FROM HARD HATS
The History & Future of He

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HISTORICAL INDUSTRIAL USE of helmets can be traced to Polish salt mines in the early 1500s. Workers needed protection from salt blocks tumbling down from above their heads (Hanik, 1988). In addition, Cornish tin and copper miners wore hats made of leather or felt hardened with resin to protect the worker's head (Simpson, 1996). These early helmets also helped create today's standards for head protection.

E.D. Bullard Co. received a trademark for the hard-boiled hat in 1926; the company applied for a patent for a hat crown in 1927 that was granted in early 1929. Bullard's application noted that this hat crown consisted of steamed canvas, a leather brim, glue and black paint (Bullard, 1929). The invention was inspired by the helmets soldiers wore into battle during World War I. Widespread use of the hard hat began in 1931 with the construction of the Hoover Dam (Snell, 2018).

The first use of chin straps to secure the helmet from falling off the wearer's head was cited by Simpson (1996): "In battle, Homer's aristocratic tribal leaders wore bronze helmets, plumed with horsehair and secured with a leather chin strap." Helmets then became the standard for Roman soldiers around 400 BC, usually made from iron plates.

As the use of this PPE gained popularity through the early 1900s, manufacturers and companies began mandating hard hats to keep workers safe. Construction of the Golden Gate Bridge in San Francisco, CA, was the first big project in the U.S. that mandated hard hat use. The chief engineer, Joseph Strauss, required the Bullard hard hat to be worn when working (Snell Foundation, 2018). Use of the term "hard hat" to describe head protection may stem from Bullard's 1929 patent for the hard-boiled hat.

Since that first patent in 1929, the hard hat has advanced from its hard-boiled design. Steel was the primary material first used, as it was more protective than canvas. Afterwards, fiberglass and thermoplastics were implemented to provide more comfort for the worker without foregoing durability. The hard hat shell is usually made from a high-density polyethylene or a polycarbonate resin. Figure 1 shows an example of the modern hard hat design with a diagram of the common components. ANSI/ISEA Z89.1-2014 (R2019), Industrial Head Protection, which was first published in 1969 and most recently revised in 2019, specifies the criteria for an acceptable hard hat as well as what hat should be worn for each task (Table 1). This standard stems from ANSI Z2.1-1959, Head, Eye and Respiratory Protection, the first ANSI standard that specifically used the term "helmet" to describe head protection.

KEY TAKEAWAYS

- **Some 25,684 worker fatalities occurred in the U.S. construction industry from 2017 to 2021 with an estimated 16% (4,109) of those fatalities occurring because of a fall to the same level or a lower level and 4% (1,079) occurring from injuries to the head.**
- **Hard hats may not adequately protect from side or lateral impacts and may be provided and used incorrectly without a chin strap. Participation in professional or recreational sports may result in sustaining head injuries such as traumatic brain injuries or fatalities.**
- **Military helmets have been used for more than 4,500 years; they have been the design source for patented head protection at least since the 1920s. Safety helmets have been designed with increased head protection as well as a chin strap to protect the head from lateral and vertical impacts and to secure the helmet to the head in case of a fall.**
- **Advancements especially for military, cyclist, auto racing and football helmets in recent years show improvements in head protection that could be applied to hard hats and helmets. Inspection, maintenance and user instruction are critical components of head protection gear.**

The Transition From Hard Hats to Safety Helmets

In late 2023, OSHA announced a switch from the traditional hard hat to the safety helmet for the agency's employees, stating that the hard hat can "fall off a worker's head if they slip or trip, leaving them unprotected," while the safety helmet will stay secure on the user's head with the help of a chin strap and provide improved protection from side impacts (ASSP, 2023; OSHA, 2023). OSHA also states that safety helmets have improved impact resistance and comfort for the user as well as reduced neck strain and overall weight. Safety helmets can be accessorized to mitigate certain safety risks in the workplace such as with face shields or goggles to protect against projectiles and chemical splashes, headlamps for better visibility and earmuffs to better protect the user's hearing on a construction site (OSHA, 2023). Welding shields from multiple manufacturers can be added to the front or back of hard hats and safety helmets, depending on the model of welding shield and head protection. OSHA requires safety helmets to be compliant with ANSI/ISEA Z89.1. Welding shields are required by OSHA to be compliant with ANSI Z87.1-2020, Occupational and Educational Personal Eye and Face Protection Devices.

