This is what it's like to be struck by lightning

May 23 2017, by Charlotte Huff

A thunderstorm above Unna, in Germany. Credit: smial/Wikipedia.

Sometimes they'll keep the clothing, the strips of shirt or trousers that weren't cut away and discarded by the doctors and nurses. They'll tell and retell their story at family gatherings and online, sharing pictures and news reports of survivals like their own or far bigger tragedies. The video of a tourist hit on a Brazilian beach or the Texan struck dead while

out running. The 65 people killed during four stormy days in Bangladesh.

Only by piecing together the bystander reports, the singed clothing and the burnt skin can survivors start to construct their own picture of the possible trajectory of the electrical current, one that can approach 200 million volts and travel at one-third of the speed of light.

In this way, Jaime Santana's family have stitched together some of what happened that Saturday afternoon in April 2016, through his injuries, burnt clothing and, most of all, his shredded broad-brimmed straw hat. "It looks like somebody threw a cannonball through it," says Sydney Vail, a trauma surgeon in Phoenix, Arizona, who helped care for Jaime after he arrived by ambulance, his heart having been shocked several times along the way as paramedics struggled to stabilise its rhythm.

Jaime had been horse-riding with his brother-in-law and two others in the mountains behind his brother-in-law's home outside Phoenix, a frequent weekend pastime. Dark clouds had formed, heading in their direction, so the group had started back.

They had nearly reached the house when it happened, says Alejandro Torres, Jaime's brother-in-law. He paces out the area involved, the landscape dotted with small creosote bushes just behind his acre of property. In the distance, the desert mountains rise, rippled chocolate-brown peaks against the horizon.

The riders had witnessed quite a bit of lightning as they neared Alejandro's house, enough that they had commented on the dramatic zigzags across the sky. But scarcely a drop of rain had fallen as they approached the horse corrals, just several hundred feet from the back of the property.

Alejandro doesn't think he was knocked out for long. When he regained consciousness, he was lying face down on the ground, sore all over. His horse was gone.

The two other riders appeared shaken but unharmed. Alejandro went looking for Jaime, who he found on the other side of his fallen horse. Alejandro brushed against the horse's legs as he walked passed. They felt hard, like metal, he says, punctuating his English with some Spanish.

He reached Jaime: "I see smoke coming up – that's when I got scared." Flames were coming off of Jaime's chest. Three times Alejandro beat out the flames with his hands. Three times they reignited.

It wasn't until later, after a neighbour had come running from a distant property to help and the paramedics had arrived, that they began to realise what had happened – Jaime had been struck by lightning.

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Justin Gauger wishes his memory of when he was struck – while fishing for trout at a lake near Flagstaff, Arizona – wasn't so vivid. If it weren't, he wonders, perhaps the anxiety and lingering effects of post-traumatic stress disorder wouldn't have trailed him for so long. Even now, some three years later, when a storm moves in, the flickering flashes of light approaching, he's most comfortable sitting in his bathroom closet, monitoring its progress with an app on his phone.

An avid fisherman, Justin had initially been elated when the rain started that August afternoon. The storm had kicked up suddenly, as they often do during the summer monsoon season. Fish are more likely to bite when it's raining, he told his wife, Rachel.

But as the rain picked up, becoming stronger and then turning into hail,

his wife and daughter headed for the truck, followed later by his son. The pellets grew larger, approaching golf ball size, and really started to hurt as they pounded Justin's head and body.

Giving up, he grabbed a nearby folding canvas chair – the charring on one corner is still visible today – and turned to head for the truck. Rachel was filming the storm from the front seat, planning to catch her husband streaking back as the hail intensified. She pulls up the video on her phone.

Initially all that's visible on the screen is white, a blur of hail hitting the windshield. Then a flash flickers across the screen, the only one that Rachel saw that day, the one that she believes felled her husband.

A crashing boom. A jolting, excruciating pain. "My whole body was just stopped – I couldn't move any more," Justin recalls. "The pain was… I can't explain the pain except to say if you've ever put your finger in a light socket as a kid, multiply that feeling by a gazillion throughout your entire body.

