The Mechanisms and Prevention of Sports Eye Injuries

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Introduction

The ideal scenario for a sports (or any other) eye injury is for it never to have happened. Prevention, effective in terms of both injury reduction and cost savings to society, [1-6] should be part of the core curriculum of anyone who prescribes, manufactures, or dispenses eyewear, as well as those in the capacity of formulating and implementing rules in the athletic environment. [7] According to the Centers for Disease Control and Prevention, "Injury is probably the most unrecognized major health problem facing the nation today, and the study of injury presents unparalleled opportunities for reducing morbidity and mortality and for realizing significant savings in both financial and human terms—all in return for a relatively modest investment." [8] By following the guidelines for specific sports presented here, eye care professionals, sports officials, and participants will significantly reduce the risk of eye injuries without changing the essential nature or appeal of sports.

Epidemiology

Without knowledge of the incidence and severity of sports-related eye injuries, it would be difficult to attempt injury reduction since there would be no way to determine whether preventive methods were indicated or if they had an adverse or beneficial effect. A major potential pitfall in studying epidemiologic data is that the data obtained may reflect only the risk of a sport and not the benefits that may or may not justify the risk. [9] The objective is to reduce preventable eye injuries to the minimum consistent with retaining the benefits—the fun and appeal that draw participants into the sport. It is possible to achieve this goal most of the time after the incidence and mechanism of eye injuries are ascertained and a committee representing all concerned with the sport—athletes, coaches, officials, and the medical profession—meets to solve the problem.

In 1991, the National Institutes of Health Conference on Surveillance Strategies for Sports Injuries in Youth recommended the creation of a universal data base, [10] yet two decades later there still is no system that records all sports eye injuries with a numerator (injuries, injury details, and use of protective equipment) and a denominator (participants, exposures, player skill) from which the injury risk to both the individual and society can be calculated. In the absence of such a system, the incidence of sports eye injuries and the effect of injury prevention programs must be approached either from studies that emphasize the risk to society and attempt to measure the total number and severity of injuries in a given population or from the study of a small controlled population from which risks to the individual can be estimated.

It is essential to realize that injuries are not accidents. Instead, they have definite patterns and distinct nonrandom characteristics. [11, 12] By carefully evaluating the underlying mechanisms, patterns, and rates of injury in a given sport, it is possible to design and implement extremely effective preventive programs.

Risk to Society

Although incomplete, the data show that eye trauma is a major public health problem, [13,14,15] of which sports comprise a significant proportion. [3] Sports and recreation accounted for 10% of all hospital-treated eye injuries in Dane County, Wisconsin in 1979 [16] and 65% of all eye injuries to children in Israel from 1981 to 1983. [17] Sports-related injuries were responsible for 60% of hyphemas and 10% of open globe injuries in 3184 patients seen in the Massachusetts Eye and Ear Emergency Room over a 6-month period. [18] Approximately one fourth of all trauma admissions to the Manchester Royal Eye Hospital in 1987 and one sixth of all trauma admissions to the Wills Eye Hospital over a three-year period were secondary to sports-related injuries. [19-21] Sports-related injuries (BB gun, golf, basketball) resulted in four enucleations in Olmstead County, Minnesota, between 1956 and 1988. [22] BB and other sports injuries are common in children. [21, 23] In 11 to 15-year-old children, sports and recreational activities accounted for 27% of all eye injuries. [24] Injuries result in visual acuity of less than 20/200 secondary to the development of amblyopia in the injured eye in over 40% of children injured before the age of 10. [25] The vast majority of injured players were not wearing any form of protection at the time of injury.[4, 26, 27]

Regional injury data often reflect the local popularity of a sport and do not necessarily reflect the risk to an individual participant. Playing with bow and arrow and gilli-danda accounted for a majority of the sport injuries (47.2%) in northwest India, [28] but neither of these activities appear in the data from the United States and Canada. From a societal perspective, the focus of prevention must vary from one location to another. However, basic mechanisms of injury are often similar for different sports.

Data Sources

There are several sources of injury data, some more useful than others:

The *National Safety Council system* and *state data collecting systems* have been of little value in the study of sports-related eye injuries because their data are difficult to obtain and are often inconsistent. Gathering of statewide data [29] from hospital records is often impeded by the method of hospital record keeping, which often fails to identify the cause of injury or the circumstances surrounding the injury.

The *National Athletic Injury/Illness Reporting System (NAIRS)* has, in the past, obtained useful data by following injury rates in participating schools. [30] However, the data are no longer available.

In 1985, *The Centers for Disease Control (CDC)* consolidated its non-occupational injury research efforts into the Division of Injury, Epidemiology, and Control. The reports on eye injuries thus far have not been detailed enough for use in monitoring sports eye injuries.

The *National Electronic Injury Surveillance System (NEISS)* was established under a 1973 congressional mandate that established the U.S. Consumer Product Safety Commission (CPSC) to protect the public from unreasonable risks of injury and death associated with consumer products. [31] NEISS is the core of CPSC's Bureau of Epidemiology, and currently comprises 100 hospital emergency departments that make up a stratified sample of all hospital emergency departments throughout the United States and its territories. NEISS data—categorized by body part, product, and activity—are good for

Table 1. Estimated Number of Eye Injuries Treated in Hospital Emergency Departments

	1998	2004-2009	2009
Basketball ***(activity, apparel or equipment)***	8,723	25,433	5,796
Baseball ***(activity, apparel or equipment)***	4,029	10,655	2,428
Softball ***(activity, apparel or equipment)***		3,182	
Racket sports ***(racquetball. tennis, squash, paddle ball, badminton, and handball)***	2,767		
Tennis ***(activity, apparel or equipment)***		4,452	
Squash, Racquetball or paddleball		2,504	
Hockey ***(activity, apparel or equipment)***	1,614	1,313	
Football ***(activity, apparel or equipment)***	1,464	9,602	2,139
Soccer	1,325		
Ball Sports	1,270		
Golf ***(activity, apparel or equipment)***	828	4,177	
Swimming ***(activity, apparel or equipment)***		11,470	
Water and pool sports	4,593		
Fishing ***(activity, apparel or equipment)***		7,675	
Bicycles and accessories		9,355	1,831
Exercise ***(activity, apparel, W/O equipment)***		3,219	
Trampolines		1,981	
Gas, air or spring-operated guns		19,821	3,464
Combatives ***(boxing, martial arts, and wrestling.)***	448		
Other sports	12,236		

Note: The NEISS data are inconsistent from year-to-year, and limited to only sports that met all three of CPSC's reporting rules: (1) National estimate ≥1,200 (2) National estimate based on a minimum of 20 or more NEISS cases (3) Coefficient of variation (used for confidence intervals) < .33.

**Source: National Electronic Injury Surveillance System, U.S. Consumer Product Safety Commission, Washington, DC.*

estimating the total social cost of injuries that affect large segments of the population. NEISS is limited because only emergency department visits related to injuries caused by products are recorded as the basis for projections of a national probability. Since specialty eye hospitals and private ophthalmologists' offices, where most of the sports-related eye injuries are seen, are not included in the sample, NEISS data must be viewed with caution. For example, the extreme eye injury hazard of boxing is not apparent from NEISS data. Yet national trends (e.g. the large number of basketball and baseball eye injuries) are often apparent from these data. ***(Table 1).***

The National Eye Trauma System (NETS) is a consortium of approximately 50 regional eye trauma centers that prospectively gathers information on the etiology, treatment, and final results of open-globe eye injuries. However, most sports-related eye injuries are caused by blunt objects and do not penetrate, perforate or rupture the globe, and thus are not recorded. Despite the fact that the consortium misses most sports-related injuries, it is astounding that 14.1% of all injuries in the NETS database are from sports. As expected, injuries caused by projectiles (38.1 % of reported recreational injuries were due to BB/air guns) lead the NETS list of perforating injuries due to sports.[2, 32]

The United States Eye Injury Registry (USEIR) was formed in December 1988, modeled on the Eye Injury Registry of Alabama, which began in 1982. USEIR, now a federation of 40 state registries and the United States Military Eye Injury Registry, collects and disseminates comprehensive data on the occurrence of serious (involving permanent or significant structural or functional changes to the eye) ocular injuries. USEIR provides data on a broad spectrum of eye injuries, including blunt trauma and chemical injuries that are frequently seen only in ophthalmologists' offices. Because of under reporting by ophthalmologists, USEIR captures approximately 0.3% of sports and recreational eye injuries (about 400,000 in NEISS and 1,300 in USEIR over 10 years). [33] ***Table 2*** is a summary of USEIR sports eye injury data.

Data collected by the cooperating ophthalmologists of the *Canadian Ophthalmological Society (COS)* [4] under the leadership of the late Tom Pashby (March 23, 1915 – August 24, 2005), have been useful for following trends in sports-related injury and the results of intervention with rules changes and/or protective devices. Since, like USEIR, the COS system depends on the voluntary reporting of cases by individual ophthalmologists, the reported cases are an indeterminate small percentage of the actual injuries. Without Tom's leadership, data collection and reporting have atrophied and no update is available.

SGMA International compiles the most reliable estimates of sports participation in the United States. [34] Data for specific sports are included in the discussions of individual sports. SGMA International details participation trends in 103 fitness, sports, outdoor, and recreational activities, based on a nationally representative sample of 14,276 adults and children. Sports participation falls into approximately three fairly equal groups: 86.1 million participate frequently; 83.6 million participate occasionally; 81.3 million do not participate. Combining these data with the data of NEISS gives a somewhat better perspective. The fact that soccer participants increased from 2.3 million in 1990 to 4.3 million in 2001 suggests that the increase in total soccer eye injuries (1492 in 1990 to 2153 in 2001) may be due to an increase in players at risk rather than a change in incidence.

Risk to the Individual

More important to the athlete than the injury statistics noted above, is the risk of a specific sport to an individual participant. Despite the lack of an ideal data collecting system, it is possible to ascertain the eye injury potential of various specific sports and follow the results of intervention, with rules changes or protective equipment, by means of limited, specifically designed studies. [35]

The National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) was developed in 1982 to provide

Table 2. USEIR Sports Eye Injuries: Dec.,1988 to Sept.,1999 and Jan.,2000 to Jan.,2010

	Total		Open globe		Blind eyes (<20/200)		Shattered eyewear (shat./total)		Sex (% male)		Age (median)	
	1988-1999	2000-2010	1988-1999	2000-2010	1988-1999	2000-2010	1988-1999	2000-2010	1988-1999	2000-2010	1988-1999	2000-2010
Fishing	113	42	50	18	34	19	0/1	0/0	82%	79%	27	24
Hunting Shooting	59	12	28	7	29	7	2/4	0/0	98%	83%	32	29
Baseball	104	106	11	3	15	23	5/8	0/10	87%	84%	14	15
Softball	65	42	3	1	8	9	3/12	0/2	63%	38%	29	25
Basketball	66	41	11	4	12	7	1/1	0/1	95%	95%	24	20
Racket Sports**	55	70	1	2	8	14	0/6	1/1	83%	74%	25	20
Hockey	13	10	2	3	0	3	0/0	0/0	100%	90%	30	37
Paintball	12	118	1	11	1	67	0/3	*	100%	91%	17	18
Golf	29	18	12	5	12	8	4/6	0/1	72%	61%	40	16
Soccer	24	62	0	2	1	11	0/1	0/0	67%	73%	17	21
Football	13	29	0	0	0	4	0/1	0/1	100%	97%	15	17
Motor Sports	11	42	5	8	5	13	0/0	0/2	82%	93%	22	25
Fireworks	21	226	3	39	4	112	0/1	0/3	80%	84%	21	15
Total	585	818	127	103	129	297	15/44	1/21	85%	80%	24	22

Note:

1. Significant increase in fireworks and paintball blinding injuries.
2. * There were no documented injuries to paintball players wearing protection that met the ASTM F1776 specifications. 95 of those injured with a paintball from 2000 to 2010 used no eye protection. 3 wore goggles and 3 used safety glasses. Several reports noted that injury occurred when goggles were removed for cleaning. Paintball should only be played on refereed certified fields.
3. Decrease in fishing and hunting injuries. Were more fishermen and hunters wearing polycarbonate or Trivex-lensed eyewear?
4. Softball now causes more eye injuries in women.
5. Less shattered eyewear as polycarbonate and Trivex lenses are gaining on popularity.

Hunting/Shooting include: air rifle/BB gun, hunting, shooting (trap, skeet).
Racket Sports include: badminton, handball, racquetball, tennis, and lacrosse.

Thanks to LoRetta Mann for help in gathering the data.

current and reliable data on injury trends in collegiate sports.[36] The NCAA was established in 1906 in response to the concerns of Theodore Roosevelt for college football injuries and deaths, thus, at first, only football data were collected. The ISS has expanded to also include wrestling (men's); basketball, soccer, lacrosse, and gymnastics (men's and women's); field hockey, volleyball, and softball (women's). Participation is limited to the 977 NCAA member institutions with ISS participants picked at random to have a minimum 10% representation of each NCAA division (I, II, and III). Data from the NCAA do not record every injury, but are a sampling that is representative of the total population of NCAA institutions sponsoring a particular sport. ISS gives the eye injury rate per 1,000 exposures,[37] but it is difficult for many to judge risk unless the NCAA data are put into more understandable terms. The NCAA incidence figures can be multiplied by the average exposure (number of games and practices) to give an easily understood risk to the individual per season and per school career—8 years high school and college ***(Table 3)***.

It has been more than 30 years since the National Society to Prevent Blindness (NSPB-now called Prevent Blindness America— made recommendations that sports-related eye injury data gathering fulfill the following criteria: (1) to permit population-based comparisons involving a known denominator; (2) to record demographic data and details of the injury at the time of presentation to the medical facility; (3) to record the diagnosis of the physician at the time of examination; and (4) to record the final outcome of the injury.[3] As can be seen from the data gathering systems presented, data collection has a long way to go to realize these recommendations.

The analysis of input from many reporting sectors is needed to comprehend the magnitude of sports injuries, the need for protective programs, and the effectiveness of implemented programs. From the preceding and the data to follow, it is possible to approximate the eye injury risk to the *unprotected* participant from selected sports. ***(Table 4)***

Economics of Eye injuries

The social cost of eye trauma, the most common ophthalmic indication for hospitalization, is enormous. National projections estimate annual US hospital charges of $175 million to $200 million for 227,000 eye trauma hospital days.[38] Eye injuries seen in 6 months in one emergency department are responsible for direct and indirect costs totaling $5 million and a loss of 60 work-years.[18] The average societal cost for an eye injury to a child under the age of 15 playing basketball is $3,996.[39] It is estimated that of the 1.6 to 2.4 million Americans who sustain eye injuries each year, 40,000 will be legally blinded in the injured eye. About one third of these injuries result from sports.[40] Since essentially all sports-related eye injuries are preventable, the potential economic savings resulting from the prevention of these injuries is great. There is no question that prevention of traumatic sports-related eye injuries is cost-effective. 41 In 1980 dollars, the hockey face protector saves society $10 million a year by preventing approximately 70,000 eye and face injuries in 1.2 million protected players.[42]

Total expenditures for preventive health care amounted to under 2.5% of total health care expenditures with less than 0.5% spent on health education.[43] Despite the fact that injuries are one of the leading causes of physician and hospital visits, the amount allotted by Congress and the National Institutes of Health (NIH) for trauma research is less than 1 % of the money allotted for cancer and heart disease.[11]

Mechanisms of Eye Injuries

The analysis of trauma is commonly expressed in International System of Units (SI), which are the worldwide standard.[44] Since it is hard for many of us to visualize what some SI

Table 3 Eye Injury Risk, NCAA

	Annual Risk		8-Year Risk	
	Men	Women	Men	Women
Wrestling	1.67%		12.58%	
Basketball, men's	0.97%		7.52%	
Lacrosse, women's		0.88%		6.79%
Field hockey		0.50%		3.97%
Basketball, women's		0.50%		3.90%
Softball		0.40%		3.17%
Soccer	0.26%	0.24%	2.06%	1.94%
Baseball	0.20%		1.59%	
Volleyball		0.12%		0.99%
Football	0.11%		0.87%	
Ice hockey, men's	0.08%		0.63%	
Lacrosse, men's	0.06%		0.45%	
Ice hockey, women's		0.00%		0.00%
Gymnastics	0.00%	0.00%	0.00%	0.00%

Open-globe injuries: softball (4); football (4); baseball (2); men's basketball (1)
Mean of 5 years (1997-2002) except for women's ice hockey (2 years: 2000-2002)
Based on NCAA data, probability calculation advice courtesy of Randy Dick and Preston Fiske.
Note: Data from 2002 to 2010 could not be obtained.

Table 4 Sports Eye Injury Risk to the Unprotected Player

High Risk:		
	Small, Fast Projectiles:	
		Air rifle/BB gun
		Paintball
	Hard Projectiles, Sticks, Close Contact	
		Basketball
		Baseball/Softball/Cricket
		Lacrosse, Men's and Women's
		Field Hockey
		Ice Hockey
		Street Hockey
		Squash/Racquetball
		Fencing
		Wrestling
	Intentional Injury	
		Boxing
		Full-Contact Martial Arts
Moderate Risk:		
		Tennis/Badminton
		Soccer/Volleyball
		Water Polo
		Football
		Fishing
		Golf
		Cycling
Low Risk:		
		Swimming/Diving/Water Skiing
		Skiing
		Non-contact Martial Arts
Eye safe:		
		Track and Field*
		Gymnastics

*Javelin and discus have a small potential for injury that is preventable with good field supervision.

units actually measure (Is it very dangerous to collide with a football player who weighs 200N at 5m/s?) more understandable units, such as miles-per-hour (mph) will be used when appropriate. It is easier for most of us to grasp the speed of a baseball when the velocity is expressed as 75mph rather than as 33.53m/s.

The severity of an eye injury is correlated with the total impact force, expressed in Newtons (N), and the impact force onset rate, expressed in Newtons-per-millisecond (N/ms), and the kinetic energy, expressed in Joules (j) of an impacting object. There is an eye-injury progression from chamber angle damage to peripheral vitreoretinal damage to ruptured globe as the force increases and the time to maximum force decreases. [45] If we slow the velocity of a BB (0.345 g) to 29 mph (13 m/s; 43 ft/s), the energy will be beneath the kinetic energy of 0.03 J required for an ocular contusion and there will be no eye injury. However, when fired in the horizontal direction from a height of five feet, the BB would travel only 24 feet. [46] As the BB velocity increases, the injuries get more severe: 62.3 m/s (205 ft/s) will result in injury at the vitreous base and retinal tear; 72.0 m/s (236 ft/s) penetrates the globe; 124 m/s (408 ft/s) penetrates skin, bone, and moderate tissue. [46, 47]

Test devices [48] and mathematical models [45] have been devised for the laboratory testing of various products, such as toys, to access the potential for eye injury. The force onset rate needed to produce clinically detectable contusion injury by a blunt object is approximately 750 N/ms. Some toy dart guns (896 N/ms) that propel suction cups exceed this level, while most toy ping-pong ball shooters (428 N/ms) do not. [49] Computer modeling using finite element analysis has led to better analysis and understanding of the mechanisms of eye injury ***(Figure 1)***. [50-53]

Many protectors (such a football helmets) for sports and some protective eyewear [54] prevent or reduce injury by decreasing the force onset rate and the peak force by spreading the total force over time. However, the injury as related to force onset rate only applies total forces in a limited range, which has not yet been determined.

Injury classification

Sports eye injuries can be classified in accordance with the Birmingham Eye Trauma Terminology (BETT) in which all terms relate to the whole eyeball as the tissue of reference. [55] Injuries may be:

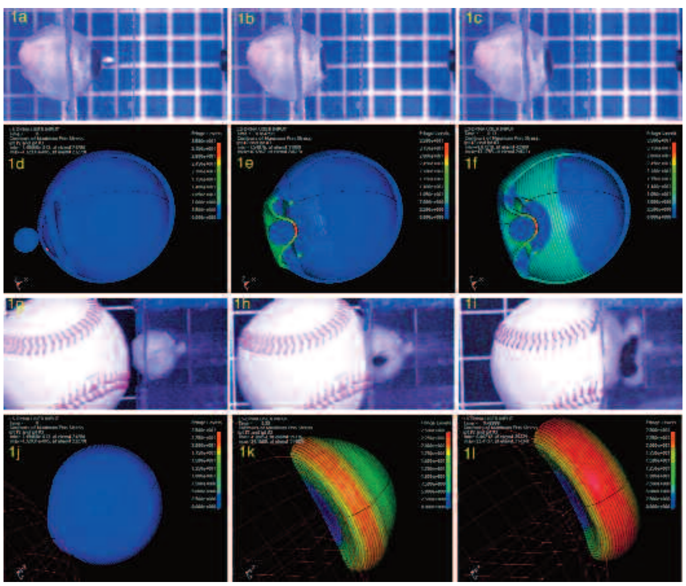
I. **Open-globe injury** in which there is a full-thickness wound of the eyewall:

A. ***Rupture:*** (wound caused by a blunt object, eye ruptures at weakest point ("inside out" mechanism).

B. ***Laceration*** (wound caused by a sharp, or small-high-velocity, object at site of impact ("outside in" mechanism):

1. *Penetrating*. Each entrance wound caused by separate agent, includes intra ocular foreign body.

Figure 1 Finite element analysis correlated with motion analysis of impacts on human eyes.



1a-c. BB, moving right to left at 92.0 m/s (301.8 ft/s; 0.58J) impacting a human cadaver eye held in an artificial orbit with clear gelatin. The sequence will be continued in the section on BB's to follow.

1 d-f finite element analysis (FEA) of the BB impact to a point just before globe penetration.

1g-i. Baseball, moving left to right at 41.2 m/s (92.2 mph; 124.3J) impacting a human cadaver eye held in an artificial orbit with clear gelatin. Note globe rupture (dark area) at equator of the globe starting in 1h and enlarging in 1i. See Figure 5 for the baseball rebound.

1 j-l finite element analysis (FEA) of the baseball impact to a point just before globe penetration. This FEA model has potential usefulness as a simulation tool for ocular injury and it may provide useful information for developing protective measures against sports, industrial and traffic ocular injuries.

Courtesy of Stefan Duma and Joel Stitzel. Virginia Tech Impact. Biomechanics Laboratory (duma@vt.edu).

2. *Perforating*. Entrance and exit wound caused by same agent.

II. **Closed globe injury** in which there is no full-thickness wound of eyewall:

A. ***Contusion:***

1. Due to *direct energy* delivery by the object.
2. Due to *changes in the shape* of the globe.

B. ***Lamellar laceration:*** Partial-thickness wound of the eyewall.

Open globe injuries.

The eyewall (the cornea and the sclera) can modeled as the union of two thin walled (approximate 0.5mm wall thickness) spheres (radii 8mm and 12mm) with the centers 5mm apart. [56] At the junction of the optic nerve sheath, which may be represented by a cylinder (radius 2mm), the larger (scleral) sphere is perforated by multiple openings, the lamina cribrosa. [57] However, the eyewall is not of uniform thickness, [58] is significantly thinner in myopic eyes, [59] and becomes less elastic with age. [60] The eyewall tends to rupture in three specific locations: (1) where the radius of curvature changes at the limbus, (2) where the sclera is the thinnest, near the equator behind the ocular muscles, and (3) where the sclera is perforated at the lamina cribrosa. [56]

Even with the best surgical techniques, approximately 50% of children with open globe injuries recover good visual acuity. [61]

Rupture.

Ragged rupture of the globe secondary to injury by a blunt object significantly reduces the likelihood of recovery of useful vision. [13, 62-65] Only seven of 13 ruptured eyes regained counting fingers or better vision. [66] Rupture of the globe occurs when the intraocular pressure is greatly elevated or when a blunt external force is applied to the eye quickly. The energy required to rupture the eye varies with the dimensions and the properties of the impacting object ***(Table 5)***. ***Figure 2*** shows a matched pair of cadaver eyes impacted with baseballs that had similar physical properties—except for the ball hardness. Impact with a major league baseball (143.9g) at 55mph ruptures the globe at 3 milliseconds. Impact with a softer ball (146.5g) at 74mph does not rupture the globe, despite the fact that the softer ball delivered more energy (80.2 joules) than did the harder ball (43.5 Joules). [67] The harder baseball causes extreme flattening of the globe (2ms) immediately followed by rupture at the limbus (3ms). After the ball has totally rebounded from the eye and orbit, the ocular contents continue to be extruded by the retained energy in the globe. When compared to the softer baseball that does not rupture the globe, it is apparent that the harder ball delivers energy faster, deforms the eye more, and rebounds faster. The softer ball has a lower peak force and slower force onset rate (peak force 3208 N; onset rate of 2686 N/ms) than the harder ball (peak force 3768 N; onset rate of 3486 N/ms). It appears that the slower application of force allows the globe to retract into the orbit and undergo less compression than when the force is applied faster. The rupture pressure of a healthy human eye varies with force onset rate and is in the range of 2000 to 4400 mm Hg.[68, 69]

Table 5. Globe Rupture: Correlation Among: Intraocular Pressure, Object Hardness, Size, and Kinetic Energy *

		HUMAN EYE	MONKEY EYE	PIG EYE
Elevated Pressure [827]	Intraocular Saline	2,800 to 6,400 mmHg 54.1 to 123.8 psi		
Metal Rod [828]	12.5 mm diameter 303 g		12.2 ft/s (8.3 mph) 2.1 j	
Paint Ball [315]	17.5-mm diameter 3.55 g			290 ft/s (198 mph) 13.9 j
Golf Ball [327, 328]	43.0-mm diameter 45.4 g			86 ft/s (59 mph) 15.6 j
Squash Ball [327, 328]	41.0-mm diameter 24.7 g			150 ft/s (102 mph) 25.8 j
Baseball [7]	73.2mm diameter 143.9 g	80.7 ft/s (55 mph) 43.5 j		

** Approximate averages. Rupture of individual eyes varies.*

The sports that cause ruptured globes to unprotected players typically use a stick with a blade end that fits into the orbit (hockey, field hockey, golf, polo), a small soft fast projectile (BB, paintball), a soft or hard ball that deeply penetrates the orbit (squash, golf), a hard projectile that partially enters the orbit with great force (hockey, baseball, softball, cricket, field hockey, polo), or a one in which there is the potential of contact with a body part that enters the orbit with force (basketball, football, soccer, rugby, boxing, martial arts).