Despite the improvements in head protection, some workers may be reluctant to begin wearing a safety helmet, citing reasons such as the added weight making work uncomfortable, the lack of ventilation making workers hot, and the helmet itself making the work harder to see (Nazri et al., 2020). Researchers have been working on strategies to make this transition easier. One method involves employees in the safety helmet selection process, allowing them to feel the weight and fit of the gear before bulk purchases are made. Reinforcing the idea that wearing these helmets will keep the employees safe has been noted to improve PPE usage. Helmet safety may also be

TO HELMETS
ead Protection

improved by identifying employees who always wear protective gear or by rewarding consistent compliance. Warning employees when they are seen not wearing PPE and reprimanding unsafe behavior may also improve safety helmet usage. Another strategy involves using daily toolbox meetings and audiovisuals to demonstrate proper helmet fitting and advise employees of the effects of not using proper PPE (Adade-Boateng et al., 2021). Presenting statistics of head injuries in construction and other areas may help employees understand the severity of not wearing proper head protection.

U.S. Bureau of Labor Statistics (BLS) data show that as of May 2022, more than 6 million U.S. individuals have jobs within the construction industry that mandate head protection. Table 2 (p. 36) shows the 2020 calendar year distribution of employees, head injuries, and head injury rates within the 10 largest construction and extraction (removal of natural resources from the land and sea) occupations in the U.S. obtained from BLS data. The term "construction and extraction occupations" is used by BLS (2023a) to define workers who "use a variety of resources to build and repair roads, homes, and other structures." Construction occupations (e.g., carpentry, concrete finishing, ironworking, pipefitting) require workers to perform physical labor on construction sites while extraction workers (e.g., earth drillers, mining machine operators, oil and gas roustabouts) operate and maintain equipment used to extract natural resources from the earth. Injury rates are calculated per 10,000 full-time workers. Injuries and injury rates specific to only extraction work were not sufficiently high to be in the top 10 construction and extraction occupations.

Injuries sustained from falls are considered the leading cause of death in construction. According to Konda et al. (2016),

> A 2016 study in the *American Journal of Industrial Medicine* revealed that from 2003 to 2010, 2,210 fatal [traumatic brain injuries] occurred, comprising 25% of construction fatalities. [BLS] reported more than 5,000 construction fatalities between 2015 and 2019 from falls.

Furthermore, BLS (2023c) data from 2011 to 2021 show that:

- Approximately 38.7% of fatal falls to lower levels resulted in intracranial injuries, with 39% of the falls affecting the head.
- 52.5% of the fatal falls to a lower level occurred due to falls from structures and surfaces, with construction and extraction occupations accounting for 51.4% of those falls.
- Construction and extraction occupations account for 51.4% of fatal falls from 19.2% of nonfatal falls to a lower level.

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Traumatic Brain Injuries

The enforcement of head protection under occupational standards has saved many lives, but numerous falls and injuries still occur annually. Traumatic brain injury (TBI) is a disruption of normal brain functions, usually caused by a bump, blow, jolt or penetrating injury to the head. Most of these injuries occur in automobile incidents, but a significant number are caused by recreational sports and construction worker falls (Peterson et al., 2022). Construction is the leading industry for serious work-related TBIs (Pan et al., 2021) and these injuries can be debilitating for workers. According to Bottlang et al. (2022),

FIGURE 1
HARD HAT ILLUSTRATION

Illustration of a hard hat with diagram of its components.

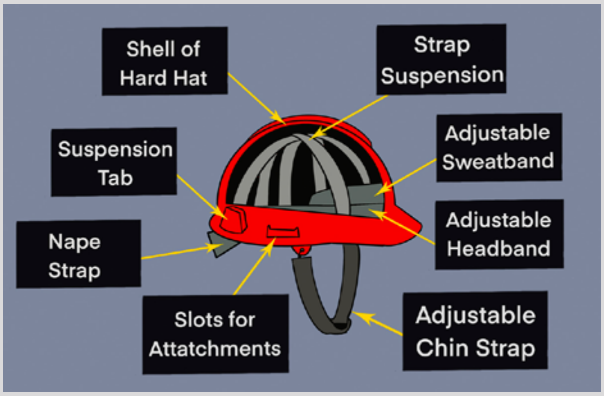

TABLE 1
HELMET CLASSIFICATION

Helmet type	Type I	Reduces force of impact from a blow only to the top of the head
	Type II	Reduces force of impact from a blow to the top or sides of the head
Helmet class	Class C	Conductive, does not offer protection from electrical hazards
	Class E	Electrical, contact with higher voltage conductors (rated for 20,000 V)
	Class G	General, contact with low voltage conductors (rated for 2,200 V)
Designations	HV	High visibility
	HT	High temperatures: 140 °F (60 °C)
	LT	Low temperatures: 22 °F (-30 °C)
	Looping arrows	Reverse donning

Note. ANSI/ISEA Z89.1-2014 (R2019), Industrial Head Protection, 2019.

"[TBI] is among the most serious and disruptive occupational injuries, as those surviving TBI can face long-term cognitive, psychological and emotional impairments."

