a coronary angiography, a test that uses dye injection directly to heart vessels and special X-rays. This will determine whether there are blockages in the coronary arteries, the most common cause of a heart attack. They might also use an echocardiogram (an ultrasound image) or another imaging technique that would show abnormal movements in the walls of the left ventricle.

As to how it's treated, there's no real answer to this — it all depends on the severity, and if the person has other conditions such as low blood pressure or fluid in the lungs. Generally, heart failure medications — such as beta blockers, angiotensin-converting enzyme inhibitors, and diuretics — are used and sometimes aspirin for patients with atherosclerosis, or plaque buildup in the arterial walls. To prevent recurrence (which is rare), beta blockers may be continued for extended periods of time in order to reduce the effects of stress hormones, although this has not been widely studied.

There is some silver lining to all of this, though. Broken heart syndrome is very treatable, and, remarkably, the ventricle returns to normal within weeks, with no lasting heart damage. Although there can be complications such as arrhythmias (abnormal heart rates), obstruction of blood flow from the left ventricle, and rupture of the ventricle wall, they are very rare — and the possibility of death even slimmer.

PHOTO BY SHUTTERSTOCK

Is COVID-19 damaging our hearts?



BY SARA GANNON, BEHAVIORAL NEUROSCIENCE, 2021
DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

Loss of taste and smell, persistent cough, stubborn fever, chills and aches, and maybe blue toes. These are typical symptoms of COVID-19 that we have all come to know too well; yet, much of the virus still remains a mystery, like why some experience no symptoms while others suffer enormously. Many are quick to claim that COVID-19 is no more than a mere cold, but one of the most worrisome aspects is the potential for long-term effects — most concerning, prolonged heart inflammation.

Since early 2020, researchers across the world have been studying how SARS-CoV-2 affects the body, and some of them, such as Valentina Püntmann at the University Hospital Frankfurt, have studied its cardiovascular effects. Through analysis of MRI data and images, Püntmann and her team examined the hearts of 100 COVID-19 patients. The study revealed some startling statistics; 3 out of every 4 patients showed cardiac abnormalities, with two-thirds appearing to have active inflammation. Moreover, they found that the majority of patients in the study reported still having unresolved symptoms, such as shortness of breath and fatigue, even though these scans were taken two to three months after their initial diagnosis. The results from Püntmann and her team indicate that there may be significant long-lasting cardiovascular effects that come with a SARS-CoV-2 infection that have yet to be thoroughly explored.

These results do not stand alone; other scientists and institutions have come to the same startling conclusions. Particularly, there has been extensive physiological documentation and research of how professional and amateur athletes react to COVID-19 exposure. Just last month, a small study of more than two dozen COVID-19 positive Ohio State University student athletes revealed stunning results about myocarditis, another term for heart inflammation. The researchers found significant evidence for myocarditis in 15 percent of the athletes, and other cellular damage or swelling was found in an additional 30 percent of athletes. Surprisingly, the researchers indicated that very few of the athletes reported having severe symptoms, or even any symptoms at all, despite exhibiting prolonged cardiovascular inflammation.

The concern for lasting physiological damage has not gone unnoticed by those with the responsibility to research and protect the health of collegiate athletes. In May, the cardiology research journal *JAMA Cardiology* published an article that addresses the numerous studies indicating risks of cardiac inflammation associated with COVID-19 and outlines specific timelines and health plans for recovery for collegiate athletes who test positive for COVID-19. This letter not only addresses relevant healthcare issues in a raging pandemic, but it also inspires further questions: Why is this the first disease to motivate such prompt communication and health plan outlining? Do other diseases, such as the flu or common, also affect the cardiovascular system like COVID-19 does?

The answer is that we don't know. Research thus far suggests long-lasting inflammation of the heart that occurs during recovery from COVID-19, but it is not clear that these effects are any greater than that of the flu or a bad case of the common cold. The cardiovascular effects of more common viruses simply haven't been studied at all, or at least to the rigor that is required to draw scientific conclusions. Peter Lui, a cardiologist and chief scientific officer of the University of Ottawa Heart Institute, specializes in studying cardiac inflammation and has occasionally studied heart-related phenomena associated with influenza. Lui has preliminarily claimed that it is possible that up to 10 percent of flu patients have transient heart abnormalities that normally remain undetected. This may suggest that the cardiovascular system's inflammatory response is more common than one would initially expect and that there still needs to be extensive research done in this area across all diseases, common or otherwise.

For now, the best strategy going forward seems to be to wait for more research and insight from the scientists. And, as always, to stay safe, wear masks, and wash your hands.

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PHOTO BY SHUTTERSTOCK

IN COLD BLOOD

All about therapeutic hypothermia

BY YASMINE MYFTIJA, BIOLOGY, 2021

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

Therapeutic hypothermia, as the name suggests, is a method of purposefully lowering a patient's body temperature to approximately 93 degrees Fahrenheit in an effort to increase survival rate and decrease the likelihood of further damage to the brain.

Take for example, a patient who's suffered cardiac arrest and, after an intense round of CPR, has been brought back from the brink of death. They now face brain death from a lack of oxygen for prolonged periods — or even the inflammation and swelling of the brain that comes with resuscitation as the body overcompensates and rushes to send blood through the veins and to all its tissues. For those who are recovering from a cardiac arrest, the risk of neurological damage is all too real — but recent research has brought therapeutic hypothermia to the forefront of medicine as a potential way to minimize that risk.

The process of decreasing a patient's internal body temperature is complex and calls for extreme precision. In the case of a patient who's been revived after cardiac arrest, in the event that their temperature decreases below the desired point of 93 degrees, the patient may undergo arrest again. While the patient receives a cold saline solution infused intravenously and is cooled using a blanket which helps the saline solution spread throughout the veins to the rest of the body, one must keep a close eye on their temperature. Then, to minimize shivering that occurs after anyone's temperature decreases enough, the patient must be sedated heavily and given measured doses of paralytic agents. If the patient were to shiver throughout the process, they would use up oxygen far too quickly; a flood of oxygen to the body and brain tissues, which have been without it for quite some time, would actually be detrimental to the patient as the excess could damage the aforementioned tissues. Afterward, the patient is kept in the intensive care unit for 24 hours — and only after is their temperature slowly increased and brought back to normal, their oxygen levels following in time.

Therapeutic hypothermia is quickly becoming a standard for post-resuscitative patient care throughout the world — and for good reason. According to a journal article published in the *Scandanavian Journal of Trauma, Resuscitation and Emergency Medicine* titled, "Therapeutic hypothermia for acute brain injuries," the aforementioned therapy has an incredible usefulness in more than just cardiac arrest cases. Patients suffering from various types of strokes, hemorrhages in the brain, or physical trauma to the brain, among others, can also benefit from this treatment plan.

> "Patients suffering from various types of strokes, hemorrhages in the brain, or physical trauma to the brain, among others, can also benefit from this treatment plan."

Though it has its drawbacks, such as a decrease in the rate of the body's metabolism, which would usually kick in to supply oxygen from head to toe after asphyxia (a prolonged period without oxygen), most research agrees that the benefits are far greater. For example, when targeted temperature management is used, swelling of the tissues in the brain — which, if left uncontrolled, are a potential killer — can be greatly minimized. It can also decrease the likelihood of neurons being damaged or even killed permanently as a result of overstimulation of their receptors when reperfusion occurs in the body's tissues. Therapeutic hypothermia can also keep ATP stores from depleting, prevent cell death, and even reduce the production of free radicals — unstable molecules, which, when produced in excess, can cause lasting damage to the body's tissues.

However, despite all of its benefits, therapeutic hypothermia is most effective when begun immediately after a cardiac arrest or other brain injury. It seems to most experts that strengthening the chain of survival — that is to say, CPR, transport by emergency medical technicians (EMTs), and other post-resuscitative care that occurs in a hospital — as well as decreasing the time it takes for those steps to occur can be the difference between irreversible brain damage and a chance at a full recovery.

