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# Headbanger Nation

By Jeffrey Kluger

I didn't get a good look at the little boy who injured my daughter in the science museum in Mexico City. He seemed to be about 7, my daughter Elisa was not yet 3, and the two of them were part of a scrum of kids playing on an indoor patio. At precisely the wrong moment, she turned left, he turned right, and they collided. Physics being physics, the smaller mass yielded to the larger one, and my daughter fell down. She landed first on her bottom, then tipped backward and hit her head on the floor.

The sound was one that parents dread: the singular clunk of skull striking cement. I winced, Elisa wailed, and I gathered her up. Soon she stopped crying and went off to play, but even as she did, a dangerous process had begun to unfold inside her skull. (Read Dr. Mehmet Oz's column about concussions.)

When Elisa's head hit the floor, the deceleration was sudden, but — physics again — her brain stayed in motion for an instant, moving through the small intracranial space until it collided with the back of the inside of her skull. Concussive energy radiated through the tissue. As it did, channels in the neurons opened wide, allowing calcium ions to flow into the cells, depressing their ability to metabolize energy. Brain tissue began swelling, but with nowhere to go, it squeezed up against the skull wall. Shearing forces tore axons connecting the cells, damaging their myelin sheathing, which can disrupt nerve signals. All of that was the best-case scenario. The worst case was a brain bleed, which could be fatal without immediate surgery.

Within 20 minutes, Elisa grew withdrawn. An hour later, back in our hotel, she vomited and then began thrashing convulsively. We rushed her to a hospital, where doctors struggled to get a line into one of the tiny veins in her arm, shouting at her to stay awake.

"Open your eyes!" I shouted at her in English. "*Abre tus ojitos!*" my wife echoed. Elisa understood both languages; she answered in neither.

Finally, the doctors got her into a CT scanner, then administered an EEG. There was no bleeding, but there was swelling. Elisa spent three days in the hospital taking antiseizure and antiswelling medication and finally was released. On the flight home, she was a terror — but only in the way a toddler is supposed to be. (See a graphic on the physics behind concussions.)

For us, that was a first-time — and, we dearly hoped, last-time — experience, but we're hardly alone in having gone through it. In the U.S., concussions are an alarmingly commonplace injury, particularly among kids and most particularly among active, athletic ones. Up to 3.8 million Americans are getting concussed per year, according to the Centers for Disease Control and Prevention, and even that big a figure is a moving target. In 2005, the number of children who visited emergency rooms for treatment of concussions was more than twice what it had been in 1997, according to a new study in the journal *Pediatrics*. High school football players alone sustain 100,000 full-blown, diagnosed concussions per year. Flying under the radar are injuries mild enough to get passed off by coaches as a mere ding or ignored by players anxious to get back on the field.

According to a study by neuroscientist Kevin Guskiewicz of the University of North Carolina, the average college football player sustains a breathtaking 950 to 1,100 subconcussive blows per season — hits that are enough to do cumulative damage to young brain tissue but not enough to cause immediate symptoms. "There's what we call a dose response," Guskiewicz says. "After a certain number of hits, the damage starts to show."

But while football is responsible for more than half the concussions kids suffer playing team sports, there's a lot more blame to go around. The success of Title IX, which forbids gender discrimination in scholastic athletics, has led to a 900% increase in girls' sports teams since the law's passage in 1972. But guaranteeing girls equal access to sports also guarantees them equal access to injuries. Girls' soccer accounts for nearly 12% of total team-sports concussions, compared with just 6.6% for boys' soccer. Girls' basketball causes 7%. Even volleyball weighs in at 1.1%. (See a special report on women and health.)

What's more, a third of all concussions among kids are caused by nonteam activities such as ice skating, bicycling and playground recreation. Gaining fast too are newer head-cracking activities like snowboarding and extreme skateboarding. Kids may be the first group to fall in love with such sports, but they're the last group — neurologically speaking — that should engage in them.

"The immature brain is still developing," says Julian Bailes, a neurologist at West Virginia University and the medical director for the Pop Warner Youth Football program. "That makes it more susceptible to damage and more likely to suffer repetitive injury." How this shapes overall development is unknown. A child's brain is like a ship en route to somewhere: a concussion can blow it off course.