Prior surgery or eye disease. An eye that would have had a closed-globe injury may sustain an open-globe injury (rupture) because surgery has weakened the eyewall. [70] Deeper, longer incisions, especially in the cornea, permanently weaken the eyewall and predispose the eye to an open globe injury. ***Table 6*** lists the approximate risk from various surgical procedures. All patients who have had surgical procedures that weaken the eyewall should be advised that eye protection is essential when there is the probability of impact. [71] The concept that a ruptured globe is a "safety valve" that prevents contusion injuries cannot be supported by injury data. ***(Figure 3)***

Table 6. Predisposition to Traumatic Ruptured Globe After Eye Surgery

High	
	Penetrating keratoplasty
	Large incision, butt joint ICCE, ECCE
	Standard RK with incisions to limbus
	Hexagonal keratotomy
Moderately high	
	Large incision tapered joint ICCE, ECCE
	Trabeculectomy or other filtration surgery
	Prior repair of corneal and/or scleral laceration
Moderate	
	Small incision butt joint ECCE
	“mini” RK
	astigmatic keratatotomy
Moderately low	
	Small tapered incision ECCE
	Scleral buckle with diathermy
No more than unoperated	
	Paracentesis
	Scleral buckle with cryo or laser
	Strabismus surgery
	Lamellar keratoplasty/pterygium
	LASIK*
	PRK
	Keratomieleusis*

**Late traumatic dehiscence of corneal flap is a potential problem*

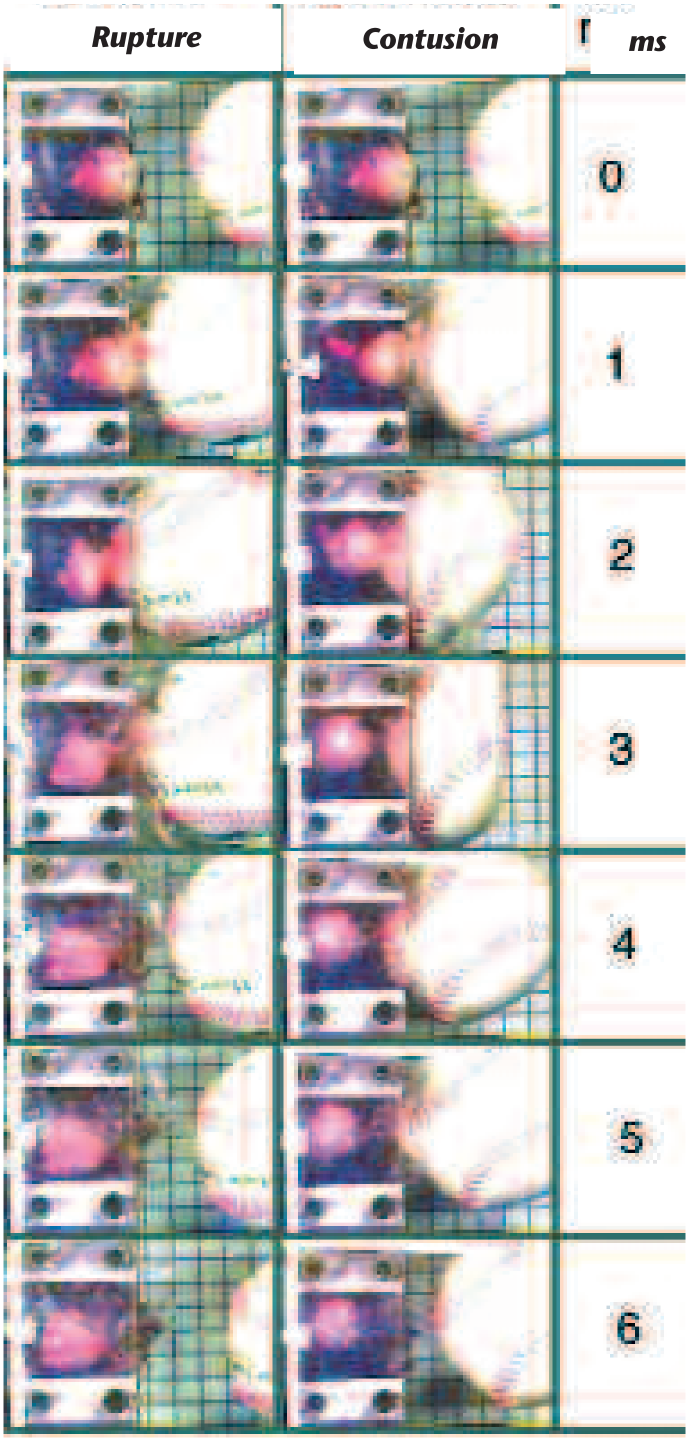
Laceration

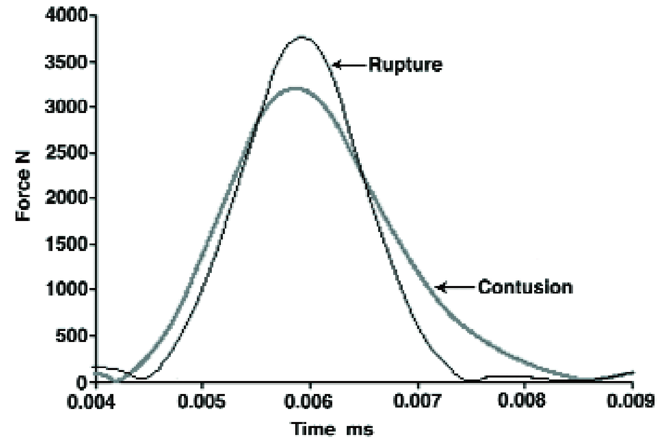
Perforating injuries, in which the same agent causes an entry and an exit wound, are usually due to a high-speed projectile (air rifle/BB, firearm, shrapnel) or a slower sharp projectile (shattered eyewear, fishhook, tip of ski pole, arrow, dart). There is little data on the energy required to cause perforating injuries, which are similar to but more severe than penetrating injuries.

Penetrating injuries. The same agents that cause perforating injuries result in penetrating injuries or intraocular foreign bodies when there is sufficient energy to penetrate the eyewall, but not enough energy to exit the globe. A knife-edged missile is in a class by itself for ease of penetration. The mechanical advantage of the cutting edge is exerted until the hole it makes is the full diameter of the missile. A 20-gauge knife-edged missile penetrates the globe with a momentum of 17 mg·ms [72] as compared to the momentum of 24,840 mg·ms as the no-penetration value for the BB. [47]

The energy present in many sports is capable of causing severe eye injury and often exceeds the capacity of ordinary eyewear to withstand the impact and protect the eye. Frequently, the lacerating instrument is a fragment of the athlete’s own spectacle lens. Thus, the wrong eyeglasses can convert blunt trauma into penetrating ocular injury and permanent visual impairment [73-75] Globe laceration caused by spectacle lens shatter has a poor prognosis and is underestimated. Keeney [76] found 491 cases of spectacle glass injuries resulting in 369 ocular injuries and 37 lost eyes. Over a 1-year period, 3.6% of 446 cases of penetrating ocular injury in Canada were due to shattered spectacle lenses—40% of the shattered lens injuries were to adult male amateur athletes. [77] Between 1978 and 1986, at least 21 racket sport players sustained serious ocular injuries when their prescription glasses (hardened glass or plastic, but not polycarbonate or Trivex) shattered. [78, 79] Of 298 eyes injured by shattered spectacle lenses in a nonindustrial setting, 157 suffered significant damage and 27 were lost. Sports accounted for 53 (17.8%) and BBs for 16 (5.4%) of the shattered eyeglasses. [80] Sixteen of 635 work-related penetrating eye injuries resulted from shattered streetwear spectacle lenses. [81] One of the two penetrating ski eye injuries reported to NETS was the result of dress spectacles shattering on impact from the handle of a ski pole. Two soccer players had significant structural changes to their lids and globes when the ball shat-

Figure 2. Rupture and contusion related to time in milliseconds (ms) and force onset rate





tered streetwear glasses. [82] A homemade "potato-gun" caused a sight-threatening corneal laceration when the spectacle lens worn by a 14 year-old boy shattered. [83]

Since approximately half of the population wears eyeglasses, [84] the prescription of the appropriate spectacle lens ***(Figure 4)*** can protect a huge segment of the population, whereas an incorrect recommendation by the practitioner exposes the patient to the risk of a shattered lens, a perforated globe, and the good chance of permanent disability. [85]

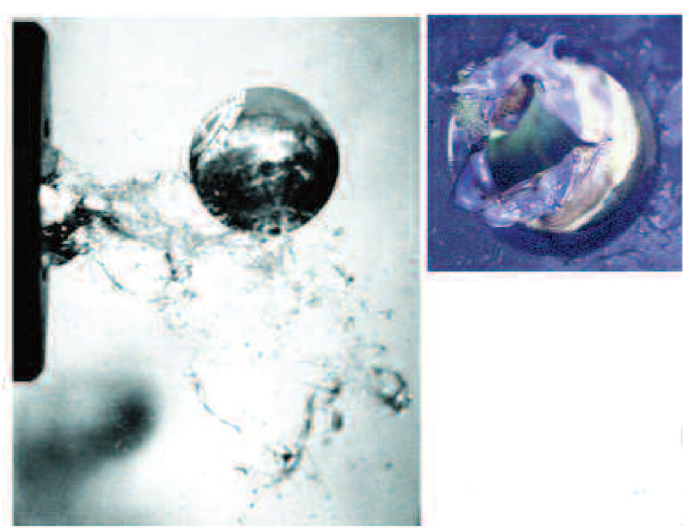
Apart from shattered eyewear, the principle causes of intraocular foreign bodies seen in sports are BB's, shotgun pellets, and fishhooks.

Closed globe injuries

Contusion

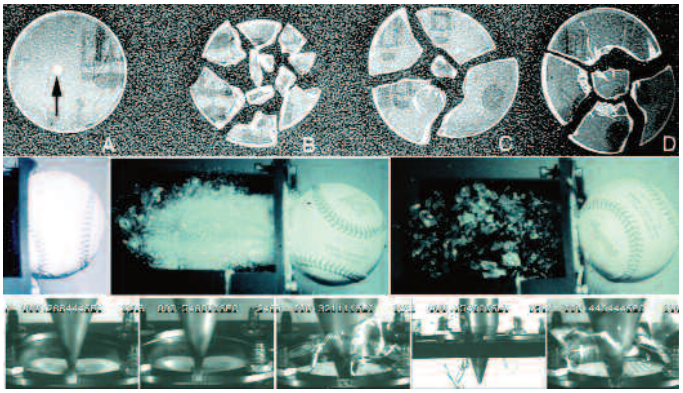
Nonpenetrating trauma results in a wide variety of tissue damage involving chamber angle deformities and injury to the retina, choroid, vitreous, and lens. The injury to the eye depends on the maximum force, the time to the maximum force, the area of contact, and the properties of the impacting

Figure 3. Total extrusion of RK eye contents
Squash ball impact at 90 mph



object. The expansion of the eyeball perpendicular to the direction of impact, has been proposed as the major cause of the contusion injuries that result from blunt trauma ***(Figures 1, 2)***. When a small, high-velocity object (such as a BB) hits the eye on the cornea, the entire eye deforms, and the weakest portion of the retina (upper nasal) often fails. [47, 86] When a large object (such as a soccer ball) hits the eye (especially in younger players where the orbital rims are less developed) more energy is directly transmitted to the exposed temporal retina while the nasal retina is protected by the nose. A suction component [87] ***(Figure 5, Table 7)*** most likely adds to the distortion of the globe

Figure 4. Impact resistance of eyewear lenses



Top row. BB impacts on (a) polycarbonate, (b) glass, (c) allyl resin plastic [CR-39], (d) high-index (1.6) plastic lenses.

Center row. baseball impact on industrial safety lenses (left) polycarbonate at 169 ft/s [note flattening of baseball], (center) glass, chemically tempered at 142 ft/s, (right) allyl resin (CR-39) plastic at 137 ft/s

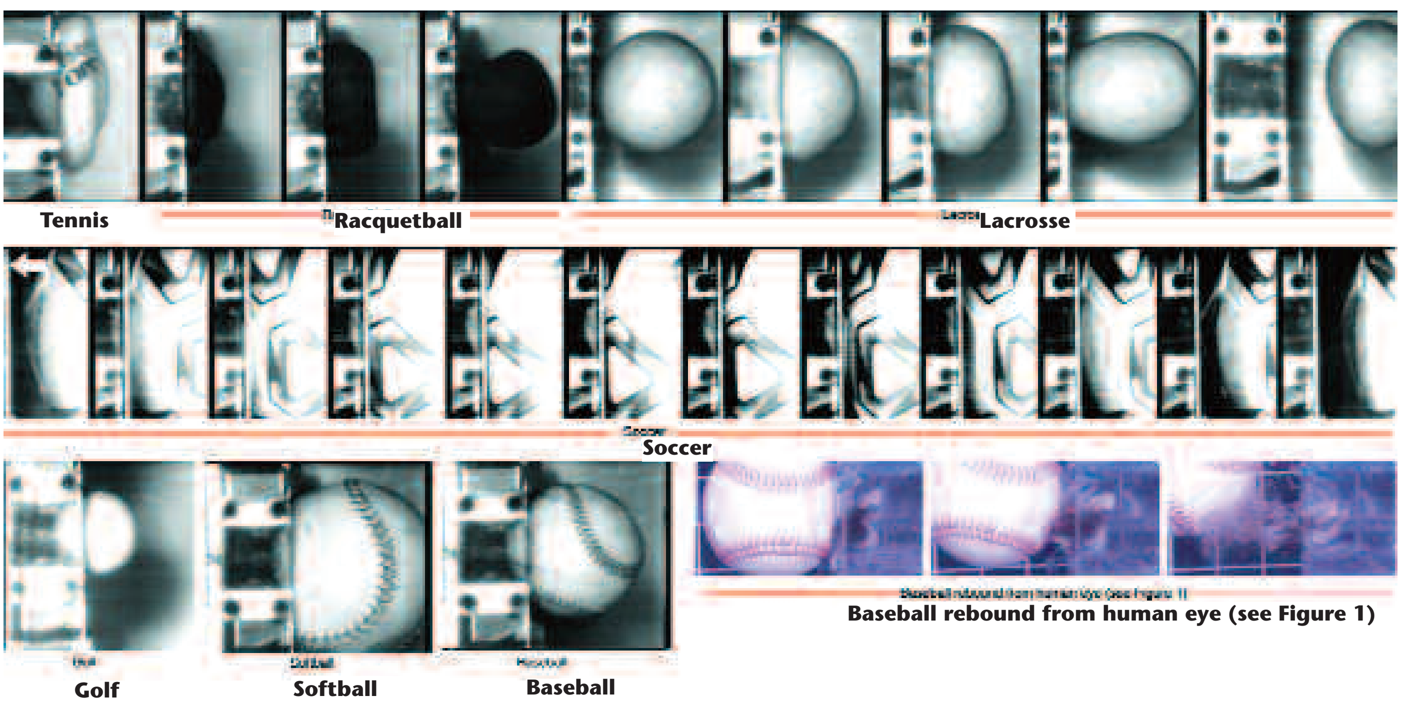
Bottom row. 500 g high mass Z87 test object from left to right onto Trivex, polycarbonate, CR-39, high-index (1.6), and Spectralite lenses. All lenses 2mm thick plano. Mass dropped from 75” (9.34J) onto Trivex and polycarbonate which did not shatter, and from 50” (6.23J) on the other lenses that shattered . At velocities expected in typical sports, glass, allyl resin, and high index plastic lenses shatter, while polycarbonate (and also Trivex) remain intact. *(Bottom row courtesy of Nancy Yamasaki)*

anatomy that causes stresses resulting in tearing of structures in the anterior [88] and posterior [89] segments of the eye. This extreme distortion in the anatomy results in tearing of internal ocular structures (sphincter pupillae, peripheral edge of the iris, anterior ciliary body, attachment of the ciliary body to the scleral spur, trabecular meshwork, zonules, attachment of the retina to the ora serrata, and Bruch's membrane) that are resistant to stretching when the globe undergoes the deformations induced by the force of the impact. [88, 90] Because there frequently is a long interval between ocular contusion and the appearance of retinal detachment, and retinal breaks are formed at the time of injury, it is essential to examine the peripheral retina of all eyes that have had a contusion injury. [91] Blunt trauma may cause transient high myopia by anterior shift of the lens-iris diaphragm and thickening of the crystalline lens. [92] Hyphema may be caused by the shock wave of a pure blast injury. [93]

A blow by a blunt object smaller than the orbital opening, such as a BB, paintball, golf ball, finger, or hockey stick, will transmit great forces to the globe. To produce eye injury, less energy is required with high-speed and small-mass missiles (BB shot) than with low-speed and large–mass missiles (soccer ball).

A blow by a blunt object larger than the bony opening, such as a tennis ball, elbow, or fist, has some of the energy absorbed by the surrounding bones, soft tissues, and orbital floor, which may fracture. There is a high incidence of internal ocular injury in these cases. [94] The concept that an impacting object with radius of curvature above 2 inches (4-inch diameter) rarely causes eye injury because the ball delivers most of its energy to the orbital rims [95] is incorrect. Large balls (such as

Figure 5. Orbital penetration and suction effect.



The penetration, into an artificial orbit, of tennis ball, racquetball, lacrosse ball, golf ball, softball, baseball, and soccer ball. Adjacent frames are at intervals of 1ms. The frames with the human ruptured eye are a continuation of the sequence depicted in Figure 1 g-i. Note the suction effect of the ball on the ocular contents as the ball. rebounds. (All balls travelling right to left except baseball impacting human cadaver eye, which is traveling left to right)

Table 7 Orbital Penetration and Penetration Duration (Orbital Contact) of Sportsballs

Sports Ball	Soccer Ball psi	Weight g	Diameter cm	Velocity m/s (mph)	Impact energy J	Orbital penetration mm	Orbital contact ms
Soccer #3	9	355.9	19.6	18.0 (40)	57.5	7.5	8.7
Soccer #3	6	355.9	19.5	18.3 (41)	57.5	7.8	9.3
Soccer #3	3	355.9	19.3	17.7 (40)	57.5	7.7	10.0
Soccer #4	9	369.1	20.8	17.4 (39)	55.7	7.6	9.0
Soccer #4	6	369.1	20.6	17.4 (39)	55.7	7.6	9.0
Soccer #4	3	369.1	20.4	17.4 (39)	55.7	8.4	10.6
Soccer #5	9	435.6	21.8	18.6 (42)	75.3	8.0	9.0
Soccer #5	6	435.6	21.6	18.6 (42)	75.3	7.8	10.0
Soccer #5	3	435.6	21.4	18.6 (42)	75.3	8.7	11.0
Tennis		57.9	6.4	39.9 (89)	46.2	18.6	4.0
Racquetball		40.1	5.6	42.0 (94)	35.6	16.1	3.0
Squash soft		23.5	4.0	41.1 (92)	23.5	completely enters orbit	stuck
Squash hard		21.0	4.0	41.1 (92)	17.8	completely enters orbit	stuck
Lacrosse		151.7	6.3	24.4 (54)	45.4	20.0	3.0
Softball		186.8	9.6	32.6 (72.7)	103.0	10.3	1.3
Baseball		144.2	7.4	30.2 (67.3)	66.1	10.8	1
Field hockey		176.0	7.3	27.4 (61)	66.2	7.5	2
Polo		124.5	7.8	38.4 (86)	91.8	7.9	2
Golf		45.5	4.3	43.0 (96)	42.0	13.4	2

a soccer ball) and boxing gloves deform significantly on impact, allowing a small "knuckle" of the ball or glove, with a smaller radius of curvature, to enter the orbit and impact the globe. It is only by experiments utilizing high-speed photography, coupled with injury data, that the true mechanism of injury can be elicited and appropriate protective devices designed.

Lamellar laceration

The primary lamellar laceration potential from sports is the dislocation of a LASIK flap. All patients who have had LASIK should be warned of this potential complication [33, 96-100] and be advised of appropriate protection, lest their flap be dislocated by a finger while playing basketball, [101] or by a tree branch. [102]

Injuries to higher visual pathways

Blows to the skull with direct or indirect injury to the visual pathways may result in permanent or temporary visual loss. [103-110] The huge forces required to produce these injuries can be encountered in many sports (e.g., collision sports, skiing, cycling, motor sports). [111-114] With high-energy loads, eye protection must be considered as part of an integrated eye/face/head/brain protection system.

Principles of Preventing Sports Eye Injuries

There is a sequence of events that decrease the eye-injury risk of a sport to the individual player.

1. Those involved with a particular sport see a number of injuries and get an impression that the sport has a high risk of eye injury.

2. Data on the incidence and severity of injuries are collected to confirm or deny the initial clinical impression. This data collection may involve the establishment of special study groups and usually takes several years before the risk is confirmed or denied to the satisfaction of those involved with the sport.

3. If the initial impression is confirmed by the data, then a study of the sport and eye injury mechanisms (usually done simultaneously with no. 2) is conducted. This determines whether rules changes alone (e.g., eliminate fighting and high sticking in hockey) will reduce eye injuries to an acceptable level, or whether protective devices (e.g. hockey face shields) are necessary.

4. If protective devices are necessary, then performance standards must be written to ensure that the protective devices will meet the visual requirements of the game while reducing the probability of injury to a specified level.

5. In addition to the development of standards, certification councils must be established to ensure that protective devices sold to the athletes meet the standard requirements.

6. If needed, rules changes are implemented.

7. Data collection is continued to document the effect of rules changes and protective equipment on eye injuries and also the effect of the changes on injuries to other areas of the body. (For example, there was concern that the use of total head protective devices for hockey players might increase injuries to the neck. Extensive studies on change of center of head mass, skating attitudes, [115, 116] and analysis of all neck injuries to both protected and unprotected players have shown no increase of neck injury risk due to the protective device. [117] However, the referees and coaches must enforce the rules of the game and not allow the level of violence to offset the effects of injury prevention programs.

8. Adjustments in rules/standards/protective devices are made as data collection shows the need for modification. It may turn out that serious injuries are impossible to prevent, since in protecting one area of the body injuries may be transferred to another. Then society must decide whether it is possible that the sport as it now exists presents too high a risk and should be banned. (For example, the once popular, but dangerous, sport of jousting would not be permitted a return, but what criteria should we use in deciding whether to ban an existing sport with significant risk to the athlete, such as boxing?) [118]

Distribution of Forces

Forces are best dissipated if they are transmitted over a wide area and the duration of time over which the force is allowed to act is lengthened. [119] If possible, the best area for distribution of forces when one tries to protect the eyes is the frontal bones. These bones are the sturdiest about the orbit and have the tendency to transmit energy into the mass of the face by the lateral orbital margins. [120-122]

Whenever a large force is transmitted anywhere on the head the prime consideration must be the ultimate dissipation of this force as it relates to the brain. It is senseless to protect an eye if in so doing the damaging forces are transmitted directly to the brain. All protective devices for the head and face thus require two areas of consideration: (1) is the primary area of concern (e.g., eye, face, teeth) protected? and (2) is the transmission of forces such that there is no added risk to the brain? In collision sports such as hockey or football, this result is best achieved by mounting a face protector on a properly designed helmet. In this manner, the desirable goal of total head (not isolated eye, face, teeth, etc.) protection is achieved. Helmet design must be monitored by comparing predicted force [116, 119] with actual measurements of injury to real players in action. [123]

Table 8 Standards and Test Energies

		Test	Energy (j)
ANSI Z80 Fashion eyewear		5/8" steel ball dropped 50"	0.2
ANSI Z87 Industrial eyewear			
	glass and allyl resin Rx lenses	1" steel ball dropped 50"	0.9
ANSI Z87+ Industrial eyewear			
	polycarbonate and Trivex lenses	1/4" steel ball at 150 ft/s	1.1
		500g pointed mass dropped 50"	6.4
Military fragments			
		0.15 caliber 376 mg at 640 ft/s	7.2
		0.22 caliber 1.1 g at 550 ft/s	15.5
ASTM F803 sports eyewear			
	tennis	Tennis ball at 90 mph	46.7
	squash	Squash ball at 90 mph	19.4
	racquetball	Racquetball at 90 mph	32.4
	women's lacrosse	Lacrosse ball at 45 mph	29.6
	baseball, under age 9	Baseball at 40 mph	23.7
	baseball ages 9 to 15	Baseball at 55 mph	45.6
	baseball over age 15	Baseball at 70 mph	70.2
		and at 85 mph	77.8

Sports with less energy potential require less protection. A squash ball has little potential for injuring the brain; therefore, attention need only be directed toward protecting the eye. In this case, one might consider it acceptable to transmit the forces to the frontal bone (best) or even less desirable areas (the bridge of the nose, the lateral or infra-orbital rims) and still achieve good eye protection. One could accept a cut on the cheek, a broken nose, or even a fracture of the zygoma as far preferable to the potential loss of the eye.

Eyewear Standards

The best sports standards are performance standards that specify how a protector must perform (e.g., visual fields, impact resistance, distribution of forces) rather than design standards that contain certain design elements that may or may not relate to performance. By and large, design standards are unnecessarily restrictive, tend to stifle the introduction of better, more innovative protector designs, and are more likely to encounter antitrust problems than performance standards. [124]

It is clear to those who write standards that one cannot tell how a protector will perform until it is tested under game conditions or conditions that approximate game conditions. [125] If those who write standards and test protectors cannot tell how a protector will perform until the protector is tested, it is obvious that the untrained consumer will be unable to determine which products will provide adequate protection with minimal impact on performance by inspection in the retail shop. Severe eye injuries in sports can be prevented by writing performance standards that specify the protector's energy attenuation and visual requirements followed by certification of the protective equipment produced by manufacturers. [126] Sports regulatory bodies must mandate the use of equipment that passes the standard requirements, and governing bodies must legislate against uncertified products gaining access to the marketplace. [127]

Test requirements of relevant eyewear standards are listed in ***Table 8***.

ASTM International

The majority of sports eyewear standards writing in the United States comes under the jurisdiction of the American Society for Testing and Materials (ASTM). The largest of the approximately 400 standards-writing bodies in the United States, ASTM is neither a government nor a manufacturer's organization but a nonprofit corporation organized in 1898 for development of voluntary standards arrived at by consensus, with strict guidelines for due process, among all interested parties. [128, 129]

ASTM committee F-8 on sports safety standards and sports safety was formed in 1968 to address the sharp increase in head and neck injuries in football. [130] ASTM F-8 now has subcommittees that write standards for many sports, including gymnastics, golf, archery, wrestling, fencing, trampolines, fitness products, racket sports, hockey, and baseball, as well as groups concerned with the more general problems of medical aspects and biomechanics, playing surfaces, headwear, footwear, padding, statistics, warning labels and signs, the female athlete, and eye safety.

Standards are designed to be revised as experience is gained. No matter how well the protector performs on paper or in the testing laboratory, it is only the use by thousands of players and continued injury monitoring that prove the protective value or demonstrate the failures of a particular design. For this reason, the ASTM mandates review of every published standard every 5 years. Other standards organizations (e.g., Canadian Standards Association (CSA), [131] American National Standards Institute (ANSI), Deutsches Institut fur Normung, International Organization for Standardization) operate under various bylaws.

At present, ASTM has completed the following standards for sports eye protectors:

ASTM F803 Eye protectors for selected sports (racket sports, women's lacrosse, field hockey, baseball, basketball)

ASTM F513 Eye and face protective equipment for hockey players

ASTM F1587 Head and face protective equipment for ice hockey goaltenders

ASTM F1776 Eye protectors for use by players of paintball sports

ASTM F910 Face guards for youth baseball

ASTM F2713 Standard specification for eye protectors for field hockey

ASTM F659 Standard specification for skier goggles and faceshields

ASTM F2530 Standard specification for protective headgear with faceguard used in bull riding

ANSI

ANSI writes standards for protective eyewear in the United States with the exception of sports eyewear. It is the central body responsible for the identification of a single, consistent set of voluntary standards called American National Standards, and is the U.S. member of international standards organizations. ANSI follows the principles of openness, due process, and a consensus of those directly and materially affected by the standards.