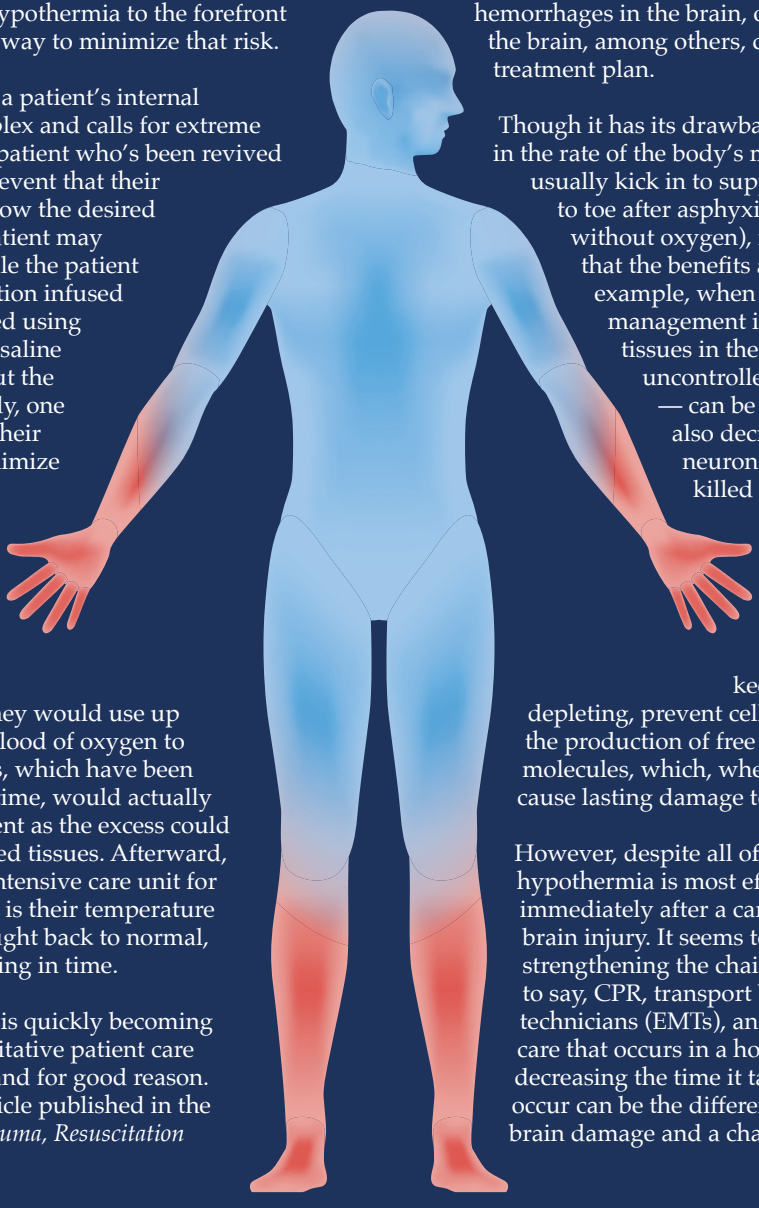


PHOTO BY SHUTTERSTOCK

Scandanavian Journal of Trauma, Resuscitation and Emergency Medicine (2015). DOI: 10.1186/s13049-015-0121-3

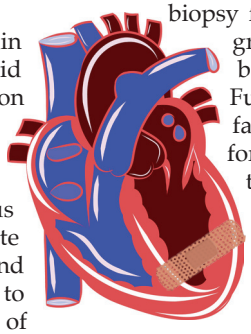
Heart health and wound recovery

BY KELLI VALENTINI, BIOENGINEERING, 2024

DESIGN BY HEATHER WELCH, ENVIRONMENTAL SCIENCE, 2020

It's no secret that cardiovascular health is essential to overall body health. According to the Centers for Disease Control and Prevention, cardiovascular diseases have been the leading cause of death in the United States for approximately 80 years, and cause one in every four deaths. However, the risks of these diseases extend even further: poor heart health can increase the time the body takes to recover from injuries.

The process of wound healing occurs in four main stages. Hemostasis, the first stage, involves rapid clotting with platelets and blood vessel constriction to prevent excessive bleeding. The release of cytokines and growth factors (signaling and regulatory proteins) promotes the next step: scabbing and inflammation. A tough, fibrous protein called fibrin facilitates scabbing, and white blood cells such as neutrophils, macrophages, and lymphocytes clear microbes and cellular debris to fight infection. Blood vessels open, and circulation of fresh blood brings oxygen and nutrients to the injury. This is essential for the proliferation stage, in which red blood cells use collagen, a structural protein, as a scaffold for new skin tissue. In the final maturation stage, this area is strengthened, and the wound is fully healed.



However, this does not occur when the heart is unhealthy and doesn't adequately circulate blood. Cardiovascular diseases such as peripheral arterial disease, coronary artery diseases, and heart failure can hinder the flow of oxygen and nutrients to impede healing.

The National Heart, Lung, and Blood Institute sponsored a 2005 study that was among the first to suggest improving cardiovascular health for wound healing. Half of its subjects underwent a three-month exercise program and half did not. After one month, all subjects were given a minor skin punch biopsy for observation of healing progress. The exercise group was found to be more cardiovascularly fit based on VO2 max levels, or oxygen consumption. Furthermore, wound healing was significantly faster, at a mean of 29.2 days compared to 38.9 days for the control group. However, it's important to note that exercise immediately increases circulation. A greater VO2 max wasn't significantly correlated with wound healing, so the action of exercising may be more important for injury recovery than simply being fit.

The healing process is complex, but continual blood flow has been shown to be a critical part of the rebuilding phase. Poor circulation increases the risk of delayed healing or even chronic wounds. These findings suggest the therapeutic significance of physical activity.

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PHOTOS BY SHUTTERSTOCK AND PIXABAY

Cerebral organoids raise ethical questions of consciousness

BY JULIA BREED, CELL & MOLECULAR BIOLOGY, 2021

Few organs are held in as high regard as the human brain. It's incredibly complex with many mysteries that still puzzle researchers. As the keeper of all thoughts, emotions, memories, and senses of self, it's what makes humans human.

Traditional in vitro models can be useful, but they fail to imitate communication between the different brain regions and are too simplistic for realistic disease modeling. In vivo methods, such as rodent studies, are more representative, but lack complexity. This can create obstacles when scientists want to model human neurological disorders or test a treatment in a mouse or rat.

One potential solution is to use human cerebral organoids (HCOs). Organoids are 3D models of human organs derived from pluripotent stem cells and more accurately reproduce spatial morphology, key cell types, and physiological responses of fully developed organs.

These "mini brains" can consist of different types of neurological cells and display heterogeneous brain regions. HCOs in culture for six months will form mature neurons and functional synapses. After nine months, spontaneously active neuronal networks are created. Action potentials have been observed at this stage, and some cells with photoreceptors reacted to light stimulation. In fact, HCOs have displayed similar features of a fetal brain, including gene transcription and epigenetic properties. This similarity to human brains is incredibly useful to neuroscience researchers in the study of autism, schizophrenia, Alzheimer's, and other neurological diseases.

However, developing neuronal activity and stimuli responses have raised ethical questions regarding sentience within the organoid. Current models consist only of a few million cells, compared to 86 million in an adult brain. Although currently too simplistic to pose any dilemmas, the ethical path forward must be considered. A 2018 symposium hosted by the University of Oxford discussed cerebral organoids and their ethics, including concepts of scientific and philosophical consciousness. Additionally, the NIH's Brainstorm Project raised questions surrounding rapidly improving HCO technology and explored their ethical use.

While scientists are far from re-creating a human brain in a dish, they do approach an ethical gray area. Are action potentials the first pulses of sensation and thought? When should HCOs be considered for consent or autonomy? When does consciousness fully occur? The brain is so strongly connected to our sense of identity and, indeed, *creates* that identity. As HCOs grow more complex, scientists must balance the search for answers with the knowledge that they may spark something unthinkable.

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Good vibrations

(And how to sense the really bad ones)

BY HIBA HUSSAIN, BIOENGINEERING, 2024
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

Monitoring the heart for long periods of time has become easier than ever because of the development of wristwatches, smartphones, and wearable devices in the age of today's biosensing revolution. The most notable of these devices is perhaps the Apple Watch, which comes embedded with a built-in electrocardiogram (ECG) and heart rate monitor and now has around 43 million global users, making healthcare data quite literally as accessible as looking at the time.

Biosensing applications to monitor the heart's electrical activity are actively being programmed into smartphones and wearable devices as cardiovascular disease continues to be the leading cause of death worldwide. These technologies are incredibly useful and are able to analyze cardiac rhythms to prevent life-threatening conditions, such as cardiac arrest, from occurring. Some particularly notable mentions include the Zio Patch, smartphone apps to detect atrial fibrillation, and cvrPhone, a 12-lead smartphone sensing system.

The Zio Patch, developed by engineers at iRhythm technologies in San Francisco, is a sensor that is worn on the left pectoral and can be worn for at least 14 days. What makes the sensor unique is that it contains a single-lead ECG that doesn't need to be charged, allowing it to collect accurate data for long periods of time. The device is currently prescribed by physicians who use the Zio Patch to determine the best course of action, such as drugs or minimally invasive surgery, to treat cardiac problems based on the number of arrhythmias detected as well as the intervals in between them.

Smartphone applications to monitor for different arrhythmias are also becoming widely available. A collection of smartphone apps are now utilizing the red LED light built into the phone camera to monitor for atrial fibrillation by simply touching a finger to the camera lens. These applications are able to produce results in under a minute, but are not the most effective for long-term monitoring. In order to ensure long-term monitoring is possible, physicians at Massachusetts General Hospital have developed cvrPhone, a 12-lead system that can be attached to a smartphone for use in a clinical setting and eventually in the home as well. The system is able to detect various indicators of cardiovascular disease, including occlusions to the heart within two minutes of their occurrence, apneic episodes, and repolarization alternans — all of which mark susceptibility to arrhythmias and cardiac death.