"And I saw a white light surrounding my body – it was like I was in a bubble. Everything was slow motion. I felt like I was in a bubble for ever."

A couple huddling under a nearby tree ran to Justin's assistance. They later told him that he was still clutching the chair. His body was smoking.

When Justin came to, he was looking up at people staring down, his ears ringing. Then he realised that he was paralysed from the waist down. "Once I figured out that I couldn't move my legs, I started freaking out."

Describing that day, sitting on his sofa at home, Justin draws one hand across his back, tracing the path of his burns, which at one point covered

roughly a third of his body. They began near his right shoulder and extended diagonally across his torso, he says, and then continued along the outside of each leg.

He leaves and returns holding his hiking boots, tipping them to show several burn marks on the interior. Those dark roundish spots line up with the singed areas on the socks he was wearing and with the coin-sized burns he had on both feet, which were deep enough that he could put the tip of his finger inside.

The singed markings also align with several needle-sized holes located just above the thick rubber soles of his size 13 boots. Justin's best guess – based on reports from the nearby couple, along with the wound on his right shoulder – is that the lightning hit his upper body and then exited through his feet.

Although survivors frequently talk about entry and exit wounds, it's difficult to figure out in retrospect precisely what path the lightning took, says Mary Ann Cooper, a retired Chicago emergency physician and long-time lightning researcher. The visible evidence of lightning's wrath is more reflective, Cooper says, of the type of clothing a survivor had on, the coins they were carrying in their pockets and the jewellery they were wearing as the lightning flashed over them.

Lightning is responsible for more than 4,000 deaths worldwide annually – according to those documented in reports from 26 countries. (The true scope of lightning's casualties in the more impoverished and lightning-prone areas of the world, such as central Africa, is still being calculated.) Cooper is one of a small global cadre of doctors, meteorologists, electrical engineers and others who are driven to better understand how lightning injures people, and ideally how to avoid it in the first place.

Of every ten people hit by lightning, nine will survive to tell the tale. But

they could suffer a variety of short- and long-term effects. The list is lengthy and daunting: cardiac arrest, confusion, seizures, dizziness, muscle aches, deafness, headaches, memory deficits, distractibility, personality changes and chronic pain, among others.

Many survivors have a story that they want to share. In postings online and during annual gatherings of Lightning Strike & Electric Shock Survivors International, they swap tales of their brush with nature's brutal force. The group has convened in the mountains of the south-eastern US every spring since its first meeting was held by 13 survivors in the early 1990s. In those pre-internet days, it was far more difficult to meet other survivors coping with the headaches, memory troubles, insomnia and other effects of a lightning strike, says Steve Mashburn, the group's founder, who has been living with symptoms since he was struck near a bank teller's window in 1969.

For nearly 30 years, he and his wife have run the organisation – which now has nearly 2,000 members – from their North Carolina home. They nearly cancelled this year's conference, as Mashburn, who is 72 years old, has been having some health issues. But the members wouldn't allow it, he says, a bit proudly.

The changes in personality and mood that survivors experience, sometimes with severe bouts of depression as well, can strain families and marriages, sometimes to breaking point. Cooper likes to use the analogy that lightning rewires the brain in much the same way that an electrical shock can scramble a computer – the exterior appears unharmed, but the software within that controls its functioning is damaged.

Both Mashburn and Cooper credit the organisation's very existence with saving lives, with it preventing at least 22 suicides according to Mashburn. It's not unusual for him to field a call in the middle of the

night and talk for hours with someone in dire straits. He is drained afterwards, unable to do much for the next few days.

Cooper, who has attended some of these gatherings, has learned to hang back as survivors and their loved ones describe their symptoms. "I still don't understand all of them," she says. "A lot of times I can't understand what's going on with these people. And I listen and I listen and I listen."

Despite a deep vein of sympathy for survivors, some symptoms still strain Cooper's credulity. Some people maintain that they can detect a storm brewing long before it appears on the horizon. That's possible, Cooper says, given their heightened sensitivity to stormy signs in the wake of their trauma. She's less open to other reports – those who say that their computer freezes when they enter a room, or that the batteries in their garage door opener or other devices drain more quickly.