ANSI standards for eyewear are:

ANSI Z80.5 Requirements for ophthalmic frames

ANSI Z80.1 Prescription ophthalmic lenses-recommendations

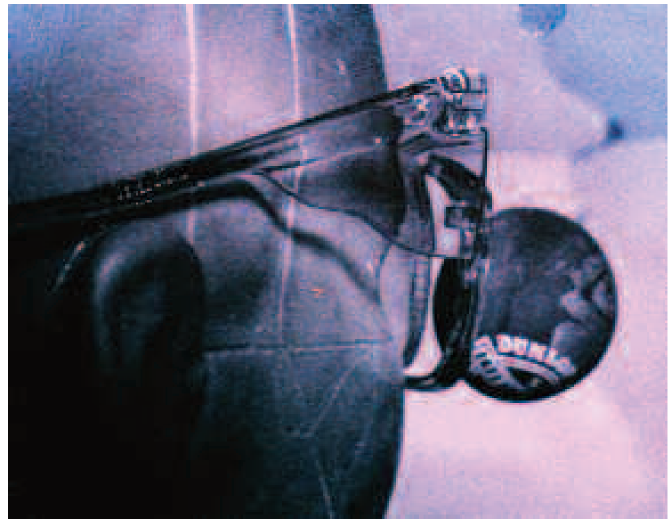
ANSI Z80.3 Requirements for nonprescription sunglasses and fashion eyewear

ANSI Z87.1 Practice for occupational eye and face protection

The ANSI Z80 standards are for dress eyewear, also called streetwear spectacles. The test requirements are minimal and geared to the desire for a diversity of styles in fashion eyewear. Streetwear spectacles are not appropriate for work or sports with impact potential. Impact-resistant polycarbonate or Trivex lenses should be used for dress eyewear. Streetwear frames are often fragile and have poor lens retention properties. Significant eye injuries have resulted from frame failure. Yet a streetwear frame with an impact resistant polycarbonate or Trivex lens does give protection from low impact injuries, such as a fishhook or a snapping twig.

The ANSI Z87.1 Industrial eye protectors are not satisfactory for sports for which there are ASTM standard specifications **(Figure 6)**. Yet ANSI Z87+ eyewear, designed to stop small high velocity fragments, is an excellent choice for moderate impact sunglasses and eyewear for shooting, fishing, cycling, and other activities that involve the potential of impact with a small fragment.

Figure 6. ANSI Z87 spectacle failure with squash ball at 90mph



Department of Defense

Military eyewear will be coordinated under a single umbrella program called the Military Eye Protection System (MEPS) http://www.dod.mil/) in which testing is done with fragment-simulating (T-37) projectiles ***(Figure 7)*** either 0.22 caliber, 17 grain (1.1g) at 168 m/s (550 ft/s) or 0.15 caliber, 5.8 grain (376mg) at 195 m/s (640 ft/s). Sun, wind and dust goggles (MIL-V-43511); ballistic/laser protective spectacles (MIL-PRF-44366B); and special protective eyewear, cylindrical system with interchangeable lenses (MIL-PRF-31013) standards assure eye protection from the majority of fragments anticipated in military combat. Although this eyewear has not been tested for sports use, it would provide excellent protection for the hunting and shooting sports, but not for sports for which specific ASTM standards apply (such as paintball, hockey, and sports covered under ASTM F803.)

NOCSAE

The National Operating Committee on Standards for Athletic Equipment (http://www.nocsae.org) has standards for baseball, football, and lacrosse helmets; baseballs and softballs; and face shields for football and men’s lacrosse.

Current NOCSAE standards include:

***Figure 7*. Military fragment simulators and ANSI High velocity test object**

Left: military 0.15 caliber.
Center: military 0.22 caliber.
Right: ANSI 1/4” steel ball

Standard Drop Test Method and Equipment Used in Evaluating the Performance Characteristics of Protective Headgear. NOCSAE Doc. 001-00m02

Standard Performance Specification for Newly Manufactured Football Helmets. NOCSAE Doc. 002-96m98

Standard Performance Specification for Recertified Football Helmets. NOCSAE Doc. 004-96m98

Standard Projectile Impact Testing Method and Equipment Used in Evaluating the Performance Characteristics of Protective Headgear, Faceguards or Projectiles. NOCSAE Doc. 021-98m02

Standard Performance Specification for Newly Manufactured Baseball/Softball Batter's Helmets. NOCSAE Doc. 022-98m02

Standard Performance Specification for Newly Manufactured Baseball/Softball Catcher's Helmets with Faceguards. NOCSAE Doc. 024-98m02

Laboratory Procedural Guide for Certifying Newly Manufactured Football Helmets. NOCSAE Doc. 003-96m02

Laboratory Procedural Guide for Recertifying Football Helmets. NOCSAE Doc. 005-96m02

Laboratory Procedural Guide for Certifying Newly Manufactured Baseball/Softball Catcher's Helmets with Faceguards. NOCSAE Doc. 025-98m02

Troubleshooting Guide for Test Equipment and Impact Testing. NOCSAE Doc. 100-96m97

Equipment Calibration Procedures. NOCSAE Doc. 101-00m02

Headforms

Headforms are necessary for testing and development. Headforms may be impacted without injury and give consistent results. Choosing the proper headform is essential to any protector design or testing. The anthropomorphic features, hardness, and energy-absorbing characteristics all affect test results. Comparison of the results on the test headform with those actually achieved on the human head are essentia1. [132, 133] The Canadian headforms, which are based on actual physical and radiologic measurements of thousands of heads, [134] are better proportioned for eyewear testing and design than the commonly used US head forms (Alderson 5, 50, and 95 percentile), which are based on projections made from measuring a sample of military men. NOCSAE revised its test forms with anthromorphic measurements based on CSA data.

Equipment Certification Councils

Some manufacturers lie and falsely advertise that products pass a standard, when—in fact—they do not. Major manufacturers of industrial [135] and sports eyewear fall into this category. Sports protectors, certified by the manufacturer to meet the standard specifications of ASTM F803 (in advertising, with hang-tags, and labeling on the packaging), have not met the standard specifications when I and others have tested them, and one that failed resulted in significant injury to a racquetball player. In the United States, manufacturers made certain that the ANSI Z87 industrial standard allows the manufacturer alone to certify that their products conform to the standard specifications. In Canada, the CSA acts as both the standards writer and the certifying agency for industrial and sports protectors—a far better system for the safety of the users.

Figure 8 Certification seals

It is only certification, or documented testing by a certified test laboratory, that gives the user the assurance that the protector will afford reasonable protection. A sports equipment certification council is composed of coaches, participants, scientists, physicians, manufacturers, and administrators. Its purpose is to seek out and select codes and standards, including test methods and procedures, for equipment used in athletic, sporting, recreational, and leisure time activity. In addition, the council identifies and publishes all factors associated with safety, whether it be protective equipment, playing surfaces, rules, attitudes, officiating, training, conditioning, and administration. [136] The Council will usually have a seal **(Figure 8)** that manufacturers affix to a protective device that is assurance to the consumer that a product meets the specifications of a performance standard (***Figure 9***).

HECC

The Hockey Equipment Certification Council (http://www.hecc.net) is an independent, nonprofit organization that was established in 1978 through the joint efforts of the Amateur Hockey Association of the United States and a number of interested volunteers. HECC certifies ice hockey equipment, including helmets and face shields; selects codes and standards to certify playing equipment and facilities; monitors the effectiveness of its certification program; and promotes research pertaining to the prevention and reduction of ice hockey injuries. HECC is extremely effective in fulfilling its mandate of reducing injuries in hockey.

PECC

The Protective Eyewear Certification Council is unfortunately not operating at this time (May 2010). When it was operational, PECC certified protectors complying with ASTM standards (except for ice hockey). Since the infrastructure is in place, it should be easy to get up and running—if the manufacturers and sports officials will cooperate and support the program.

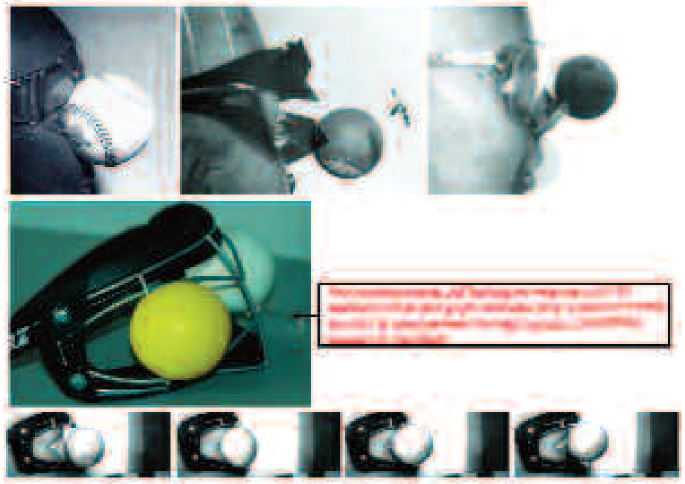
CSA

The Canadian Standards Association (http://www.csa.ca) certifies products complying with the Canadian racquet sport and ice hockey standards, which are similar to the ASTM standards.

Certified testing laboratories

Although not true certification councils, certified testing laboratories are a good option for the eye care professionals, sports officials, and users to be certain the protector meets standard requirements. A testing laboratory must be able to provide evidence of the successful completion of the American

Figure 9. Buyer beware of uncertified products, advertised for sports, that do not protect.



Each of these products was advertised as a protective device for the sports depicted (baseball, squash, women's lacrosse). None of the major US distributors of these products would produce evidence that the product was tested by an independent laboratory, but gave assurance that "rigid tests" were done by the manufacturer. Each product failed when tested to ASTM F803 for the advertised sport. None of the manufacturers recalled their product when informed of the test results.

The women's lacrosse "protector" (row 2) allowed lacrosse balls through right and left eye openings with little finger pressure, despite the centrally placed hang tag with the false claim of compliance to the standard specifications of ASTM for women's lacrosse. When actually tested to the standard, motion analysis revealed severe eye contact with the lacrosse ball (row 3).

Association for Laboratory Accreditation (A2LA) (http://www.a2la2.net/) evaluation process to perform the tests that are specified in the standards. A manufacturer should be able to supply a test report from an A2LA certified laboratory on request from any potential user of their product.

Obsolescence in Protective Equipment

Protective equipment is obsolete when it no longer provides adequate protection, cannot be purchased under normal circumstances, is no longer in the desired style, is unreconditioned "hand me down" equipment, or is worn out, broken, or ill-fitting. [136] As injury data result in standard modification, certification councils must publish a list of equipment that has become obsolete by newer advances, and this obsolete equipment must be discarded.

Guidelines for Sports Participation

The American Academy of Pediatrics classifies sports into three main categories (contact/collision, limited contact/impact, and noncontact) [137 138, 139] and suggests that some sports are contraindicated for the one-eyed participant. The traditional contraindications to athletic participation are more appropriate to the systemic, musculoskeletal, cardiac, respiratory, paired-organ and central nervous systems than to the eye. Whereas musculoskeletal injuries and cerebral concussions are inevitable in contact/collision sports (such as rodeo) and are rare in noncontact sports (such as golf), eye injuries may be more common and severe in the "safer" sport. The recommendations of the American Academy of Pediatrics may be considered over-restrictive as society becomes more aware of the civil rights of athletes and the need to allow the handicapped to participate in sports. [140-142] It is apparent that more realistic guidelines for participation in sports by persons with various ocular handicaps and ocular diseases could be devised. Although such a list is dependent on reliable injury data that are not available at this time, there was sufficient information for the International Federation of Sports Medicine to release a position statement on eye injuries and eye protection in sports, which should help reduce eye injuries worldwide. [143]

The one-eyed athlete

Severe eye injury to a child can result in posttraumatic stress disorder, even if the vision is restored to reasonable levels after surgery. [144] The emotional, psychological, and legal impacts of severe eye injuries are often neglected but attention to them is essential in the management of all patients who have suffered severe injury—especially that involving the loss of an eye. [145] The risk of becoming blind is markedly higher for the amblyopic patient (1.75 ± 0.30 per 1,000) than for the general population (0.11 per 1,000 for children, 0.66 per 1,000 for adults). Trauma (work, sports, violence, accidents) causes over 50% of the resultant blindness. [146]

How can we define one-eyed? For the purpose of recommending extra safety precautions, a person is functionally one-eyed when loss of the better eye would result in a significant change in lifestyle owing to the poor vision in the remaining eye. [147] A person certainly should be considered functionally one-eyed if his or her best-corrected vision in the involved eye is 20/200 or less, with the other eye found normal by an ophthalmologist. On the other hand, most of us would function fairly well with 20/40 or better vision in the remaining eye. More difficult is advising patients with between 20/40 and 20/200 best-corrected vision in the affected eye. The loss of the ability to drive a vehicle legally in most states would be a handicap to most persons. The inability to drive would significantly interfere with the jobs available to a youngster when he or she is older, and studies would be more difficult throughout the school years. Therefore, a child should be considered functionally one-eyed when the best corrected vision in the poorer eye is less than 20/40, and an adult is functionally one-eyed if he or she believes the level of vision in the poorer eye would interfere with life or livelihood if the better eye were lost. [148] Functionally one-eyed athletes (and their parents in the case of minors) must be well informed of the potential long-term consequences if the better eye were lost. They should also be informed of the risks of injury (without and with various eye protectors) and the possibility of repair of injuries typically seen with the sport in question.

It is only by full discussion of the potential serious long-term consequences of injury to the better eye that the ophthalmologist, the athlete, and the parents can agree on the wisdom of participation in a particular sport as well as the level of protection necessary for the better eye. The most effective protection is possible only when the athlete understands the risks and is anxious to cooperate in the effort to protect the eyes while still allowing participation and enjoyment of the preferred sport. Having the athlete wear an occluder over the better eye for several days will allow him or her to better evaluate the ability to function with the poorer eye. Usually, if the athlete is sincere and honest with himself or herself, it is fairly easy to reach agreement among the athlete, parents, ophthalmologist, and sports officials as to whether the athlete is functionally one-eyed.

As protective devices improve and effective sports eye protectors are developed, more and more sports become quite safe even for the one-eyed athlete. [149] The division of sports into contact/collision (boxing, field hockey, football, ice hockey, lacrosse, martial arts, rodeo, soccer, wrestling); limited contact/impact (baseball, basketball, bicycling, diving, high jump, pole vault, gymnastics, horseback riding, ice and roller skating; cross country, downhill, and water skiing; softball, squash, handball, volleyball), strenuous noncontact (aerobic dancing, crew, fencing, discus, javelin, shot put, running, swimming, tennis, track, weight lifting), moderately strenuous noncontact (badminton, curling, table tennis) and non-strenuous noncontact (archery, golf, riflery) [150] tells little of the risk of eye injury. From an eye injury perspective, it is far more dangerous to play badminton (moderately strenuous noncontact) without an eye protector than to play ice hockey (contact/collision) with a full-face mask.

Any banning of athletic participation in certain sports should be based on guidelines using an experiential framework rather than tradition or anecdote. [151] The athlete deserves a true discussion of the risk of eye injury involved in a chosen sport. The outright ban, by some schools, of the one-eyed from participation in collision and contact sports, while the one-eyed students are permitted to play more dangerous (to the remaining eye) sports, such as tennis, is not prudent and should be reevaluated. Unless the athlete is especially gifted in a particular sport, or has psychological reasons to participate in a chosen sport, a safer sport (e.g., track and field, gymnastics) should be encouraged and will usually be chosen. The American Academy of Pediatrics recommendations now take into account that with adequate protection, the one-eyed may participate in most sports. [150] The medical/school committee should specify that the one-eyed athlete follow the safety guidelines presented in this text or modified in the future.

At this time, the only sports absolutely contraindicated for the functionally one-eyed are boxing and full-contact martial arts, since the risk of serious injury is very high and there is no known effective eye protector. Wrestling and the non-contact martial arts, while they have a lower incidence of eye injury, also do not have effective eye protection available and should be strongly discouraged for the functionally one-eyed and banned for the monocular athlete. If the player, parents, and possibly their lawyers are persistent and insistent after an informative discussion, they should be required to sign appropriate waivers as dictated by the school committee. The waiver has a dual purpose: it helps ensure that the athlete will wear appropriate protective devices for practices and games, and it often affords the only possible legal protection for school committees and members of sports-medical committees faced with the dilemma of the one-eyed athlete who insists (or whose parents insist) he or she play a sport with high risk of eye injury, such as wrestling, for which there is no adequate known protection. The best medical advice says that the functionally one-eyed athlete should not, but it seems that there may be confusion in the law. [152] The Massachusetts law reads, "the health and safety of each student must be paramount in every phase of the instructional physical education program," and also "each school shall provide equal opportunity for physical education for all students." [153] Federal law states, "students who can participate in regular physical education programs for all or some aspects of physical education must be placed in such programs." [154] The physician becomes hard put to prove that he or she is not discriminating against the handicapped by excluding the one-eyed student from some sports. [155]

From a performance standpoint, the one-eyed can usually function quite well in most sports, adding very little risk to cause other injuries because of the monocular condition. Ocularists (makers of prosthetic eyes), who deal with many one-eyed people, are aware of this fact; [156] however, ocularists should also have expertise in available eye protection and give appropriate recommendations to the patient. The reinforcement of the protective message is very important. If the athlete is informed of the need for protection, and also given specific advice by the ophthalmologist, optometrist, optician, [157] and ocularist, there is a far greater likelihood of protection compliance.

Protective devices

Fortunately, most sports-related eye injuries are preventable with properly designed equipment. The following is a practical guide for sports eye protection so that persons whose responsibilities involve the eye in athletics can easily determine the protective equipment they should recommend or provide. [158] A protective device should prevent damaging forces from reaching the eyes by dissipating potentially harmful forces over time and area. This theory is simple enough, but the practical application can be difficult. As soon as design is begun on a protective device for a sport with an ocular hazard, many problems arise. What forces are involved in this sport? Are they high-velocity, low-mass (hockey puck); low-velocity, high-mass (player sliding into a goal post); or a combination of high-velocity and high-mass (bicycle racer collision)? Does a protector have to be designed differently for each type of force? How? Where on the head will the forces be transmitted, and how will it be done? Will the player be killed or suffer brain damage if the force is transmitted to his or her brain through the protective device, rather than being dissipated into broken facial or orbital bones as was the case before the protector? Will the protector change the form or appeal of the game? What about the design, player acceptance, expense, weight, interference with vision, product liability, and full disclosure to the consumer?

These questions cannot be answered by any one individual, since expertise at many levels and different areas of interest is required. The best way to design and build a protective device is by the development of a performance standard as discussed above.

Various kinds of eye protection and different brands of sports goggles vary significantly in the way they fit. An experienced ophthalmologist, optometrist, optician, or athletic trainer can help an athlete select appropriate protective gear

Table 9 Recommended Eye Protectors for Selected Sports

	Minimal Eye Protector	Comment
Baseball/Softball Youth Batter/Base Runner	ASTM F910	Face guard attached to helmet
Baseball/Softball, Fielder	ASTM F803 for baseball	ASTM specifies age ranges
Basketball	ASTM F803 for basketball	ASTM Specifies age ranges
Bicycling	Helmet plus: Streetwear ANSI Z80, industrial ANSI Z87.1, or sports ASTM F803 eyewear	Use only polycarbonate or Trivex lenses. There are excellent plano industrial spectacles that are inexpensive and give good protection from wind and particles
Boxing	None available. Not permitted in sport.	Contraindicated for functionally one-eyed
Fencing	Protector with neck bib	
Field hockey (both sexes)	Goalie: full face mask others ASTM F2713 for field hockey	
Football	Polycarbonate eye shield attached to helmet-mounted wire face mask	
Full-contact martial arts	None available. Not permitted in sport.	Contraindicated for functionally one-eyed
Ice hockey	ASTM F513 face shield on helmet HECC or CSA certified full face shield	
Goaltenders	ASTM F1587 face shield on helmet	
Lacrosse, Men's	NOCSAE face mask attached to lacrosse helmet	
Lacrosse, Women's	ASTM F803 for women's lacrosse	Should have option to wear helmet with attached face mask
Paintball	ASTM F1776 for paintball	
Racket Sports: (badminton, tennis, paddle tennis, handball, squash, racquetball)	ASTM F803 for specific sport	
Soccer	ASTM F803 for any selected sport	Eye protectors that comply with ASTM F803 for any specified sport are recommended
Street Hockey	ASTM F513 Face mask on helmet	Must be HECC or CSA certified
Track and Field	Steetwear/fashion eyewear	Use only polycarbonate or Trivex lenses
Water Polo, Swimming	Swim goggles with polycarbonate lenses	
Wrestling	No standard is available	Custom protective eyewear can be fabricated, but no standards available. Not recommended for functionally one-eyed.

For sports in which a face mask or helmet with eye protector is worn, functionally one-eyed athletes, and those with previous eye trauma or surgery for whom their ophthalmologists recommend eye protection, must also wear sports protective eyewear which conforms to the requirements of ASTM F803.

that fits and looks well. The best-designed protective device, if it does not appeal to the tastes of the player, will remain on the dealer's shelf. Sports programs should assist indigent athletes in the evaluation process and in obtaining protective eyewear.

Criteria for protective eyewear:

1. Proper fit is essential. Protective eyewear will only be worn if it is comfortable and allows good vision. Helmets should have a properly fastened chin-strap for optimal protection. The athlete should be fit with a protector that feels comfortable and fits snugly. A good test for a snug fit is to lightly run a finger around the perimeter of the eye protector. There should be no gaps large enough to permit the finger to lightly touch the eye. The user should compare several protectors for comfort, vision, and fit. Anti-fog treatment is often factory applied or may be applied by the user.

2. Protectors with clear lenses (plano or prescription) should have impact-resistant polycarbonate or Trivex lenses. If for some reason, a polycarbonate or Trivex lenses cannot be used, the athlete who participates in an eye-risk sport should either: (1) wear contact lenses plus an appropriate protector as listed in **Table 9, Figure 11** or (2) wear an over-the-glasses eyeguard

that conforms to the specifications of ASTM F803 for sports for which an ASTM F803 protector is recommended.

3. For sports requiring a face mask or helmet with an eye protector or shield, functionally one-eyed athletes should also wear sports eye protectors that conform to the requirements of any sport specified in ASTM F803 to maintain some level of protection if the face guard is elevated or removed (as in ice hockey or football by some players on the bench).

4. Contact lenses offer no protection. Therefore athletes who wear contact lenses must also wear appropriate eye protection.

5. Athletes must replace sports eye protectors that are damaged or yellowed with age, because they may have become weakened.

Classification of sports eyewear

Sports have very different eye, face, and head-brain risk, and thus require specifically designed protective equipment, The equipment can be classified into:

1. A helmet with an integral face protector for sports that combine very high energy with a significant potential for eye contact (football, men's lacrosse, youth baseball batter/base runner, baseball catcher, polo, ice hockey, automobile and motorcycle racing, downhill ski racing).

2. A helmet with separate eyewear for sports with a significant brain injury potential, but less potential eye contact (riding a bicycle, horse, or motorcycle). Note: many motorcycle, and some bicycle activities require a helmet with an integral face protector.

3. A face-supported protector for sports that have significant eye and face danger, but less potential for brain injury (paintball, fencing, baseball behind-the-plate umpire.

4. An eye protector that conforms to the requirements of ASTM F803 for sports that pose mainly an eye injury risk (racket sports, basketball, women's lacrosse, field hockey, baseball fielders. It is recognized that baseball, women's lacrosse and field hockey also have head and face injury potential, but, other than the helmet mounted face protectors for youth baseball batters, base-runners, and catchers, full face protection has not been accepted by most players and sports officials of these sports.

5. Eyewear that conforms to the military fragment or the high velocity ANSI Z87 test requirements for the shooting sports.

6. Fashion eyewear when there is negligible eye injury risk. There are several types of clear material (glass, allyl resin, high-index plastic, acrylic, polycarbonate, and Trivex) from which prescription or non-prescription (plano) lenses may be fabricated. Polycarbonate and Trivex are the most shatter resistant lens materials and are recommended for all eyewear.

Sunglasses for sports

The improper choice of sports sunglasses may be hazardous and degrade visual performance. [159] Both visible and ultraviolet light can result in eye injury, which may be minimized with the use of appropriate sunglasses. It is controversial whether or not short-wavelength visible (<510 nm, blue) light increases the tendency to macular degeneration, but there is evidence that chronic exposure to sunlight is associated with the development of early age-related maculopathy. [160-163] Exposure to ultraviolet light causes cataracts, [164-168] corneal changes (climatic droplet keratopathy, pinguecula, pterygium, and acute photokeratitis),[169-171] uveal melanoma, [172, 173] premature skin aging and sunburn, [174] skin cancers (basal cell carcinoma, squamous cell carcinoma, melanoma) [173, 175] Even relatively brief exposure to viewing the sun when high in the sky (zenith above 60%) may result in solar retinitis due to photochemical injury from intense short wavelength (blue) and UV radiation. [176-178] Many clinicians have the impression that herpes simplex keratitis and recurrent corneal erosion may be precipitated by exposure to sunlight.

Reflected UV light also must be considered. Fresh snow reflects about 80%, older snow over 50%, clean white sand about 30%, water 5%, and earth and grass less than 5% of the ambient ultraviolet light. Thus the greatest UV light exposure occurs at high altitude on a field of fresh snow. Mountaineers, skiers, sailors, and lifeguards, are exposed to large doses of visible and ultraviolet light, at times in situations in which there is the potential for injury from impact, in adverse conditions of high wind or dust. The inability to see well because of photokeratitis, windburn, corneal foreign bodies, or traumatic injury from shattered spectacles may be life threatening as well as eye threatening, therefore the proper choice of sunglasses is essential. Dark sunglasses permit one to be comfortable in bright light without squinting. However, one must be certain that the glasses have adequate absorption in the toxic UV and blue light ranges. [179] Wearers and those observing them should be aware that the reflection from the front surface of mirrored sunglasses may result in severe sunburn to the nose unless extra protection is used. [180]

Sunglasses are especially important for those who have had cataract surgery. Removal of the lens of the eye exposes the retina to wavelengths above approximately 300 nm. In the 325 and 350 nm UV radiation range, the retina is approximately six times more sensitive to damage than to short wavelength visible radiation of 441 nm. Since untreated polymethyl methacrylate intraocular lenses (IOL) absorb UV radiation only below 300 to 320 nm; [160] many intraocular lenses, classified as UV protective, offer less than optimal protection; [181] and it is not known how long the UV filter on UV absorbing IOLs lasts, it is prudent for all aphakic or pseudophakic athletes to wear sunglasses that absorb 99% of light below 470 to 500 nm.