Another exciting avenue of cardiac sensing is one that researchers from the Inan Lab at the Georgia Institute of Technology have developed to detect hemorrhages more efficiently. Hypovolemic shock is currently difficult to recover from due to exsanguination, or severe blood loss. Current metrics that physicians use to determine the severity of hypovolemic shock are based on heart rate and blood pressure. However, these vitals are not the most effective indicators of shock once blood volume starts to decrease. The Inan Lab has found that a better indicator of the severity of shock is the time until cardiovascular collapse, which is also known as blood volume status, or BVS.

To test the sensing system, Inan and his team placed wearable sensors on the aortic root, femoral artery, and right and left atria on a porcine model. He used three different types of sensors (electrocardiogram, seismocardiogram, and photoplethysmogram) to best capture the function of the heart (or lack thereof) as blood volume started to decrease. Together, these sensors measured changes in the heart's electrical activity, movement of the chest wall as blood volume changed, and the interval between ejection of blood by the heart and the blood reaching its respective place in the body. Based on these three sensing modalities, Inan and his group now plan to create a scale from 0 to 100 using a machine learning algorithm to quantify a patient's need for treatment, which is especially useful in triage settings seen often in emergency medical services or military settings. In the future, the Inan group also plans to develop a 10 millimeter wearable patch that filters out background noise to allow for accurate monitoring of cardiovascular function.

> "Biosensing applications to monitor the heart's electrical activity are actively being programmed into smartphones and wearable devices, as cardiovascular disease continues to be the leading cause of death worldwide."

Cardiovascular sensing is changing the lives of both physicians and patients alike, and will only continue to do as more technology is developed and tested. Thanks to improvements in sensing technology, physicians are now able to provide more accurate diagnoses backed by long-term data, leading patients to have more confidence and ownership of their own health. For now though, it's promising to say that arrhythmias and other cardiac problems can be detected accurately through these exciting new innovations, one pulse at a time.

Science Advances (2020). DOI: 10.1126/sciadv.abb1708
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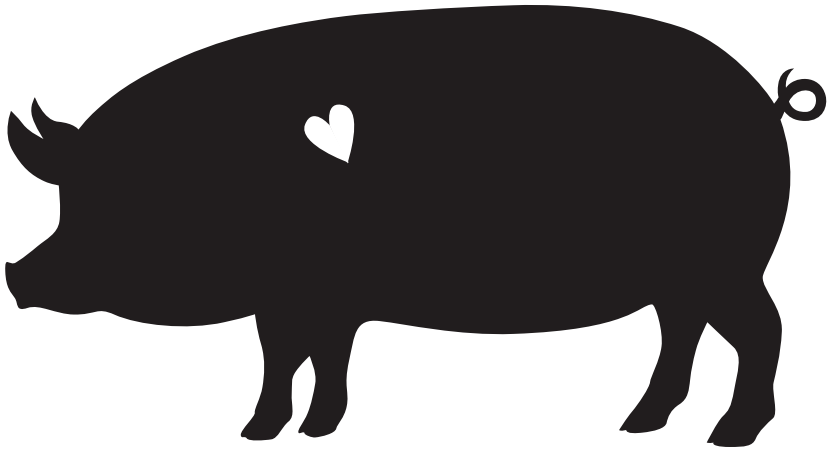
PIGS:

The solution to organ shortages?



BY JASON DENONCOURT, CHEMICAL ENGINEERING, 2023

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

Since the first successful kidney transplant in 1954, human-to-human organ transplantation has remained the best method of treatment for most patients with late-stage organ failure. Although medicine has rapidly advanced since 1954 — including innovations from the insulin pump to CT scans — the fundamental problem of allotransplantation has yet to be resolved: the number of people requiring organ transplants is far greater than the number of organs available.

With roughly 17 people dying each day waiting for a human organ to become available, scientists have responded with a number of novel solutions to the organ shortage. The first major advancement came in 1982, when Dr. William DeVries implanted the Jarvik 7 — the first artificial heart device invented by Dr. Robert Jarvik. Today, engineers and doctors have been able to optimize these devices, enabling patients to live up to five years after transplantation. Though five years may not seem like a long time, artificial hearts are utilized as a bridge for eligible patients on the transplant waitlist or for adding on quality years of life to ineligible patients.

However, artificial hearts lack the complexity and longevity to adapt to each individual patient, so scientists have turned to regenerative medicine and xenotransplantation — animal-to-human organ transplants. While recently resurging in interest, these ideas are not new. For years, scientists have envisioned a future of 3D-printing or xeno-manufacturing organs. In 1964, James D. Hardy attempted a chimpanzee-to-human heart transplant on a comatose, dying man. Similar attempts have also been made, though patients generally survive only hours to days. The failures of most of the xenotransplants can be attributed to the smaller size of animal organs or to immunological barriers.

Conversely, 3D-printing of organs is still in development but has seen tremendous growth of popularity among biotechnology companies as of late. A race has emerged between 3D-printing organs and xenotransplantation. While 3D-printing can offer autologous organs, it faces a number of challenges in mimicking the complex tissues and muscles of a real organ. On the other hand, animal-to-human transplantation has the benefit of already constructed, non-autologous organs, despite the complex issue of optimizing acceptance by patients. Furthermore, xenotransplantation, rightfully so, has a number of ethical concerns. Questions arise whether or not animals should be used as organ factories for the benefit of human healthcare. Likewise, other than human welfare, the COVID-19 pandemic raises additional concerns with xenotransplantation. The pandemic has driven attention to the risks of zoonotic diseases, bringing along public skepticism for the future of xenotransplantation. However, as studies demonstrate, xenotransplantation poses low risks of passing along viruses such as SARS-CoV-2, HIV, and hepatitis B and C.

Xenotransplantation can be optimized by two methods: donor species selection and donor species bioengineering. The donor species with the highest likelihood of a successful transplant needs to be identified. While primates are phenotypically the most similar to humans, the size of their organs, risks of infection, and greater ethical concerns limit their likelihood of success. Currently, many scientists believe that swine are the best species to work with, as pigs are easy to breed, have appropriately sized organs, and present lesser ethical barriers. Still, since pigs are so phenotypically different from humans, the xenotransplantation of pig organs is likely to cause rejection in many cases by human patients. As a result, genetic engineering is likely the solution. For example, removing the α1,3-galactosyltransferase enzyme from the swine prevented hyperacute rejections in some pig-to-primate studies.

Though pig-to-human heart transplants are likely years away, a number of companies have recently made breakthroughs in xenotransplantation. For example, a Boston-based biotechnology company, Xanotherapeutics, has developed a pig-to-human skin transplant, called Xenoskin. In October of 2019, surgeons at Massachusetts General Hospital in Boston performed a first of its kind xenotransplantation. Surgeons temporarily planted a patch of Xenoskin and a patch of human skin on a burn of a patient. Five days later, surgeons removed both patches and the results were encouraging—both grafts were stuck to the wound bed and were indistinguishable from one another. Though this achievement is very small, it marks a major, successful first step in 21st century xenotransplantation.

Ultimately, both the regenerative medicine and xenotransplantation approaches to organ manufacturing still require much greater study. Though the approaches are vastly different, the primary objective is the same: eliminate the shortage of organs and the dependency on traditional allotransplantation.

PHOTO BY SHUTTERSTOCK

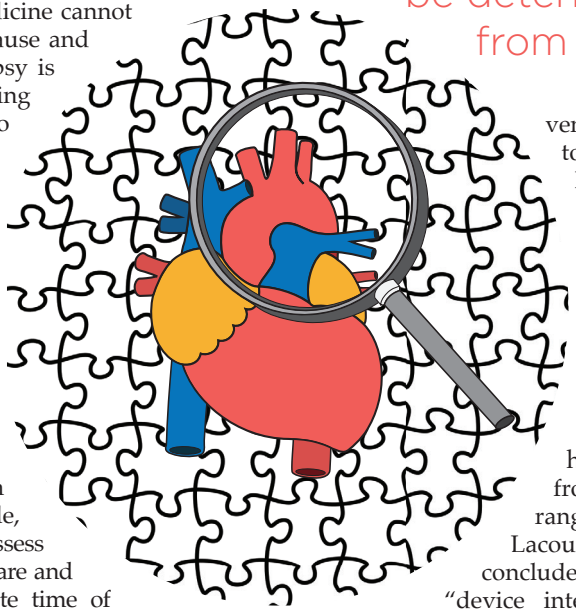
International Journal of Surgery (2015). DOI:10.1016/j.ijsu.2014.12.011

THE PACEMAKER PIECE OF THE PUZZLE

BY BEIYU (PAM) LIN, BIOLOGY, 2021

DESIGN BY EVAN DIAZ, ARCHITECTURE, 2025

When a doctor calls time of death on a 35-year-old female lying motionless on a stretcher, it is usually definite. He has watched the patient's vital functions slowly cease, giving him the needed certainty to call the time at which physiologic death has occurred. These types of cases, where death occurs in the presence of a skilled medical professional, are the only circumstance in which time of death is absolutely accurate. However, this is not very often the real-life scenario. In circumstances where death is not directly observed, determining the cause and time is much more involved and often includes a medical examiner or coroner conducting autopsies. Time and cause of death are not only critical factors in criminal investigations, but also in many civil situations for legal purposes, such as those dealing with disputes over life and accident insurance. Despite their importance, approximately 30 percent of cases in forensic medicine cannot be solved because of an unclear cause and time of death, even after an autopsy is performed. This is where a surprising tool, the pacemaker, has proven to be advantageous.