Yet, even after decades of research, Cooper and other lightning experts readily admit that there are many unresolved questions, in a field where there's little to no research funding to decipher the answers. It's not clear, for example, why some people appear to suffer seizure-related symptoms after their lightning injury. Also, are lightning survivors more vulnerable to other health problems, such as heart conditions, later in life?

Some survivors report feeling like medical nomads, as they struggle to find a doctor with even a passing familiarity with lightning-related injuries. Justin, who could move his legs within five hours of being struck, finally sought out help and related testing last year at the Mayo Clinic for his cognitive frustrations.

Along with coping with post-traumatic stress disorder, Justin chafes at living with a brain that doesn't function as fluidly as it once did. He doesn't see how he could possibly return to the type of work he used to

shoulder, leading a small team that presented legal cases and helped defend the county against property value disputes. Talking on the phone one day, sounding quite articulate, he tries to convey the struggles lurking just beneath. "My words in my head are jumbled. When I think about what I'm trying to say, it's all jumbled up. So when it comes out, it may not sound all right."

When someone is hit by lightning, it happens so fast that only a very tiny amount of electricity ricochets through the body. The vast majority travels around the outside in a 'flashover' effect, Cooper explains.

By way of comparison, coming into contact with high-voltage electricity, such as a downed wire, has the potential to cause more internal injuries, since the exposure can be more prolonged. A 'long' exposure might still be relatively brief – just a few seconds. But that's sufficient time for the electricity to penetrate the skin's surface, risking internal injuries, even to the point of cooking muscle and tissue to the extent that a hand or limb might need to be amputated.

So what causes external burns? Cooper explains that, as lightning flashes over the body, it might come into contact with sweat or raindrops on the skin's surface. Liquid water increases in volume when it's turned into steam, so even a small amount can create a 'vapour explosion'. "It literally explodes the clothes off," says Cooper. Sometimes the shoes too.

However, shoes are more likely to be torn or damaged on the inside, because that's where the heat build-up and vapour explosion occurs. "That's it," Cooper responds when she's told about the singed markings on Justin's hiking boots.

As for clothing, steam will interact with it differently depending upon what it's made of. A leather jacket can trap the steam inside, burning the

survivor's skin. Polyester can melt with just a few pieces left behind, primarily the stitching that once held together the seams of a shirt or a jacket that's no longer there, says Cooper, who has seen a decent quantity of post-lightning relics through the years.

Along with the burn marks visible on Jaime Santana's clothes, the cellphone he was carrying in his pocket melted, bonding to his pants. (His sister, Sara, now wishes that they had kept the phone but they tossed it, fearful that it carried some residual lightning current – a bit paranoid, she now realises.) While Jaime's family believes that lightning shredded his hat, causing it to expand upward and outward, Cooper is more dubious when she sees a photograph. There's no visible singeing, she notes. And the chunk of straw could have been lost during Jaime's tumble from the horse.

Cooper authored one of the first studies looking at lightning injuries, published nearly four decades ago, in which she reviewed 66 physician reports about seriously injured patients, including eight that she'd treated herself. Loss of consciousness was common. About one-third experienced at least some temporary paralysis in their arms or legs.

Those rates might be on the high side – Cooper points out that not all lightning patients are sufficiently injured that doctors write about their cases. But survivors do often describe temporary paralysis, like Justin suffered, or a loss of consciousness, although why it occurs is not clear.

More is understood about lightning's ability to scramble the electrical impulses of the heart, thanks to experiments with Australian sheep. Lightning's massive electrical current can temporarily stun the heart, says Chris Andrews, a physician and lightning researcher at the University of Queensland in Australia. Thankfully, though, the heart possesses a natural pacemaker. Frequently, it can reset itself.

The problem is that lightning can also knock out the region of the brain that controls breathing. This doesn't have a built-in reset, meaning a person's oxygen supply can become dangerously depleted. The risk then is that the heart will succumb to a second and potentially deadly arrest, Andrews says. "If someone has lived to say, 'Yes, I was stunned [by lightning],' it's probable that their respiration wasn't completely wiped out, and re-established in time to keep the heart going."

