

The Collision of Concussion Prevention and Concussion Culture

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Joseph Chernach was the kind of kid that everyone has known and a son that any parent would be lucky to have (1). He was the archetypal high school standout—a living reminder that sometimes talent does not distribute evenly. He excelled at any sport he played: wrestling, pole vaulting, and especially football. Joseph started playing Pop Warner in the fifth grade and continued into high school where he was named team captain during his senior year. Though he was too small to play college football, he was deeply passionate about the game. In a different life, in a different body, he might have played professional football. Beyond the world of athletics, Joseph had a bright future; he was an honors student with a magnetic personality to compliment his motivation and work ethic. Looking to combine his academic ability with his love of sports, he enrolled in classes at Central Michigan University hoping to one day become a physical therapist. During college Joseph began to change, despite his outstanding academic record he gradually stopped going to class. Joseph's father recalls the sudden change in his son's personality, "He became angry, and paranoid, and totally unmotivated. He just couldn't function, and never wanted to leave his room." It was around this time, Joseph started to have frequent bouts of confusion and thoughts that strangers were talking about him. Soon after, he dropped out entirely and moved back home. He took a job as a school custodian and was fired within a week for not showing up. Joseph's mother knew her son was suffering and tried to intervene: "I went to counselors, and I told them, 'I'm scared my son is going to die, and I don't know what to do.'" On the evening of June 6th, Joseph went for a walk as he often did when he was feeling upset, but he did not return. Joseph's mom called every possible relative and friend to no avail. She was about to fill out a missing persons report when her husband came home. She recalls, "he went out to the shed to get something. He said that just before he was going to walk out the door of the shed, he saw something hanging inside. [...] [he] ran inside, saying that we needed to call 911, and trying to stop me from going out there. But I ran out to the shed. I guess I imagined him alive in there, bleeding or hurt. And there he was, hanging. I was so shocked that I couldn't even scream. I just held on to him until the first responders

got there. They had to pull me off.”

Joseph’s death left behind the profound grief of a bright life cut short. “He had a lot of [friends], and that showed at his funeral. The church was full. You could tell how well-liked he was,” his mother remembers. In the year after his death Joseph’s mom struggled to understand her son’s sudden change into a tortured recluse, “it made no sense: he had been a happy kid, with a lot of friends. How could this happen?” In the midst of the media coverage of several NFL player suicides, her other son, Tyler, suggested that the family send Joseph’s brain to the Sports Legacy Institute, a nonprofit whose mission is to “advance the study, treatment and prevention of the effects of brain trauma in athletes” (2). Joseph’s parents had heard of the link between football players and suicide, but those cases had occurred after a long career of unrelenting head impacts—far removed from Joseph’s few years of play at Forest Park High School. In September, doctors called with their diagnosis: the most severe CTE¹ they had ever seen in a 25-year-old². For Joseph’s mother, the diagnosis snapped the despair of their son’s last year into focus: “I don’t want to say it was a relief, but...it was an explanation. It finally made some sense.” What had doctors seen to so thoroughly convince them football was the cause of Joseph’s death? On first inspection Joseph’s brain looked like any other—a marvel of white, grey, and tan architecture. After performing histology, however, ugly brown deposits of tau protein were revealed like cigarette burns on a linen. In healthy neurons, tau proteins play a role in stabilizing microtubules—a structure that is both a skeleton and a highway for the world within the cell (5). In CTE for reasons that are still being investigated, the cell modifies tau protein in a way that causes it to stick to itself (6). Eventually the previously soluble tau protein, forms thick clumps called inclusion bodies which build up and slowly squeeze the life out of the cell. This aggregation of tau protein is shared between several different neurodegenerative diseases, known as Tauopathies, including Alzheimer’s disease, Pick’s disease, and frontotemporal dementia (7). In CTE the

1. Chronic Traumatic Encephalopathy (CTE) is a progressive degenerative disease of the brain found in athletes (and others) with a history of repetitive brain injury (3).