Pacemakers are small medical devices that are inserted into a patient's chest or abdomen in order to regulate arrhythmias, or abnormal heart rhythms. They provide a variety of functions, such as speeding up a slow heart beat, controlling a fast heart beat, and coordinating electric signals between ventricles. Not only does a pacemaker function in aiding a heart patient's lifestyle, but it has now been shown to possess the ability to go beyond just healthcare and actually help determine an accurate time of death of a deceased individual.

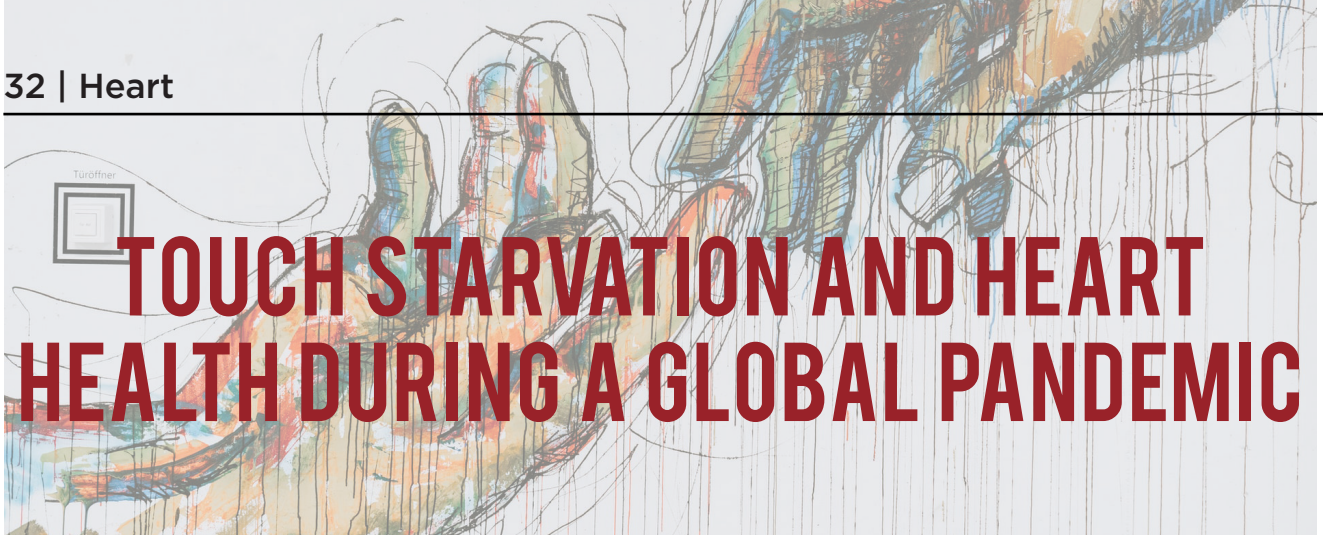
A study published in 2017 pulled data from 150 autopsies conducted at the Medical University of Berlin for patients who had used cardiac implantable devices at the time of their death, such as pacemakers and implantable cardioverter-defibrillators. Within this cohort, about a quarter were cases in which time of death was unable to be determined from the standard tests and procedures that normally suffice, such as an autopsy. This prompted researchers to focus on cardiac device interrogation, a step that's not routinely performed. Astonishingly, they found that in 76 percent of the cases they did this for, time of death was able to be determined using data from the device.

The way that a cardiac device can function as a tool in time of death determination is contingent upon whether or not the patient died from a type of heart irregularity. For example, if the individual died from tachycardia, which is a rapid heartbeat, this would show up on the device. Another instance highlighted in the study was one in which, while the pacemaker did not possess the ability to reverse a lethal ventricular fibrillation, it was able to record the time it had occurred. In addition, researchers were also able to investigate instances when a cardiac device malfunctioned, potentially preventing it from saving the individual from cardiac-related death.

"Astonishingly, they found that in 76 percent of the cases they did this for, time of death was able to be determined using data from the device."

Ultimately, the study saw that the addition of device interrogation resulted in a decrease in cases that had unclear times of death, going from an estimated 30 percent to a range of 10 to 20 percent. Dr. Philip Lacour, the head researcher, promptly concluded that the team believed that "device interrogation should be routinely performed in all autopsy cases." He highlighted that this routine would not only clarify uncertain times of death, but could also catch malfunctions in cardiac devices that need to be underscored.

The connection between pacemakers and medicolegal investigations may be surprising, but the impact could mean the uncovering of unsolved criminal cases or the end of long legal insurance disputes. It's the shared common end goals of justice and closure for both medicine and forensics that make discoveries that intertwine the two appealing and satisfying to research. In the future, there may be an even larger number of scientific tools created that can help aid in crime investigation.



TOUCH STARVATION AND HEART HEALTH DURING A GLOBAL PANDEMIC

BY LAUREN CHRISTENSON, BEHAVIORAL NEUROSCIENCE, 2023

DESIGN BY SOPHIE PATE, ARCHITECTURE & DESIGN, 2024

American author and therapist Virginia Satir once said, "We need 4 hugs a day for survival. We need 8 hugs a day for maintenance. We need 12 hugs a day for growth." Amidst a global pandemic, hugs have become a part of the distant past as we embrace a world where social interactions are six feet apart. As social distancing becomes the new norm, it is time to think about the long-term impacts of lacking physical touch and connection.

Experiencing little to no touch from others, sometimes called "touch starvation," can have tangible impacts on heart health. In particular, lacking physical contact has been linked to an increase in overall stress levels measured based on levels of the hormone cortisol (often referred to as the stress hormone). When the body secretes increased amounts of cortisol, both heart rate and blood pressure can be negatively affected.

> "Not being able to connect with others physically is not the end of the world for our heart health, but it is not something that should be brushed aside."

A study conducted in 2013 by Sumioka et al. tested the difference in cortisol levels following communication both with and without physical contact. They discovered that participants who had 15-minute conversations with a huggable device (a human-shaped cushion) had lower cortisol levels, in both blood and saliva samples, than individuals who had a 15-minute conversation on the phone. This study emphasized the benefits of touch, even if it came from a human-like object, as opposed to no touch at all.

Another important hormone that is impacted by touch is oxytocin. Oxytocin is often referred to as the "cuddle" or "love" hormone. This is because oxytocin levels fluctuate with human contact. A study conducted in 2005 at the University of North Carolina at Chapel Hill observed how frequent physical contact was linked to oxytocin levels. In this study, women's oxytocin levels were measured before and after either experiencing physical touch (hugs) with their partner or not. The study found that higher oxytocin levels were related to how frequently their partner hugged them — the more hugs, the higher the oxytocin levels and the lower the baseline blood pressure. So why is this important?

Oxytocin plays an important role in cardiovascular regulation; it lowers blood pressure and heart rate in addition to playing a role in anti-inflammation. Gutkowska et al. investigated the role of oxytocin in cardiovascular regulation in 2014 by studying the effects of in vivo oxytocin during heart attacks in rats. They discovered that oxytocin can help fight inflammation, heal injured cardiac tissue, and lower heart rate by stimulating the release of atrial natriuretic peptide. However, it is important to note that while these results were significant, they have only been tested in rat cardiovascular systems.

In quarantine, it is important to find things, such as a pet, a weighted blanket, a human pillow, or a body pillow that can, if only to a small degree, provide the touch we need. Even if it is not a fellow human, there is potential that this physical feeling can decrease cortisol levels. Decreasing the amount of stress hormone in your body has important physiological consequences: lowering blood pressure and lowering heart rate. These are integral components of overall heart health.

In a time where we must remain six feet apart and socially distance, it is imperative to pay attention to our stress and blood pressure levels. Without the oxytocin boost from cuddling or the reduction in cortisol levels offered by contact with one another, we should instead focus on getting connected in ways that we can. Over Zoom or FaceTime, by attending a virtual dance party, getting a pet, or even a weighted blanket. Not being able to connect with others physically is not the end of the world for our heart health, but it is not something that should be brushed aside. It is critical that we keep goals of virtual connection and communication in mind in our day to day lives.