The severity of the damage — both acute and chronic — is what researchers are now trying to understand and what legislators and the sports-equipment industry are trying to control. Even as scientists look deeper into the physics, neurochemistry and genetics of brain injury, lawmakers are imposing new rules governing how kids should be assessed for concussions and when they should and should not be eligible to play. Equipment manufacturers, particularly those who make football helmets, are being pushed to redesign their product lines and reform the testing standards that essentially allow the industry to police itself. Pro teams too are feeling the heat for selling an elbow-throwing, stick-swinging, head-butting ethos that may be fine for millionaire athletes who know what they're getting into but is hurting, and in some cases killing, the kids who emulate them.

"I keep telling kids, Your brain is not your knee. It's not your shoulder. It's your future," says neuropsychologist Gerard Gioia, chief of pediatric neuropsychology at Children's National Medical Center in Washington. "We have to protect it better than we are." (See TIME's special report "How to Live 100 Years.")

**The Science of a Hit**

If it's football that receives most of the attention in conversations about concussions, it's partly because the hits inflicted in the game can be so shocking. In soccer, basketball or even hockey, violence is typically a by-product of aggressive play. In football, it is the play. Guskiewicz conducts his studies by placing accelerometers in players' helmets and recording not just how often they get hit but also how hard. The unit of measure he uses is g-force. Liftoff of a Saturn V moon rocket exposed its crew to a maximum of four g's. A roller coaster may exceed six g's. College football players, by contrast, collide with each other with an impact of nearly 23 g's — and that's the average. Higher-end blows range from 85 to 100 g's. "The highest we ever recorded was 180 g's," says Guskiewicz.

Worse, it's not necessary to be hit in the head for that kind of impact to do concussive damage. A player struck in the chest can suffer whiplash just like a passenger in a car accident, and when the head snaps back and forth, the brain sloshes around with it. "One sign," says Gioia, "is when a player complains of neck pain. That's often an indicator that the head has moved around hard."

Many of those blows don't necessarily lead to a concussion, and in a way, that's unfortunate. Only about 10% of concussions lead to loss of consciousness, but the other signs are hard to miss, including headache, vomiting, dizziness, balance problems, sensitivity to light or noise, confusion, irritability and amnesia. A player with any of those symptoms is likely to be sent to the bench — at least for a while. A player whose brain has been jolted at a subconcussive level is much likelier to stay on the field and return there week after week with no recuperation time. The damage that does can be deadly. (Read Dr. Mehmet Oz's column about concussions.)

In April 2010, University of Pennsylvania football star Owen Thomas committed suicide in his off-campus apartment, having never before exhibited any sign of mental illness. When researchers at Boston University examined his brain, they found it flecked with what are called tau proteins, telltale signs of a condition known as chronic traumatic encephalopathy (CTE), which is often seen among dementia patients and NFL players with a lifetime of concussions behind them. Thomas had never sustained a concussion, but that might not have mattered.

"He'd been playing since he was 9," says neuropsychologist Robert Stern, part of the team that conducted the analysis. "That suggests he had a great deal of exposure to repeated subconcussive blows."

The link between tau and brain damage is straightforward. The protein is one of the major structural materials of nerve tissues. When the brain is shaken too hard, nerve fibers are torn and the tau is released. The brain tries to clean up the mess, and given enough time, it could. If the hits keep coming, however, the proteins just accumulate. "I describe [the tau deposits] as a form of sludge," says Bailes.

It's not unusual for players like Thomas suffering from CTE to die in violent or otherwise dramatic ways. Bailes was part of a team that found tau protein in the brain of Chris Henry, a player for the Cincinnati Bengals who was killed in 2009 when he got into an argument with his fiancée and jumped on the back of her pickup truck as she drove away — taking a fatal tumble onto the road. In 2007 wrestler Chris Benoit murdered his wife and son and then hanged himself. In 2004 former Pittsburgh Steeler Justin Strzelczyk, who suffered from hallucinations, died when he drove his car into a tractor trailer while fleeing police. Both Benoit and Strzelczyk had CTE. "This disease starts young and progresses through life," says Stern.