The three different types of TBIs are mild TBIs, which can be classified as a concussion, mild repetitive TBIs and severe TBIs. Physicians and other healthcare providers use several methods to classify TBIs such as the Glasgow Coma Scale, the Rancho Levels of Cognitive Functioning, post-traumatic amnesia duration and neuroimaging of the brain (University of Alabama at Birmingham, 2023). The Glasgow Coma Scale was published in 1974 and came to widespread use in the 1980s (Matis & Birbilis, 2008). This method is often used first to assess the degree of brain injury, while the Rancho Levels of Cognitive Functioning Scale is used to determine how the patient is recovering. The Glasgow scale assesses three categories of response: eye-opening response, verbal response and motor response. The level of response is scored from 1 to 4 for eye-opening response, 1 to 5 for verbal response, and 1 to 6 for motor response, with 1 representing no response on all sections and the highest in each section being a significant response (Jain & Inverson, 2023). This scale can help to rapidly detect complications a patient might have after a head injury by using patient responses during preliminary treatment and recovery (Matis & Birbilis, 2008). The Rancho Levels of Cognitive Functioning, formally known as the Ranchos Los Amigos Revised Scale (RLAS-R), was developed in 1972. As a patient continues to recover from a TBI, the individual's progress is described on 10 levels, ranging from level 1, no response: total assistance (no response to external stimuli), to level 10, purposeful, appropriate: modified independent (independently solves tasks, makes decisions, interacts with others). With this scale, healthcare professionals can continuously adjust a patient's treatment according to their progress (Lin & Wroten, 2022).

Repetitive and mild TBIs can cause conditions such as dementia and chronic traumatic encephalopathy, while severe TBIs can cause more serious conditions such as Alzheimer's disease and other neurological impairment (DeKosky et al., 2010). TBI symptoms are different depending on whether the brain injury is mild or severe. Mild TBIs can cause headaches, blurred vision, ringing of the ears, trouble with memory or concentration, and nausea. Severe brain injury symptoms include slurred speech, seizures, loss of vision in one or both eyes, increased confusion, loss of consciousness, and a headache that will not abate (NICHHD, 2020).

Enforcing helmets with chin straps and shock absorption padding can better protect workers from such traumatic injuries due to the helmet's external and internal shell. According to Ivancevic (2008):

> If a human head covered with a solid helmet collides with a massive external body, the skull will be protected by the helmet—but the brain will still be shocked by the [external Euclidean jolt, an impulsive loading that strikes the head in several coupled degrees-of-freedom simultaneously], and a TBI will be caused. As a result, a proper helmet would have to have both a hard external shell (to protect the skull) and a soft internal part (that will dissipate the energy from the collision jolt by its own destruction).

Finding a proper helmet may differ based on an individual's job requirements. Industrial consensus standards exist to make this process easier.

TABLE 2

FATAL/NONFATAL HEAD INJURIES & RATES

Fatal/nonfatal head injuries and injury rates for the 10 largest construction and extraction occupations in the U.S., 2020.

Occupation	Employment	Fatal injuries	Fatal injury rate	Nonfatal injuries	Nonfatal injury rate
Construction laborers	971,330	308	1.81	16,590	207.1
Carpenters	699,300	79	0.78	11,960	202.7
Electricians	656,510	70	0.80	7,270	128.2
Frontline supervisors of construction trades and extraction workers	614,080	88	1.17	5,090	93.50
Plumbers, pipefitters and steamfitters	417,440	25	0.52	6,520	187.9
Operating engineers and other construction equipment operators	402,870	56	1.72	2,450	85.90
Painters, construction and maintenance	217,880	53	1.16	1,600	89.90
Cement masons and concrete finishers	195,580	7	1.30	950	57
Highway maintenance workers	149,890	15	1.60	90	118.6
Roofers	128,680	88	4.70	1,960	185.6
Total	**4,453,560**	**789**	**---**	**54,480**	**---**

Industrial & Construction Head Protection Standards

Industrial consensus standards are "consistent protocols, methodology, technical specifications, or terminology for a product or process" (Standards Coordinating Body, n.d.). These differ from regulations as they are not legal requirements issued by a government authority unless adopted by a local government. Many industrial consensus standards pertaining to head protection have been established to properly provide safe working conditions on a jobsite and to reduce the number of worker's head injuries. Standards specific to helmets outline requirements for performance, construction, marking/labeling, education and training for use, fitting and maintenance. A list of these standards is provided in the "Helmet-Specific Standards" sidebar (p. 38).

While the U.S. has no regulations or standards in place requiring the use of chin straps unless in certain conditions, countries such as Taiwan updated its standards to include chin straps in 2004. According to Fung et al. (2014), "In Taiwan, it is a statutory requirement to wear chin straps on construction sites. If workers do not wear chin straps, the work can be suspended." Fung et al. also state that Japan added chin straps as a requirement to its industrial standard:

> The Ministry of Land, Infrastructure, Transport and Tourism issued a guideline on safety management which mentioned chin straps as basic requirements of safety helmets to be worn on construction sites as it functions to prevent helmets from dropping (falling) off.