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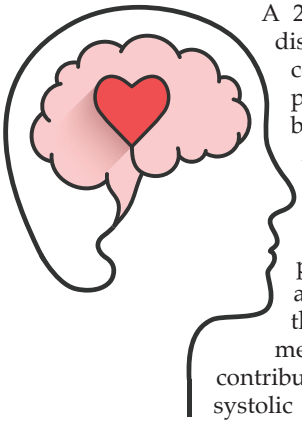
PHOTO BY UPSPLASH

FIX THE HEART TO HEAL THE MIND

BY AMANDA BELL, DATA SCIENCE & BIOLOGY, 2023

Imagine yourself years into the future — your joints are aching, you've been prescribed blood pressure medication, and you can barely remember how to perform everyday tasks like reading, cooking, and cleaning. According to the World Health Organization, this is the reality for 50 million people worldwide living with dementia, along with an estimated 150 million by the year 2050.



A 2014 study published in *BMC Psychiatry* discovered that the most common comorbidity with dementia is high blood pressure, but found no other association between the two. However, Sweeney et al found in 2018 that high blood pressure breaks down the blood-brain barrier, which exacerbates dementia, and when this barrier breaks down, neurotoxic products and pathogens can enter the brain and initiate inflammation, which leads to the degeneration of brain cells. In addition, medication to reduce high blood pressure also contributes to dementia if it lowers both diastolic, systolic blood pressure. Systolic pressure, the top number in a blood pressure reading — measured when the heart beats, naturally rises with age. Diastolic pressure, or the bottom number — measured when the heart relaxes, stays relatively consistent with age. Since systolic pressure rises while diastolic pressure stagnates, taking blood pressure medication could lower diastolic pressure below the recommended measurement. When this happens blood flow to the brain is reduced, thereby worsening dementia symptoms. Because of this phenomenon, scientists developing new high blood pressure treatments should consider engineering therapies that reduce only systolic pressure or target blood pressure in the brain rather than the entire body. A 2020 article published in *Frontiers in Neuroscience* suggests that therapies that reduce high blood pressure could treat dementia too — and thus solve two problems at once.

Current clinical trials of dementia treatments have thus far been unsuccessful, but none have targeted blood pressure. Most target amyloid beta proteins, which create plaque in the brain, or inflammatory stress molecules. However, none of these trials have been successful in improving brain function because it's difficult to pass anti-amyloid beta and anti-inflammatory drugs through the blood-brain barrier. The other issue is that high blood pressure still induces the release of amyloid beta and inflammatory molecules. As such, reducing blood pressure may be the best option for treating dementia. While no treatment currently exists to safely reduce blood pressure for people with dementia, perhaps the next few months will be the time when research moves in that direction.

Frontiers in Neuroscience (2020). DOI: 10.3389/fnins.2020.00669.
Nature Reviews Neurology (2018). DOI: 10.1038/nrneurol.2017.188.
BMC Psychiatry (2014). DOI: 10.1186/1471-244X-14-84

TAPS AND WHISPERS

WHAT IS BEHIND THOSE ASMR TINGLES

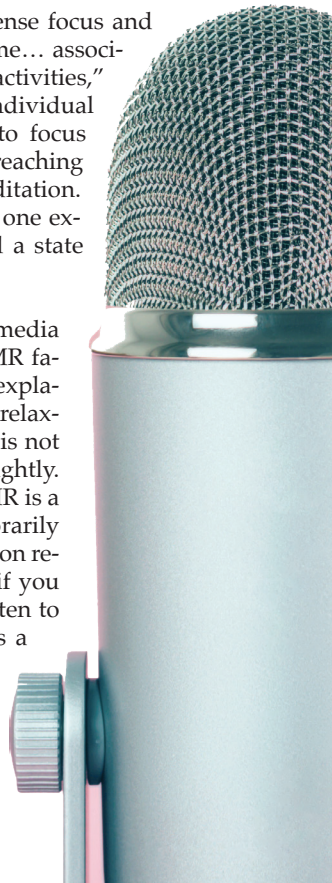
BY THERESA CHUNG, HEALTH SCIENCE, 2023

If you've been keeping up with online trends, then you've probably heard of ASMR; it's an acronym for autonomous sensory meridian response, used to explain the experience of feeling tingly sensations in response to certain audio-visual stimuli, or "triggers." These triggers include personal attention and close-up ear attention. In response to these triggers, tingles start from the crown of your head and end at your back, and ASMR viewers have claimed to feel more calm and relaxed after these experiences. While it cannot be denied that some individuals are able to experience these calming tingles, not much is truly known about ASMR or the relaxing sensations it brings.

However, there are other existing phenomena and states that share similarities with ASMR, according to a paper published by researchers at Swansea University in 2015. Synaesthesia is a phenomenon in which "specific external stimuli cause an internal experience in a second, unstimulated modality" (here modality refers to another sense). Like ASMR, synaesthesia involves the body feeling automatic responses to audio-visual stimuli while also feeling the positive emotion of calmness. Although similar, the two differ in that the tingles one feels in response to ASMR seem more tangible than the involuntary responses felt during synaesthesia.

In another sense, "flow," or a state of "intense focus and diminished awareness of the passage of time… associated with optimal performance in several activities," could be compared to ASMR. When an individual consumes ASMR media, they are found to focus only on the audio or visuals playing while reaching a state of deep relaxation, almost like meditation. The state of pure focus and relaxation that one experiences during ASMR can be considered a state of flow.

Despite the growing popularity of ASMR media online as well as the rising number of ASMR fanatics, there has yet to be a clear scientific explanation as to why ASMR induces tingles and relaxation in certain individuals. However, that is not to say that ASMR should be considered lightly. Studies and personal claims show that ASMR is a beneficial method for individuals to temporarily forget about their stressors and rather focus on relaxing through audio-visual stimuli. Even if you cannot feel the tingles, taking a break to listen to calming sounds and soothing words offers a unique way to relax.



DESIGN BY YECHAN YANG, BIOLOGY & PSYCHOLOGY, 2022

Peer J (2015). DOI: 10.7717/peerj.851

PHOTOS BY SHUTTERSTOCK

OPINION: WHAT THE 2020 US PRESIDENTIAL ELECTION MEANS FOR THE FUTURE OF STEM

BY BINH DANG, ENGLISH, 2022

DESIGN BY KAI GRAVEL-PUCILLO, PSYCHOLOGY, 2022

In most messaging intended to encourage voter turnout, we are reminded of the "issues on the ballot." From *Roe v. Wade* to the Affordable Care Act (ACA), many key issues are used as justification to vote for the candidate who supports one's own stance. For many Americans, this rhetoric works because 20 million people have coverage under the ACA and, according to a CBS News poll from June 2020, 63 percent of Americans support upholding *Roe v. Wade*. While these issues affect millions across the country, the future direction of science and research has received little attention. Depending on which candidate is sworn into office in January, STEM's support could drastically increase or decrease across social, fiscal, and policy realms.

Those in the field of science ought to consider that their research may be affected by the election. The National Science Foundation's (NSF) budget alone provided $6.5 billion for research and related activities in 2019, and many research institutions — including universities — rely heavily on federal funding for their research. Within the federal government, President Donald Trump's budget proposal for the 2020 fiscal year would have reduced the National Institute of Health's budget by $5 billion from 2019's $34.4 billion, the NSF's by $603 million from $8.1 billion, and the Environmental Protection Agency's by 31 percent, with further cuts across other agencies. The exception, however, was the $362 million increase that would go to the Food and Drug Administration. Despite President Trump's record of reducing science and research funding across the federal government, his future plans for science funding have largely been undiscussed. However, given the significant cuts to the same departments in the 2021 budget proposal, it's unlikely that the President will provide more funding for scientific research in a second term.

Conversely, Democratic candidate Joe Biden favors funding federal scientific agencies. He proposes a $300 billion dollar increase, over the next four years, in research and development across the same agencies that Trump proposed budget reductions for. Although, his campaign doesn't detail how that funding will be distributed.

However, there's one scientific issue that has been detailed and is making headlines: climate change. Biden's plan would commit $1.7 trillion from the federal government over the next 10 years to invest in clean and renewable energy. While not as ambitious as the more recognized Green New Deal, it aims to reach net-zero emissions by 2050 and has been considered the most ambitious climate action plan by a presidential candidate in a general election.

The Trump administration, however, has already reversed 68 environmental regulations and protections, with 32 more reversals in the process. The President's campaign website also features his administration's actions to promote the production and use of fossil fuels with little mention of climate change action. The administration's only action to reduce carbon emissions came with the enactment of the Affordable Clean Energy rule, which sets vague standards for emission reductions and is internally inconsistent — resulting in higher emissions at some coal plants and overall being ineffective in combating climate change.

Trump and Biden's stances on science don't only differ in funding or policy; at a more fundamental level, they have different beliefs and attitudes about the field. During the COVID-19 pandemic, the Trump administration acted late to control the spread of the virus, neglected the advice of public health officials, and downplayed its severity in its nascent stages. In spite of the public health guidelines to socially distance and wear masks, President Trump didn't aggressively advocate for either. He contracted the disease himself and spread it to other members of his party. Biden, on the other hand, claims he will rely heavily on public health officials to communicate credible information and make decisions.