2. The earliest evidence of CTE ever reported was in an 18 year old multi-sport athlete (4). Further study is needed to determine the prevalence of CTE in young athletes.

tau protein has a characteristic pattern of deposition³ in areas of the brain that correlate with personality, higher-order thinking, memory, and emotions (3). The occurrence of CTE in football players was discovered by Dr. Bennet Omalu in 2002 after examining the brain of Mike Webster⁴, beloved center for the Pittsburgh Steelers for two decades (9). Though the Nigerian-born neuropathologist did not know Mike Webster's decorated career, his body told a story of years of abuse, "Mike looked older than his age. He looked beat up. He looked worn out. He looked drained. If I had not been told his age, I would say he looked like 70." Mike had numerous souvenirs from his career: fractures in the bones of his feet, many missing teeth, broken vertebrae, torn rotator cuff, separated shoulder, etc. When Dr. Omalu moved on to exam Mike Webster's brain, he expected the worst: "I had a mental picture of what his brain would look like [...] a shriveled, ugly-looking brain. But upon opening his skull, Mike's brain looked normal." Though the gross appearance of the brain suggested otherwise, Dr. Omalu's intuition pushed him to take a closer look under the microscope. His findings—degeneration uncharacteristic for a 50 year old man and accumulation of tau protein—shocked him and led him to diagnose Weber with CTE. Before this discovery, these changes had only previously been described in boxers as *Dementia pugilistica*. The common name for this disease, punch drunk, comes from the unusual or uncoordinated behavior of longtime fighters (10). Dr. Omalu published his findings in a landmark paper with some of the leading Alzheimer's disease experts, neuropathologists, and coroners in the country (11). Following the mounting evidence of a second case report on Terry Long, an offensive lineman for the Pittsburgh Steelers who committed suicide by drinking antifreeze at age 46, the NFL's doctors tried to discredit Omalu with conflagratory letters to the journal's editor. The damage, however, had already been done as more researchers including Dr. McKee, founder of the Boston University CTE Center, found evidence of CTE in nearly every NFL

3. This allows pathologists to distinguish CTE from other Tauopathies.

4. Although the Steelers originally said Webster's death was from a heart attack in a press conference this statement was later retracted (8). His cause of death has not been released at the request of his family, however given history of debilitating neurological and psychiatric illness, it is presumed he committed suicide.

player with neurocognitive changes. The 2013 book by Mark Fainaru-Wada, *League of Denial: The NFL, Concussions and the Battle for Truth* and the eponymous documentary produced by PBS Frontline, revealed the NFL's ongoing effort to suppress the link between football and CTE. This drama has entered public consciousness, national news outlets, and the lives of affected families like Joseph's parents. In the time after Joseph's death his mother was contacted by other parents, "they've told me that their sons died from suicide after playing football, just like Joseph. I think it's going to come to a head. I think more kids who played football will die [...] and parents will have their brains tested, and they'll see."

The current concussion crisis⁵ is not merely a product of media sensationalism or the growing health literacy of the new millennium(12). In its infancy, football garnered a savage reputation, and the public was well aware of both short term and long term head injury. The New York Times once famously reported that football carries "nearly the same risk that a soldier [assumes] on the battle field" (13). Harvard president, Charles Eliot, summarized the public's opinion on football's the safety and morality saying:

"Many serious injuries occur which are apparently recovered from in good measure, but which are likely to prove a handicap to the victim in later life." The main objection lies against its moral quality [...] The common justification offered for these hateful conditions is that football is a fight and that its strategy and ethics are those of war [where] the weaker man is considered the legitimate prey of the stronger" (14).