The Taiwanese requirement for chin straps on construction sites occurred just 1 year after combat helmets with chin straps were developed in 2003 for the U.S. military. Chin straps are now an essential feature in head protection for cyclists.

Enforcing helmets with chin straps and shock absorption padding can better protect workers from such traumatic injuries due to the helmet's external and internal shell.

Bicycle Couriers & Bicycle Helmet Standards

Bicycle couriers and express delivery services are two occupations that need the use of head protection when working. These workers delivered telegrams in the late 19th and early 20th centuries in the U.S. The number of workers has declined since then. According to Daddio (2020), "In 1999, there were 120,000 couriers and messengers in the country, compared to just under 75,000 in 2019." However, this trend may be reversing due to the rise of online shopping and demand for same-day food delivery services:

> Food-delivery apps employ tens of thousands of cyclists across the country, many of whom deliver for multiple apps to make a living. Some 50,000 cyclists work for food-delivery apps in [New York City], according to a 2012 estimate by the New York Department of Transportation. (Daddio, 2020)

Growing demand for these workers also means that they are exposed to more risks on the job. According to Daddio (2020), "A 2002 study on Boston's bicycle messengers found an annual incidence rate for injuries to be 47 out of 100 couriers." Data from BLS shows that the U.S. national average incidence rate for all full-time workers in 2002 was 5.0, which is approximately 162% below the rate at which couriers experienced recordable injuries.

Conducted over a 1-year period, a case-control study in Seattle concluded that bicycle helmets reduced the risk of head injury by 85% and reduced brain injury by 88% (Cripton et al., 2014). A larger case study conducted 7 years later found that bicycle helmets decreased head injury, brain injury and severe brain injury by 69%, 65% and 74%, respectively. Some anti-helmet groups critical of these statistics argue that helmets cause rotational injuries such as diffuse axonal injury, which occurs when the brain shifts and rotates inside the skull (Cripton et al., 2014). However, a multitude of studies show that helmet use is an effective measure to reduce head injuries from cycling (Olivier & Radun, 2017).

Increased popularity of biking, and subsequent increased biking injuries, among children and adults led to the development of safety regulations aimed at curbing many avoidable biking incidents that occur in part due to the lack of proper PPE. In the 1990s, many Australian territories declared a mandate requiring individuals of all ages to wear helmets when biking. This led to Australia creating its own nationwide mandate requiring all individuals to wear helmets when biking unless they are on a foot or cycle path and over the age of 17 (Esmaeilikia et al., 2018). Many other countries have also enacted helmet legislation. A review of international bicycle helmet laws mandating protection for individuals of all ages shows that fines for not wearing a helmet range from zero in countries such as Argentina, Finland and South Africa up to $330 in some Australian territories. In addition, 16 countries and territories have helmet restrictions for individuals ages 18 and younger, while 16 countries and territories have helmet restrictions in place for children aged 18 and younger. Finally, 273 laws have been enacted around the world about helmet mandates, with only two of those mandates being repealed (Esmaeilikia et al., 2018).

The U.S. was not included in this source's table as the country does not have a nationwide mandate, but 22 of the 50 states have their own statewide regulation and the ones without a statewide rule often have many cities that create their own regulations (Esmaeilikia et al., 2018). These regulations were created in the 1990s and early 2000s. The fine for not wearing a helmet in the U.S. can range from $2 to $100, and the ages required to follow this regulation are usually 15 and younger. North Carolina has the strictest of these regulations, requiring anyone age 17 and younger to wear a helmet when cycling. The North Carolina fine for not wearing a helmet is 2 hours of community service in an area related to a child injury prevention program. In many states, the fine for not wearing a helmet can be waived if a cyclist can provide proof of purchase for a cycling helmet (Esmaeilikia et al., 2018). Construction workers may not be subject to individual fines if they are working without a helmet, but OSHA may issue citations to employers who are found liable for not ensuring that their workers wear head protections.

Recreational Sports & Head Injury Risk

Cycling has been estimated to be the main cause for head injuries that required emergency room treatment, but many other recreational activities have their own risk of head injury to participants without the proper head protection (Agarwal et al., 2019). Table 3 shows the 10 sports or recreational activities resulting in the most head injuries in 2018 based on U.S. Consumer Product Safety Commission data for head injuries treated at U.S. hospital emergency rooms that year. These sports and recreational activities are also common among children who may need more head protection to protect them from TBI or chronic traumatic encephalopathy (Agarwal et al., 2019).

