Collective Force of Head Hits, Not Just the Number of Them, Increases Odds of C.T.E.

The largest study of chronic traumatic encephalopathy to date found that the cumulative force of head hits absorbed by players in their careers is the best predictor of future brain disease.

By Ken Belson and Benjamin Mueller
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When Jeffrey Vlk played running back in high school in the 1990s and then safety in college, he took and delivered countless tackles during full-contact football practices. Hitting was a mainstay, as were injuries, including concussions.

When he became a coach at Buffalo Grove High School outside Chicago in 2005, Vlk did what he had been taught: He had his players hit and tackle in practices to “toughen them up.”

By the time he became head coach in 2016, though, he saw that many of his players were so banged up from a week of hitting in practice that they missed games or were more susceptible to being injured in those games.

So, starting in 2019, Vlk eliminated full-contact practices. Players wore shoulder pads once a week, on Wednesday, which he called contact day. That’s when they hit tackle bags and crash pads, and wrapped up teammates but did not throw them to the ground. Vlk said no starting player had been injured at his practices in four years.

“Those types of injuries can stay with you for a long time,” he said, “and knowing that I’m keeping the kids safe, not just in our program, but beyond the program, is reason enough to go this route.”

Vlk's approach to limiting the number of hits players take has been spreading slowly in the football world, where much of the effort has focused on avoiding and treating concussions, which often have observable symptoms and are tracked by sports leagues.

But researchers have for years posited that the more hits to the head a player receives — even subconcussive ones, which are usually not tracked — the more likely he is to develop cognitive and neurological problems later in life.
A new study published on Tuesday in the scientific journal Nature Communications added a critical wrinkle: A football player's chances of developing chronic traumatic encephalopathy, or C.T.E., are related to the number of head impacts absorbed, but also to the cumulative impact of all those hits.

Estimated cumulative force of head hits for 631 former football players

Researchers in a new study estimated the cumulative force of head impacts absorbed by 631 former football players who donated their brains to studies overseen by researchers at Boston University. Those players who absorbed the most cumulative force from head hits had the worst forms of C.T.E.

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The study, the largest to look at the causes of C.T.E. to date, used data published in 34 studies that tracked the number and magnitude of head hits measured by football helmet sensors. Using the data, which went back 20 years, the scientists estimated the number and force of head hits absorbed by 631 former football players who donated their brains to studies overseen by researchers at Boston University.

Head Injuries and C.T.E. in Sports

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- **Q-Collar:** Many pro and college athletes are trying on this wearable device as they search for something that might keep their brains safe. But does it work?
- **One Man's Crusade:** Dr. Christopher Nowinski challenges sports leagues to acknowledge the link between concussions and C.T.E. by using a confrontational style he honed in the ring as a W.W.E. wrestler.

The paper tried to address one of the most persistent challenges for brain trauma researchers: identifying what aspects of head hits contribute most to C.T.E. They looked at the number of hits to the head, the number of years playing football, the force of those hits and other factors.

The best predictor of brain disease later in life, the study found, was the cumulative force of the head hits absorbed by the players over the course of their careers, not the number of diagnosed concussions.

"We're now getting a better understanding of what causes C.T.E. pathology, but we're also getting a better understanding of what's not causing C.T.E. pathology," said Dr. Daniel Daneshvar, an assistant professor at Harvard Medical School and the lead author of the study. "And in this case, it's the largest study of C.T.E. pathology ever, and concussions were basically noise."

Of the 631 brains examined, 451 players, or 71 percent, were found to have C.T.E., while 180 did not. The players who were estimated to have absorbed the greatest cumulative force had the worst forms of C.T.E., which has been associated with symptoms including memory loss, impulsive behavior, depression and suicidal thoughts.

Which high school players get hit most? Hardest?

This table shows the number of head hits and the average force of impacts experienced by high school football players, according to the results of the study. The researchers used tables like this to estimate a player's lifetime exposure to head hits based on the positions they played at each level.

Linemen, who collide on nearly every play, had the most hits per season.

Other positions had fewer hits, but each hit was harder on average.

POSITION	HITS PER SEASON	FORCE PER HIT	TOTAL FORCE PER SEASON
Defensive Line	782	25.8	**20,183**
Defensive Back	317	28.5	**9,023**
Linebacker	460	27.3	**12,563**
Offensive Line	734	25.8	**18,948**
Quarterback	320	26.8	**8,581**
Running Back	475	27.7	**13,160**
Tight End	517	27.1	**14,022**
Wide Receiver	302	28.8	**8,695**

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Eric Nauman, a biomedical engineering professor at the University of Cincinnati who was not involved in the study, said the results strengthened the idea that an accumulation of subconcussive hits, rather than concussions, was the driving force behind long-term cognitive decline.

The latest data "seems to support the idea that, yes, all these hits matter, they all add up," Dr. Nauman said. "If you accumulate damage faster than the body can repair it, now you've got a problem."