Andrews is well suited to conducting lightning studies, having trained both as an electrical engineer and as a physician. His research, looking at the impact of electrical current on sheep, is frequently credited with demonstrating how lightning's flashover current can still inflict damage within the body. One reason sheep were chosen, Andrews says, is that they're relatively close to humans in size. Another advantage is that the specific breed chosen, the barefaced Leicester, doesn't grow much wool around its head, making it similar to a human's.

During his studies, Andrews shocked anesthetised sheep with voltage levels roughly similar to a small lightning strike and photographed the electricity's path. He showed that as lightning flashes over, the electrical current enters critical portals into the body: the eyes, the ears, the mouth. This helps explain why damage to the eyes and ears is frequently reported by survivors. They might develop cataracts. Or their hearing can be permanently damaged, even after the initial post-boom ringing stops.

Particularly worrisome is that, by penetrating the ears, lightning can rapidly reach the brain region that controls breathing, Andrews says. Upon entering the body, the electricity can hitch a ride elsewhere, through the blood or the fluid surrounding the brain and the spinal cord. Once it reaches the bloodstream, Andrews says, the passage to the heart is very quick.

In Arizona, Jaime Santana survived the immediate lightning strike. The family's beloved horse Pelucha – from the Spanish for 'stuffed animal' – did not. One possibility, the trauma surgeon Sydney Vail and others speculate, is that the 1,500-pound steed absorbed a good portion of the lightning that nearly killed his 31-year-old rider.

Another reason Jaime survived is that, when he was struck, the neighbour who came running – someone who the family had never met before – immediately started CPR, and continued until the paramedics arrived. At one point, Alejandro says, one of the paramedics asked the other if they should stop, as Jaime wasn't responding. The neighbour insisted that they continue.

That CPR occurred immediately is "the only reason he's alive," says Vail. The neighbour later told the family that he had performed CPR "hundreds and hundreds of times" in nearly two decades as a volunteer paramedic, says Jaime's sister, Sara, her voice cracking as she talks. Before Jaime, no one had survived.

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Lightning begins high up in the clouds, sometimes 15,000 to 25,000 feet above the earth's surface. As it descends toward the ground, the electricity is searching, searching, searching for something to connect with. It steps, almost stair-like, in a rapid-fire series of roughly 50-metre increments. Once lightning is 50 metres or so from the ground, it searches again pendulum-style in a nearby radius for "the most convenient thing to hit the fastest," says Ron Holle, a US meteorologist and long-time lightning researcher.

Prime candidates include isolated and pointed objects: trees, utility poles, buildings and occasionally people. The entire cloud-to-ground sequence happens blindingly fast.

The popular perception is that the chance of being struck by lightning is one in a million. There's some truth here, based on US data, if one only looks at deaths and injuries in a single year. But Holle, who believes that statistic is misleading, set out to crunch some other numbers. If someone lives until 80, their lifetime vulnerability increases to 1 in 13,000. Then consider that every victim knows at least ten people well, such as the friends and family of Jaime and Justin. Thus, any individual's lifetime probability of being personally affected by a lightning strike is even higher, a 1 in 1,300 chance.

Holle doesn't even like the word 'struck', saying it implies that lightning strikes hit the body directly. In fact, direct strikes are surprisingly rare. Holle, Cooper and several other prominent lightning researchers recently pooled their expertise and calculated that they're responsible for no more than 3 to 5 per cent of injuries. (Still, Vail, the trauma surgeon, surmises that Jaime was directly hit, given that he was riding in the desert with no trees or other tall objects nearby.)

Justin believes that he experienced what's called a side flash or side splash, in which the lightning 'splashes' from something that has been struck – such as a tree or telephone pole – hopscotching to a nearby object or person. Considered the second most common lightning hazard, side splashes inflict 20 to 30 per cent of injuries and fatalities.