American football and auto racing have contributed significantly to athletes sustaining head injuries and blunt force head trauma. As football and auto racing have grown in popularity, safety standards for head protection in these activities have also been improved. These developments did little to prevent players continuing to experience brain injuries from these activities, leading to the founding of the National Operating Committee on Standards for Athletic Equipment (NOCSAE) in 1970. In 1973, this group established the first safety standards for helmets with impact tests, which involved dropping a helmeted head form onto an elastomer-padded anvil. The head form had a three-axis linear accelerometer to measure impact acceleration and deceleration (Bartsch et al., 2012). In addition to NOCSAE,

HELMET-SPECIFIC STANDARDS

Standards specific to helmets outline requirements for performance, construction, marking/labeling, education and training for use, fitting and maintenance. A list of these standards is provided here, by country or region of authority.

U.S.
•ANSI Z89.1-2014 (R2019), Industrial Head Protection
•29 CFR 1910.135, Head Protection
•29 CFR 1926.100, Head Protection

Canada
•CSA Z94.1-15 (R2020), Industrial Protective Headwear

Britain, Germany, Europe
•BS DIN EN 397 (2012), Industrial Safety Helmets

Europe
•EN 14052 (2012), High Performance Industrial Helmets
•EN 50365 (2003), Electrically Insulating Helmets

Australia, New Zealand
•AS/NZS 1801 (1997), Occupational Protective Helmets

China
•GB 2811 (2019), Safety Helmet

Russia
•GOST (1983), 12.4.128 Safety Helmets

International
•ISO 3873:1977, Industrial Safety Helmets

several standards organizations specify impact test criteria for different kinds of helmets used in recreational activities and athletics. These include:

•ASTM International
•British Standards Institution
•CSA Group
•U.S. Consumer Product Safety Commission (CPSC)
•European Committee for Standardization
•U.S. Department of Transportation
•Fédération Internationale de l'Automobile (FIA)
•International Organization for Standardization (ISO)
•Snell Foundation
•UN Economic Commission for Europe (UNECE)

The performance requirements that these standards test for include (with the last three not applying to some athletic helmets):

•force transmission,
•helmet stability,
•impact attenuation,
•penetration resistance,
•shock absorption,
•electrical insulation/resistance,
•flame resistance, and
•retention system (chin strap) strength.

After the NOCSAE standards took effect, head injuries associated with football decreased substantially in the U.S. According to Bailey et al. (2021), "By 1979, fatal head injuries in junior and high school football were down 51%; skull fractures were down 65%; and concussions were down 35%." The NOCSAE introduced standards in the 1980s to further decrease incidents of head injuries and brain trauma by adding padding and switching the materials of the helmet to a hard polycarbonate outer shell with an energy-absorbing interior padding, faceguard, and chin strap to keep the helmet on and in place (Bailey et al., 2021).

The U.S. military has had influence on occupational head protection, including the first helmets used for stock car racing in the late 1940s. Repurposed military helmets were used, then later upgraded to motorcycle-style helmets in the 1960s (Firestone, 2013). These helmets first had an open-face design, but significant safety improvements were made by the National Association for Stock Car Auto Racing (NASCAR) in 2001 after the death of race car driver Dale Earnhardt. Earnhardt was on the final lap of the 2001 Daytona 500 race when he crashed into a retaining wall, resulting in a basilar skull fracture (fracture involving at least one of the bones that compose the base of the skull). His death led to a push for greater safety by NASCAR, especially to ensure top-of-the-line head protection for its drivers (McKinley & Hill, 2012; Simon & Newton, 2023). The helmet Earnhardt wore during the crash was a Simpson Model Open-Face with a chin strap at the bottom of the helmet to secure it to his head (Figure 2, p. 40). He was not the only person that season to die from a basilar skull fracture. According to McKinley and Hill (2012):

> In the nine months prior to Earnhardt's death, three NASCAR drivers—Adam Petty, Kenny Irwin Jr. and Tony Roper—died of the same injury (as Earnhardt) from the same cause: basilar skull fracture, resulting in part from violent movements of their unrestrained heads during crashes.

Earnhardt's crash led to NASCAR mandating closed-face helmets as well as the requirement that the head and neck support (HANS) system be used by drivers (Figure 2, p. 40). According to McKinley and Hill (2012):

> The HANS device is a semi-hard collar made of carbon fiber and Kevlar, which is fastened to the upper body by a harness worn by the driver. Two flexible tethers on the collar are attached to the helmet to prevent the head from snapping forward or to the side during a wreck.

This device ensures that all parts of the body are secure, keeping the head and neck safe from any excessive movement that can occur during a crash. The HANS device was implemented in the early 2000s. As Fair (2021) describes, "the 2010s decade was the first decade not to feature any fatalities in any form of NASCAR racing." Enforcing PPE usage is an important way for employees across several industries to remain protected from hazards.

Head Protection in Construction

In a 2022 construction incident, a worker fell 6 ft then slid and landed headfirst in a silo at a ready-mix concrete plant. The worker was performing maintenance on a bearing while on a conveyor belt. He was fatally injured sustaining an occipital condyle fracture, a type of head and neck injury involving the area where the skull meets the spine (Watts & Moore, 2022), and subsequent brain bleeds starting from the base of the skull. He was not wearing head protection at the time of the incident (*Everett v. Shelby Concrete Inc.*, 2022).