Athletes who want maximum UV light protection should wear a hat with a brim, which reduces ocular exposure by half, [182] and close-fitting sunglasses that absorb UV when in conditions in which they could get sunburned. [183] There is considerable variability in the quality of sunglasses [184] that is of concern in children's sunglasses [185] since children frequently spend more time in the sun; damage to the lens (and possibly retina) from UV is cumulative, and the crystalline lens of children transmits more short-wavelength visible radiation and UV light to the retina than does that of the adult. [160]

Even with darkly tinted glasses, there is no way to predict by gross visual inspection which lenses effectively filter reasonable quantities of the near infrared light (700 to 800 nm) and near UV light (300 to 400 nm) that are not visible to the

Figure 10. Safety Recommendations

1. Eyewear should be fabricated with highly shatter-resistant polycarbonate or Trivex lenses unless there is a specific reason for another lens material. Children, functionally one-eyed people and active adults require polycarbonate or Trivex lenses.
2. For sports that have the potential for eye contact, use eyewear that is certified to ASTM F803 (racquet sports, women's lacrosse, baseball, and basketball) or ASTM F2713 (field hockey). For other sports, such as soccer, protectors should meet or exceed ASTM F803 standard specifications for squash. Prescription sports eyewear requires 3-mm-thick polycarbonate lenses
3. Sports with high impact, such as ice hockey, men's lacrosse, and youth baseball (batter/base runner) require a face shield mounted on a helmet designed for the sport. Paintball protectors must conform to the requirements of ASTM F1776.
4. People working with exposure to flying chips or with power tools should use protectors that meet ANSI Z87.1 specifications. Goggles are the safest. Only polycarbonate or Trivex lenses should be used.
5. Many workplace activities, such as using a chain saw, require, in addition to safety glasses or goggles, a helmet with a face shield designed for the activity.
6. Sunglasses should conform to the above safety recommendations. Sunglasses lenses should attenuate blue light, which is potentially hazardous to the macula. Gray, amber, or brown lenses are preferred. Blue-colored sunglass lenses that transmit blue light should not be used.

human eye. Cost, color, and lens composition are unreliable indicators of adequate filtration. In one study, 53% of glass and 11 % of plastic lenses had an unfavorably high near UV light transmission peak greater than 25%. [186] Eighty percent of the amount of infrared light present in daylight is transmitted to the retina. Although the infrared light present in daylight is not toxic in itself, some believe that infrared light may contribute to damage from UV light and lower wavelengths and may contribute to ocular discomfort of fatigue. Since infrared light contains no useful visual information, it is probably wise to filter it out. [160] UV light absorption is quite different for various lens materials. [187]

The vast majority of sunglasses sold for sports use are deficient in impact resistance. A sports sunglass should prevent rather than contribute to injury. The combination of lens and frame must prevent ocular contact by either the missile or the sunglass lens. Manufacturers should state the sports for which the sunglass is intended. Safety requirements are the same as for protective eyewear with clear lenses. Manufacturers should be required to provide the following information, in a statement easily understood by the consumer, on all sunglasses sold for use in sports: the standard specifications to which the sunglass conforms, the percent of visible light transmitted through the lens, the percent of UV light and infrared light (wavelengths specifically stated) transmitted through the lens, additional treatments or coatings (for example, polarization) to reduce glare.

The ideal sports sunglass should have the following characteristics:

- UVB (280-315 nm)—less than 5% transmittance; less than I % transmittance for wavelengths less than 310 nm.
- UVA (315-400 nm)—less than 10% transmittance, and absolutely less than maximal visible light transmittance; for aphakes, less than 1 % transmittance.
- Blue light (400-500 nm)—less than 10% transmittance and absolutely less than the maximal visible light transmittance. A blue light transmittance of 25% to 50% of the peak visible transmittance would be desirable.
- Long wavelength visible light (500-760 nm)—less than 15% transmittance for bright conditions, such as sand or snow.
- Infrared (above 760 nm)—filtration desirable but not essential.
- Allow color discrimination sufficient to recognize traffic signals.
- Have side shields and either a rim across the top or be used in conjunction with a brimmed hat to protect against oblique incident radiation in very bright conditions.
- Have the option of polarization to decrease glare from water for fisherman and boaters.
- Have aerodynamic efficiency to combat the drying effects of wind in speed and wind sports (e.g., cycling, yachting, mountaineering, skiing).
- Be lightweight. Heavy sunglasses will tend to fly off the face with rapid changes in head position.
- Have cosmetic acceptability.
- Be impact resistant, consistent with the intended use.

These recommendations point to dark amber polycarbonate or Trivex lenses (although lighter shade lenses could be used if the user wore a brimmed hat). [178, 179]

How Do I Know What to Buy, Prescribe or Dispense?

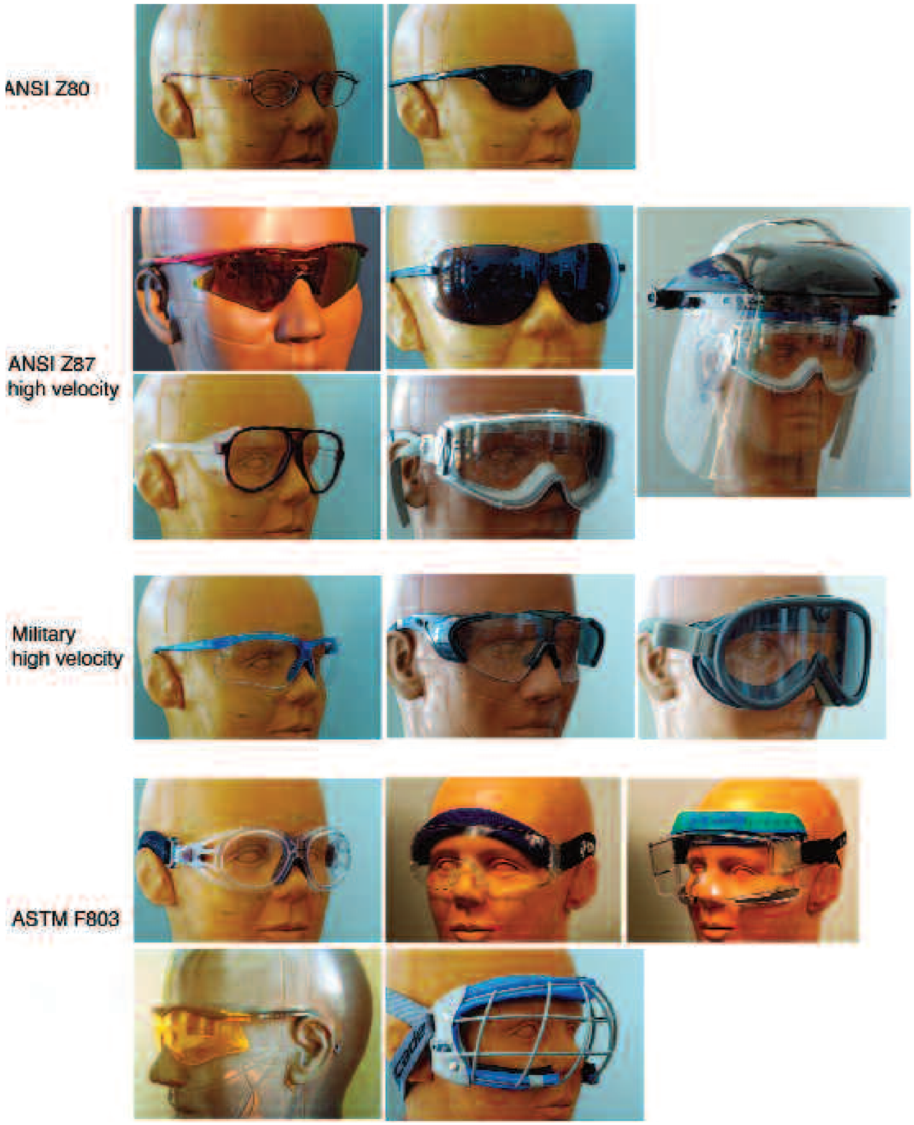
It could be disastrous to buy, prescribe or dispense what you believed was protective eyewear and then have the eyewear fail. Compounding the problem is the fact that some manufacturers make "sports" eyewear that do not conform to safety standards ***(Figure 9)***, and that most ophthalmologists and consumers do not know what protection standard should apply for a specific activity.

The safest way to choose an eye protector is to look for a certification seal **(Figure 8)** to assure that the protector has been tested by an accredited laboratory to a specific safety standard.

The spectacle prescription will be clear to the optician if the note—*Polycarbonate or Trivex lenses are required for children, functionally one-eyed people and active adults*—is printed on the front of the prescription.

Although a fashion eyewear frame has little impact resistance, it is far better to have a lens that is shatter resistant in front of the eye than risk a lacerated globe from a shattered

Figure 11. A summary of protective eyewear



ANSI Z80 Fashion eyewear. Use only with polycarbonate or Trivex lenses. OK for eye safe sports and dress eyewear.

ANSI Z87+ Industrial eyewear and sports eyewear that passes the Z87 high velocity test must bear the Z87+ mark. Goggles are safer than spectacles when there is the potential for flying particles (grinding) or for use with chemicals. Z87+. Spectacles or goggles are ALWAYS worn under a face shield, when a face shield is required for safety. These protectors are satisfactory for sports with no ASTM standards, such as Frisbee or cycling, and are a good choice for daily-wear sunglasses. Never for paintball.

Military eyewear and industrial or sports eyewear that passes the military fragment high velocity test. Military eyewear is not available to the general public, but other eyewear that passes military tests is good for shooting and hunting.

Eyewear certified to ASTM F803 or F2713 must be certified by an A2LA accredited laboratory for the specific sport. Necessary for sports covered by ASTM F803 (racket sports, women's lacrosse, basketball, baseball) or ASTM F2713 (field hockey). ASTM F803 protectors are adequate for soccer. Available for prescription eyewear (upper left) for use over Z80 eyewear (upper right), as a polycarbonate eye shield (top center) or wire (bottom center), and as a plano spectacle with interchangeable lenses (clear, yellow, and gray) for sunglass use.

lens. It is almost certain that the eye care professional who dispenses or prescribes a spectacle lens that shatters easily will be sued if the shattered lens results in significant injury. Therefore it is prudent to prescribe, dispense, and wear eyewear with extremely shatter resistant polycarbonate or Trivex lenses. To test the strength of these lenses, try to break them with a hammer.

Safety recommendations on Rx pad

Recommendations, printed on the reverse side of all spectacle prescriptions, should help the patient choose appropriate protective eyewear ***(Figure 10)***.

Contact lenses

Because contact lenses offer no protection from impact, it must be stressed to patients that protective devices, where indicated, should be worn in addition to the contact lenses. Patients who request contact lenses for sports use deserve a few minutes of discussion of injury prevention. [188]

Despite the fact that contrast sensitivity may be decreased with daily wear soft lenses, [189] contact lenses, especially for people with large prescriptions, do offer advantages for many sports—better visual field, no fogging, and staying in place with rapid motion. Lens technologies that combine the excellent visual acuity of rigid gas-permeable contact lenses with the comfort and retention characteristics of soft lenses are preferred by many athletes, especially those with astigmatism. [190] Large-diameter (15.5 mm) and scleral (18-24mm) soft lenses are available for athletes who cannot wear standard soft or rigid gas-permeable lenses because of decentration with sports activity. [191-193]

Many sports are played in environments that make contact lens wear more difficult because of increased exposure to water, wind, sun, dust, and dirt. The use of wraparound polycarbonate sunglasses over the contact lenses frequently allows the mountain bicycle racer to have the benefits of contact lens vision in the face of wind and debris. For sports, such as ice hockey, in which low humidity may be encountered, low-water, low-soiling, low-dehydrating, larger-diameter, thin, soft contact lenses, seem to give satisfactory results. [194] Wind, dry air, UV light, and decreased oxygen at high altitude often cause punctate keratitis in skiers and mountaineers. [195-197] Skiers who wear contact lenses should be encouraged to wear goggles that absorb UV light and break the wind. If contact lens wear becomes impossible, spectacles could save an otherwise ruined vacation.

RISK OF EYE INJURY AND EFFECTIVENESS OF PROTECTIVE DEVICES

In this section, sports are arranged roughly according to the size of the potential impacting object. Data estimating the participant demographics in selected sports activities have been gathered by the Sporting Goods Manufacturers Association (SGMA). [34]

Small, Penetrating Projectiles

Penetrating projectiles, mostly shrapnel, shotgun pellets, BBs and air rifle pellets, fishhooks, and shattered eyewear lenses, have the highest ratio of eyes lost to injured eyes, yet these injuries are relatively easy to prevent. Street-wear spectacles with polycarbonate or Trivex lenses would stop most fishhooks. Plano industrial ANSI Z87+ eyewear gives adequate protection from BB and air gun pellets. Military eye armor will stop most small land-mine and small artillery fragments. Industrial eyewear that passes military standard specifications would stop most shotgun pellets.

BB's and air rifles

Considering that competitive air gun shooting is a safe sporting activity, with no reported injuries to any competitor, it is reasonable to conclude that injuries related to BB guns and air guns are secondary to inappropriate and unsafe use of the equipment. If BB guns and air guns are viewed in their proper role as sports equipment, and used safely with appropriate supervision, the injury problem can virtually be eliminated.

There are no reliable participation data for non-target-shooting air rifle and BB guns, but there are many air guns in circulation. In the Chicago area, 6% of families that included at least one three-year-old child and 11% of families with a boy between the ages of 10 and 14 years owned an air gun. [198]

Yet, eye injuries related to the shooting of BB guns and air guns have been a source of concern and frustration for ophthalmologists. Despite the recommendations of Canadian ophthalmologists, non-powdered firearms were excluded from the Canadian Firearms Act of 1995—and still have not been included in 2003. [199, 200] BB or pellet guns are responsible for 5.13% of all injuries in the USEIR database. [201] There is no information as to the injury incidence. What is known is: approximately 3 million air guns were sold in the United States in 1980; there are about 31,500 BB/pellet-gun-related injuries every year, of which about 2,000 are hospitalized; and 80 % of the injuries occur in the 5-14 age group. [202] Unsupervised access to air guns and unstructured gun use are the principal risk factors for ocular injury. The victims were most likely to have been shot unintentionally shot by a male friend at the friend's home, using the gun for a purpose other than target practice, using it without adult supervision. [203, 204]

Gas-propelled guns have three primary methods of propelling the projectile: (1) A spring-piston air gun, when cocked, draws air into a cylinder and tensions a spring, When the trigger is pulled, the spring pushes the piston forward, compressing the air that fires the projectile at muzzle velocities up to 600 ft/s. (2) Pneumatic air guns compress air that is released when a valve is opened on trigger depression. The multiple pump compression system, introduced in 1972, achieves the higest velocities—more than 900 ft/s. (3) Compressed-CO2 guns have typical muzzle velocities in the 400 to 500 ft/s range. [202, 205, 206] The velocity loss of a BB over a typical 20 foot firing distance is negligible. A BB starting at 260 ft/s loses only about 1 ft/s velocity per foot of distance traveled. [207] The original, inefficient "toy" BB guns, with smooth barrels that were larger than the missile have been replaced with air guns with rifled barrels, tight-fitting missiles, and pneumatic chambers that can be pumped to dangerously high levels. Technology has converted a "toy" into a potential weapon with the ability to kill. [205 208]

Despite advances in surgical technique, [209] the majority of eyes perforated with pellets or BBs suffer permanent visual loss, with many resulting in enucleation. [204, 210-213] Most (77%) of the patients are in the 7-14-year age group, and almost all the others in the slightly older 15-24-year age range. Forty percent of injured eyes become legally blind, and 12.5% to 18% are enucleated as a result of the injury, which most commonly occurs at Christmastime to unsupervised children, often from ricochets from improper (hard) target backstops. Complete blindness may occur from sympathetic ophthalmia affecting the uninjured eye. [214-216]

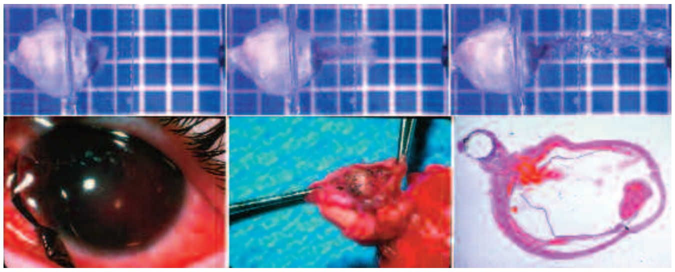
Injuries secondary to BB guns and air guns were the principal diagnosis in 16.6% (4,982 cases) of eye injuries resulting in hospitalization in the United States between 1984 and 1987. [217] BBs caused 8 of 48 perforating (through and through) injuries to the globe. The fact that BB perforating BB injuries have a poor prognosis is due to the tremendous force transmit-

Table 10. Comparison of Injuries From BB Gun by Type of Gun and Muzzle Velocity

Muzzle Velocity (ft/s)	Eye Injury from BB	Hits Ground (ft)*	Type of Gun
0	None	0	
44	Iritis, abrasion, hyphema	24	
205	Injury at vitreous base	115	
236	Penetration of globe	132	
350	Deep tissue penetration		Spring-powered BB gun
408	Skin, bone, moderate tissue	228	
410			Pump BB gun—2 pumps
454			Pump BB gun—4 pumps
680	Through orbit into brain	347	
710			Pump BB gun—10 pumps

* Distance from gun muzzle that BB hits ground when gun is fired parallel to the ground at a height of 5 feet above the ground.

Figure 12. BB perforation of human eyes



Top: BB perforation of human cadaver eye. Continuation of Figure 1a-c. BB moving right to left at 92.0 m/s (301.8 ft/s; 0.58j). Note continued extrusion of intraocular contents after BB has passed through posterior sclera. *Courtesy of Stefan Duma and joel Stitzel. Virginia Tech Impact Biomechanics Laboratory (duma@vt.edu).*

Bottom: BB perforation of a child's eye through lamina cribrosa into optic nerve sheath. *Courtesy Ann Bajart.*

ted to the globe as it creates two blunt openings approximately 5 mm in diameter ***(Figure 12).*** [218] BBs were responsible for 16 of 222 ocular injury cases in patients admitted to a childrens' hospital. Six of the 16 resulted in blindness in the injured eye. [219] Twenty-three of 278 childhood traumatic eye injuries admitted to Wills Eye Hospital were the result of BBs. [21]

BB guns and air guns are not given the respect they deserve as potential weapons with blinding and killing power. [211, 220, 221] In 2001, NEISS estimated that 29,617 injuries from gas, air, and spring-operated guns were seen in U.S. emergency departments, of which 2,994 involved the eye. Of the total injuries, about two thirds were to children aged 14 or younger, and about one third of the eye injuries required hospitalization. [31] Patients that require hospitalization and surgical intervention from BB eye injuries have a high risk of enucleation. [213] Of 32 patients treated with surgical intervention at the Wilmer Eye Institute between 1970 and 1981, 22 had penetrating injuries from the pellets, 19 had their penetrated eyes enucleated, and the remaining three had vision worse than 5/200. [222] Of the 80 eyes removed due to sports-related injuries at the Massachusetts Eye and Ear Infirmary between 1960 and 1980, 36 were due to injuries from BB guns. [223]

A standard BB (0.345 g) will penetrate the globe at speeds higher than 236 ft/s (72,0 m/s) and result in injury at the vitreous base at an average speed of 205 ft/s (62.3 m/s). [47] Round, smooth, relatively light-weight BB's are prone to embolize if they enter the vascular system, with potential severe visual and systemic results. [202, 206, 224] Higher-powered general-purpose air rifles, advertised in children's magazines, may have muzzle velocities as high as 620 ft/s (189 m/s), which is well above the 408 ft/s (124 m/s) velocity required "for penetration of skin, bone, and moderate tissue, or if no bone is encountered, of skin and deep tissue." ***(Table 10)***

Since BB guns cannot be made safe and still have any utility, the only means of controlling injuries is to keep them out of the hands of unsupervised children and subject them to the same safety precautions and laws as apply to weapons using gunpowder (firearms). [201] Air and BB gun sales are closely controlled in New York City, [206] but are mentioned in the laws of only 28 states. Some of that legislation explicitly excludes them from consideration as dangerous weapons or firearms. [205] National legislation that specifically equates all guns with lethal potential as firearms is an essential first step in the educational process.

In future attempts to control BB and air gun injuries, several points must be considered:

(1) With supervision, BB and air-powered weapons can be safe training devices for children who will later move up to the responsible use of gunpowder-propelled firearms. BB injuries, deaths, and blindness will continue as long as children have the feeling they are playing with toys and the true danger of these weapons is not stressed or their use supervised. Because it has been shown that parents who allow their children to have BB or pellet guns appear to misperceive their potential for injury and allow their children to use the guns in an unsafe manner, [225] specific educational material should be available to the parent before purchase, and both parent and child should jointly take a gun-use training program before using the gun. [226] When parents purchase such a gun, they must recognize it is a firearm [227], dangerous both to the child using it and to innocent bystanders. The child must never be allowed to use the gun except under direct, personal supervision of the adult. [228]

(2) The immediate answer does not lie in the development of better surgical techniques. Our record for salvaging these eyes has been, and remains, quite poor. [204, 210, 214, 222, 229-232] As is the case of most eye injuries, the best way to prevent loss of vision from air guns it to prevent the injury from occurring. [203]

(3) The BB gun or air gun cannot be made safe. For a BB projectile to be beneath the kinetic energy of 0,03j that will result in contusion eye injury, the muzzle velocity would have to be reduced to 43 ft/s (13 m/s). When fired in the horizontal direction from a height of 5 ft, the BB would travel a mere 24 feet, 46 thus would appeal only to the most placid child. The child and the parent realize that an air rifle pellet contains more energy than an individual duck/pheasant shotgun hunting shot. ***(Table 11)***

(4) A major legislative battle to ban BB guns and air guns

Table 11. Target and hunting gun muzzle velocity and energy

	Total shot mass g	Number of projectiles	Individual shot mass g	Muzzle velocity	Total shot energy J	Individual shot energy J
Shotgun 12ga trap/skeet size 8	31.9	461	.07	1290	2465	5
Shotgun 12ga duck/pheasant	35.4	169	.21	1330	2912	17
Air rifle Pellet	0.51	1	0.51	950	21	21
Rifle 22 cal long rifle	2.3	1	2.3	1410	212	212
Rifle 7mm magnum	9.7	1	9.72	3110	4367	4367

would probably be ineffective even if won. There would be years of appeal on Constitutional grounds, and the extensive reservoir of several million BB guns and air guns would still be available to youngsters.

(5) Eye protectors are available which will give essentially total protection, but how do we get persons to wear them? The use of protective goggles, which several manufacturers package with the firearm, would prevent most ricochet injuries (26% of BB eye injuries) [204] to the user [233] but would not help the person usually injured—the one accidentally or intentionally shot by the person with the gun.

Thus, it seems we are presented with the hard truth. BB guns and air guns are widely distributed throughout the United States; they are dangerous; they cannot be recalled. In one study, more than 40% of BB and pellet eye injuries occurred when someone actually pointed the air gun at a person and pulled the trigger, showing a lack of respect for the dangers of air guns. [203] Therefore, our best means of decreasing eye injuries is by a massive educational campaign aimed at teaching the user to have the same respect for a BB gun or air gun as they do for a firearm. (Children are rarely injured with firearms—everyone knows you can get killed with a shotgun.) To emphasize that BB guns and air guns should be treated as firearms, legislation classifying BB guns and air guns as firearms is recommended.

The National Rifle Association (NRA) has committed its vast educational resources including its 25,000 NRA-certified instructors, to a stronger initiative in the area of air gun safety, particularly as it pertains to eye injury. This includes special air gun safety training programs for use by schools and other community agencies and organizations. The NRA has also revised its training material—used by millions of persons annually—to place a special emphasis on air gun safety, including coordination of safety programs with groups such as the Boy Scouts, the 4-H, and the American Legion. [234] There needs to be a more concentrated effort to make available community recreational facilities for persons who wish to shoot air guns in a supervised and safe environment, as well as an emphasis on parental responsibility and supervision of youngsters using air guns. [235] The Non-Powdered Gun Products Association (NPGPA), which has published targeting safety rules, should establish a certification council to ensure that BB guns and air guns meet the safety standards specified in the Standard Consumer Specifications for Non-Powder Guns (ASTM standards F589 and F590). Prospective studies are needed to evaluate the effectiveness of educational programs on the incidence of eye injuries.

It is time for a coordinated approach by the public, police, sporting associations, manufacturers and retailers, and politicians. [236] The impetus to start an effective process should come from the medical community since this is where both the greatest exposure to the problem and the greatest expertise in solving it are to be found.

Shooting

The shooting sports include hunting for game and birds with rifles and shotguns, shooting at stationary or moving targets with pistols or rifles (air or gunpowder), and downing clay discs (pigeons) with shotguns. The main participants in the shooting sports are males in their thirties with a concentration of veterans and relatively few beginners. About 19.1 million people hunted with a firearm in 2007. Only about 8% of the hunters were new to the sport in 2001, and nearly 60% have been involved 10 years or more. There is a relatively heavy cross-participation among gun users—64% of trap/skeet/clay shooters, 46% of rifle target shooters, and 37% of pistol target shooters are also hunters.

It is so rare for elite shooters to be cross-dominant that a right-handed shooter with a dominant left eye should be coached from the start of his or her career to shoot left-handed (or vice versa), since the dominant eye is more important than the dominant hand for shooting accuracy. [237-239] However, when one shoots right-handed for a lifetime, switching hands may prove inconsistent with good performance—even if the dominant sighting eye is lost in an accident. In these cases, a parallel sighting rib will allow trap shooters to use the non-dominant eye while maintaining the preferred shooting shoulder. It is usually stated that pistol shooters need 20/20 near visual acuity, for proper sight alignment, while elite rifle shooters usually need 20/20 distance acuity. [240, 241] However, I have found that most presbyopic shooters prefer to have the target blurred by no more than an add of +0.50 to +0.75 D, which makes the combined blur of sight and target approximately the best combination for both pistol and rifle. Shooting glasses frequently are tinted or polarized. Choice of tint varies among shooters, with waterfowl and snowfield hunters often having a preference for glare-reducing polarizing lenses and skeet and trap shooters tending towards brown, bronze, yellow or light gold tints. [242]

Although most firearms injuries are the result of intentional assault, [81, 243] and are thus largely unpreventable, there is also a potential for blinding ocular injury from target shooting and hunting accidents. Of the 590 gunshot eye injuries in the USEIR database, 541 (92%) were secondary to violence. The 39 injuries from sport shooting and hunting were serious (72% open globe, 21% enucleation or no-light-perception) and occurred mostly in males (97%) between the ages of 20 and 50 (79%). None of the injured shooters was wearing protective eyewear. Two of the seven injured target shooters were struck by fragments of the target (aluminum can) or casing from a misfired bullet; three were accidentally shot by another shooter on the range; and two were injured by the swinging arms of the clay/skeet throwing apparatus. Twenty hunters were accidentally shot, usually with a shotgun, by another hunter in their party. Two hunters were shot by the landowner for hunting while trespassing. Two elderly men (76 and 85) were injured by the gun on recoil, with one suffering dehiscence of a long-incision cataract wound by the telescopic sight that rebounded through his streetwear eyeglasses. Eight of the 32 injured hunters were not injured with a firearm; 3 cut their eye while cleaning a shot deer, 3 were hit by tree branches, and 2 were hit with wire used for towing or fences.