What does this all mean for the future of STEM? Based on prior attitudes and actions, it would stand to reason that science under a Trump administration would continue to be relegated to a marginal priority and ethos, have reduced funding, and be undermined by the commander-in-chief. Under a Biden administration, science would be at the forefront of policy making and gain funding and support.

I haven't conjectured about any of the candidate's actions or stances — I've merely reiterated their viewpoints and the consensus amongst the scientific community. As much as we in the field would like to believe it, science has never been apolitical. More than ever, the 2020 election proves that fact — and that science itself is always on the ballot.

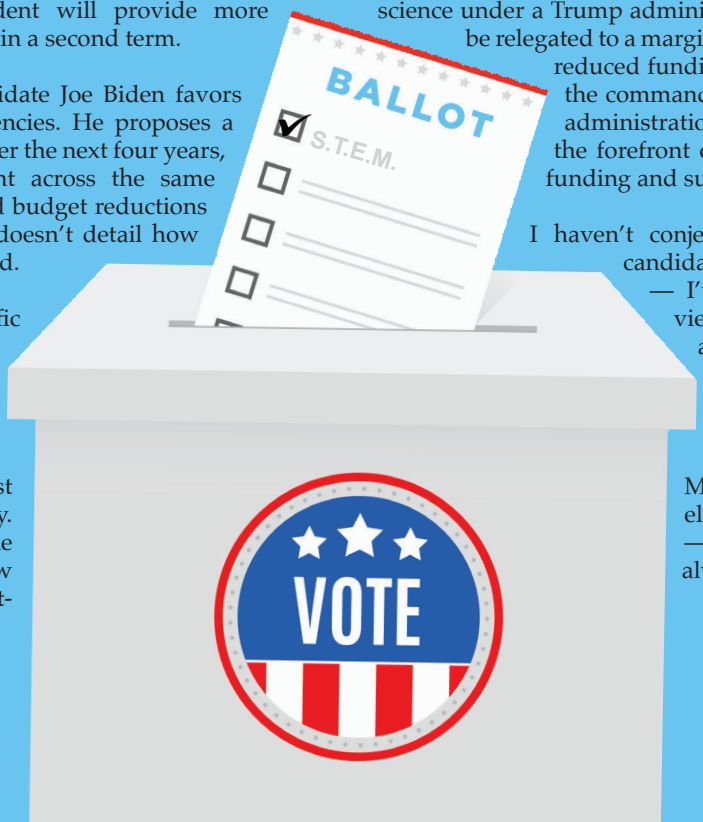


PHOTO BY SHUTTERSTOCK

TO THE OTHER SIDE AND BACK

Near-death experiences and what they tell us about our brains

BY KRISTINA KLOSOWSKI, BEHAVIORAL NEUROSCIENCE, 2022

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

As humans, we tend to be both afraid of and fascinated by death. It is virtually the only thing that we are all certain to experience, yet no one can say for sure what happens to us when we die. However, some individuals who've had particularly close brushes with death claim to have had a glimpse at what's waiting for us on the other side.

Near-death experiences (termed NDEs several decades ago) refer to self-reported psychological experiences that occur when an individual has a real or perceived close call with death. This could accompany any number of situations, but some of the most common are cardiac arrest, blunt head trauma, traumatic accidents, comas, or other losses of consciousness. Once revived, people describe having had an overwhelming sense of peace, transcendence, and euphoria while they were unconscious. Some even report a brilliant light, the presence of a divine force or supernatural being, or reunions with loved-ones who have died.

While these experiences have understandably been met with much skepticism, they are surprisingly well documented in scientific literature, and about 20 percent of individuals who have been in cardiac arrest have independently reported a similar series of events. Additionally, NDEs have been reported across different cultures and religious backgrounds, which has led scientists to begin searching for a universal physiological cause. So far, a number of working theories have been generated. These include the loss of oxygen to the brain (hypoxia), increase in carbon dioxide levels in the blood (hypercarbia), increased temporal lobe activity (part of the brain that plays a role in processing emotions and visual perception) and the release of endogenous (naturally-occuring) chemicals in the brain.

Although none of these explanations can account for all aspects of an NDE, the latter is supported by the fact that experiences similar to NDEs have been reported in drug-induced states. There have been a few studies that compare the similarities between NDEs and the psychological effects of LSD, ketamine, DMT, PCP, nitrous oxide, and various other psychoactive drugs. Of these, ketamine, an NMDA receptor agonist, was concluded to produce the most similar effects that are present in NDEs. This finding would support a theory that the brain releases an endogenous chemical with a similar mechanism of action either in the proximity of death or in certain high-stress situations.

Despite the curiosity surrounding near-death experiences, scientists have not been able to make any conclusions about what causes them or even determine whether there is a definitive neurological cause. However, as medicine advances and more and more people are resuscitated, it is possible that this phenomenon will become even more widely reported.

Croatian Medical Journal (2015). DOI: 10.3325/cmj.2015.56.392

PHOTO BY SHUTTERSTOCK

TRAILBLAZING THE WAY TO FIND THE PERFECT SNEAKER

BY LOUISE HOLWAY, ARCHITECTURE & CIVIL ENGINEERING, 2022 DESIGN BY KAI GRAVEL-PUCILLO, ENVIRONMENTAL SCIENCE, 2022

It often seems like finding the perfect running shoes is more strenuous than running a race. Do you have high, low, or medium pronation? Do you heal or toe strike? What's your weekly mileage? What type of ground are you running on? With all of the options on the market, choosing the right pair can be overwhelming.

While some designs claim to make you faster, the most important quality a sneaker can provide is injury prevention, because running slowly is faster than not running at all. Injuries are extremely common in long distance runners, with numerous studies claiming that anywhere between 20 – 75 percent of runners have been benched during their career.

Minimalist

Many recent trends have promoted healthy running, one of which being minimalist sneakers. They tend to have high flexibility, are lightweight, and have a low heel-top drop. The lack of cushion is promoted to prevent injuries by allowing a more natural heel strike, motion control, stabilization, and foot strength. Many studies have shown that minimalist shoes also improve running economy, the energy used to go a certain speed because runners wearing minimalist shoes tend to strike the ground with their mid- or front-foot, as opposed to their rear foot. This increases strike rate for a more efficient gait and theoretically allows the runner to go faster. The lightweight design requires less force during turnover, further increasing strike rate. A study by *Journal of Science and Medicine in Sport* found that training in minimalist shoes leads to improved time-trial performance by benefitting stride rate, stride length, and footfall pattern.

This being said, minimalist sneakers may have adverse effects. A study from Shanghai University of Sport found that, because minimalist sneakers promote forefoot strikes, they lead to more forefoot stress fractures. Another study found that, when compared to conventional running sneakers, minimalist sneakers can lead to bone marrow edema, the buildup of fluid in the bone marrow, more often.

Maximalist

Minimalist sneakers aren't the only type of sneaker that promote injury prevention; maximalist shoes have similar promises with a nearly opposite design. Their design is centered on lots of cushioning and increased stack height — the height of material between your foot and the ground. Maximalist sneakers have a stack height above 30 millimeters, which is nearly 50 percent more than conventional sneakers. The increased cushioning can absorb much of the shock that would otherwise be absorbed in the runner's joints. The high side walls also increase stability, which can be beneficial for people with ankle problems. Overall, they make walking and running very comfortable, similar to walking on a cloud.

This being said, there are numerous drawbacks of maximalist sneakers. While the cushion can take stress off of the runner's joints, it can decrease strength in the foot muscles and increase load in the knee. A study from *Orthopaedic Journal of Sports Medicine* found that, when compared to a neutral sneaker, runners experienced increased impact forces and loading rate, the rate at which forces are applied to your body. Another study from *Scientific Reports* found that maximalist shoes increase leg stiffness and impact loading.

So, what is the truth? Both maximalist and minimalist shoes have their benefits. Many runners wear a shoe with a larger cushion on easy runs and a minimalist shoe during races and hard workouts. John Murray, Women's Varsity Cross Country and Track Coach at Northeastern University, comments that, "Minimalist shoes, such as racing flats, are good for workouts and races because they are light... and develop strong stabilizing muscles in your foot and lower legs, which translates to better reaction off the ground." He adds, "It might not be good to train in these shoes all the time, because sometimes your feet need more cushion in order to recover, adapt, and regenerate your foot muscles."

Neutral

A poll from the Northeastern Men and Women's Varsity Cross Country team found that 20.7 percent prefer a minimalist shoe, 37.9 percent prefer a maximalist shoe, and 41.4 percent prefer a neutral shoe. There is no right or wrong answer when it comes to finding the perfect running shoe. Murray states, "More than anything you want a shoe that fits your foot well to your foot and is comfortable."