The early concussion crisis dissolved because leaders of the game reshaped America's perception of risk by reducing visible and acute injuries (12). The helmet was instrumental in this effort. In the 1950's Dr. Theodore Van Dellen, the medical columnist for the Chicago Tribune, questioned whether the game's popularity would have endured without the development of the helmet considering the gruesome injuries that characterized the era before protective equipment (15). The first helmet⁶ was invented by George Barclay in 1896 perhaps in

5. The term "concussion crisis" was most famously defined in *The Concussion Crisis* by Linda Carroll and David Rosner published in 2012. The term has been used by the media to describe the NFL's ongoing public relations struggle since the discovery of CTE.

6. It was called a "head harness" by its inventors.

response to rule changes that made tackling below the waist legal in 1888. Today's players would hardly recognize Barclay's leather cap as a helmet; it shares more in common with the equipment of water polo than modern football. The helmet made its next major change in 1917 when University of Illinois football coach Bob Zuppke changed the single layer design into two layers with padding in between them (16). Though players complained of its bulk and impedance, the comparative advantage of Zuppke's design was clear. Its use spread rapidly throughout college football and soon after both the NCAA and the NFL mandated the use of helmets (17). Despite these improvements, helmets were still woefully insufficient—more useful against cuts, scraps, and bruises than blunt force trauma. Following a series of serious head and neck injuries, the National Operating Committee on Standards for Athletic Equipment (NOCSAE) was established in 1969 to research, test, and authorize helmets used in many of America's contact sports. In 1971 with the development of harder and more durable plastics, the Riddell corporation added an air or fluid⁷ filled bladder to the previous dual layer design (19), hoping to prevent the highly publicized head injuries occurring at the time. Coincidentally, this engineering solution is similar to the system that protects our brain. Trapped between two layers of tissue covering of the brain, the arachnoid mater and the pia mater, the cerebrospinal fluid (CSF) softens any potential impact between the brain and the skull (21). Both the Riddell 1971 helmet and the CSF absorb the force generated by a collision and slowly release the kinetic energy as they return to their undeformed shape (22). Thus helmets reduce the total force the brain experiences though they increase the effective duration of the impact. These helmets were effective at preventing the potentially lethal injuries caused by a rapid linear acceleration, such as cerebral hematoma and skull or cervical fractures (23). Following this success, the Riddell company enjoyed a halo effect that enabled sweeping and often spurious claims regarding the helmet's effectiveness against other kinds of injury. In 2006 a study published

7. The Green Bay Packers filled the helmet bladder with antifreeze to combat the cold. A current practice called, 'hot hats' places helmets on heated posts. The maker of these products claim in their sales copy that warm helmets protect better against concussions than cold ones (20).

by the University of Pittsburgh Medical Center claimed that Riddell's newest Revolution model decreased the occurrence of concussion by 31% (24). This finding drove Riddell's helmet to be the most popular in the NFL despite the preponderance of evidence demonstrating no significant preventative effect of helmets against concussion (25). As the concussion crisis escalated, Riddell's claim and the University of Pittsburgh's research came under the scrutiny of law makers. In 2011 Senate Commerce Committee consulted several concussion experts including Jeffrey Kutcher, the then chair of the American Academy of Neurology's sports division. Their response was unanimous: there was an utter lack of evidence needed to support the claim that concussion could be prevented. The Federal Trade Commission later ruled in 2013 that Riddell would have to expunge all references to the 31% reduction in its marketing materials (26). In reality, helmets do little to affect the rotational acceleration thought to be the primary contributor to concussions (27). And while the NOCSAE may have had a noticeable effect on player safety at the time of its inception, today the organization is largely funded by the makers of football helmets. Although the NOCSAE drafts standards for helmet performance, it does not enforce these outdated and minimal standards in any way (18). Even with stricter enforced standards, Dr. Timothy Gay, a professor of physics at University of Nebraska and consultant for several helmet manufacturers describes the diminishing returns of helmet design, "I think that it's true that football helmets are 85% as good as they're ever going to get [...]. The optimal football helmet won't be much better than the helmet you can buy right now because there are [...] limits on what padding materials can do for a given thickness" (28). Today's athletes may not be familiar with the quadriplegia, brain bleeds, and skull fractures that almost destroyed the institution of American Football at the turn of the century, but instead are faced with a far more insidious threat. Lulled by a false sense of security, modern helmets seem to encourage risky behavior because of an increase in perceived safety (29). DeLamielleure who played football for Michigan State University and professionally with the Buffalo Bills and the Cleveland Browns, believes