The primary way to avoid shooting eye injuries is by proper gun handling and shooting technique. In 1994, 32% of American households owned a shotgun or rifle, 25% owned a pistol, and 59% owned no guns. [244] Only 56% of gun owners have received formal training and 21% of gun owners keep a firearm both loaded and unlocked in the home. Appropriate gun storage (keep a gun locked, unloaded; store ammunition locked and in a separate location) and training would help to reduce firearm injuries. [245, 246] New York State requires that all first-time hunting license holders complete a hunter-education course. Of 125 incidents in which the injured hunter is mistaken for game (the primary contributing factor for gunshot injuries to hunters), 117 hunters (94%) were not wearing hunter orange. [247, 248] The time to start training for safe gun handling is in youth. A number of training programs, such as the Home Firearms Responsibility courses given by the NRA and safety pamphlets are available, but the best education is a good example set by responsible adults.

There is no currently available protective eyewear that can withstand the impact of a high-powered rifle bullet from long distances or shotgun pellets from within 15 yards. Yet, serious, [249-251] sometimes bilateral, [252, 253] eye injuries frequently occur with shots from longer distances, gunpowder blasts, [254] blank cartridges, [255] ricochets, and impacts with other objects (tree limbs, knives, wire) [201] that can be prevented with appropriate eyewear. Eyewear with polycarbonate lenses, integral side shields, and a retention strap is extremely effective in protecting the eyes from shotgun pellets in the very hazardous 15-40 yard range. [256, 257] Eyewear that passes both ANSI Z87+ and the much more stringent military ballistic test for eye armor [258] is readily available and inexpensive.

Archery

Archers with uncrossed eye dominance are more accurate when the bow is used without sights, but the use of sights seems to eliminate this effect. [259] Archery target shooting (longbow, recurve, compound or cross bows, with or without sighting aids) has a minimal eye injury risk.

About one in four archers were involved 10 years or more, and 29% of the archers were first time participants. Twenty nine percent of archers also hunted with a bow. The USEIR database includes three archery-related eye injuries. A six year old girl had an open-globe injury when shot with an arrow. Two male archers had contusion injuries (retinal detachment, retinal hemorhage), one, wearing streetwear glasses, was struck with the bow while shooting an arrow, the other was struck in the eye with the sighting tube that dislodged while shooting. Playing with bow and arrow is a significant cause of eye injuries in India. [28, 260, 261] and Norway. [262] Adult [263] and toy [264] bows and arrows have sufficient energy to penetrate through the orbit into the brain.

Suggested protection is eyewear with shatter resistant lenses for those archers who wear Rx eyewear. The functionally one-eyed should wear eyewear that passes ANSI Z87+ or ASTM F803. There are ASTM standards to assure that bows (F1832, F1880, F1544 F1363), scopes (F1753), cords (F1752, F1648, F1436), and arrows (F1889, F1435, F1352, F2031) are properly constructed. Bows and arrows should not be given to children for use as toys.

War

Although military injuries are not truly sports-related injuries, the same principles of prevention apply. Witnessing the results of monocular or bilateral blindness suffered by young men during the Vietnam War and realizing that a substantial percentage of war-related blindness is preventable provided my personal impetus for involvement in the prevention of traumatic eye injuries. The incidence of eye injuries increased with the development of war munitions—land mines, artillery shells, and bombs—that accurately disperse high-velocity shrapnel fragments among the targeted personnel. Between 6% and 9% of all Vietnam War injuries involved the eye, resulting in permanent visual impairment and blindness in thousands of American soldiers. [265, 266] Of all hospitalized casualties of the Yom Kippur War of 1973, 6.7% sustained ocular injuries, of which 24.4% were bilateral. [267] Ophthalmic injuries, usually caused by munitions blast fragments, [268] accounted for 13% (19/149) of all ground war casualties from October 17, 1990, to April 13, 1991 in Operations Desert Shield and Desert Storm. Although most troops were issued protective goggles, only three of the 92 U.S. soldiers with eye injuries were wearing them at the time of their injury. [269] None of the military who suffered eye injuries (6.8% of all casualties) in the Lebanon war were wearing eye protection. [270] Devastating eye injuries continued to be a major problem in Operation Iraqi Freedom where in a 33-month period (March 2003 through December 2005), of the 797 severe eye injuries treated, there were 438 open globe injuries (49 bilateral) and 116 eyes were removed (6 bilateral). These injuries were most commonly caused by explosions. [271] Iraqi chemical warfare with mustard gas resulted in keratitis, chronic blepharitis and decreased tear secretion in 48 victims. [272]

Between 1980 and 1993 there were over 27,000 deaths among the U.S. military personnel who served 28 million person hours on active duty, averaging approximately five deaths per day. Hostile action or war accounted for only 2% of the total while 60% died from largely preventable unintentional injuries that occurred during their day to day activities and off duty. [273] Most military eye injuries also were not combat related, but occurred from motor vehicle accidents, fighting, and occupational or sports activities. One in 58 eye injuries required treatment in a hospital. [274]

Laser weapons, small enough to be attached to an M-16 assault rifle, yet effective at a distance of more than 1 km, can produce blindness with a micro-second pulse of light from retinal burns and subretinal hemorrhage. [275] Laser eye protection can impact performance and color identification in protected military personnel. [276] Since huge numbers of civilians and military personnel will not have appropriate laser protection and may be exposed to blinding lasers mounted on rotary turrets attached to tanks or other military vehicles, there has been a plea from concerned physicians to ban the anti-personnel laser. [277, 278]

The need for a comprehensive eye protection program in the military cannot be overemphasized. [279] If eye armor had been worn by troops in the Vietnam War, it is estimated that 39% of the eye injuries collected by the Wound Data and Munitions Effectiveness Team would have been prevented. [280] In Iraq, many, but not all of devastating ocular and ocular adnexal injuries (most commonly caused by IEDs) would have been prevented by polycarbonate ballistic eyewear. [281, 282]

The military has a combat eye armor program underway that is well accepted and has prevented eye injuries. [283, 284] Since soldiers have occupational exposure to eye hazards that are comparable to those in civilian industry, [285] the military should enforce interventions to prevent work-related eye injuries that have been effective in preventing civilian occupational eye injuries. [286-288] Those who have had refractive surgery require the same eye armor that should be issued to all military personnel. [289] Protective sports eyewear should be issued to military personnel at risk for sports eye injuries.

Fencing

Although fencing is a relatively safe sport, two fatal injuries (penetration of a face mask ***(Figure 13)*** by a broken foil with intracranial entry through the orbit and penetration of the neck over protective bib) and a serious hand laceration with the side of the blade have prompted the formation of an ASTM committee on fencing safety, which wrote performance standards for fencing surfaces (F1543) and the impact attenuation properties of body padding and protective wear (F1631). Since the mask that permitted fatal penetration tested as "good," there is at least one known death that might have been prevented by stricter mask penetration requirements. There is a significant discrepancy between the "punch test," mandated by the International Federation for Fencing (FIE), which requires that a mask resist perforation by a conical punch (69N) and the force of a broken épée blade for an extension lunge from a stationary position on a hard stationary object (4,000N).

The breakage characteristics of foils are an important consideration. Better foils break with a relatively square end, although they almost always have one or two sharp, short protrusions and a small cross-sectional area at the break point (2.5 x 4 mm for foil, 1.5 x 5 mm for sabre, and 4 x 4 x 5 mm [triangular] for épée). [290] The rate of breakage is high. (A competitive fencer usually breaks six or seven blades a season and takes four to five weapons to a match.) Some experts believe that metal blades will someday be replaced with fiberglass or carbon-fiber blades, which would be lighter, have fewer breaks, and have less lethal-shaped break surfaces; others believe that metal blades can be improved with newer metallurgical techniques.

Figure 13. Fencing face mask

Darts

A lawn dart is about 12 inches long with a heavy metal or weighted plastic tip on one end and three plastic fins on a rod at the other end. Although the tip may not be sharp enough to be obviously dangerous, these darts, even when thrown underhand, can penetrate the skull and the eye. Lawn dart injuries have a 4% fatality rate and account for an estimated 675 emergency department visits per year; head injuries account for 54%, eye injuries 17%, and face injuries 11%. Hospitalization (54%) is often required for eye and brain injuries The 10 to 15 million sets of lawn darts remaining in the homes of Americans after their sale was banned by the CPSC on December 19, 1988, should be discarded. [291]

Indoor darts, with an eight-inch maximum length and 18g maximum weight, rarely result in eye injuries when National Dart Association rules of play are followed. However, children rarely follow the rules and their thrown darts may cause penetrating or perforating eye injuries with poor visual outcomes, from the initial injury, or later irreversible amblyopia or endophthalmitis. [292-294] Games involving darts are not appropriate for children unless there is strict adult supervision and the rules of play are followed.

Fishing

Fishing (62 million participants) is one of the most popular of all sport activities. Fishing attracts all age groups (32% under age 12 and 12% over age 55), and about 20% of those who fish call it their favorite activity.

Fishing was responsible for [143] (19.5%) of the 732 total sports eye injuries in the USEIR database. [295] The fact that 44.1% of fishing eye injuries were open globe injuries is due to several factors: fishhooks are sharp; sinkers have a concentrated mass that fits within the orbit; the fishing line can act as an elastic cord when the hook suddenly releases from an underwater obstruction—propelling the hook and sinker towards the sighting eye; pole tips are whipped around in close proximity to other fishermen on shore or a boat. Fishing injuries from hooks, [296-299] sinkers, [300-304] pole tips, [201] fishing spears or harpoons, [305, 306] or the fish itself, [307] are usually serious. Available data do not always separate fishhooks from sinkers or other causes of fishing eye injuries, so it is not yet possible to determine how many fishing injuries, from sinkers or pole tips, really belong in the "somewhat larger" category to follow. Spectacles, with polycarbonate or Trivex lenses, whether in the form of sunglasses (preferably polarized) or corrective lenses, offer protection and should be worn at all times by fishermen. [308]

Shattered eyewear

As discussed previously, lacerating eye injuries from shattered eyewear are almost totally preventable.

Small, somewhat larger high-velocity projectiles

Airsoft

The airsoft is a "toy" gun that shoots 6mm-diameter plastic bullets (0.12, 0.2, and 0.25 g) at 61.5 to 74.9 m/s. The projectiles have caused hyphema, vitreous hemorrhage, and cataract. The airsoft has blinding potential and should not be sold as a toy. [309-311]

Paintball

Paintball (often called war games, survival games, Pursuit, or Gotcha) started in New Hampshire in 1981 when 12 friends used air guns that fired capsules—filled with paint and designed by foresters to mark trees for harvest—in a "survival game" where the participants were able to eliminate opponents from the game by shooting them with paint pellets. Paintball is now played in over 40 countries, with 5.5 million participants in the United States in 2007. The average player is a man (82%) 25.7 years old, who plays 15 days a year for three years.

Paintball violates the basic teachings of traditional firearms safety courses, which emphasize two absolute rules: always positively identify the target and never point a firearm (including an air gun) in the direction of any person, animal, or object other than the intended target. [235] The intentional firing of a missile at another individual in peacetime, as a game, has been criticized by the Boy Scouts, The NRA, and the Shooting, Hunting and Outdoor Trade (SHOT) industry, who strongly emphasize the safe use of firearms and strict adherence to firearm safety rules. Yet, the appeal of war games has lured players and what started as a cottage industry of air gun and paint capsule manufacturers and field operators is now a big business. Early on, the rapidly growing sport had no controls—as exemplified by the lack of age restrictions on the sale of paintball guns.

Figure 14. Paintball eye and face protector certified to ASTM F1776
Note chin-strap which is recommended to help keep protector in place when impacted from below.

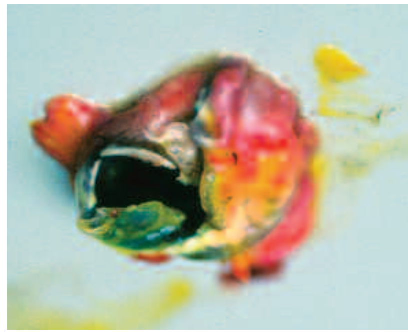


Figure15. Eye damage from paintball
Rupture, with complete extrusion of ocular contents, of a pig eye that was mounted in an artificial orbit, adjusted to a normal intraocular pressure, and impacted with a yellow-colored paintball at 280 ft/s from 3 meters.

It soon became apparent that the paint capsules were responsible for severe (7.8% open globe) eye injuries. Players and field operators then began to use or distribute industrial safety, motorcycle, or ski goggles, despite the fact that these goggles were never tested for paintball and that industrial goggles have the warning that they are not designed for sports use. [312] This eyewear often failed, resulting in severe injury to players who had assumed they were protected ***(Table 12).***

As the sport grew, there was a slow shift in philosophy away from the original "hunt and be hunted." [313] In a concerted effort to make the sport safer, the paintball industry asked the ASTM eye safety committee for assistance, and an ASTM task force on eye protectors for paintball was formed in May 1994. Paintball now has its own ASTM subcommittee and there are now standard specifications for paintball eye protective devices (ASTM F1776) **Figure 14**, field operation (ASTM F1777), marker warnings (ASTM F2041), paintballs (ASTM F1979), and markers (ASTM 2272). Tree-marking capsules, with indelible paint, have been replaced by water-soluble paintballs. The paintball "gun" is now a paintball "marker," and a player who is eliminated from competition is "marked" rather than "killed." Organized paintball is now a variant of "capture the flag" in which there are team objectives, and opponents are eliminated by being "marked." Red paintballs (which may be confused with blood) are prohibited from many fields.

At this time, the paintball mark is a nontoxic, water-soluble dye, contained in a spherical, usually gelatin capsule—the paintball (3.3g, 17.3 mm diameter)—that is designed to break on impact. The paintball is propelled by an air gun, called a paintball marker, at a velocity not to exceed 91.4 m/s (300 ft/s, 204.5mph). Although participants normally wear protective clothing and safety equipment, if a direct impact of a paintball on the body does occur, it is moderately painful and results in bruising and localized hematoma, 2-3 cm in diameter. These welts are usually taken in stride by the player and are regarded as part of the game. However, the impact of a paintball on the unprotected eye is associated with severe injury. [314] Pig eyes rupture

Table 12. Paintball eye injuries related to protective eyewear

Author	*Reported cases*	*Open globe*	*Eyewear use not stated*	*Not worn*	*Eyewear available but not worn or removed prior to injury*	*Industrial or other eyewear in place but failed*	*ASTM F1776 protector failure*
Acheson (1989) [829]	6				4	2	
Anders (1994) [830]	3			3			
Dawidek (1989) [831]	1					1	
Easterbrook (1985/8) [317, 832]	44	2		43	1		
Farr (1998) [833]	2			1	1		
Fineman (2000) [834]	35	2		13	19	3	
Gazagne (1994) [835]	6			6			
Hargrave (2000) [836]	4			4			
Hansen (1994) [837]	1			1			
Karel (2002) [838]	1		1				
Kruger (1999) [839]	6			5		1	
Mamalis (1990) [840]	1			1			
Martin (1987) [841]	1					1	
Mason (2002) [842]	10			7		2	1 (? ASTM)
Morgan (1989) [843]	2		2				
Pakoulas (1989) [844]	2				1	1	
Ryan (1986) [845]	1				1		
Schwartz (2000) [846]	141	16	52	63	19	7	
Tardif (1986) [847]	13	1			13		

when impacted with paintballs fired from closer than 4 meters ***(Figure 15)***. [315]

As paintball increased in popularity, the problem of associated eye injuries became increasingly obvious. Of 77 paintball-injured eyes reported to the Canadian Ophthalmological Society between 1984 and 1998, 33 (43%) were legally blinded. [4] As paintball increased in popularity, eye injuries became apparent. While no eye injuries from paintball were reported to the Eye Injury Registry of Indiana from June 1992 to June 1996, 11 injuries were reported over the next two years, representing 4% of all ocular trauma reports. [315, 316]

The widespread use of protective eyewear has greatly decreased paintball eye injuries, [317] but more work needs to be done in this relatively new and rapidly growing sport. The current ASTM F1776 eye protector standard will need some modification to help prevent dislodging of protective devices by tree branches and field equipment. Sadly, advances in paintball eye protection have had little if any effect on children who are unlikely to wear eye protection voluntarily when playing at undesignated or unsupervised locations. Changes should be made to restrict availability of markers and paintballs to children and parents should supervise the use of paintball equipment. [318]

Despite objections from ophthalmologists, automatic markers, in which 15 paintballs per-second are discharged while the trigger is depressed are permitted in the ASTM 2272 marker standard. While automatic markers are usually safe in supervised competition, where there are field rules, referees, and all participants wear adequate eye and face protection, the automatic marker has the real potential of blinding both eyes when used by unprotected players in a situation with no referees or field rules. The sport needs a governing body with the authority to control potentially unsafe practices of some marker manufacturers and field operators.

Golf

There were 8.6 million (76% male) frequent (more than 25 days/year) golf players among the 29.4 million people who played golf at least once in 2001, and the participants only decreased by 1% in 2008. Golf players tend to be older (average 38.2 years), participate longer (average 13 years) and are more affluent than the players of most other sports.

A typical male PGA Tour player produces an initial ball velocity of approximately 160mph with his driver. In comparison, a typical male recreational golfer may only generate a ball velocity of 130mph—about the same velocity as a PGA Tour player's 5 iron. The extreme elasticity of the golf ball results in a ball velocity up to 1.5 times more than the club head velocity before impact. [319] A United States Golf Association (USGA) approved ball must weigh less than 45.9g (1.62 ounces) and must be more than 4.27cm (1.68 inches) in diameter.

Right-eyed dominant golfers have significantly better performance using the right-handed stance than the left-handed stance, whereas left-eyed subjects show the opposite. [320] Cross-hand and one-handed grips result in smaller variations in eye and head movements than the conventional grip. The longer duration for the one-handed grip, which improves tempo, may explain why some senior players prefer the long-shaft (effectively one-handed grip) putter. [321]

Golf is not a common cause of eye injuries, but those that do occur from the ball or club (or rarely the golf tee) [322] are usually very serious. [323-326] A 59mph golf ball ruptures a pig eye. [327, 328] Of the 28 golf injuries [21 ball, 5 golf club, 1 shattered eyewear (club), 1 uncertain] in the USEIR data base, 12 were open globe, [201] Golf accounted for 11 (14%) of 80 sports-related eye injuries that resulted in enucleation at the Massachusetts Eye and Ear Infirmary from 1960 to 1980. Golf balls were responsible for 8 of the 11 lost eyes and golf clubs for the other 3. The only sports resulting in more enucleations were those involving BBs (45%) and arrows/ darts (15%). [223] The reason for the high enucleation rate is that both a golf ball and the head of the golf club are hard, travel at high speed, and can fit within the bony orbit, transmitting all of the energy directly to the globe with resultant rupture or disorganization of the eye. The impact from a golf club between the globe and the temporal orbital rim had sufficient energy to cause optic nerve avulsion in a ten-year-old boy. [110]

Most persons do not realize that liquid center (liquid contained under pressures as high as 2,000–2,500psi) [329] golf balls may explode [330-333] and are potentially hazardous if cut open, releasing the liquid with force sufficient to penetrate the eye and orbital structures. [329, 334, 335] Fortunately, major manufacturers use nontoxic liquids (such as corn syrup with added salts) [319, 336] rather than the sulfuric acid, barium sulfate and zinc sulfide compounds used in the past. [329, 334, 337, 338] Since products change without notice, and one cannot be sure what is in a liquid center golf ball, it is wise to avoid the temptation to cut open a liquid center golf ball.

Most golf injuries could be avoided if golfers check to be sure the way is clear and that they yell "Fore" before hitting the ball or swinging the club, with special care to be certain that no curious children are directly behind at the start of the backswing. [339] As contrasted with adults, where most injuries occur on the golf course, the majority of pediatric injuries occur off the golf course, emphasizing the need to keep golf clubs safe from use by unsupervised children. [340] Golfers should wear sunglasses or prescription eyewear with polycarbonate or Trivex lenses.

Racket and paddle sports

These sports are enjoyed by approximately 47 million Americans. Racquetball and squash have the strongest core (over40%) of frequent players. The traditional family game—badminton—has suffered as family time diminished and children turned to TV, computers and video games. Overall the participation in racket and paddle sports diminished between 1995 and 2000, but has increased (except for badminton) from 2000 to 2008

Racket sports are a common cause of serious eye injuries. In Canada, the 1,135 racquet sport injuries (47 blind eyes) accounted for 24.5% of all reported sports eye injuries and 8.8% of eyes blinded from sports. [341] In the United States, racket sports were responsible for 40.3% of sports eye injuries seen in one private practice and 23% of all admissions for hyphema to the Massachusetts Eye and Ear Infirmary. [3] Racket sports caused 42% of the injuries and 57% of admissions, including two open-globe (one enucleation) injuries, to the Manchester Royal Eye Hospital from January to July 1987. [342] A survey of

Figure 16. The original (ineffective) eye guards for handball, squash, and racquetball

Figure 17. Racquetball eyeguard testing for ASTM F803 (1983)

These high speed film frames, taken by Chauncey Morehouse on commission by the ASTM eye safety subcommittee in 1983 were the first proof of the mechanism of open eyeguard failure and were instrumental in developing the standard requirements for ASTM F803 for the racket sports. [352]

Left two frames: racquetball impact on lenseless open eyeguard at 100mph. Eye contact demonstrated by adherence of paste, that was applied to eye of headform before impact, adhering to the rebounding ball.

Right frame: racquetball impact on lensed polycarbonate eyeguard at 100 mph. despite extreme flattening of the ball, there was no contact of the ball or the protector with the eye of the headform. The increase in diameter of the ball on impact explains the mechanism of eye injury when the initial point of contact is adjacent to the orbit.

797 Midwest ophthalmologists uncovered 848 racket sports eye injuries (tennis 207, racquetball 70, badminton 5, squash 10, racket sport not specified) [458] which included 16 open-globe injuries and 10 loss of vision or eye. [343] The risk of eye injuries for 100,000 playing sessions varies depending on the racket sport: squash, 5.2; badminton, 3.6; tennis, 1.3; table tennis, 0.1. [344] Many studies have shown the ocular risk of participating in squash, racquetball, tennis, and badminton. [345] There is no correlation of player's level of experience with eye injury. [346-348]

Initially, most handball, racquetball, and squash eyeguards were wire or injection molded polycarbonate lensless protectors ***(Figure 16)*** that seemed to offer protection by reducing the size of the orbital entrance. [95] Impact testing with rackets showed that these eyeguards were virtually indestructible, yet injuries were occurring to an alarming number of players wearing lensless protectors.

The choice of inappropriate eyewear has resulted in many preventable racket-sport eye injuries. Shattered spectacles caused the most serious of these (open globe injuries). An open-globe injury from shattered eyewear was especially distressing to a one-eyed attorney, an avid racquetball player, who lacerated his only eye when he was hit with the opponent's racket and his streetwear spectacle lens shattered. [349] Glass and allyl resin spectacles have shattered, lacerating globes, spectacle frames have failed, and lensless eyeguards have allowed the ball to deform, passing through the protector into the eye ***(Figure 17)***. [346 348, 350-352]

Table 13. Racket sport eye injuries in Canada

Year	***Injuries***	***Racquetball / Squash (%)***	***Badminton / Tennis (%)***
1982	90	73	27
1983	87	59	41
1984	115	58	42
1985	82	50	50
1986	83	38	62
1987	86	38	62
1988	45	38	62
1989	62	35	65
1990	38	37	63
1991	35	23	77
1992	33	24	76
1993	31	23	72

Data collected by T. Pashby from members of the Canadian Ophthalmological Society)

In 1979 and 1980, the eye safety committees of the CSA and the ASTM began independent but cooperative studies on the mechanism of failure in existing protective devices. The committees determined the speeds of racket and ball and tested various types of eye protectors by mounting them on a headform, impacting the mounted protector with balls and rackets at various speeds, and using high-speed photographs to record the results for analysis. This work resulted in the publication, in 1983, of performance standards for racket sport eye protectors. [131, 353]

Despite the acceptance of ASTM and CSA racket sport standards, some major manufacturers still promote unsafe eyewear for use in racket sports ***(Figure 9)***. The wearing of inappropriate eyewear is especially dangerous for two reasons: the player is not given the protection that certified eyewear affords, and the potentially hazardous eyewear may give the wearer a false sense of security about the amount of protection available and may encourage risk taking and / or bad habits on the court. [351, 354]

Table tennis requires no eye protection, and there is not enough data on jai alai to make specific recommendations. All other racket sports players should be wearing eye protectors that conform to ASTM F803 or CSA P400. 79 [131] Several squash, handball, and racquetball governing bodies have accepted their responsibility for preventing predictable injuries to their player-members. Tennis and badminton governing bodies should, as a minimum, make players aware of the eye injury hazard in these sports and recommend appropriate eyewear.

Since around 1980, when the St. Louis Jewish Community Center required eye protection for all racquetball and squash players, only two of the club's 14,000 members have resigned because of this policy, which is strongly enforced. Strong support to eye protection for all racquetball players has come from National Racquetball magazine, which has published numerous informational articles on protective eyewear and taken strong editorial positions on mandatory eye protection for racquetball players since the early 1980s. The American Amateur Racquetball Association (AARA), which took the place of the United States Racquetball Association (USRA) in 1982, has given wholehearted support to preventing racquetball-related eye injuries. In 1982, M. Arnolt of the AARA found that 61% of the membership and 77% of the former USRA officials thought that eye protection should be mandatory. A variety of racket sport eye protectors are available ***(Figure 11)***. Their widespread use will reduce eye injuries in these sports. [78]

The increased use of protective eyewear in racquetball and squash, compared to the lack of protective eyewear use in tennis and badminton caused a dramatic shift in the distribution of racket sport eye injuries in Canada—injuries are increasing in unprotected players and decreasing in protected players. ***(Table 13)***

Handball

Handball (the original "racquet sport") type games date back to 2000 BC in Egypt and 1500 BC in Central America. The modern game is played by two players (singles) or two pairs (doubles) on a court (20' wide, 45' long, and 20' high) with one, three, or four (the most popular) walls. The 4.8cm diameter, 65.2g, moderately lively (bounces 3'6" to 4' when dropped from height of 5'10" at 200C) rubber ball is struck with either hand (55 to 70 mph), [352] with the hand wearing a non-webbed, snug-fitting, soft glove. Left-handed players may have a visual reaction time handball advantage. [355]

Handball, responsible for about 900 eye injuries a year, is of historic significance since the first racket sport eye protectors developed were the lensless rubber-covered-wire eyeguards designed in an attempt to reduce eye injuries in this sport. Because presently available lenseless eyewear has not prevented hyphema, commotio retinae, and retinal tears, [356] the US Handball Association board of directors voted to require the use of one-piece, lensed, polycarbonate eye protectors by all players participating in nationally administered events in June 1988. [357] No eye injuries have been reported in any player wearing the required protector.