So yes, the search for the perfect running shoe may seem daunting, but don't let it serve as an excuse not to get out the door!

Journal of Science and Medicine in Sport (2017). DOI: 10.1016/j.jsams.2017.04.013
Sci Rep (2018). DOI: 10.1038/s41598-018-35980-6
Orthopaedic Journal of Sports Medicine (2018). DOI: 10.1177/2325967118775720

PHOTOS BY SHUTTERSTOCK

Human cryopreservation

How and why (not)?

BY CATRIN ZHARYY, BEHAVIORAL NEUROSCIENCE, 2023

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

There may already be time-travelers among us: people who elected to be frozen solid after their death to live once again in a scientifically updated future. It can certainly be argued that these individuals are quite literally in over their heads (in liquid nitrogen), but even though hardly anything is known about how exactly they will be revived to their full, pre-death mental and physical capacities, science has made some remarkable strides in that direction.

To put a pause on life is theoretically possible because of thermodynamics. All chemical reactions (millions of which are happening in a cell every second) slow down at cooler temperatures because there is less energy available to initiate them. At extremely low temperatures, biochemical processes arrive at a stand-still, effectively stopping aging and decay. Some species, like the Siberian salamander, can use this fact to their advantage and wait out a harsh winter by willingly letting their bodies cool down into a hibernative state. Hypothermic animals like humans, though, have some cells, like neurons, which are particularly oxygen-sensitive, and these cells cannot handle temperatures below 35 degrees Celsius. This is why the Siberian salamander will wake up healthy and refreshed from its cold nap, while you will get nerve damage, or die.

In 1999, Swedish radiologist Anna Bågenholm was trapped under ice for an hour and 20 minutes. Her heart stopped for three hours and her body temperature lowered to 13.7 degrees Celsius. When she got to the hospital, her blood was gradually warmed up over the course of nine hours, and although she spent two months in intensive care after multiple organ systems failed, she survived with only some nerve damage to her hands. So although freezing a human body while it is still alive (putting it into cryosleep) is very dangerous, stopping and restarting it through temperature change is clearly possible somehow. This is the motivating force behind scientists who research cryonics — the study of preserving a human body after death in a very cold temperature in the hope that it can be brought back to full health and vitality in the future.

For anyone being cryogenically frozen, the moments after they are legally pronounced dead are critical. Their circulation and breathing are temporarily reinitiated to keep the brain cells alive long enough to take up protective medications, ice bath. Their blood is pumped out and replaced by an organ preservation solution to avoid blood clotting. After the body is transferred to an operating room at one of the world's three cryonics organizations (Alcor in Arizona, Cryonics Institute in Michigan, or KrioRus in Russia), a cryoprotectant is "perfused" throughout the body via the blood vessels. Finally, the patient is cooled down to -196 degrees over the course of about a week and stored in liquid nitrogen in a vacuum-sealed cylindrical metal container called a dewar.

> "At extremely low temperatures, biochemical processes arrive at a stand-still, effectively stopping aging and decay."

The reason why a body cannot be immediately frozen without the addition of special solutions is to prevent the formation of dangerous ice crystals. When water freezes in the space between cells, salt and other dissolved chemicals fall out and accumulate. Due to the concentration gradient of salt across the cell membrane, water inside the cells exits to establish equilibrium through osmosis. All of this fluid coming out of the cell causes it to crumple and lose its structure. Cryoprotectants (biological antifreeze) are chemicals that dissolve in water and lower the temperature needed for it to freeze.

An updated version of cryoprotection, which is better at protecting cells and maintaining the structure of organs, is vitrification. Here, the body is perfused with a very high concentration of cryoprotectant and cooled very quickly, not giving water the chance to form crystals. Incredibly, in 2015, Robert McIntyre and Gregory Fahy successfully froze and unfroze rabbit and pig brains via vitrification, keeping the structure and organization of the neurons perfectly preserved. So we might be able to preserve the structure of the human brain and body through freezing, but whether or not it can be brought back to life with full functionality is an entirely different question — one we'll leave for future us to figure out.

Regardless, the research going into cryopreservation certainly isn't a waste of time. Even if we are only able to freeze and restore select tissues and organs, it will be a great success for the future of research and medicine. Meanwhile, it won't hurt to hold out a little hope for our frozen time-travelers.

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Cryobiology (2015). DOI: 10.1016/j.cryobiol.2015.09.003
Current Opinion in Organ Transplantation (2018). DOI: 10.1097/MOT.0000000000000534

TELEPATHY MAY BE A REALITY
BRAIN-TO-BRAIN COLLABORATION

BY EMMA TUSUZIAN, PSYCHOLOGY, 2023 DESIGN BY PREETI MAKARAM, COMPUTER SCIENCE & COGNITIVE PSYCHOLOGY, 2024

Telepathy may no longer be pseudoscience. New technological frontiers are pushing the boundaries of human capability, edging scientific fiction closer to scientific reality. One such feasible experience is direct brain-to-brain collaboration. In 2015, researchers at the University of Washington explored such information exchange but were limited by the need for physical interaction with interfaces (taking away from its "telepathy") and a maximum of merely two participants. The same team has now revolutionized this technology, attracting media attention even before publishing their work in April 2019.

BrainNet is claimed to be "the first multi-person non-invasive direct brain-to-brain interface (BBI) for collaborative problem solving." The interface combines electroencephalography (EEG), a method to record electrical activity of the brain, and transcranial magnetic stimulation (TMS), a procedure using magnetic fields to stimulate nerve cells in the brain, to non-invasively record brain signals from the scalp and deliver information through visual cortex stimulation. It allows *three* humans to collaborate on a task using direct communication between their brains. In their 2019 study, researchers describe the roles of two "Senders" and one "Reciever" in integrating information for decision-making. Senders, whose brain signals are decoded using real-time EEG analysis, convey decisions of "yes" or "no" by controlling a moving cursor using visually-evoked potentials. The cursor position provides a live visualization of their translated brain activity when making decisions. In the study example, a Sender's decision is decoded to determine whether or not to "rotate a block in a Tetris-like game before it is dropped to fill a line" by focusing on different lights on the screen. Both Senders' decisions are then transmitted via the Internet to the brain of the Receiver, who does not see the game screen.

Once it reaches the Receiver, this transmitted information is compared with the Receiver's predetermined magnetic stimulation levels associated with the binary "Rotate" and "Do Not Rotate" decisions. Magnetic stimulation enables the Receiver to interpret both decisions, prompting the use of an EEG interface to decide whether to turn the block or preserve its orientation.

A second round of the game acts as a chance for Senders to evaluate the Receiver's decision and send feedback to the Receiver's brain. This way, the Receiver can change a possibly incorrect decision made initially. When five groups performed this collaborative task, they demonstrated an average accuracy of 81.25 percent. Despite this relatively small sample size, the accuracy and outcome have exciting potential for a multitude of applications.

> "As technology continuously expands, ethical discussions become especially important when involving human subjects."

When explained through technological interactions with biology, a seemingly paranormal process comes together in clear steps. Now that this is a reality with widely used EEG and TMS methods, BrainNet could be comparable to an express pass for communication. According to an article from University of Wshington News, since their initial breakthrough in 2015, the team has been exploring "brain tutoring," which would transfer signals from a healthy brain to one that is developmentally impaired. Similarly, it could also have the potential to transfer knowledge from teachers to students. Along with this endeavor, the team had also reported an interest in transmitting brain states, such as from the state of a focused student to one with ADHD. "When the non-ADHD student is paying attention, the ADHD student's brain gets put into a state of greater attention automatically," said co-author Chantel Prat, a faculty member at the Institute for Learning & Brain Sciences and a UW associate professor of psychology. Though the team hopes to stimulate future BBIs within a "social network" and similar collaborative applications for problem solving, the paper does not mention other uses.

The density of complications in further experiments, especially with adding brains interacting through the Internet, can pose communication dilemmas. BBIs have potential with multiple specific uses, but their very recent development comes with unresolved ethical issues, including "autonomy, privacy, agency, accountability, and identity," according to a *Frontiers in Neuroscience* article. The future use and development of this technology must be carefully considered before continued research. BrainNet researchers are working to address the ethical issues of such brain augmentation research by developing protocols for privacy protection. As technology continuously expands, ethical discussions become especially important when involving human subjects.