By far the most common cause of injury is ground current, in which the electricity courses along the earth's surface, ensnaring within its circuitry a herd of cows or a group of people sleeping beneath a tent or a grass-thatched hut.

As a general rule, in high-income regions of the world men are more likely than women to be injured or killed by lightning; at least two-thirds of the time they're the victims, and possibly higher depending upon the study. One possibility is the propensity for "men taking chances," Holle

quips, as well as work-related exposure. They are more likely to be on the younger side, in their 20s or 30s, and doing something outside, frequently on the water or nearby.

But what should you do if you find yourself stranded a long way from a building or car when a storm kicks up? Some guidance is available: avoid mountain peaks, tall trees or any body of water. Look for a ravine or a depression. Spread out your group, with at least 20 feet between each person, to reduce the risk of multiple injuries. Don't lie down, which boosts your exposure to ground current. There's even a recommended lightning position: crouched down, keeping the feet close together.

Still, don't dare to ask Holle about any of these suggestions. There's no such thing as a lightning-proof guarantee, he repeats more than once. "There are cases where every one of these [strategies] has led to death." In his cubicle at the control centre of the US National Lightning Detection Network (NLDN) in Tucson – operated by Vaisala, a Finland-based environmental observation company – Holle has accumulated stacks and stacks of folders filled with articles and other write-ups detailing a seemingly endless litany of lightning-related scenarios involving people or animals. Deaths and injuries that have occurred in tents, or during sports competitions, or to individuals huddled beneath a golf shelter or a picnic shelter or some other type of shelter.

That word whitewashes the reality, Holle says, as so-called "shelters" can become "death traps" during a lightning storm. They provide protection from getting wet – that's it.

On a series of large screens lining two walls of a room at NLDN's offices in Tucson, Holle can see where cloud-to-ground lightning is flashing in real time, picked up by strategically positioned sensors in the US and elsewhere. Satellite data has shown that certain regions of the

world, generally those near the equator, are lightning-dense. Venezuela, Colombia, the Democratic Republic of the Congo and Pakistan all rank among the top ten lightning hotspots.

Initially, lightning safety campaigns promoted the 30/30 rule, which relied upon individuals counting off the seconds after lightning flashed. If thunder rumbled before they reached 30, lightning was close enough to pose a threat. But there's been a move away from that advice for various reasons, Holle says. One is practical: it's not always easy to figure out which rumble of thunder corresponds to which lightning flash.

Instead, for simplicity's sake, everyone from schoolchildren to their grandparents these days is advised: "When thunder roars, go indoors."

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Better education isn't the only reason why lightning deaths have steadily declined in the US, Australia and other high-income regions. Housing construction has improved. Jobs have moved indoors. In the US alone, annual fatalities have fallen from more than 450 in the early 1990s to fewer than 50 in recent years.

There's always room for improvement, though. Arizona, for example, ranks high in the US when looking at lightning deaths per state population. Holle's theory is that people stay outside longer in the desert as the rain isn't necessarily heavy during storms. That's why casualties can occur, even before the storm arrives, with people dallying their way to shelter while lightning stretches out in front of the dark clouds.

Still, people in high-income countries have it easy, compared to those in regions where people have no choice but to work outside in all conditions and lightning-safe buildings are scarce. In one analysis of agricultural-related lightning deaths outside of the US, Holle learned that

more than half of them occurred in India, followed by Bangladesh and the Philippines. The victims were young (early 20s for the men, early 30s for the women) and were working in farms and paddy fields.

Cooper was hit full-force with the emotional impact of what lightning can do in Africa when she attended a 2011 lightning conference in Nepal. The presenters were arranged in alphabetical order by country, so Cooper, by then retired as an emergency physician but still doing lightning-related work, was sat between the presenters from Uganda and Zambia. Richard Tushemereirwe, the Ugandan representative, kept fussing with his slides while waiting to present.

"When he got up to give his presentation, he was almost in tears," she recalls. "He said, 'I found out from my research that we had 75 people die in Uganda during the last lightning season.'" And just that summer, he related, 18 students had died in a single lightning strike to a school in central Uganda.