Squash

Singles or doubles squash games are played in an enclosed court (21' wide, 32' long, 18' high) with 255g, 27"-long rackets that have a head 8.4" in diameter. The hollow rubber ball (23.3-24.6g; 39.5-41.5mm) is propelled 115 to140mph when struck with a racket head speed of 80 to 115 mph. On a backhand follow-through, when the racket is above the shoulder, the racket head velocity drops to 15-25 mph. [352]

The ocular hazards of squash were first documented in the early 1970's. In 56 reported cases, the ball caused about three fourths of the injuries and the racket the remainder. Approximately one sixth of the injuries were caused by shattered spectacle lenses, which resulted in 6 open-globe injuries. The most common injury was hyphema, with traumatic glaucoma, retinal detachment, and vitreous hemorrhage, and corneal laceration (from shattered eyewear) accounting for the remainder of the significant injuries. The vast majority of injured players were working-age men. Persons with one eye were advised not to play squash and protective spectacles were advised for all players. [358, 359] Protective eyewear is especially important in players whose eye(s) have been weakened by prior surgery or disease. A 34-year-old man, struck with a squash ball, had limbus to limbus dehiscence of RK incisions with expulsion of the lens, total aniridia, and total retinal detachment. [360]

Serious squash eye injuries reported from several countries in the following years have supported the concept that traumatic eye injuries are not accidents but predictable events, 18 almost boring in their regularity and predictability ***(Table 14)***. In New Zealand, there was a yearly incidence of 100 squash-related eye injuries, with 50 persons losing useful vision in the injured eye and four eyes lost completely. [361] In Germany, 26 retinal detachments caused by squash balls were compared with 500 non-traumatic retinal detachments. The squash ball detachments had significantly worse results 24 months after the injury because of a higher incidence of macular detachment, macular pucker, and proliferation of the retinal pigment epithelium. [362]

The risk of one eye injury for each 5,329 squash matches [363] shows that the estimated risk that a dedicated squash player has the odds of 1 in 4 for a serious eye injury if he or she plays once or twice a week for 25 years [364] (2 matches a week x 50 weeks x 25 years = 2,500 lifetime matches) may actually be conservative and that the risk of serious eye injury to the serious squash player over 25 years may actually approach 50%.

In 1990, the incidence of eye injuries to Australian pennant squash players was found to be 17.5 per 100,000 playing hours, with 26% of players having sustained an eye injury (61% from the racket). Although squash-specific-lensed eye protection has been advocated by ophthalmologists and squash governing bodies, and one third of the Australian squash players who suffered eye injury were injured more than once, less than 10% used eye protectors in 1990 (mostly after having suffered at least one eye injury from the sport) and 2% still believed that streetwear spectacles offered eye protection. [365] As recently as 1995, only 10% of Australian squash players wore protective eyewear, 35% still wore streetwear prescription eyewear, and 15% of players already suffered an eye injury (mostly from the racket). [366] The resistance to protective eyewear is evident in an English player who suffered an open globe injury to an eye already weakened by a prior squash-racket-induced perforating injury that was struck by a squash racket and still does not wear eye protection. [20]

Eye protection for United States and Canadian squash players has been promoted since 1976, and is now mandated for most players ***(Table 15)***. England Squash now mandates eye protection (conforming to British Standard for Eye Protectors for Racket Sports—Part 1 Squash BS7930-1, or ASTM, CSA, Australia/New Zealand standards) for doubles, and specified events for junior players, and recommends eye protection for all squash players.

In the future, perhaps eye injuries from squash will be eliminated by the use of certified products by all players. This will not happen until the governing bodies in all countries have the courage to mandate protective eyewear for all. As long as there is peer pressure not to wear protective eyewear, some players will continue to take a needless risk that they do not fully comprehend.

Table 14 Squash eye injuries

Author	Year	Cases	Ages 21-50	Men	Ball/ Racket	Shattered spectacles	Open globe injury from shattered spectacle lens	Permanent visual disability from injury	Hyphema	Retinal detach-ment or tear	Lenseless eyeguards
North [359]	1968-70	35	33	34	27/8	5	1 (racket)	3	30	1	0
Ingram [358]	1973	21	20	21	Of 14 severe injuries 7B; 6R; 1U	8 of 14 severe injuries	4 (R3; B1)	7	4	2	0
Moore [853]	1974-5	38			22/11	5 (all racket)	3 (racket)	2	33	1	0
Easterbrook [854]	1974-6	23	22	22	14/9	4 wearing spectacles at time of injury 2 shattered, 1 lens popped out of frame	1	5	9	0	advocated at this time
Blonstein [855]	1975	NA				4	2			6	0
Vinger [348]	1976-7	6			1	2	1 (racket)	1	2		0
Easterbrook [856]	1978-80	67	mean age: 32	56	40/27	6 lenses shattered; 1 lens popped out of frame	2 (racket)	6	43	5	7 players wearing at time of in-jury
Easterbrook [857]	1978-9	7	7	7	6/1				4		All injuries to players wearing lenseless eyeguards. Lensed eyeguards recom-mended
Mondon [858]	1981	11	11	9	8/3	Probably 2			4	2	
Easterbrook [354]	1978-81	154				1 lens shattered 1 frame failed	1 (racket)	10	80	7	16 players wearing at time of injury
Barrell [344]	1978-9	58			41/17			1		1	
Bankes [859]	1982-3	339	251 be-tween 20 and 39	278	235/103 3 collision with wall			40	147	5	

Racquetball

This new sport (invented in 1949) is played singles or doubles in an enclosed room 20' wide, 40' long, 20' high. The 5.7cm-diameter, 40g hollow rubber ball is propelled at 85-110mph by a 56cm racket with a head diameter of 25cm and a head velocity of 80-95 mph. [352]

Racquetball is usually played by those in the working ages of 20 to 55. The racquetball professional usually reaches top performance between ages 20 and 30. [367] Over a 14-month period from January 1, 1977, to April 1, 1978, six courts at California State University, Long Beach, were used 14 hours per day for a total of approximately 35,280 player hours. Of 70 injuries that required medical attention, 20 involved the eye, and three players required hospitalization for hyphema. The incidence of eye injury was one for each 1,764 hours of racquetball play with a hospitalization required for eye injury after each 11,760 participation hours. [368] Injuries to the face and scalp account for between 50% and 55% of all racquetball injuries, with eye injuries 5.7% to 12.9%. However, it is likely that the 5.7% figure is too low since globe injuries were triaged from the emergency department directly to the ophthalmology department and therefore not included in the data. Racquetball-related injuries are caused by both the ball and the racket ***(Table 16)***, with the racket injuries often self-inflicted. [347, 369]

Paddleball

Two, three, or four players play on a court (20' wide, 34' to 40" long, 20' high) that has one wall, three walls, or three walls and a ceiling. The approximately 1 pound oval or square wooden paddles are 16" (40cm) long and have a head 8" The hollow rubber ball is 4.8cm in diameter. The other paddle racket sports are platform tennis, paddle tennis, and Padel, which have somewhat different playing rules, but similar eye hazards.

Pelota vasca (Basque ball)

Of the seven forms of pelota vasca, jai alai—played as singles, doubles, or triples—is the most extreme. A 2 foot wicker basket (the cesta) extends the player's throwing and catching hand. The ball approaches the characteristics of a baseball (2" (5cm) diameter, 4.5oz). The court is a huge 3 walled (front, side, back) structure 40' high, 40' wide, and 176' long. There are no data on eye injuries in pelota vasca.

Badminton

A 2'6" net, 5' off the ground in the center, bisects the 20' by 44' court and separates the singles or doubles opponents. The 4.74-5.50g shuttle has 16 feathers fit into a cork base that is 1" in diameter. The feathers are approximately 2 3/4/ inch long and spread to 2 5/8" (68mm) at the rear of the shuttle. The 27" light weight (85-140g) racket has an oval head 9" wide and 11" long. Shuttlecock velocities of experienced players range from 105 to 135 mph. [352]

Although the shuttle decelerates rapidly, sufficient energy is present, especially after the smash, to cause significant ocular injury. In southeast Asia, badminton is played seriously; in Malasia it accounts for two thirds of all sports eye injuries and 53% to 56% of hyphemas from all causes. [370] Fifty percent of all persons with badminton-related injuries suffer some permanent decrease of best-corrected vision and 11% result in 20/200 or worse, with macular changes, traumatic cataract, and glaucoma the main causes of visual impairment. In doubles, shuttlecocks hit the eye off both the partner's and opponent's racket; but racket impacts, which occur 14% to 48% [371] of the time, are only caused by the doubles partner. Because of the potential of injury in doubles from the racket as well as the shuttle fired by friendly forces it is not surprising that 70% of all badminton eye injuries occur in doubles. The racket has enough force to shatter eyeglasses, causing corneoscleral laceration, [342, 372] but there have been no reports of a spectacle lens shattering on impact from the shuttle. [373] Most injuries from the shuttle are to players at the net. [342]

In Canada, where two of the 11 eye injuries reported in the 1976-1977 season resulted in legal blindness, [374] the relative incidence of badminton-related eye injuries increased from 1982-1989. In a 3-year period ending June 1989, there were 64 badminton-related eye injuries reported by ophthalmologists in Canada; 57 of the 64 were caused by the shuttle. [375] School children, suffer badminton induced hyphemas while supervised by physical education teachers who rarely recommend protective eyewear. [376] Badminton is responsible for 19% of severe sports-related eye injuries in the United Kingdom. [19]

Sixteen of 231 (7%) competitive badminton players in the 1976-1977 season received an eye injury; three players required hospitalization, and one player required surgery. All of these injuries were from the shuttle, with 81% hit by the opponent and the rest hit by the player's doubles partner or glancing off the player's own racket. 7% of surveyed players reported a badminton eye injury. [377] No eye injuries have been reported in any player wearing an eye protector. The Ontario Badminton Association mandated protective eyewear for all junior players and recommended eye protection for all badminton players in 2005.

Tennis

The 27' by 78' (singles) court is divided by a net that is 3' high at the center. A felt-covered rubber ball (2 1/2 to 2 5/8 inch diameter, 2 oz) is propelled at 85-140 mph by a racket 29" long with a head diameter of 12 1/2".

Although it is likely that streetwear glasses give some protection from eye injury from a tennis ball, [348] sturdy frames that pass ASTM F803 with polycarbonate lenses are preferable to the weaker streetwear frames that can fracture on impact with sufficient force to cause macular injury [378] or have lenses weak enough to fracture on racket impact. [379] Tennis is the leading cause of eye injuries in west suburban Boston working-aged women 3 for three reasons: Massachusetts women enjoy the game, eye protection is rarely worn, and the tennis ball has sufficient energy to detach the retina. [380] Injured players tend to return to the game, even after loss of an eye [381] or a retinal detachment. [382] Even injured players tend not to wear eye protection. [382]

Why do tennis players refuse to wear eye protection? In addition to eye protectors not being fashionable, especially to women, ophthalmologists do not promote, and even discourage, proper protection. Tennis is the most common sport de-

TABLE 15 Organizational Positions on Protective Eyewear for Racket Sports

	Date	Organization	Level of Play for Which Eyeguards Mandated
Racquetball	Sept. 1, 1978	Canadian National Racquetball Association	All sanctioned tournaments
Squash	June 1980	Canadian Squash Rackets Association	Juniors in sanctioned tournaments
Racquetball	1980	St. Lewis Jewish Community Center	All players
Squash	Oct. 7, 1982	Massachusetts Squash Rackets Association	"The MSRA strongly urges that all members, in league and other play, wear polycarbonate, lensed eye protection."
Squash	Sept. 1, 1982	Massachusetts Independent School League	All practices and competitions
Racquetball	1982	American Amateur Racquetball Association	Eye protection required for juniors (and for doubles as well in Wyoming, Georgia, Illinois, New Mexico, Missouri, District of Columbia, Montana, Vermont, and Kentucky)
Squash	1982	Ivy League Schools	All practices and competitions
Squash	1983	United States Squash Rackets Association	All national championships, all levels of play
Racquetball	1983	Spaulding Racket Clubs (35 facilities)	Staff and junior players
Racquetball Squash Handball	June 19, 1983	American Medical Association	Endorsed safety glasses exceeding requirements of ANSI Z 87.1 for these sports
Racquetball	1985	Air Force (regulation 215-22)	Eye protection mandatory on all Air Force racquetball courts
Squash	1986	United States Squash Rackets Association	All sanctioned tournaments
Squash	May 1987	United States Squash Rackets Association	Eyeguards made part of the rules of squash play
Racquetball	Dec. 1987	American Amateur Racquetball Association	All players
Squash	1998	England Squash	Doubles, Specified junior events up to U/19 level
Badminton	2005	Ontario Badminton Association	Juniors

picted in refractive surgery advertisements as an example of the ability to "play sports without glasses". A well-known ophthalmologist who had RK [383] and continues to play tennis without eye protection gave as his reason "it's a risk I choose to take, like sailing or driving a fast car". [384] If an eye surgeon who knows that his RK eye is prone to rupture if struck by a tennis ball chooses not to wear eye protection, how do we convince the general public that eye protection is worthwhile? Protectors will be worn by most tennis players only if the player believes that performance will be enhanced and that the protector is fashionable (with protection as an added benefit). Unfortunately, some glasses and contact lenses that are promoted as performance enhancers, actually may degrade perception of the ball. [159, 189]

Table tennis

Despite a table only 1.525 by 2.74 meters, relative proximity of the players, and high velocity of competitive table tennis, there are almost no eye injuries. The 2.5g, 38mm-diameter celluloid ball, developed in 1900, when driven by a rubber-covered wood paddle, does not have sufficient energy to cause serious eye injury.

Table 16 Racquetball eye injuries

Author	*Year*	*Cases*	*Ages 21-50*	*Men*	*Ball/ Racket*	*Shattered spectacles*	*Open globe injury from shattered spectacle lens*	*Permanent visual disability from injury*	*Hyphema*	*Retinal detachment or tear*	*Lenseless eyeguards*
Rose [368]	1975-6	20	19	75%	15/5				4		no players wore eye protection
Vinger [348]	1976-7	1	1	1	0/1	1 lens popped through frame, struck eye			1		0
Doxanas [347]	1978-9	37			15/22				5		no injured players wore eye protection
Easterbrook [856]	1978-80	18	mean age: 32	15	15/3	1	1 (racket)	2	17	1	7 players wearing at time of injury
Easterbrook [857]	1978-9	12		7	11/1				4		All injuries to players wearing lenseless eyeguards. Lensed eyeguards recommended
Easterbrook [354]	1978-81	91			82/9	21 (squash plus racquetball)	8 (squash plus racquetball)	3	46	2	36 players wearing at time of injury

Stick and ball sports

In some stick and ball sports, where the players are in close proximity, using a stick or crosse to propel the puck or ball, there is eye injury potential from both the ball and the stick. Lacrosse is primarily an aerial game; hockey (ice, field, roller) bandy, and polo are primarily ground games; hurling and shinty have ground and aerial components. There are few injury data for hurling, shinty, and bandy, but the mechanisms of injury and protective suggestions would be similar to the close-proximity ground and aerial sports to be discussed. In other stick and ball sports—baseball, softball, rounders, and cricket—only one player at a time swings a stick or bat, and eye injuries are almost always caused by the ball.

Ice hockey

Ice hockey has had a 21.8% decline in participation between 2000 and 2008 to 1.9 million participants. Intrinsic to hockey are high-mass collisions (checking, sliding into boards and posts); low-mass, high-speed impacts (puck); and slashes (stick). [385, 386] Despite efforts to control fighting, [387] intentional fist, stick, and illegal body contact are hockey facts of life. Before the widespread use of head and face protectors, 37% to 64% of the total injuries were to the head, with the face receiving the majority of the head injuries. [388-393] The probability of a facial injury to the unprotected hockey player is extremely high: 7% in the first year of play, increasing to 66% after eight seasons, and up to 95% for professional players. The average professional player has had, from playing hockey, 1 facial bone fracture, 2 lost teeth, and 15 facial lacerations that required sutures. [394, 395] Among the most significant ice hockey related injuries were those to the eye. [396]

Documentation of blinding hockey eye injuries started when Pashby and the Canadian Ophthalmological Society reported 287 eye injuries (20 eyes legally blinded) in the 1972-1973 season and 253 eye injuries (35 eyes legally blinded) in the 1974-1975 Canadian amateur hockey season. [397] Castaldi pushed for mandatory face protection when two Hartford students each lost an eye in the same season. [398] Horns reported 47 ice-hockey-related eye injuries, of which 7 resulted in legally blind eyes, including three ruptured globes. [399] Thirty-eight hockey-related eye injuries seen in a Massachusetts suburban practice included an enucleation and legal blindness from a macular scar. [400] Prospective studies in Massachusetts during the 1974-1975 season showed that 105 of 124 schools with hockey teams had players that suffered 209 facial injuries with 5 eye injuries and 110 injuries involving the eye area; the only players injured while wearing facial protection were four goalies, who were wearing molded face masks. [401] In Montreal, 33 (13.2%) of 250 retinal detachments secondary to contusion of the globe involved ice hockey. The mean interval between injury and preoperative examination was three years. Despite surgery, 42.4% of these eyes became legally blind. [402] Injuries to the musculoskeletal system are most frequently caused by collisions with players, goal posts and the boards; however, about two thirds of hockey-related eye injuries are due to the stick and the rest are due to the puck. Only a few percent were from collisions, fighting, and other causes. [397, 399, 400, 403] Rules changes to keep the stick low and decrease violence certainly help, [404, 405] but the majority of eye and face injuries would remain despite the rules changes. Since most injuries are accidental, the only means of prevention is protective equipment.

In the 1975-1976 season, hockey face protectors were voluntary in Massachusetts. All of the 70 facial injuries in the continued prospective study involved unmasked players, except two to goalies wearing form-fitting face masks and a small chin laceration from an improperly fitted wire cage face mask that rotated on impact. As face protectors became more widely used, the injuries to the eye and face dramatically decreased, so that the only significant injuries seen were to unprotected players (unorganized outdoor games, older players, professionals, and those playing for paid gate) and goalies wearing molded facemasks. There have been no instances of injury caused by the facemask either to the wearer or to another player who was not wearing a protector. [400, 406-414]

To further reduce these preventable injuries, it will be necessary to induce the older players to wear face protectors. [415] A major step in encouraging older players to wear protection is the rule in Canada that, starting with the 1993-1994 hockey season, only players wearing full face protection, or a half shield (visor) plus either an internal or external mouthguard, are allowed to submit a medical or a dental claim for facial injury. [4]

The full-face hockey protector ***(Figure 18)***, one of the most efficient sports protective devices, was designed as part of a total head protection system in which forces are transmitted to a helmet designed to protect the brain. The current ASTM and CSA standards prevent penetration by the 2-inch x 0.25-inch hockey stick blade, which was a problem with some early wire face masks. [416, 417]

The hockey visor ***(Figure 19)*** is not recommended because the visor: (1) does not prevent maxillofacial and dental injuries (38% of the total cost of all ice hockey injuries), [117, 418-420] (2) allows penetration and eye contact by a stick or puck from below (9 blind eyes with visors, 0 blind eyes with full face shields. [421]

Despite the fact that goalies are far outnumbered by forwards and defensemen, nearly all eye and head injuries to protected hockey players involve goalies who are wearing form-fitting masks. [409] The form-fitting goalie face mask is no longer acceptable because: (1) there is little or no protection to the temples and occipital areas of the goalie's skull; (2) players (and the parents of school-age players) often enlarge the eye openings for a larger visual field, thus decreasing eye protection; (3) the form-fitting masks neither spread forces over a wide area nor substantially lengthen the duration over which a force is allowed to act because they bottom out in critical regions [422, 423] and transmit the forces to the skull, brain, face, and eye; (4) breathing, heat dissipation, and conversation are markedly compromised; and (5) a great range of products exists, from those that are well made with better padding to cheaply mass-produced or incompletely fabricated ones with little or no padding ***(Figure 20)***. The average player usually owns an inferior mask, yet is subjected to slap shots driving the puck at 100-105 mph. [424]

Better protection for goalies lies in a sturdy wire-mask-helmet combination that conforms to the standard specifications of ASTM F1587 ***(Figure 20)***. [425, 426] With this combination, the head is better protected against blows from the rear and side; the brain is better protected against concussion as energy is dissipated through the helmet and thicker padding; and the wire mesh allows for better vision, improved communication, and better protection at less cost. Form-fitting goalie face masks are no longer permitted by HECC.

Hockey full-face protectors are now worn by over 1.2 million North American ice-hockey players. These players suffer 70,000 fewer eye and face injuries than they would have were they not protected, with a savings to society of over $10 million in medical bills each year. [42] The 1988 Government of Quebec regulation imposing the use of a full face protector on the 100,000 adult recreational ice hockey players of the province resulted in a net saving of $1.9 million in health care costs between 1988 and 1993. [427] Ice hockey injuries occurring above the shoulder have decreased by over 50% since 1976 after face mask and helmet use became widespread. [417] Economic studies have shown that if every hockey player were given a hockey face protector for free, society would still make a profit in medical expenses avoided by use of the protective device. [428]

Eye and face injuries accounted for two thirds of all injuries in ice hockey before the introduction of mandatory eye and face protection in play sponsored by schools, colleges, and amateur hockey associations. The widespread use of these protective devices ***(Table 17)*** has virtually eliminated serious eye and face injuries to protected players. [429, 430] The existing facial lacerations that are secondary to rotation of loose-fitting helmets could be diminished by converting the single-strap helmet fixation to a more secure helmet fixation system. [431] It seems that this obvious problem, with its relatively easy solution, should have been soluble in less than 10 years. [432]

Yet constant vigilance is needed. [433] Injuries to the cervical spinal column appear to be increasing in ice hockey players. [434-440] Some blame cervical injuries, increased player violence, loss of individual freedom, and injurious behavior on the protective helmet/face mask and believe that cervical injuries can be reduced by educational initiatives, [441, 442] changing from full face shields to less effective visors, [443] or even a return to risk-taking no mask-no helmet play. [444] Others believe that removing helmets and/or face shields is not an option because: (1) facial and blinding eye injuries will return—it is neither acceptable nor ethical [445] to trade one catastrophic injury for another, (2) prospective studies have shown that the use of full face shields is associated with significantly reduced risk of sus-

Table 17. Hockey face guards: Safety Rules and Organizations

Year	Organization	Suggestion/Rule
1976	Minnesota State Medical Association	Suggested all Minnesota amateur hockey players wear full facial protection
1976	Minnesota State High School League	Full face protection advocated for 1976-1977 season and mandated for 1977ñ1978 season and beyond
1976	Amateur Hockey Association	Full face protection required for nearly all amateur hockey players
1976	Connecticut	Full face protection required for all amateur players
1976	New England	Full face protection plus internal mouthguards required for all players up to age 16
1976	Connecticut Interscholastic Athletic Conference	Full face protection plus internal mouthguards required for all high school players
1978	Amateur Hockey Association US	Full face mask required for all players except those playing in Junior A or B paid gate teams
1979	Canadian Amateur Hockey Association	CSA certified face mask and helmet mandated for all minor hockey players
1980	Quebec Major Junior Hockey League	Full face mask required for all players
1980	Eastern Collegiate Athletic Conference	Full face mask required for all players
1980	NCAA	Full face mask required for all players
1982	Minnesota Medical Association	Goalies required to wear full-face cages instead of fiberglass masks
1983	Ontario Hockey Association	Junior B players will keep mandatory face masks
1983	NCAA	Goalies required to wear full-face cages instead of fiberglass masks
1983	Massachusetts Interscholastic Athletic Association	Goalies encouraged to wear full-face cages instead of fiberglass masks
1985	National Federation of State High School Associations	Full face mask required for all players
1988	Province of Quebec	Full face mask required for all players including adults
1993	Canadian Amateur Hockey Association	CSA certified face protector or visor for seniors

Figure 18. CSA and HECC certified full-face hockey protectors. Recommended.

Any of these full-face protector designs are excellent. All are certified by CSA and HECC and should be chosen by the player for fit, comfort and vision. Left to right: Childs wire, child's polycarbonate, adult wire, adult polycarbonate, adult composite of polycarbonate visor with molded opaque lower face protector.

Figure 19. Hockey visors. Offer only partial eye protection and no protection to the teeth and lower face. Not recommended.

Left: A hockey visor certified by HECC and CSA to CSA Z262.2 M90. ASTM F513 does not apply, since only full-face protectors have ASTM standard specifications.

Center: A visor that has had material removed from the lower central portion (a common practice among professional players) and no longer passes the coverage requirements of CSA Z262.2 M90. Note how a stick may impact the eye from a sharp inferior angle. It is very difficult for an official to recognize that the inferior portion of a visor has been altered.

Right. Slightly tilting back the helmet, as is often done by hockey players—and is not at all limited by the single chin strap—allows direct passage of the stick blade into the eye from a nearly horizontal angle of attack.

taining facial and dental injuries without an increase in the risk of neck injuries, concussions, or other injuries, [117, 446] and that concussion severity is reduced by the full face shield, [447] (3) the most violent form of hockey (professional) is played without full face shields, and (4) aggression and violence in ice hockey is a complex psychosocial problem that requires changes in behavior, coaching, and rules. [448] Violence and aggression are more predominant in men's ice hockey (in which many players do not wear full face shields) than in women's ice hockey (in which all players wear full face shields. [449]

The National Hockey League, with its apparent acceptance of violence and fighting as a part of the game is a poor role model for youth hockey. [450, 451] The attitudes of the coach, players, and referees to the style of play cannot be overemphasized as a factor in injury reduction. The solution to youth ice hockey injuries is rooted in the aggressive safety stand taken by USA Hockey, the national governing body for US ice hockey, which has instituted approximately 40 safety rules since 1983, stresses coach training on safety, and has appointed a risk manager to each of its 11 districts. The Massachusetts Medical Society and Massachusetts Hockey have combined to form the Heads Up, Don't Duck program to decrease the risk of spinal cord eye injuries. Think First Canada has produced an excellent video emphasizing more safety and more fun by playing "smart hockey". Eye and facial injuries to spectators [452] have resulted in taller protective barriers or nets in some arenas and a CSA standard to help reduce injuries to protect spectators at indoor sporting events. [453]

Street, floor, rink, and in-line roller hockey

Testing as to the actual energy levels in these sports has not been done, but total eye and face protection would be achieved with an ice hockey full-face mask mounted on a helmet. This combination should be required for all participants.