He said the analysis pointed the way toward obvious changes that could make football safer, like the elimination of hitting in practices and the development of helmets that absorb more impact, especially to the back of the head.

Dr. Nauman noted that the new study included brains of players with and without the disease, sparing it from the common concern that the researchers looked only at the most damaged brains.

It also found links between the estimated number and types of hits players sustained during their careers and their health many years later, a factor Dr. Nauman said would make it more difficult for detractors to argue that players had possibly suffered

unknown injuries in the decades after they stopped playing football that caused later cognitive problems.

Dr. Nauman said the new research was still bound by limitations. The study counted all of the head impacts detected by helmet sensors, except for those caused by jostling or incidental motion. But previous research has suggested that the most important hits appeared to be those above a certain threshold, a distinction the study was not able to make.

More G-force than a fighter pilot, but less than a car crash

The study used G-force as a measure of the linear acceleration experienced during a head hit. This table compares the intensity of a football hit and other kinds of impact.

G-FORCE	EQUIVALENT
10 g	A fighter pilot during a roll
27	An average high school football head hit
30	A car crash at 30 miles per hour
50	A boxer's punch to the head
80	An average concussion

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Because the N.F.L. has not published its helmet sensor data, the study used college sensor data as a proxy for professional players.

Helmets have improved in recent years, and it is likely that players whose careers predate the improvements absorbed more of the impact from any given hit. But football players in decades past were on average smaller and slower than those playing today, making any given hit less forceful, Dr. Nauman said.

"That certainly is a caveat, but it's not something that would make me think the basic conclusions are wrong," he said.

Joseph J. Crisco, a professor at Brown University who helped devise a sensor used in Riddell helmets, said the study tried to overcome a basic challenge — that researchers had not tracked how many hits the brain donors had accumulated during their careers.

Rather, the study used helmet sensor data from a more recent set of players to estimate the number and force of head impacts for the older players, based on what positions they played, at what levels of the sport and for how long.

While studies using players' actual lifetime head impacts were needed, he said, the findings suggest that "the players that are getting hit the hardest and most often are more likely to have C.T.E. down the road."

Steve Rowson, who studies helmet impacts and concussion risk at Virginia Tech, said the study's emphasis on the force and number of hits that players sustain fits with how scientists understand brain injuries.

The odds of developing C.T.E. increase exponentially with more force to the head

This table shows the increased risk of developing C.T.E. for each additional year played compared with someone who played only two years of youth football. Players who absorb more head hits, like linemen who play for many years, are at higher risk for the disease.

	INCREASED RISK OF C.T.E. COMPARED TO ONLY PLAYING YOUTH FOOTBALL		
ADDITIONAL SEASONS OF PLAY	QUARTERBACK	RUNNING BACK	DEFENSIVE LINEMAN
HIGH SCHOOL			
1	1.2 ×	1.3 ×	1.4 ×
2	1.4 ×	1.6 ×	2.1 ×
3	1.6 ×	2.1 ×	3.0 ×
4	1.9 ×	2.6 ×	4.4 ×
COLLEGE			
5	2.0 ×	3.3 ×	6.0 ×
6	2.2 ×	4.2 ×	8.3 ×
7	2.4 ×	5.4 ×	11 ×
8	2.6 ×	6.8 ×	16 ×
PROFESSIONAL			
9	2.8 ×	8.7 ×	22 ×
10	3.0 ×	11 ×	30 ×
11	3.3 ×	14 ×	41 ×
12	3.6 ×	18 ×	57 ×
13	3.8 ×	23 ×	79 ×
14	4.2 ×	29 ×	109 ×

Note: The study used college sensor data to estimate the risk for professional players.

“Every time you hit your head, your brain undergoes some loading, and there’s going to be a pressure response and a brain strain response — a stretching of the brain tissue,” he said. “And if you exceed some threshold, you would expect some injury response, and the severity of that injury response is going to be dependent on the acceleration values.”

Researchers have managed to pinpoint some factors that explain different players’ exposure to head impacts, he said. For example, he said, linemen are most often hit on the fronts of their helmets, while quarterbacks are more likely to suffer severe impacts to the backs of theirs.

But, Dr. Rowson said, it would be a mistake for people to think that they could now use the findings to predict anyone’s chances of long-term cognitive problems.

“What I don’t think we can do right now is look at an individual and really get a good idea of their head impact exposure relative to another,” he said, “because there’s this huge difference person to person that we can’t quite account for.”

The study notes that future research should examine different thresholds for counting hits, an advancement that Dr. Rowson said was important. Some head impacts, he said, are mild enough that the brain can probably tolerate them. But at exactly what point the impacts become damaging is not clear, he said.

“Not all impacts are created equal,” he said. “Trying to figure out which impacts are the most important, I think, could really help this kind of analysis.”

Ken Belson covers the N.F.L. He joined the Sports section in 2009 after stints in Metroand Business. From 2001 to 2004, he wrote about Japan in the Tokyo bureau. @el_belson

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