that the vinyl-coated steel face mask⁸ is the most significant contributor to head injuries: “Without face masks or with single-bar masks (still used by some kickers), there would be more broken noses and lost teeth (and more unhappy wives and girlfriends), but far fewer serious head injuries” (30).

While football is, at its very core, a contact sport, there has been a steady escalation of dangerous practices since the 1970’s coinciding with the adoption of Riddell’s helmets. As one of the hardest structures⁹ of the body, the skull is useful in the collision between offensive and defensive linemen (31). With the head protected from the consequences of acute injury, tactics such as “head hits,” “the wedge,” “bump and run,” and “head slaps” became commonplace (30). The most iconic and notorious of these practices is the wedge. Originally developed at Harvard where the game was born, the wedge is a brutal application of the law of momentum. The average weight of a NFL player is 242 pounds, and when 6 of them lock arms and sprint, they become an unstoppable 900-pound net of human flesh. The wedge’s sole purpose is to block a single kick returner; though the tactic is effective, there is an undeniable excess of force. To counter the wedge, the returning team would often employ a wedge buster, a player who would use their head as a battering ram. The collision between the wedge and the wedge buster would often produce a groan-inducing spectacle that heightened the entertainment value of televised professional football(9). Matt Bowen who spent seven seasons in the NFL as a wedge buster for the Green Bay Packers notes this discrepancy, “You have a 50-yard head start and you run into your garage door – that’s what it feels like. [Wedge busting] looks cool on TV, guys dance around when they get up, but they’re dying inside” (32). When the NFL’s competition committee met to discuss possible rule changes, they invited current players to watch a video of collisions. Mike Pereira, the NFL’s head of officiating sat at the back of the room and watched his fellow players: “when you showed them collisions, you could feel them quiver.” In the midst of the concussion crisis, the NFL ceded to outside pressure

8. The face mask was added to the helmet during the 1970’s, a time of helmet innovation (19).

9. One ton of force is needed to compress the skull by a centimeter (31).

and banned the wedge and other dangerous techniques in 2009. Though the NFL prized the entertainment value of the wedge, the overwhelmingly apparent danger forced the decision. The wedge was an objectively dangerous play, causing a 30% increase in serious injuries including concussion. Even after the rule changes however, the wedge did not disappear from kickoffs; instead, it mutated to fit into the gray area of officiating. The New York Jets developed a version of the wedge where the formation was split in half and converged forming a wedge at the last moment. Mike Westhoff, former special teams coach for the Jets, criticized the NFL for the potential loophole, "If you're going to put this rule in, the intent of the rule is not to form a wedge. If at the point of impact, they're all four together, what the heck was the difference? This game is played at a thousand miles per hour.[...] You take one thing away, it just leads to something else." Reformers have pointed to the rule changes as a simple way of improving football's safety, however this view ignores the amount of the money, time, and expertise invested into developing and applying these tactics. Given a potential obstacle, teams may use alternative means to accomplish the same end as the wedge rule change demonstrates. These rule changes presented a significant opportunity for the NFL, shortly after the changes were announced, the NFL Players Association found that concussions occurring during kickoffs decreased 43 percent in the intervening years (33).