Street and floor hockey are played outdoors or in the school gymnasium using either regulation or lighter-weight hockey sticks and a plastic puck or a tennis ball. Face and head protection are rarely worn, even by the goalie. In 1.5 school years 10 of 400 players sustained an eye injury. [454] One player, who was wearing a helmet, but no facemask, lost an eye when struck with the blade of a plastic hockey stick. [455]

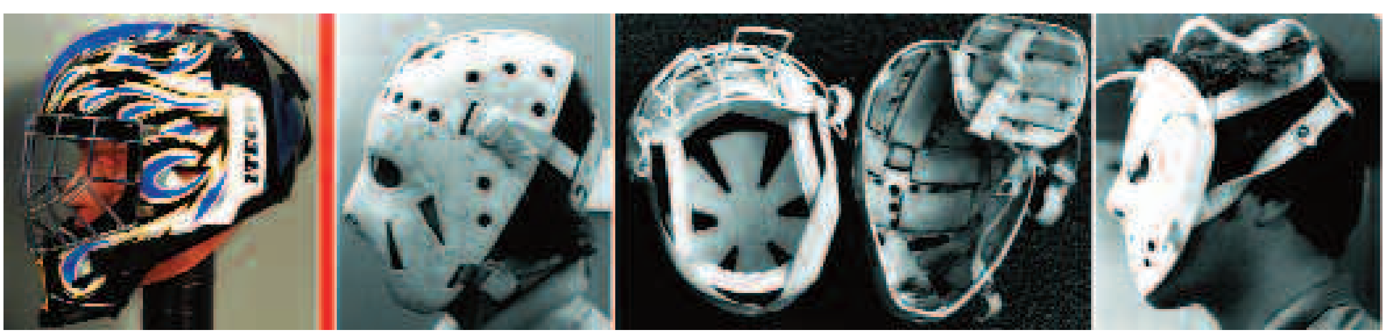
Rink hockey is played with rink (quad) skates and a lightweight (155g, 7-8 cm diameter ball. Face protection is mandated for the goalie, but not for the other players.

In-line roller hockey is similar to ice hockey and is usually played in a rink with a hard rubber puck that has ballbearings or bumps to limit surface friction. Helmets with face-masks are mandatory.

Field hockey

Injuries to the head and face are common in field hockey. The field hockey ball (diameter 7.13-7.5 cm; 156-163 g), which is extremely hard and can be driven at a velocity in excess of 50 mph by high school girls, has caused an almost fatal epidural hemorrhage from a fractured skull to a Massachusetts high-school player. Of the 14 serious injuries to women playing field hockey at California State University in Long Beach from 1976 to 1979, 4 involved the head and face (3 cerebral concussions and 1 severe cheek contusion with neuropathy of the seventh nerve that lasted several months). [456] Tooth injuries in field hockey have increased, prompting the Big Ten

Figure 20. Recommended and unacceptable hockey goalie protectors



Left: Recommended hockey goalie face mask-helmet combination certified to ASTM F1587 by HECC.

Right of divider: Custom made goalie face mask. Note difference in padding thickness when compared to helmet interior (center). Custom masks of this type are not as safe as HECC certified products and are not recommended.

Far right: A non-custom product sold in some sporting goods stores that gives a false sense of security while offering essentially no protection. Should be banned.

athletic rules committee to mandate mouthguards for female collegiate athletes in 1982. [457] A 1996 survey of Delaware, Massachusetts, Missouri, New Hampshire, Ohio and Rhode Island reported 160 occurrences of head injuries in 5,070 players. Fifteen of these injuries involved the eye, 10 the eyelids, and [19] the eyebrow. Field hockey eye injuries tend to be severe and include ruptured globes from impact with the stick. 19, [458] The risk of an eye injury over an eight-year career is approximately 4% ***(Table3)***. Head, face, eye, and teeth injuries could be eliminated with helmets and faceguards, which are mandatory for goalies but forbidden to other US players. Eye injuries can be reduced or eliminated with eyewear conforming to ASTM F2713 for field hockey. Thus far, field hockey officials have no adequate explanation as to why the ball must be so very hard, and why helmets and full-face guards are not permitted to players other than the goalie. [459]

Polo

Polo, a team sport with four riders to a side, is often described as field hockey on horseback. An adult male polo player can drive the (7.6-8.9 cm, 99-128 g) plastic ball in excess of 100 mph. Players wear helmets, but the use of eye and face protectors is spotty—ranging from wire faceguards borrowed from hockey to a double wire bar which will permit penetration by the ball and the mallet ***(Figure 21)***, to no protection at all. There is the risk of being struck in the eye with the ball or a mallet, but no standards exist for eye and face protectors.

Standards and the universal use of adequate polo face-masks will come too late for the one-eyed polo player who lost his only eye when struck by a mallet that penetrated a face mask which offered inadequate protection. [460]

Lacrosse

Lacrosse participation has doubled from 2000 to 2008 to 1.1 million players (64% male). Both men's and women's lacrosse are played with a solid, hard-rubber ball (142-149 g, 7 cm diameter) that is thrown and caught with an approximately 10 x 12 inch netted pocket on the end of a stick (the crosse) that varies in length from 36 to 44 inches for women and 40 to 72 inches for men. Despite the fact that men propel the ball faster and that men's lacrosse permits body contact, which is prohibited in women's lacrosse, eye injuries occur about 15 times more frequently in the women's game (8-year-eye-injury risk 6.69% for women and 0.45% for men (Table3).

Men's lacrosse

Men's lacrosse is played on a 60 x 110-yard, marked field. A player may "take out" an opponent who either has the ball or is within 2.7 m of a loose ball by making contact (usually with the shoulder) between the opponent's neck and knees and not from behind. Although the rules forbid taking uncontrolled swings with the stick, infractions occur. All players are required to wear helmets with facemasks and attached chin straps ***(Figure 22)***. Before 1978, some masks would admit the lacrosse ball at speeds approaching 90 mph with resultant face and eye injury. Rules now require a vertical bar that prevents ball penetration. [461] The face mask offers good eye and nose protection; eye injuries and nasal fractures are rare in protected players. [462 463]

Figure 21. Ineffective polo eye protector

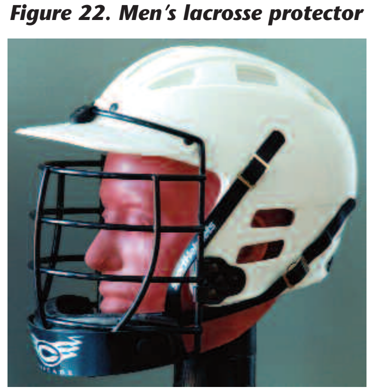
This polo wire guard and helmet combination is commonly used, yet allows easy penetration and eye contact by both the ball and the mallet. An ASTM standard that prevents such contact could easily be written with representatives from the polo community.

Women's lacrosse

The rules in women's lacrosse do not permit deliberate physical contact, but the stick can be checked. The wooden stick must have a head less than 9 inches wide. Only the goalie is permitted the use of a helmet and face protector. Should women who play lacrosse wear helmets and face protectors to prevent head, face, teeth, and eye injuries? Several women's lacrosse officials and the leadership of United States Women's Lacrosse Association (USWLA), while permitting mouthguards and the voluntary use of eyeguards, are opposed to the concept of helmets and faceguards. [464, 465] Others believe they should be worn for the good of the players and the sport. [466, 467] The Women's division of US Lacrosse, which has replaced the USWLA as the governing body for women's lacrosse in the United States, has mandated eye protection that conforms to ASTM F803 starting with the 2005 season.

There is no question that unprotected women's lacrosse players suffer eye and face injuries. More than 20% of all NCAA game injuries and 7% of serious game injuries were above-the-neck. [468] Fractured orbits, hyphema, angle recession with lifelong tendency to glaucoma, and ocular contusion have resulted when lacrosse balls or crosses struck unprotected women players. [469, 470] Among collegiate and postcollegiate women's lacrosse players, 12.6% reported eye injuries, and 4.8% reported residual problems from an eye injury sustained while playing lacrosse. [471] Data collected by the USWLA Sports Medical Committee from 1980 through 1983 revealed between 6.2% and 9.9% annual incidence of face, eye, and tooth injuries to players. Most of the injuries were accidental, with about two thirds caused by the stick and one fifth caused by

Figure 22. Men's lacrosse protector

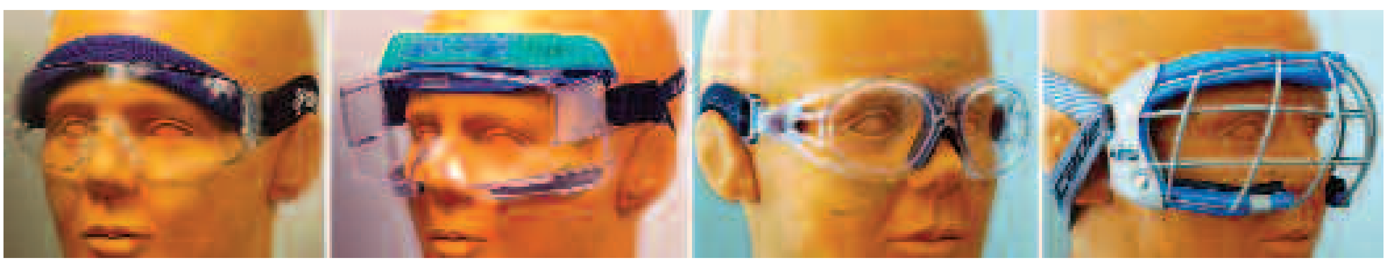


Protectors that comply with NOCSAE standard ND041-05M08 requirements are extremely effective in preventing eye and face injuries in men's lacrosse. They also would be effective in women's lacrosse.

the ball. Australian data, collected prospectively in 1991 and 1992 recorded head or face contact in 22% of the women's lacrosse players at least once per game.[472] During the 1991 season, unprotected Australian women's lacrosse players suffered 13 concussions, three broken noses, 28 black eyes, 98 facial bruises, 32 cuts to the face and head, one facial fracture, four significant eye injuries, and four broken teeth while no significant injuries were reported in the protected players. Helmeted players reported 62 examples of significant head and face contact in which they believed the protection prevented injury.[467] Based on these findings, three of the four states playing women's lacrosse in Australia allowed the optional use of helmets in their competition starting in 1993.

Women's lacrosse is currently stalled at the same crossroad that confronted ice hockey in the mid 1970s—injuries to the head, eye and face are common but are denied or trivialized by many of the officials and those who make the rules. The situation in ice hockey has changed: acceptance of total head and face protection has eliminated two thirds of all the ice hockey injuries that occurred without the protectors. Head, face, and eye injuries could be effectively eliminated in women's lacrosse with appropriately designed protectors. Although there have been no significant eye, face or head injuries to protected (helmet plus full face protector) players; or any instances of an injury caused by a helmet or face protector when protected and unprotected players played against each other;[467, 473] and women's lacrosse officials realize that they do not have the right to discourage the development of protective equipment as long as it neither threatens others players nor gives the wearer of such equipment an unfair advantage;[474] the International Federation of Women's Lacrosse Associations (IFWLA) rules still state "Close fitting gloves, noseguards, eyeguards, and mouthguards may be worn. Field players are not permitted to wear protective headgear or facemasks."

Figure 23. Eye protectors for women's lacrosse



Plano shield	Plano shield that may be worn over spectacles;	Rx or plano eyewear	Wire shield.

The argument against helmets with facemasks—that helmeted players will use the helmet as a weapon against unhelmeted players—is ludicrous. If a person has a long stick in her hand and also has a face-mask on her face, it is simply more efficient to hit the opponent with the stick. In all instances in which helmets and face-masks were optional (Australia, 1993 to present; Massachusetts, 1984 season), there was no instance of an injury caused to an unprotected player by the protective helmet and/or facemask of a protected player, while ball and stick injuries to the unprotected were commonplace.

Although the mandate (effective in 2005) for the use protective eyewear that conforms to ASTM F803 for women's lacrosse ***(Figure 23)***, will reduce eye injuries,[470, 475] women's lacrosse officials should permit women to wear the same protective head and face gear—so effective in men's lacrosse—to reduce other injuries to the head and face. In addition to protective equipment, rule enforcement and zero tolerance for rules infraction are necessary components of an injury reduction program.[476]

Box lacrosse

Box lacrosse is played in an enclosed area, such as a hockey rink, with shorter sticks and a lighter, spongier ball than field lacrosse. Although the rules prohibit wild swinging, hitting from behind, and checking at the head, face, and neck, the games can be quite physical. Head and face protection that meets CSO box lacrosse standards[477] prevents most eye and facial injury in box lacrosse.

Baseball

There are 16.4 million baseball players (82.6% male, average age: 22.8) who play an average of 43.6 games a year. Although the incidence of eye injury is greater in other organized sports ***(Table 3)*** eye injuries from baseball, because of their occurrence ***(Table 1)***[27, 478-480] and severity[481-483] are a concern. In 1995, an estimated 162,000 baseball injuries in the 5- to 14-year age range presented to emergency rooms in the United States, with ball impact responsible for 55% of the injuries.[484] Baseball is a leading cause of US sport-related eye injury.[485] In Massachusetts, 1 of every 238 children 5-19 years old was treated at a hospital for a baseball-related injury annually.[486] Of 5 million Little League players, 1.96% sustained injury of sufficient severity to require medical attention. The head suffered 38% of all injuries, and injuries to the batter accounted for 22% of the total. The pitched ball caused 22% of all injuries, but on the basis that one of five pitched balls became batted balls, the incidence of injury from the batted ball was 361% higher than that from the pitched ball.[487] Several major league players have had severe eye injuries from thrown or batted balls. A 1-year prospective study of all eye injuries among approximately 800 Major League players from 26 teams showed that the 24 injuries were fairly evenly distributed among batters, fielders, and those on the sidelines. No permanent loss of vision occurred, but 30% of those injured missed subsequent games because of their eye injury.[488]

Prevention of youth-baseball-related injuries is multifaceted and includes: 1) eliminating steel spikes; (2) eliminating sliding, or using the breakaway base; (3) eliminating or moving the on-deck circle; (4) screening the dugouts; (5) using protective equipment including batting helmets, catcher's helmets, face protectors for batters, base-runners, and catchers; (6) prohibiting intentional body contact between a base-runner and infielder making a play at a base; (7) using softer baseballs; (8) controlling the liveliness of baseball bats (9) restricting on the amount of pitching; (10) motivating players to use proper equipment; and (11) continued surveillance of baseball injuries. [484, 489-491] Controlling the baseball velocity in youth games is important to ensure there is sufficient time to respond: 8- to 9-yr-olds need exit-velocities lower than 26.8 m/s (60 mph), and 16-yr-olds lower than 33.5 m/s (75 mph) to reduce the potential for serious or catastrophic injury. [492]

The 5-oz baseball, thrown at speeds up to 100mph and batted even faster, contains an enormous amount of energy. [493] Baseball batters struck in the head by fast pitches may suffer concussion, skull fracture, or death, which may be prevented by a helmet that conforms to standards of NOCSAE. [133] Ball-player collisions are common in youth baseball. In 176 baseball games, there were 405 actual player-ball impacts, of which 29 resulted in "major" or "extreme" discomfort to the player. Eighty percent of the impacts were from the pitched ball. Impacts were most common in the 9-10 age group, and the injury severity/discomfort was directly correlated with the hardness of the ball. [494]

The safety of a baseball or softball, as far as brain and cardiac injury are concerned, is related to the hardness of the ball. [495] Major-League baseballs, wound with wool ***(Figure 24)***, are safer than many Little League baseballs, which are filled with synthetic yarns or hard molded plastics. [496] The Reduced Injury Factor (RIF) baseballs and softballs would reduce death from ball impact to the head and chest (there were 68 ball-impact deaths ages 5-14, in 1973-1995—38 from impacts to the chest, 21 from ball impacts to the head, and 9 from ball impacts to other areas) [484] but would probably not reduce eye injuries to any significant degree. [497] Since the RIF balls weigh the same (5 oz) and feel and handle remarkably like a Major League baseball with greatly increased safety, it seems reasonable that RIF balls should be used by all Little League players. [67]

Figure 24. Major League and RIF baseball cross sections

Top: The RIF balls are filled with a solid polyurethane core of which the weight, liveliness, and hardness can be varied independently.

Bottom: A major league baseball has a complex interior consisting of the central “pill”—a composite cork/rubber center—surrounded by two layers of rubber, one red, the other black. The first wrap around the pill is a four-ply gray wool winding. The second wrap is a three-ply white wool winding. The third wrap is a three-ply gray wool winding. The fourth and final wrap is a fine cotton string that's a finish winding. Both balls are covered with two figure eight shaped cowhide pieces that are double stitched (108 stitches) by hand using 10/5 red thread. It is extremely difficult to feel a difference between the two finished balls.

Ball and bat liveliness (elastic properties) also relate to injury. A livelier bat transmits more energy and velocity to the ball. ASTM F2219, F1881, and F2398 are the standard test methods for baseball bats. A livelier bat gives an advantage to a hitter (the maple used in Barry Bond’s bats is livelier than the ash used by most other players). The liveliness of both wood (by carefully selecting the species and individual blanks) and metal (to a greater degree than wood—by selecting the material and manufacturing process) bats can be varied. An aluminum bat used by high school players should not exceed a ball exit speed ratio rating of .728 because a pitcher loses the ability to protect himself when this ratio is exceeded. In 1998 the NCAA required a maximum batted-ball exit velocity of 93 miles-per-hour. [498]

A livelier ball travels faster when hit and thus contains more energy and gives the fielder less time to react than does a less lively ball traveling at slower speed. Ball liveliness does not correlate with hardness and must be measured separately. Liveliness is measured by the coefficient of restitution (COR), which is the ratio of the velocity of the ball rebounding from the surface of a hard immovable object (e.g., thick steel plate or ash boards backed with concrete) to the incident velocity. A baseball traveling at 85 ft/s (58 mph) rebounding with a velocity of 48 ft/s (33 mph) has a COR of 0.56 and loses 68% of its energy to friction [493] as compared with the extremely lively golf ball with a COR of 0.8 that loses much less energy to internal friction. Since the hardness and liveliness of the ball relate to injuries, and since brain injury potential can be measured on test headforms with the severity index (SI), [499] standards could be set for age groups or divisions that specify the liveliness, hardness, and the maximum allowable SI consistent with the performance demands and skill levels of a particular age group or division. [496] ASTM F1887 and F1888 are standard test Methods for baseballs and Softballs.

Face protectors that meet ASTM standard F910, attached to NOCSAE approved helmets are strongly recommended for Little League batters and base-runners ***(Figure 25)***. Face guards reduce oculo-facial injury in receptive youth players and should be required for youth batters and base-runners. [500, 501]

Some protectors that pass ASTM F803 for baseball fielders ***(Figure 26)*** have not gained player acceptance. Manufacturers continue trying to develop cosmetically and functionally acceptable eye protection for baseball fielders. Players and parents must be aware that some products advertised for youth baseball batters and fielders ***(Figure 27)*** may only give a false sense of security and no significant protection. The buyer should be certain that the protector was tested to ASTM stan-

Figure 25. Recommended baseball protectors

The left two protectors conform to NOCSAE ND024-03m05 performance specification for a baseball/softball catcher's helmet with faceguard.

The third protector from left has a face-shield that conforms to ASTM F910 for baseball batters and base-runners attached to a helmet that conforms to NOCSAE ND022-03m04 performance specification for baseball/softball batter's helmet. Note the recommended chin-strap. This protector would also give excellent protection for fielders.

The protector on the far right passes the standards for a batter/base-runner-helmet/faceguard combination, yet is inappropriately too large for a six-year-old child and thus is not recommended for this player.

Figure 26. Baseball fielder protectors that are effective

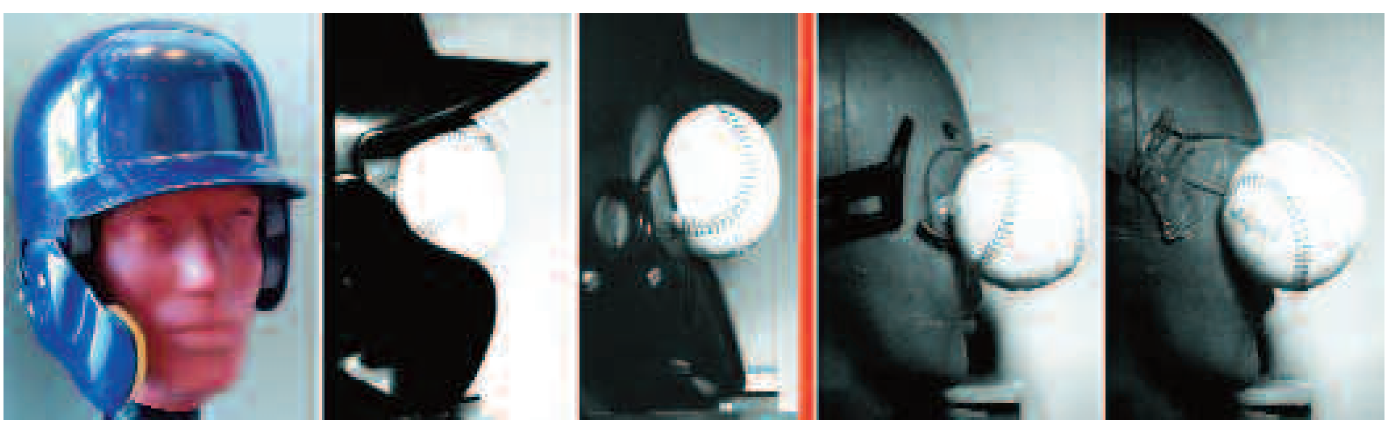
Both of these protectors are effective in preventing a baseball from contacting the eye. However, neither has gained wide acceptance from the players or baseball officials.

dards.

Professional players should be aware of the protection offered by the protectors and make their own decision as to whether to use them. The most effective approach to introducing face protectors to baseball would be along the lines that were successful with the hockey face mask—a somewhat gradual approach to younger players, continued gathering of data, then wider use of the protectors as data proved their worth. The evidence has resulted in mandatory face-masks for youth batters in Baltimore, Dover (New Hampshire), the South Side Little League and the Dixie Little League.

Players never should wear glasses that have little resistance to shattering when impacted with a baseball ***(Figure 4)***. [379] At least two major league baseball players were seriously injured (Mookie Wilson, lid lacerations, hyphema; Jackie Gutierrez, corneal lacerations) when their flip-down sunglasses shattered on impact with the ball. In 1986 the manufacturer, Vision Master, Inc, Cleveland, Ohio, switched to polycarbonate lenses and there have been no subsequent reported instances of lenses shattering.

Figure 27. Not recommended for baseball or softball



Left of dividing line: The "C Flap" type of protector for baseball and softball batters is not recommended. When impacted from the front (center), there is direct impact of the ball onto the eye. When impacted from 45 degrees, directly onto the C flap, the flap contacts the eye. Both impacts with soft (RIF 1) baseballs at 68 mph.

Right of dividing line: Both of these protectors, advertised for youth baseball, fail when tested to ASTM F803 for youth baseball.

Most baseball-related eye injuries could be prevented with real cost savings to society. Since about one third of the total eye injuries occur to batters, faceguards worn by batters (which would also protect base runners) would substantially reduce but not eliminate eye, face, and teeth injuries. The best protection for fielders is to wear eye protectors that pass ASTM standard F803 for baseball. [502] The acceptance of softer base-balls, and face and eye protection is hindered by "tradition bound resistance" on the part of sports officials and some players. [503]

Softball

Fast pitch softball, played by 2.3 million, is the fourth most popular high school sport for girls, with 1.3 million playing more than 25 times a year. Slow pitch softball has declined in popularity by 25% between 2000 and 2009 because of a loss of casual and league players, and is now played by 9.5 million (60% male, average age 30.3, average 29.6 days participation / year).

Women's softball has approximately twice the incidence of eye injuries as men's baseball ***(Table 3)***. Recreational softball has an unknown incidence, but a high occurrence of injuries, including eye injuries. Shattered sunglasses have lacerated globes. Maskless catchers and behind-the-plate umpires, batters, and fielders have all been injured. It is estimated that recreational softball players sustain more than 1.7 million sliding injuries every year—360,000 of them serious enough to require hospital emergency department treatment. Softball injuries cost the public $2.1 billion annually. The widespread use of breakaway bases would eliminate a great number of these injuries and the costs associated with them. [504 505] Bat (ASTM F1890) and ball (ASTM F1887; ASTM F1888) liveliness should be specified for the field conditions and player skill levels. [506]

Cricket

Cricket places extreme demands on the visuo-perceptual system of the batsman. The cricket ball, with an elevated seam, is thrown at approximately the same speed as a baseball but may be bounced with spin that causes the ball to change direction as it hits the ground in front of the batsman. [507] It is difficult for a cricket umpire to call an illegal throw without the assistance of video footage shot from at least three different positions. [508]

Indoor cricket most commonly causes injury to the fingers and the eyes. [509] Ruptured globe, retinal detachment, hyphema, choroidal tears with permanent loss of vision, and lid laceration have been caused by the 5.5-oz hard ball. [510, 511]

In New Zealand, about 30% of all sports injuries to the eye are due to indoor cricket. [511] In Australia cricket contributed to 14.6% of orbito-zygomatic fractures with the ball being the agent of injury in all but one of the patients. [512] At least three cricket players with eye injuries were functionally one-eyed prior to the injury. [513] The incidence of these injuries could be reduced by wearing eye and/or facial protection as suggested for baseball.

Large ball sports

Of the large-ball sports, soccer and basketball are extremely popular—very little equipment is needed and variations of the games may be played by any reasonable number of players. Basketball was played by 26.3 million people in 2008 (74% male). In the United States, soccer at 19.0 million (63% male) has increased in popularity, but has fewer participants than basketball. However, soccer is by far the most popular sport worldwide. In 2008: 13.2 million people played volleyball; 10.5 million touch football; 7.7 million tackle football; and 0.7 million rugby in the United States.