In an email, Tushemereirwe described how the lightning protection that some schools do install can create a false sense of security. A rod may be installed on the roofline of one school building. But it's not grounded. Even worse, local residents might believe that the single rod also protects nearby buildings, wrote Tushemereirwe, who serves as senior science adviser to Uganda's president.

Nor does home provide a sanctuary when lightning laces the sky, as housing in rural regions of Africa is frequently constructed from mud and grass. Thus, the mantra 'When thunder roars, go indoors' is essentially useless, Cooper notes with considerable frustration. Families are at risk 24/7.

Lightning deaths go unreported or are missed entirely. It might appear, for instance, that a fire killed an entire family. But that assumption

misses a key piece of the tragedy. Sometimes it's lightning that sets the grass roof ablaze, temporarily paralysing the family members within, so they're unable to escape the flames.

On a bus trip to a banquet after Tushemereirwe's presentation, he and Cooper fell into talking. It was a discussion that led to a collaboration and, in 2014, the creation of a non-profit organisation now called the African Centres for Lightning and Electromagnetics Network, with Cooper its founding director. Zambia was the second country to join after Uganda. Leaders of several others have expressed interest, Cooper says.

The organisation is trying to develop a cellphone alert system so that fishermen and others in the Lake Victoria region can report severe weather heading their way. They are starting to educate school teachers about lightning safety and are setting up graduate study programmes.

Another priority is Ugandan schools, frequently the most substantial structures in a given community. The first lightning protection system was installed in a school in late 2016, as were two more earlier this year. Keeping the focus on protecting children, it's been learned through other lightning safety efforts, gets adults' attention, Cooper says. Adults the world over believe they are immune, she states flatly. "But if you tell them that their kids are going to get injured, they pay attention."

Still, making headway has been an uphill climb, slowed by fundraising and installation logistics. Cooper sounded a bit weary and discouraged after her most recent trip to Uganda this spring. The country has thousands of vulnerable schools. She's now searching for deeper pockets through foundation or governmental funding. "We've protected three of them. Oh my god how will we ever be able to," she says, her voice trailing off. "It's so overwhelming, I just want to quit. I don't see how we are ever going to be able to impact this."

The rain that had threatened all afternoon didn't start to fall until Sara and Alejandro were driving to Maricopa Medical Center in Phoenix. Alejandro sat tense, holding on to his terrible knowledge. "All of this way, I was thinking, 'He's dead. How do I tell her?'"

When they arrived, Alejandro was stunned to learn that Jaime was in surgery. Surgery? There was still hope.

Jaime had arrived at the Phoenix trauma centre with an abnormal heart rhythm, bleeding in the brain, bruising to the lungs and damage to other organs, including his liver, according to Vail. Second- and third-degree burns covered nearly one-fifth of his body. Doctors put him into a chemically induced coma for nearly two weeks to allow his body to recover, a ventilator helping him breathe.

Jaime finally returned home after five months of treatment and rehabilitation, which is continuing. "The hardest part for me is that I can't walk," he says from the living room of his parents' house. The doctors have described some of Jaime's nerves as still "dormant", says his sister, Sara, something that they hope time and rehabilitation will mend.

"We're living through something that we never thought in a million years would happen," says Lucia, Jaime's mother, reflecting on the strike and Jaime's miraculous survival, Sara translating. They've stopped asking why lightning caught him in its crosshairs that April afternoon. "We're never going to be able to answer why," Sara says. So now it's time for Jaime to start thinking about "what's next" with the new life he's been given. The family is planning a party, with a mariachi band, to celebrate Jaime's first year of life moving forward.

When Sara and Alejandro returned home from the hospital the day after the strike, Alejandro called to his wife from the backyard. On the railing

of the round pen where they work the horses, adjacent to their corrals, a peacock was perched, his colourful feathers flowing behind.

Outside of a zoo they had never seen a peacock in Arizona before. They kept the peacock and later found it a mate. Now a family of peacocks fills one of the corral stalls. When Sara looked up what the striking bird symbolises, the answers scrolled back, catching her breath: renewal, resurrection, immortality.

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