Until recently, doctors didn't know just how young, but they're getting an idea. Michael (not his real name) is a ninth-grade football player visiting an outpatient concussion clinic Gioia runs in Rockville, Md. Michael got clobbered in a game in mid-September, suffered many of the immediate concussion symptoms and four months later is still not well. Recovery time varies for all patients, though three months is a good benchmark; four months suggests trouble. Michael's sleep remains disturbed, his temper remains erratic, and his school performance has cratered. An honor-roll student in eighth grade, he has gotten mostly D's and F's this year. "The change," says his mother, "it's shocking."

It's not possible to diagnose anything like CTE from just those symptoms, particularly because Michael's recent academic problems began before his concussion. But he already had a history of what he calls stingers, or head blows — none of which kept him off the field. What's more, his coach allowed him to return to play only a month or so after his recent concussion, a game in which he took another blow to the head, then lost his temper and got ejected.

Michael is hardly the only student athlete playing roulette with his brain, and his coach is hardly alone in abetting such recklessness. One study has shown that up to 40% of players who experience a concussion are back on the field before their brains have fully healed. That, Gioia says, is especially worrisome since sometimes two mild injuries can do more damage than one severe one. In some cases — mercifully rare — players who return to the field before they're fully recovered may even suffer what is known as malignant brain edema, or second-impact syndrome, in which another blow to the head leads to a fatal brain bleed. About half a dozen kids per year die from second impact. (Read Dr. Mehmet Oz's column about concussions.)

It's easy enough to make the case that any person who has suffered a brain injury needs a long period of recuperation before returning to vigorous physical activity. But what about vigorous intellectual activity? The brain is a cognitive machine, and it requires an enormous amount of energy to keep its gears moving. That's a fact concussed kids often confront when they resume their classwork after an injury and find that their symptoms return the moment they crack a book. "Cognitive exertion requires a high degree of metabolic activity," says Gioia. "If you have a brain that's already impaired, that ability is going to be reduced."

Mary, a high school junior and another patient at Gioia's clinic, has suffered three concussions over the past three years as a goalie for her soccer team. Surprisingly, it is not heading the ball that leads to most concussions in soccer — though the limited studies that have been done have looked only at young adults, and none have explored subconcussive injury. Rather, the damage is done mostly by collisions with other players or, as in Mary's case, with equipment. Her third concussion came last November, when she hit her head against the frame of the goal. She remains an honors student in the International Baccalaureate program in her high school, but the struggle to keep up that level of academic excellence has been grueling.

"I didn't have any exams until two months after the injury," she says. "But when I did, the headaches and fatigue came back immediately. I lost focus during one test and had no idea what I'd just written." She got through all the same and has gone back to school full time, but every day is a battle with pain, exhaustion and sensitivity to noise and light. She has also accepted that soccer — which was a passion — is just not an option anymore. "I can't afford another concussion," she says. (See a graphic on the physics behind concussions.)

**Digging Deep**

The fact that no two concussions follow the same recovery arc is one of the things that makes them so challenging to diagnose and treat. But that same particularity of injury also provides scientists insights into which people are at the greatest concussive risk.

Gender, for one thing, seems to play a role. Mary may be recovering faster from her injury than Michael is, but on the whole, females are both more susceptible to concussions than males are and suffer more-severe symptoms. So far, the reason for that gap is unclear. There is some thought that a girl's comparatively weaker neck muscles may leave her head more susceptible to violent shock. Hormones too may play a role. Among epileptic girls and women, rising and falling estrogen levels are known to make the brain more or less vulnerable to seizures. The thinking is that this may apply to concussion symptoms as well — though it's unclear whether a girl's hormonal makeup leaves her more concussion-prone throughout the month or just during menstruation. (See a special report on women and health.)

Genes may also be involved. The fact is, plenty of athletes make it through their careers battered and scarred but cerebrally intact, while others who may not get hit with any greater frequency suffer all manner of brain damage. Researchers at the Children's National Medical Center are studying the genomes of both concussed and nonconcussed kids, looking for markers that may explain the difference.

"There could be a genetic predisposition that affects metabolic activity," says geneticist Susan Knoblach. "People always assume that there's a genetic component in degenerative conditions but not acute ones, but of course there can be."