A construction incident in 2019 occurred when a worker was installing bar grating on a steel structure at a warehouse distribution construction site. He fell approximately 18.5 ft to a concrete slab below. He was wearing a hard hat that was not equipped with a chin strap, and the PPE fell from his head during the fall. He landed on the concrete floor headfirst and succumbed to fatal injuries, including a concussion and damage to his neck consistent with blunt force trauma to the head (*Martinez v. FedEx Corporate Systems Inc.*, 2021).

In both cases, a safety helmet equipped with a chin strap could have been beneficial in minimizing the extent of injuries sustained.

Longevity of Hard Hats & Safety Helmets

Studies on helmets in different occupational, military and recreational areas have helped to develop the modern safety helmet (see Figure 3, p. 40). The helmet is fitted with a rechargeable intrinsically safe headlamp rated 250 lumens and suitable "for use in hazardous locations: class 1 and class 2, division 1, groups A-G" (Streamlight Inc., 2020).

The improved safety features of a safety helmet include extra polystyrene) foam to line and cushion parts of the helmet that may be impacted by a fall or other impact. This liner is key to mitigating the impact force not just from the top of the head, but the sides and the back of the head as well. Safety helmets also have a built-in chin strap to keep the helmet secure on the wearer's head, even during a fall (Bottlang et al., 2022). Table 4 (p. 40) shows the different materials used to make safety helmets and hard hats. While the traditional hard hat is made of high-density polyethylene, newer safety helmets are made of high-density polypropylene, which is stiffer and has good electrical, chemical and fatigue resistance (MDI, 2022). Other advantages of these various materials include high strength, stiffness and toughness, thermal conductivity, impact absorption and water resistance (British Plastics Federation, n.d.; Witkiewicz & Zieliński, 2006).

The shelf life of hard hats and the materials used to make them is a critical factor for head protection. Hard hat manufacturers have guidelines noting when hard hats must be replaced but knowledge of this varies among construction companies. A 2015 survey was distributed to North Carolina commercial contractors to assess compliance with replacement guidelines for head protection. Similarly, a 2018 survey was electronically distributed to a list of specialty and general contractors in California. Both surveys found that most workers had not received training on hard hat maintenance, nor had they ever changed their suspension or their whole hard hat. This indicates a need for greater awareness of the limitations of hard hats among workers.

Safety Helmet Selection, Care & Maintenance

Several factors should be considered when selecting a safety helmet. Assessing the risks and accounting for potential hazards on a construction site can help point to what approved head protection is needed. The color of the helmet is an important factor, as neon aids in visibility and lighter colors typically provide better heat reflection (U.K. Occupational Safety and Health Branch Labor Department, 2018). Another element to consider is how comfortable an individual is with the helmet fit. A properly fitting safety helmet should have an easily adjustable headband and chin strap and the right shell size for wearer's head.

For safety helmet care and maintenance, wearers should consider the proper storage, cleaning and inspection of a safety helmet to determine whether it needs to be replaced. Cleaning the helmet helps to remove accumulated dust or grease. Warm, soapy water is recommended as opposed to cleaning solvents that might deteriorate the plastic of the shell. Cleaning the helmet can also make it easier to find imperfections on the helmet. Regular inspections of a helmet are essential to determining whether the head protection is still in good condition or should be replaced. ANSI/ISEA Z89.1-2014 (R2019) says:

> All components and accessories, if any, should be visually inspected prior to each use for signs of dents, cracks, penetration, and any damage due to impact, rough treatment, or wear that might reduce the degree of protection originally provided. A helmet with worn, damaged or defective parts should be removed from service.

A reliable way to ensure that head protection remains in good condition is to perform a shell inspection. A worker should test for elasticity by compressing the hard hat shell inwards from the sides simultaneously by 1 in. and then releasing the pressure without dropping the shell. If it does not return to its original shape, the PPE should be replaced immediately (Hernandez, 2018).

Advancements in Occupational & Recreational Helmets

While the level of protection of safety helmets has been significantly improved from the traditional hard hat of 1929, work is still needed to understand how helmet design affects comfort. Researchers in China interviewed workers after providing them with three different helmet types and found that adding more ventilation, along with soft elastic chin straps, greatly improves comfort levels. The researchers also discovered that switching the helmet material from high-density polyethylene to acrylonitrile-butadiene-styrene (ABS)/PVC copolymer may improve the weight and heat transfer, both of which are frequent concerns that construction workers cite when wearing safety helmets (Abeysekera et al., 1996). Helmet comfort might be further improved in hot climates by using white helmets as they have been shown to retain less heat, a common complaint for the usage of safety helmets (Adade-Boateng et al., 2021).