Although it seems counterintuitive, a major contributing factor for repeated concussions is often football players themselves, had players immediately spoken out about their concerns with the wedge formation the NFL would have been forced to consider this rule change years earlier. However, there is a strong incentive for athletes to continue playing even after they have sustained a head injury. Each additional concussion increases the severity of symptoms and the length of recovery in a nonadditive fashion (34). As of 2014 the NFL adopted a concussion protocol to standardize the assessment of players after injury and decide whether they can continue playing (35). The center of this protocol is a battery of neurocognitive tests to assess the severity of a head hit. To this end, players have found various ways of manipulating their baseline score raising the threshold for detecting

actual mTBI (36). Furthermore, traditional neurocognitive assessments are highly effort dependent leading to test inaccuracy because of player fatigue or willful failure (37). Even under controlled laboratory conditions, neurocognitive assessments were found to have a high rate of false positives when repeated multiple times (38). These significant flaws in neurocognitive assessment accuracy have not stopped entrepreneurs from capitalizing on the increased public awareness of concussion. ImPACT Applications Incorporated produces a suite of computerized tests¹⁰ that measure a broad range of psychometrics for the purpose of diagnosing concussion. The company's growth has been explosive—with many corporate partnerships from Dick's Sporting Goods to Wells Fargo and 7,000 organizations at all levels of play. While the ImPACT is hawked with the tagline—"Valid. Reliable. Safe."—a metaanalysis of literature using ImPACT in their methodology found a false positive and false negative rate of 30-40% comparable to traditional nonproprietary testing (39, 40). ImPACT's website cites "more than 215 peer reviewed and 145 independent studies to date" to prove that ImPACT's results are repeatable and evidence based. In reality, the body of literature verifying ImPACT as a meaningful clinical test is comprised mostly by studies written or funded by ImPACT founders (41, 42, 43). Dr. Lovell the co-developer of ImPACT and its former CEO defended the test in a statement to the NFL saying, "I need to emphasize this, and I have always said this: I don't think that ImPACT or any other test should be used in a vacuum. ImPACT shouldn't be looked at to say, 'He's good to go or he's not good to go.' We've never said that (40)." The evidence supporting ImPACT is tenuous, however its profit is very substantial: the company bills between \$10 to \$20 dollars for its tests and \$75 to certify coaching staff to administer them. These fees, multiplied over the 3 million ImPACT tests given at middle schools and high schools, represent an enormous cost burden. While college and professional organizations may have the funding and multidisciplinary expertise to support the ImPACT's role in the nuanced decision to return an athlete to action, many other communities lack the resources to use ImPACT. All things considered, the inherent

10. The company refers to tests collectively as the Immediate Post-Concussion Assessment and Cognitive Testing or ImPACT.

difficulties in finding reliable neurocognitive changes after concussion is testament to the complexity of the human brain and the variable way the brain responds to injury. Rather than parse the Gordian knot of total cognitive function, the field of concussion detection has turned toward our most primordial and developed sense—sight. Dr. William, director of the University of Rochester’s Center for Visual Science, says “more than 50 percent of the cortex, the surface of the brain, is devoted to processing visual information. Understanding how vision works may be a key to understanding how the brain as a whole works” (44). Recently, Dr. Steven Galetta and colleagues have found a short cut to identifying injured athletes: the King-Devick test (45). The test is so simple that it requires no medical expertise to administer; athletes are handed a card with an array of mixed up numbers and asked to read the numbers from left to right in descending lines. Galetta’s team chose to study the King-Devick test after reviewing its success in identifying concussions in boxing¹¹ and mixed martial arts fighters. Surprisingly the King-Devick test had never been validated in young athletes. Galetta and colleagues showed that the King-Devick test successfully identified 75% of concussed High School lacrosse players with only one false positive whereas the standardized assessment of concussion only correctly identified 2 of the 12 athletes (46). The test works so well because it requires the synchronized activity of several brain circuits from distant regions including the superior colliculus in the brainstem, the thalamus near the midline, and the occipital lobe at the back of the brain. The visual system is so finely tuned that it is sensitive to any major perturbation. The idea that the visual system can diagnose TBI is on the verge of changing clinical medicine as well (47). A team from NYU Langone Medical Center discovered that individuals with recent TBI have characteristic deficits in horizontal and, to some extent, vertical gaze conjugacy¹². This technology has the added benefit of detecting impairment in patients that are symptomatic but have a negative CT scan and appear normal on the standardize concussion assessment. While

11. It is interesting that boxing, the sport where CTE was first described, has now lent its method of CTE detection to football.