Maryland's Fairfax County has instituted a program in which student athletes spit into cups so their genetic profiles can be taken. The genomes of the ones who come down with concussions can then be compared for key similarities. Early attention is focusing on a gene that codes for a protein called ApoE, which has been implicated in Alzheimer's disease. In the long run, teasing out concussion genes could lead to better drugs or gene therapy to treat or prevent the injury. In the short run, it could help parents and coaches determine in advance which sports kids are best suited to play. Says Gioia: "We may actually find out, 'You know what? You're not set up to be a football player. You might be a better tennis player.'"

Newer brain-scanning technology is also making a difference, helping doctors diagnose concussions and track recovery. The microscopic size of tau proteins and nerve fibers makes them impossible to see without a postmortem exam, but three noninvasive techniques can help sidestep that problem. Magnetic resonance spectroscopy measures not direct damage to the brain but its metabolic activity — a good way to evaluate the very system that breaks down first when a brain is concussed. Diffusion tensor imaging can observe transmission along nerve-fiber tracks, providing a sense of the integrity of the neural wiring. And resting fMRI allows physicians to watch the brain when it's not performing a task, providing a look at basic function. (See TIME's special report "How to Live 100 Years.")

### Changing the Rules

Smart medicine, of course, can do only so much to reverse the number of concussions. Smart policy must do the rest. To keep kids from hurting themselves — and to prevent coaches from enabling them — 10 states, including New Jersey, Oregon, Virginia and football-mad Oklahoma, have passed return-to-play laws requiring kids who have sustained even a suspected concussion in any sport to be pulled from play and not returned until a doctor or certified athletic trainer declares them fit. A handful of other states are considering similar legislation, and last year two separate bills along the same lines were introduced in the House of Representatives. Both will have to be resubmitted under the new GOP majority. Still, the national trend is clear: "When in doubt, sit them out" is how the advocates put it.

Most major professional sports leagues in the U.S., as well as most large universities and 4,000 high schools, now also use a computer program known as ImPACT (for Immediate Post-Concussion Assessment and Cognitive Testing) that measures such basic skills as memory, word recognition and pattern recognition. Players are required to take a baseline test at the beginning of the season and are periodically retested, especially postconcussion, to determine if there's been any erosion of skills. "I used to sit across from athletes doing paper-and-pencil memory tests," says ImPACT developer Mark Lovell, a neuropsychologist at the University of Pittsburgh Medical Center. "That would never work with large groups of kids. There aren't that many neuropsychologists alive."

Reform is also coming — slowly — to the major manufacturers of football helmets, driven mostly by the NFL, which has imposed much stricter concussion and tackling rules in the past season. The NFL is anxious both to protect its players and to shake its image as a weekly tutorial for student athletes learning all the wrong safety lessons from pros who should know better. Currently, the group that certifies helmets is the National Operating Committee on Standards for Athletic Equipment (NOCSAE), which sounds reassuringly official except for the fact that it's essentially funded by the manufacturers themselves. NOCSAE has come under fire not only for this seeming conflict of interest but also for what critics consider unreliable testing. The larger problem, though, is that the standard football helmet was designed to prevent only lacerations and fractures — a job it does very well — and to do little or nothing to prevent concussions. "The science just isn't there today," says Dr. Robert Cantu, a neurosurgeon at Boston University and a member of NOCSAE's board. (See a graphic on the physics behind concussions.)

That's not NOCSAE's or the NFL's fault, but they're trying to do something about it. In December the league and the helmet manufacturers convened a sort of head-injury summit in New York — a gathering that also included officials from NASCAR and the military — to consider helmet modifications that could reduce the concussive carnage. For football, those modifications could include better padding, stronger chin straps and redesigned face masks that distribute shock differently. Kids' helmets must also be more than simply smaller versions of those used by adults. The padding inside all helmets is designed to compress at the forces generated by colliding adult bodies. With the smaller forces kids produce, the padding stays rigid, essentially becoming one more hard surface for the head to strike. Innovations introduced in football could ripple out to other sports' playing fields, to say nothing of battlefields.

Athletics will never be stripped of all danger, and terrible as the blown knee or wrecked elbow may be, there is always an assumption of those risks when you elect to play the game. But the brain is more than a joint or a limb. It's the seat of the self. We overlook that fact at our peril and — much worse — at our children's.

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