Other researchers are examining how technology can be used to further improve helmet design. The smart hard hat is a prototype with automatic noise reduction to protect a worker's ears. As Dogbe et al. (2020) explain, "The device responds to loud noises by automatically closing earmuffs

TABLE 3

HEAD INJURIES IN U.S. SPORTS

U.S. sports/recreational activities with the greatest number of head injuries in 2018.

Sport/recreational activity	Estimated head injuries
Cycling	64,411
Football	51,892
Playground equipment	38,915
Basketball	38,898
Exercise and equipment	37,045
Powered recreational vehicles	30,222
Soccer	26,955
Baseball and softball	24,516
Rugby/lacrosse	10,901
Skateboards	10,573

FIGURE 2
OPEN-FACE HELMET & HANS DEVICE

An example of the helmet Dale Earnhardt was wearing (left) in the fatal 2001 crash and an example of the HANS device (right; National Museum of American History, 1998).

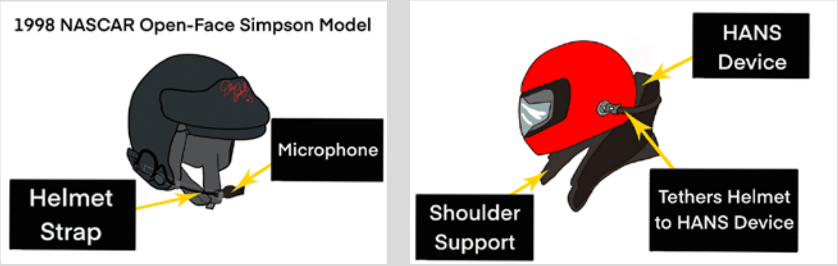

FIGURE 3
CYCLING HELMET WITH MIPS PROTECTION

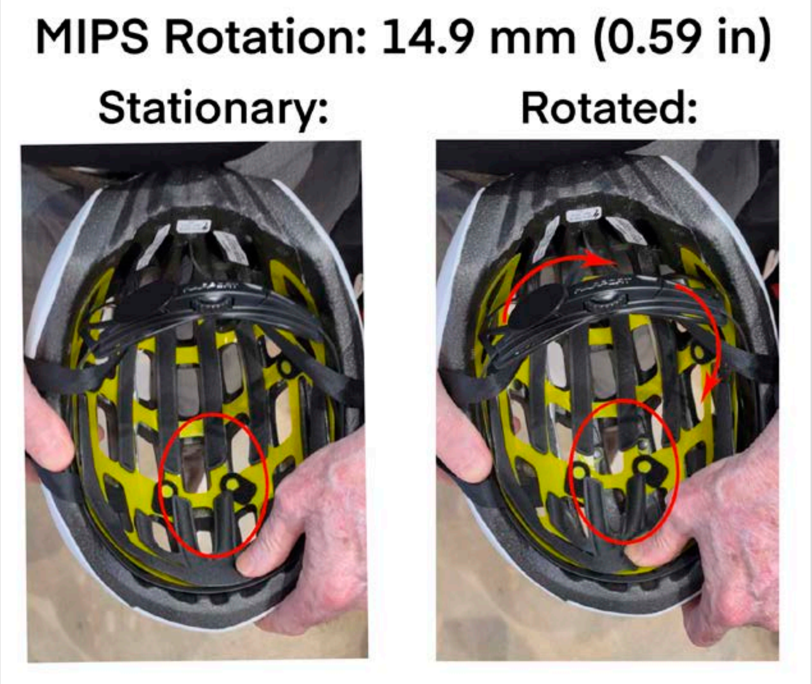

TABLE 4
HEAD PROTECTION MATERIALS

Outer and inner shell materials for various forms of head protection.

Type of head protection	Outer shell material	Inner shell material
Old hard hat	High density polyethylene (HDPE)/polycarbonate resin	Molded HDPE, nylon straps
Construction safety helmet	High density polypropylene (lighter and more resistant to high temperatures than HDPE)	High density expanded polystyrene
Bicycle	Polycarbonate	Polystyrene foam
NASCAR	Carbon composite, glass, Kevlar	Polystyrene/polypropylene
Football	Polycarbonate	Vinyl nitrile, expanded polypropylene substructure, foam and air liner; thermoplastic polyurethane (TPU)
Military	Kevlar	Polyurethane foam

around the wearer's ears, warning them of the damage that is being caused while taking away the need to consciously protect yourself." Another potential design involves biometric sensors added to a helmet for improved safety monitoring of a worker's heart rate, body temperature and concussive impact forces (Fyffe et al., 2016).