12. Gaze conjugacy is motion of both eyes in the same direction. There are four distinct neural circuits that control different kinds of eye movement.

more research is needed before the King-Devick and like tests supplant existing concussion assessment, its unrivaled ease and diagnostic value make it accessible to players of all ages and socioeconomic backgrounds.

I have known DP¹³ since the 3rd grade. We were both the new kids at Prairie Trace Elementary School in Carmel, Indiana: I had moved from Michigan and he had moved from Wisconsin. The first time I went over to his house, his dad was hunched over a plastic model of a torso filling it with plastic organs, vessels, and nerves. He saw my fascination and asked if I wanted to help. What started off as the building a plastic model quickly turned into a complete tour of the human body with an ER doctor as my tour guide. When I got home, I was impossible to calm down; I have wanted to be a doctor ever since.

I had known that DP had a concussion during Tae Kwon Do testing and another when he was away at college, but we never talked about it. Midway through my research, I called him just to see what he knew about head injury, and the story he told me was so much more severe than I expected; I had no idea.

His first concussion was halfway through high school while he was sparring with two larger men during his second degree blackbelt testing. Somehow he was caught between them and was punched repeatedly in the head. He kept sparing until he started to face the wrong direction and could not keep his hands in ready position; only then did his instructor pull him from the ring. Inexplicably, he managed to drive home without anyone stopping him. The next day at school he was so confused that his teacher sent him home. He had a headache for week before he recovered. His second concussion was during his freshman year of college. He was punched in the jaw during sparring. This time he momentarily lost consciousness and developed intermittent confusion in the week that followed. His third concussion was a year later during his college rugby game. He was on the ground after tackling, when a member of the other team purposefully stomped on his head. DP was too concussed to remember what happened during the rest of the game, but his friends told

13. My friend asked me to use his initials to protect his identity.

him that he took two other hard hits. The next day at home, his confusion was profound; it took an hour just to find a cup in the kitchen. At first he was not worried, this had happened twice before, but after three weeks of symptoms he knew something was different. This time he developed a crippling migraine every day, he would start crying for no apparent reason, and if he bent at the waist even slightly he would fall to the floor. He started to worry that he would feel this way for the rest of his life. After college he had wanted to go to medical school; he wondered if that was even possible now. He was evaluated with the standardized concussion assessment and many other neurocognitive tests, after scoring in the 95th percentile it was clear that these assessments failed to characterize the extent of his injury. Thankfully after a year of treatment his symptoms improved; by the time he entered medical school he was almost back to normal. The only lasting physical effect is that his pupils are much slower to respond to changes in light. While sitting in his Neurology class in his second year of medical school, he had the sinking realization that decisions he made at 16 may affect him the rest of his life. If an instructor or coach had intervened sooner in his line of injury, he wouldn't be facing an uncertain future. Had he gone against the unspoken athletic injury culture and confided in his parents after the first incident, the series of concussions could have been halted years earlier. Traumatic brain injury from contact sports is not a malady reserved for professional athletes, it is something that can affect any child who is involved in contact sports. The main methods of detecting and preventing concussions are not effective enough, and are often sought out only out of necessity, when the symptoms are too severe to ignore. More sensitive and accurate assessments of brain injury need to be employed to identify concussion immediately after impact. Furthermore, open dialogues about injury need to be present between coaches, parents, and athletes as soon as they start playing. Without a change in our athletic culture there is no chance of an end to the prevalence of tragic preventable brain injury seen in all ages.

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