Scientific Reports (2019). DOI: 10.1038/s41598-019-41895-7
Front. Neurosci. (2019). DOI: 10.3389/fnins.2019.01177

PHOTO BY SHUTTERSTOCK

Periodic pulses

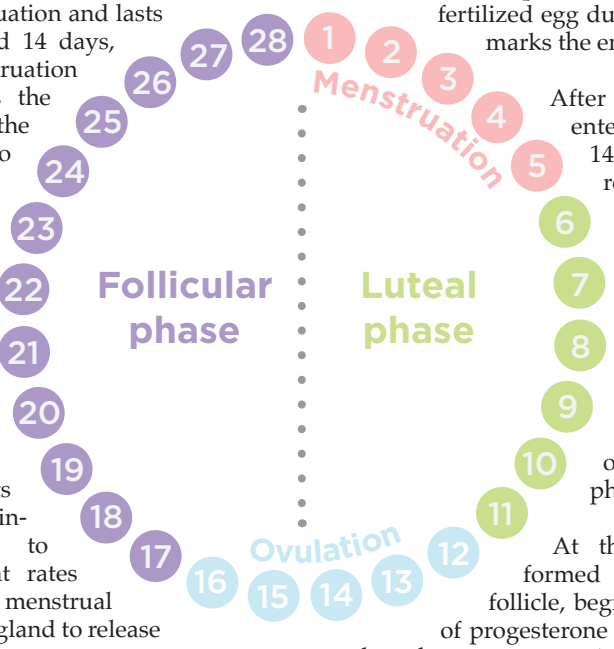
Hormonal releases during the menstrual cycle

BY MAYA KRAUSE, ENVIRONMENTAL SCIENCE, 2022

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Around once a month, I have a day where nothing seems to go right. I can't focus, everything is irritating, and all I want to do is sit in bed eating ice cream alone. I first noticed this pattern around age 14 and thought it meant I was about to start my period, but menstruation would never directly follow this 24-hour window. In fact, this day would fall right in between periods. It wasn't until I started tracking my periods that I realized this hormonal spike was correlated with ovulation. Understanding hormonal signalling in rhythmic menstrual cycles can help those who menstruate anticipate symptoms that lie ahead.

The human menstrual cycle is divided into two phases: the follicular phase and the luteal phase. The follicular phase begins on the first day of menstruation and lasts until ovulation, typically around 14 days, though sometimes longer. Menstruation occurs when the uterus sheds the endometrium, the lining of the uterus, by bleeding for three to seven days. Most people who menstruate, and indeed some who do not, know this time in the menstrual cycle well. Understanding the rest of the cycle can help identify physical and mental changes caused by hormonal processes.



To control the menstrual cycle, the hypothalamus, or hormone-controlling part of the brain, sets a rhythmic release of gonadotropin-releasing hormone (GnRH) to the pituitary gland at different rates depending on the phase of the menstrual cycle. GnRH causes the pituitary gland to release key hormones to the ovaries and uterus.

During the follicular phase, GnRH pulses from the hypothalamus around every hour. This fast-paced pulsation signals the pituitary gland to secrete luteinizing hormone (LH) and follicle stimulating hormone (FSH) to the ovaries. LH and FSH stimulate growth of ovarian follicles, which produce estradiol as they grow. After a few days, one follicle becomes the dominant follicle that goes on to ovulate, and the rest break down in a process called follicular atresia. The dominant follicle continues to grow and produce estradiol while also secreting other hormones to suppress the growth of non-dominant follicles, ensuring there is only one ovulation per cycle. When the growth of other follicles is not blocked, a second dominant follicle is produced and ovulation occurs twice, explaining how fraternal twins come about.

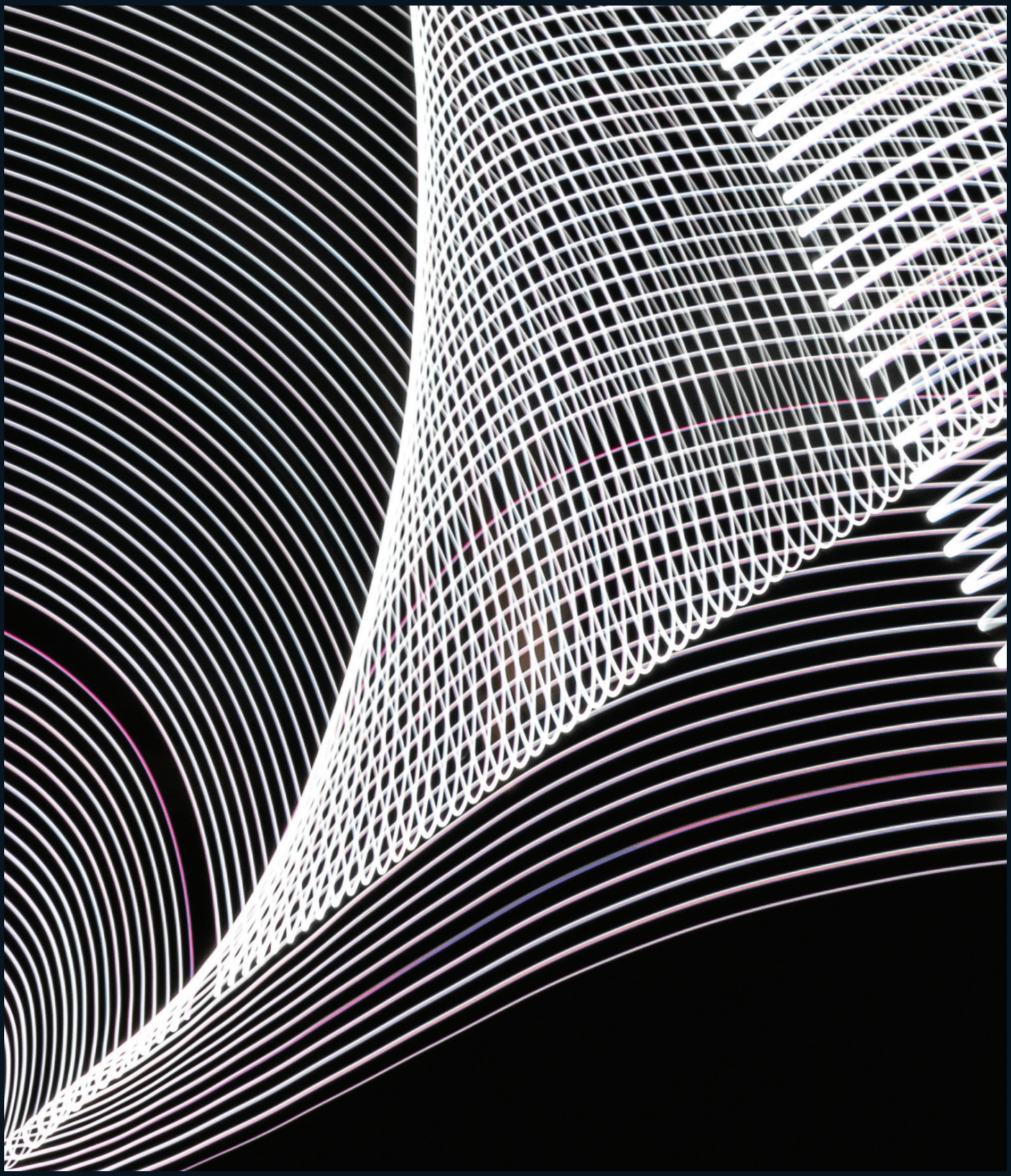
When the dominant follicle produces enough estradiol to sustain high levels for a 48-hour period, the hypothalamus releases large amounts of GnRH, signalling to the pituitary gland to spike production of LH and FSH. As a result of high estradiol levels, people who menstruate may experience symptoms such as migraines, increased libido, and acne. The pulse of LH activates enzymes to break down the follicular wall and stimulate ovarian muscles; this leads to ovulation as the egg is released from the ovary around 36 hours later. During ovulation, people who menstruate can experience increased body temperature, abdominal pain (from releasing the egg), and mood swings as estradiol levels crash down to baseline level. The LH surge also transforms the ovarian follicle into the corpus luteum, which assists in supporting a fertilized egg during early pregnancy. Ovulation marks the end of the follicular phase.

After ovulation, the menstrual cycle enters the luteal phase for around 14 days. During this phase, the released egg travels down the fallopian tube as the uterus prepares for fertilization. The hypothalamus stops releasing large amounts of GnRH and begins pulsing GnRH every two to four hours, resulting in pulses of LH from the pituitary gland. As a result, the presence of LH and FSH drop below their original levels from the follicular phase.

At this time, the corpus luteum, formed from the dominant ovarian follicle, begins releasing moderate amounts of progesterone and small amounts of estradiol. These hormones stimulate the endometrium to develop endometrial glands and spiral blood vessels to nourish the egg if fertilized. If pregnancy occurs, the concentration of progesterone in the uterus would increase to prevent the body from producing additional eggs. If the egg is not fertilized 9 to 11 days after ovulation, the corpus luteum begins to disintegrate, progesterone and estradiol levels drop, and the endometrium is shed in menstruation, restarting the cycle. The mechanisms that regulate release of progesterone are not completely understood, and moderate or high amounts typically do not cause symptoms.

The menstrual cycle is a complex process, dictated by GnRH from the hypothalamus that stimulates the release of LH and FSH. By understanding the mechanisms that result in menstruation, those who menstruate can better anticipate symptoms that accompany these hormonal swings.

Human Fertility (2014). DOI: 10.1007/978-1-4939-0659-8_7



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