Research involving football helmets is focusing on the air-bubble cushioning liner for improved shock absorption. This additional liner can stop major and frequent head injuries including TBIs and chronic traumatic encephalopathy. This air-bubble cushioning liner may also be useful on construction sites. Pan et al. (2021) proposed this liner for industrial helmet use in a U.S. pending patent, noting:

> Air-bubble cushions are able to effectively absorb and dissipate large impact forces such as those encountered in industrial work environments and that inserting one or more layers of air-bubble cushioning in between user's head and the shock suspension system of a helmet (e.g. a construction helmet) dramatically improves the impact absorption/dissipation characteristics of the helmet.

An advantage of certain safety helmets is the multi-directional impact protection system (MIPS). This slip liner was created to reduce the rotational component of an impact by "allowing the head to slide relative to the helmet during the impact" (Abderezaei et al., 2021). The two concentric layers of this system are held in place by a pin that breaks upon impact, which allows the shells to slip about 0.59 in. (15 mm) to mitigate TBIs. The interface of these layers is coated with Teflon. A patent for this system, which was granted to MIPS AB in November 2013, describes radial and tangential impacts to the brain:

> In the case of a radial impact the head will be accelerated in a translational motion resulting in a linear acceleration. The translational acceleration can result in fractures of the skull and/or pressure or abrasion injuries of the brain tissue. . . . The most common type of impact is an oblique impact that is a combination of a radial and a tangential force acting at the same time to the head, causing for example concussion of the brain. (Halldin, 2011)

The MIPS liner may be a part of the inside harness or the outer shell. Bliven et al. (2019) conducted impact testing to compare the traditional safety helmet to safety helmets using the MIPS liner. This testing involved a guided vertical drop onto anvils angled at 30°, 45° and 60° with a Hybrid III head and neck surrogate "to assess mitigation of linear and rotational head acceleration provided by different helmet technologies" (Bliven et al., 2019). The researchers found that the MIPS liner reduced rotational acceleration by 22% and brain injury risk by 34.2% compared to the traditional expanded polystyrene helmet (Bliven et al., 2019). Some PPE manufacturers now provide safety helmets with MIPS for worker protection in all industries (Ergodyne, 2023; Giro Sport Design, 2023).

Construction Industry Adoption of Safety Helmets

The advantages of safety helmets have caused many companies to transition from hard hats to helmets, despite their higher cost. This shift is needed, considering the NIOSH research finding that "the construction industry has the greatest number of both fatal and nonfatal TBIs among U.S. workplaces" (Konda, 2016). According to that study's author, construction worker deaths because of a TBI represented one-quarter of all construction fatalities from 2003 to 2010 (Konda, 2016). Other reasons for the transition to safety helmets include more foam protection for workers' heads. According to one construction company,"traditional hard hats have no high-density foam liner to absorb impact to the top, sides, front and rear of an employee's head," highlighting another feature that some safety helmets use to keep workers safe on jobsites (Skanska, 2022).

A separate study conducted by the NIOSH Division of Safety Research in collaboration with the CDC analyzed the effectiveness of Type I advanced helmets compared to basic helmets when subject to impact testing. Advanced helmets were defined in the study as having an additional foam layer between the belt-type suspension and the shell. According to the researchers, the findings showed that the probability of sustaining a head injury from a severe impact is significantly reduced when wearing an advanced helmet with foam lining (10%) compared to wearing a basic helmet without foam lining (68%; Wu et al., 2022).

Safety helmet cost most commonly ranges from $35 to $150, and many retailers offer them for sale online. To determine whether a safety helmet is approved for occupational use and appropriate for a specific work environment, check whether it has an ANSI Z89.1 designation sticker, which also typically identifies the helmet class and type.

Conclusions

Hard hats and helmets should be examined periodically using the manufacturer's checklists and the ANSI Z89.1-2014 (R2019) standard to make sure they are still in proper working condition. Safety helmets are now designed to protect from side and lateral impacts and are equipped with chin straps to keep the helmet securely attached to the wearer's head. Since at least 2017, construction companies across the U.S. have been mandating that their employees switch from hard hats to safety helmets. Enforcing the use of helmets with chin straps may help reduce the number of head injuries in all industries. Various industrial safety helmet standards apply to all industries, including standards from ANSI, ISO, CPSC, CSA Group, BSI, NOCSAE, ASTM International, FIA and UNECE.

Neurological assessments of individuals who have fallen to the same or lower level or who have been struck on the head and sustained TBIs from competitive sports or transportation incidents are necessary analyses to understanding the long-term effects and treatment protocols for these injuries. Employers that sponsor employee recreational or sports programs should ensure that the head protection used is compliant with the current standards and state-of-the-art protective practices.

Additionally, all industries should benefit from training workers in the proper long-term maintenance of their helmets. A designated person should oversee monitoring workers' helmets and compliance with industry standards and manufacturer recommendations. Appropriate personnel in facilities where head protection is being used should be conversant with helmet inspection criteria including markers indicating the need for helmet replacement. Personnel responsible for employee safety should stay abreast of these changes in standards and state-of-the-art practices and implement as appropriate these improvements at their facilities. **PSJ**

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