Soccer

Contrary to previous ophthalmology teaching that eye injuries are rarely caused by balls larger than 4" in diameter, [514] the 8.6" diameter ball is responsible for approximately 80% of soccer eye injuries. Soccer eye injuries include serious injuries (hyphema, vitreous hemorrhage, retinal tear, chorioretinal rupture, angle recession), as well as minor corneal abrasions and contusions. [26, 125, 515, 516] Soccer-related eye injuries , the leading cause of sports eye injuries in Europe and Israel, [517-520] tend to be severe, [520] with one third of all injured players suffering hyphema. [27] There is approximately a 2% risk of eye injury during an eight-year career ***(Table 3)***. Where soccer is played frequently, approximately one third of all sports-related eye injuries are caused by the soccer ball. [19]

The kicked soccer ball has a mean velocity, which increases with experience, of 45.6± 14.0 mph. Soccer balls that used in games vary with age (ages 8-10, #3 ball 240-300g; ages 11-13, #4 ball 330 –390g; over age 14 #5 ball, 420 to 480g) and have sufficient energy that some are concerned about possible brain injury from repeated soccer ball headings, [521] but the correlation of proper soccer ball heading with brain injury is uncertain. [522] Linear and angular acceleration levels for a single heading maneuver are below those thought to be associated with traumatic brain injury, however, the effect of repeated acceleration at this relatively low level is unknown. [523] Most concussions (84%) are caused by player-to-player contact, and not by contact with the ball (8%). [524] ASTM F2439 is the standard specification for headgear used in soccer. Headgear conforming to these specifications is recommended to those who are concerned with prevention of the cognitive dysfunction that is reported in some soccer players. Correctly executed headers, not associated with globe impact, do not cause significant rotational acceleration of the head and are unlikely to cause retinal hemorrhage, but incorrectly executed headers might. [525]

It is now known that sufficient energy is transmitted from the large ball to the eye to result in retinal detachment and permanent vision loss in many injured eyes, [526] because the ball deforms enough to enter the orbit between 7.5 and 8.7 mm, remains in the orbit 10m/s (longer than any other sports-ball ***(Table 7)*** and has a suction effect on the globe as it leaves the orbit. There is no correlation of injury potential with ball size and ball inflation. [527]

Since proper heading techniques are essential for brain and retinal protection, heading the ball should be discouraged for younger players. Goal posts should be stabilized and padded. [528-530] Sports eye protectors that pass ASTM F803 for squash prevent contact of the ball to the eye and should be encouraged. [527, 531, 532]

Basketball

Since 1960, basketball has progressed from a largely non-contact sport into one where significant body contact is allowed, with a corresponding increase in injuries. [533] Men's basketball is second only to wrestling as the cause of significant college sports eye injuries, with an eight-year probability of a significant eye injury to one of every thirteen players. The heightened level of physical contact in men's college basketball is the most likely cause of the increased incidence of head and facial injuries. [534]

As women's player size and the game speed increase, there is a continuing transition from a finesse to a high-risk contact sport. [535] Women's basketball has an incidence of significant eye injuries immediately behind women's lacrosse and field hockey, with an eight-year career injury probability of a significant eye injury to one in every 26 players ***(Table 3)***. When all eye injuries are considered, approximately 1 in 10 college basketball players sustain eye injuries each year. [430] Basketball was the leading cause of sports eye injury (22.2%) presenting to United States Emergency rooms and was responsible for the majority (28.7%) of sports eye injuries at the Massachusetts Eye and Ear Infirmary. [27]

Over a seventeen month period, [324] National Basketball Association (NBA) professional basketball players sustained 1,092 injuries, of which 59 (5.4%) involved the eye. Most of the eye injuries were relatively minor abrasions, lacerations, contusions, corneal abrasions, and traumatic iritis caused by opponent's fingers or elbows striking the player's eye, frequently during aggressive play under the boards, but three of the players suffered orbital fractures and the injuries caused nine players (15.3%) to miss games and five players (8.5%) to miss practices only. The incidence of 1.44 per 1000 NBA game exposures is difficult for most players to comprehend, but if the calculation is expressed as the fact that approximately one out of every six professional players suffered an eye injury in about 1.5 years of play, the risk is more apparent. Only one NBA eye injury (a periocular contusion) was caused by the ball, and only one injured player was wearing an eyeguard at the time when he received a laceration below the eyebrow, but no injury to the eye itself, when the eyeguard was displaced upward by a finger as this power forward was going up for a rebound. [536]

Avulsion of the optic nerve, usually due to the force transmitted by the extended finger, was more commonly reported in basketball than any other sport. [104, 537-539] The avulsion mechanism is most likely that the extended finger or thumb causes an extreme anterior rotation and anterior displacement of the globe, with a concomitant dramatic increase in intraocular pressure, with further anterior displacement of the globe secondary to an increase in intraorbital pressure. [540]

Because of the possibility of ruptured RK incisions [541-543] or late LASIK flap dislocation, [101] it is essential that players who have had incisional refractive surgery or LASIK be advised to wear protective eyewear for all practices and games. Adequate eye protection, recommended for all basketball players (and absolutely essential for the functionally one-eyed) would be achieved with protectors certified to ASTM F803 for basketball, which has a specification to prevent a finger from contacting the eye with the protector in place.

Football

Football faceguards have been quite effective since they have resulted in an 80% to 90% reduction in facial injuries. However, single- and double-bar protectors offer incomplete protection to the face and facial injuries comprise approximately 10% of all football injuries [544 545]

If all eye injuries (minor and serious) are considered, the rate of eye injury to Michigan State University football players was 4.1% per year. [430] Serious eye injuries are much less common than minor ones, with an eight-year risk of 0.87%. Although the average team could expect only one serious eye injury every other season, [546] there will be more than four less serious injuries each season, indicating that eye contact occurs often enough that polycarbonate visors ***(Figure 29)*** should be considered for all and mandated for the functionally one-eyed. Unless supplemented with a polycarbonate shield or separate eye protection, all presently available football face protectors allow penetration of a finger through the mask with enough force to result in retinal detachment or visual loss to the injured eye. [547, 548] Dementia-related syndromes may be initiated by repetitive cerebral concussions in professional football players, [549] but the effects of repeated concussions on visual perception are unknown. In 2004, the NCAA changed the rules related to spearing and head-down contact. [550]

Rugby

One hundred three of 150 female and male players in the Southern California Rugby Football Union were injured during the 1981-1982 season. There were 11 eye injuries, 32 injuries (including fractures) to other parts of the face, and 26 head injuries. [551] Intentional eye gouging has resulted in giant retinal tears. [552] Injury reduction by better conditioning, rules modifications, and adherence to the rules of the game has been emphasized. [553] It is not known whether sports eye protectors certified to ASTM F803 will give adequate eye protection from rugby eye injuries.

Volleyball, netball, team handball, speedball, and bombardment

Participation of women playing NCAA volleyball had greatly increased since 1988. [554] These large-ball games are responsible for some eye injuries, but the incidence is low for volleyball ***(Table 3)*** and not known for netball, team handball,

Figure 29. Football polycarbonate visor attached to face mask

speedball, and bombardment at this time. Adequate protection would be achieved with the eye protectors recommended for basketball.

Combat sports

With six million participants (2.6 million frequent), the martial arts are the most popular combat sport, and the most popular among women, who represent 37% of the participants. Wrestling (94% male) involves 2.4 million (0.5 million frequent) and boxing 0.9 million participants. Since eye trauma is intrinsic to professional boxing and the full-contact martial arts, no eye protection is permitted or available. The helmets worn in amateur boxing and amateur full contact kick boxing give partial eye protection, but still permit contact of the glove to the eye, especially if the glove has a thumb that can be extended to the "hitchhiker position". There are no standards for eye protectors for wrestling or the non-contact martial arts, but it would be possible to construct adequate protective eyewear, possibly attached to a soft helmet that would incorporate ear protection.

Boxing

If the usual sources are referenced, it would appear that eye injuries from boxing are extremely rare. Only 34 of a total 37,005 eye injuries resulting from sports and recreational activities in 1990 were attributed to boxing by the NSPB. [555] The USEIR captured only 4 boxing injuries: 3 retinal detachments (including one giant tear) in professional boxers, and 1 blowout orbital fracture sustained in an Army boxing match that resulted in 14 days lost from work. [201] As an investigator looks through available databases, it soon becomes apparent that there is no national or even regional comprehensive source of data regarding the real incidence, severity, and long-term outcome of eye injuries from boxing.

Yet it is apparent to any ophthalmologist who has examined boxers that eye injuries as a direct result of boxing are very common. [556] The ophthalmologists who actually care for the injured boxers have realized the following: Boxers tend not to be seen in hospital emergency departments since eye injuries are the accepted result of the sport and are usually "toughed out" with little or no treatment; Blinding injuries most often affect one eye, and the boxer will frequently hide the defect for fear of being disqualified from the sport; Other blinding eye injuries, such as glaucoma from angle recession, may occur many years after retirement from the sport and a correlation between the injury and the blindness will not be made or if made then not reported to any central monitoring agency. Thus, if the true incidence of eye injuries to boxers is to be ascertained, one must look to smaller studies that specifically address the problem rather than large databases that essentially ignore the sport.

Since Olympic, military, and professional boxing are dissimilar sports, they will be considered separately.

Olympic Boxing

Headgear is mandatory in Olympic boxing, yet eye injuries are not rare in this group. Of 13 Olympic boxers examined in 1984, three had retinal holes or tears, probably as a result of boxing, and one had an unrelated amblyopia that reduced his best corrected vision in the amblyopic eye to 20/400. [557] The incidence of eye injuries reported from the US Olympic Training Center from 1977 to 1987 as 23 of 447 total injuries (5% eye injuries) with only one retinal detachment [558] is almost certainly falsely low, since there was no systematic examination of the eyes of these boxers by an ophthalmologist that included dilated slit lamp examination, gonioscopy, and examination of the peripheral retina. There was a low incidence of eye injuries in a group of 20 active, elite, amateur, asymptomatic Turkish boxers among whom only one boxer with an atrophic retinal hole that was treated with laser prophylaxis. [559]

Military Academy Boxing

Military instructional programs, such as those at the US Military Academy at West Point, are fashioned after the Olympic program. Although the total injury rate seems low (less than 4% injuries in 2,100 cadets who received boxing instruction between 1983 and 1985), the incidence of eye injuries is impossible to evaluate since no asymptomatic participants had the benefit of an adequate ophthalmologic examination for this study. [560] Twenty-two of 401 (5%) soldiers hospitalized for boxing-related trauma were admitted for eye injuries, with one eye enucleated after complications of a ruptured globe. This study did not examine all boxers and underestimates the incidence of eye injuries to boxers by only reporting those requiring hospitalization, not asymptomatic injuries that may cause problems after military discharge, unless adequate predischarge examination is done. [561] The mere questioning of whether boxing should be banned from military training [562] has resulted in heated debate. [563-565] In response to mounting pressure from the medical community, the US Air Force Academy has eliminated boxing as a mandatory activity. [566] It seems reasonable that the military, with a captive population, would be the ideal arena to perform prospective studies of the true incidence of eye as well as other boxing injuries

Professional Boxing

The most reliable studies of eye injuries in professional boxing involve complete eye examinations on relatively large groups of active boxers. Seventy-four asymptomatic boxers, in various stages of their active careers, were referred to the Sports Vision Institute of Manhattan Eye, Ear and Throat Hospital on a sequential basis by the New York State Boxing Commission over a two-year period (February 1984 to February 1986). The boxers averaged 61 bouts with eight losses over nine years. Vision-threatening injuries (significant damage to the angle, lens, macula, or peripheral retina) occurred in 43 boxers (58%). Two boxers were actively boxing with best-corrected visual acuity of 20/200 in the injured eye. Retinal tears were directly related to the total number of bouts and the number of losses. Twenty-four percent of asymptomatic boxers had retinal tears. It was calculated by the authors that a boxer has a 20% chance of a retinal tear after five losses and a 90% chance of a retinal tear after 75 bouts. [567] A New Jersey study of 284 boxers confirms the high incidence of eye injuries in boxing, with 19% of those dilated having retinal problems and 15% having cataracts attributable to the sport. Three boxers (of whom two were world champions) had their careers ended following the need for cataract extraction. [568, 569] The high incidence of boxing-induced ocular injuries was reconfirmed in a study of 505 professional boxers in whom there were 18%

with retinal holes, 38.8% with angle abnormalities, and 5.9% with posterior subcapsular cataracts. [570] There have been other series of retinal injury and detachment, lids, lens, angle and vitreous. [571-577] Professional boxers, such as Sugar Ray Seales, have lost vision in both eyes.

There have been several proposals, which have resulted in state advisory boards establishing safety standards, to decrease the eye, brain, kidney and soft-tissue injuries, and deaths in boxing. [578, 579] Some believe that boxing should be banned in the United States, as it is in Norway and Sweden—a position vigorously opposed by others. [580-588] Removing the gloves would deemphasize the knockout punches by making boxing a sport of jabs and defense, [589] but would the exposed fingers and knuckles increase eye injuries? At this time, the most desirable changes would be those that not only increase public awareness of the dangers of boxing, but also make it safer for participants. [590] The American Academy of Ophthalmology has a policy statement on reforms for the prevention of eye injuries in boxing, which would promote early diagnosis and treatment and prevent visual disability with recommendations that include (1) examination of boxers before licensure and then after one year, six bouts or two losses, or at the stopping of a fight because of an eye injury, or at the discretion of the ringside physician; (2) mandatory, temporary suspension from sparring or boxing for specific ocular pathology—30 days for a retinal tear and 60 days for a treated retinal detachment, or individualized after consultation with the athletic commission medical advisory board; (3) minimal visual requirements of 20/40 or better in each eye and a full central field of not less than 30 degrees in each eye. (4) An ophthalmologist required on each state medical boxing advisory board; (5) thumbless boxing gloves to minimize ocular injuries; (6) a national Registry of Boxers for all amateur and professional boxers in the United States that records bouts, knockouts, and significant ocular injuries; (7) a program for training and recertifying ringside physicians; and (8) a uniform safety code. [591]

Wrestling

Wrestling has the highest risk of eye injury for college sports, with approximately one in eight participants suffering a significant eye injury after an eight-year career ***(Table 3)***. The USEIR database has five wrestling eye injuries, consisting of choroidal rupture, vitreous hemorrhage, retinal detachment, orbital fracture, and an open-globe injury due to dehiscence of a corneal graft in a 16 year-old young man who had a penetrating keratoplasty at age eight. The average college team with 25 players and 2600 athlete-exposures should expect one or two eye injuries each season with a significant injury every 9 or 10 seasons. [592] At Michigan State University 18.4% of wrestlers suffered eye injuries that were relatively mild (lacerated eyebrows, corneal abrasions) and left no permanent damage. [430] The case of a highly myopic (-12 diopters) teenaged young man who lost an eye to a giant retinal tear suffered while wrestling and then continued to wrestle only to lose the remaining eye the following year to a giant retinal tear secondary to a wrestling injury [593] emphasizes why wrestling is not recommended for one-eyed athletes.

Although headgear is required at NCAA competitions, and ear protectors can reduce ear injuries that result in the permanent deformity of cauliflower ear, 65% of Division 1 wrestlers don't wear headgear all the time during practice. This reluctance on the part of wrestlers to wear headgear, because of discomfort, compounded by the lack of a standard specification for wrestling eye protective devices, makes protection of the one-eyed wrestler problematic at this time. Some commercial wrestling face guards have large eye openings that readily admit eye contact by fingers. The protection afforded by custom face masks [594] must be viewed with suspicion, as custom made face masks for ice hockey goalies have proven ineffective for the prevention of hockey eye injuries.

Herpes gladiatorum, caused by herpes simplex type I, is easily spread through skin-to-skin contact. [595] Sixty of 175 wrestlers (34%) attending a 4-week intensive training camp developed herpes simplex type 1 infections. Five of the 60 (8%) in the third or fourth week of camp developed primary ocular herpes infections that included follicular conjunctivitis, blepharitis, and phlyctenular disease but no corneal involvement or late ocular recurrence. All responded to topical vidarabine ointment five times a day or trifluridine drops every 2 hours. [596] By preventing the virus from reaching the blister stage with the use of oral acyclovir as soon as the wrestler feels an itching or tingling sensation, especially at the site where blisters have developed before, the wrestler can reduce the course of the disease from 2 weeks to 2 days. [597] Since virus can be recovered up to 4 days after crusting of vesicles, it is recommended that athletes refrain from contact for 5 days after the lesions have dried and crusted. [598] Those with recurrent HG or who are HSV seropositive should be placed on seasonal prophylaxis with oral antiviral medication to reduce the risk of HG spread to susceptible teammates or opponents. [599]

After three wrestlers died during attempted rapid weight loss one month into the start of the 1997 collegiate wrestling season, the NCAA, in January 1988, implemented a wrestling weight certification program. [600]

Martial arts

The incidence of eye injury in the martial arts is unknown and there are no standard specifications for eye protection for amateur participants. The two eye injuries from karate in the USEIR database, a periocular laceration and a fractured orbit, both were caused by errant kicks. Recreational martial arts participants should consider the use of headgear that conforms to the specifications of the ASTM F 2397 standard specification for protective headgear used in martial arts.

The advent and increasing popularity of the Octagon and Ultimate Fighter competitions greatly expands the risk of severe eye injury, with injury reports (usually finger pokes) but no specific medical details (“Ace Rich Franklin suffers horror eye injury”; “Picture of Martin Kampmann’s eye injury that forced him to withdraw from UFC 111”, etc.) on the Internet. Significant, comprehensive injury data is lacking. These sports: have small gloves that leave the fingers and thumbs exposed, permit face kicking with bare feet, and allow severe beatings to the face in the “ground and pound” technique of submitting the opponent with fists and elbow blows. State and federal boxing commissions should collect data on these new combat sports, monitor injuries, and establish rules, as they do in boxing.

Water sports

Swimming is used as a fitness activity by 18.4 million Americans. Over 69 million use various types of watercraft, 5.9 million water ski and 3.0 million scuba dive. Ultraviolet (UV) light and irritation are a problem for all who engage in outdoor water sports. Surfers have a high incidence of pterygia and pinguecula that could be prevented by decreasing the UV light to the eye with sunglasses, where possible. [601]

Swimming and surfing

Immersing the cornea in water produces approximately 42 diopters of hyperopia and an unaided visual acuity near 20/4000 (6/1200). [602] For humans to see clearly underwater, the only alternative to placing a strong spherical lens (64.5 diopters in air) in front of the eye is to place an air space in front of the eyes. Into this air space, the fine tuning of any pre-existing ametropia may be obtained with contact lenses, various types of spectacles, or lenses ground or bonded to the front or rear surface of the goggle ***(Figure 30)***. [603] Swimming stroke parameters are affected by visual impairment. [604] Significantly ametropic competitive swimmers have better judgment of critical racing turns, can see competitors, and have visual communication with coaches if their ametropia is corrected. Several goggle and goggle-cap combinations that incorporate prescription lenses are available. [605] It is important that lifeguards have proper scanning techniques [606] and good vision.

Since surface swimmers breathe through both nose and mouth, most prefer goggles with elastic straps rather than face masks that interfere with breathing through the nose. Goggles protect the eyes from chemical irritants and provide the swimmer with better vision in the water. However, swim goggles have several potential safety problems. Ruptured globes, hyphema, and avulsion of the optic disc have been reported, in which the goggle was stretched from the face to be cleared ***(Figure 31)***, then slipped from the wet hands of the swimmer and rebounded toward the eye(s); propelled by the elastic band, the exposed sharp plastic goggle edge then cut open the eye(s). [109, 607-611] Pressure on the trochlea from badly fitting goggles may interfere with action of the superior oblique and result in diplopia that takes several weeks to clear. [612] This hazard could be reduced by better molding combined with fastening the goggle with a less elastic band that has an easily adjustable tightening mechanism, such as Velcro strips. Any goggle in which the foam comes loose from the plastic lens should be replaced. Unpadded goggles may cause eyelid deformities and neuromas, [613-615] and goggles with tight straps have precipitated migraine headaches. [616] Goggles with eye cups smaller than the orbital opening raise the intraocular pressure by approximately 4.5 mmHg throughout the duration of goggle wear by directly pressing on the globe and glaucoma patients should be warned about the risk of raised IOP when wearing small swim goggles. [617 618]

Figure 30. Rx lens bonded to scuba mask

Because goggles are rigid, the pressure in the goggle is equalized during descent by the movement of the eye and surrounding soft tissues into the air space of the goggles. Because of the possibility of capillary rupture and hemorrhages, the largest goggles should only be used to a depth of six feet, and the smallest goggles to a depth not exceeding 11 feet. Deeper than 11 feet, the surface diver should use a diving mask in which the pressure may be equalized with air from the nose. [619] Alcohol-containing anti-misting agents must be completely dried before use, or acute corneal erosion may result. [620]

Figure 31. Potential Swim goggle hazard

Caution must be exercised with contact lenses and the water sports. Although almost all swimming pools are contaminated to some degree with coliform bacteria, and Pseudomonas occasionally is found in pool and ocean water, infection does not seem to present a great hazard to conscientious soft-lens wearers, [621] but the risk of Acanthamoeba keratitis is most likely in those who wear contact lenses while swimming [622] Inadequately chlorinated (below 0.3 ppm) pools account for 30% of all failures of swimming pools to comply with standards for fecal coliform counts, with the greatest failure rate (44.6%) in public wading pools. [623] Because of the rich microbial potential involved in the water sports, [624] daily wear disposable contact lenses would be safer. Contact lenses that are left in the eye(s) overnight are not recommended. Swimmers who wear soft contact lenses in swimming pools can avoid lens loss by splashing pool water into the eye(s) with the lenses for approximately 1 minute so the lenses become hypotonic and adhere to the cornea. The osmotic bond lasts at least 30 minutes after exiting the pool; thus the corneal epithelium may be denuded if the lens is removed before that time, unless the osmolarity is equilibrated with normal saline drops for 15 to 20 minutes. Ocean water, on the other hand, has a high osmolarity, causes soft lenses to move excessively, and results in a high loss factor. [621, 625]

Marine envenomations can result in severe systemic reations and death, [626] The most common eye envenomations are from jellyfish, that result in a keratitis and iritis with good prognosis. [627-629] Leech and vibrio infestation from swimming have been reported. [630, 631] Goggles or divers masks would give significant protection.

In surfing, head lacerations and broken noses, from the board striking the surfer, are the most common forms of injury. Surfing eyebrow lacerations are relatively common, but blunt eye trauma is rare. [601, 632, 633]

Water polo

The most common injuries in water polo are facial lacerations and broken fingers. One high school player lost an eye. Eye injuries can occur from elbows or fingers or be caused by the ball, which is about the size of a volleyball, thrown in excess of 40 mph. [634] Swim goggles for water polo should be made of polycarbonate for impact resistance.

Diving

For high diving, significantly ametropic divers who have difficulty seeing the water or pool edge could wear hard, soft, or gas-permeable lenses. The loss rate is much lower than might be expected because divers instinctively close their eyes as they enter the water. [602] Diving from extreme heights (50feet) can result in contact and significant injury to the eye from the diver's fingers. [107]

Deep diving consists of hard-hat diving (essentially limited to commercial use), skin diving (mask plus snorkel), and scuba diving (mask plus self-contained underwater breathing apparatus). For every 33 feet of descent, the absolute pressure increases by one atmosphere (15 psi) and the surface volume of gas in goggles or a face-mask diminishes to 50% at 33 feet, 33% at 66 feet, and 25% at 99 feet. If a diver is wearing a face-mask, the air-containing space in the mask must be equalized with the ambient water pressure (by exhaling through the nose) on descent. Failure to equalize the pressure will result in face-mask barotrauma (conjunctival injection, hemorrhage, facial bruising, epistaxis). [635-639] Since the only means for equalizing the pressure with rigid goggles during descent is the movement of the eye and surrounding soft tissues into the air space of the goggles, a diving mask, rather than rigid swim goggles, should be used for dives deeper than between 6 feet (larger goggles) and 11 feet (smaller goggles). [619] Barotrauma from deep (20m) dives may result in orbital hemorrhage. [640] Breath holding diving has been associated with central vein occlusion. [641]

Because of the absorption of sunlight in water (blue light transmits further in the water than the longer wavelengths), there is a color shift as the longer rays of light are sequentially absorbed—red at 15 to 20 feet, orange then yellow at about 30 to 50 feet, greens at 100 to 120 feet where everything looks blue and becomes deeper blue-violet as the depth increases. The hard-hat diver may use spectacles that should have straps or cable temples to prevent dislodgment. Polymethyl methacrylate hard contact lenses cause corneal epithelial edema during the decompression phase of the dive by the trapping of nitrogen outgassing from the cornea and precorneal tear film. The resultant ocular discomfort, halos, specular highlights, and decreased visual acuity during and after the decompression phase may be hazardous to the diver. Soft and gas-permeable contact lenses do not result in gas trapping or corneal edema and are probably safe. [642, 643]

The best, most practical method to correct ametropia for skin and scuba divers is to bond their corrective lenses with optically clear epoxy to a standard oval face-mask made of tempered glass ***(Figure 30)***. [603] Contact lenses may be worn under a mask, but they may be dislodged if the mask is flushed with water or in an emergency situation. Because displacement of the contact lens may further impair the diver faced with an emergency, contact lenses are not recommended for snorkel or (especially) scuba divers. [643] Hollow orbital implants made of silicone may implode; thus solid implants or hollow glass implants (which withstand at least 4.5 atm of pressure) should be used for those divers who happen to require enucleation and wish to continue diving after surgery. [644] The visually impaired, and even the totally blind, are able to scuba dive with the help of specially prepared equipment and reliable diving partners. [645]

Watercraft

The United States Olympic Yachting Committee found that 23 of 44 Olympic yachting hopefuls had pterygia. Many sailors complain of constant eye irritation, the result of wind and salt spray combined with UV keratitis. Polycarbonate wraparound, UV light-absorbing sunglasses (which may be clear or tinted for comfort) relieve most symptoms and provide eye protection from impact with lines, spars, and so on. Competitive sailors are advised to wear a small spray bottle on a short cord around their necks. Fresh water from the bottle is used to clear the sunglass lenses and rinse salt build-up away from the eyes. [646]

Water skiing may be more hazardous for those in the boat than for the skier. Massachusetts state law states that there must be two persons in any boat towing a water-skier. The person who is watching the skier can be thrown from the boat if an unseen wake is struck. Three skier watchers suffered severe lacerating injuries to the face and upper extremities when they fell from the tow-boat and were run over by the propeller when the driver turned to pick them from the water. [647] A tow-boat driver lost an eye when the barefoot water skier he was towing lost his balance, fell into the water, and let go of the tow rope, which was under a good deal of tension. The metal-reinforced handle of the tow-rope snapped forward with such force that a ruptured globe and extensive fracturing of the right orbit occurred. [648]

Jet skis may be dangerous to the rider as well as the swimmer. Most injured riders are younger than 15 years old. Life jackets, helmets, age limit to 16 or over, and prohibition of jet skis from swimming areas would decrease injury and death. [649] Personal watercraft injuries have increased fourfold between 1990 and 1997. Specific training, adult supervision of minors, and personal flotation device use would help prevent these injuries. [650]

Cycling and the Motor Sports

Cycling, non-motor, and the motor sports are significant causes of visual problems from intracranial injuries to the optic nerves, chiasm, and optical pathways from extreme impact energy to the head. BMX bikers are primarily males (84%) in the 6 to 17 year age group. Of the 1.9 million BMX bikers, the average age is 22.2 years and they participate more than 61 times a year. Mountain biking participants number 6.9 million (72% male, average 39 times a year). Bicycling on paved roads involves 38.9 million (59% males), and there is a huge, uncounted population of recreational cyclists and motorcyclists. Snowmobiling has 6.8 million participants (56% male, 1.5 million more than 15 times a year).

Cycling

Each year, about 900 people in the United States are killed by bicycle crashes, which occur once for about every 4,500 riding miles. Of the 567,000 (350,000 under age 15) emergency room visits because of bicycle injuries, 130,000 were to the head. [651] Eye injuries, including ocular contusion injuries, luxation of the ocular globe, [652] foreign bodies, traumatic optic neuritis, [653, 654] result from flying debris, crashes and falls. The USEIR database has six eye injuries: one open globe from falling on a stick, one shot with a BB while riding a bicycle, two serious lid lacerations, one orbital fracture, and one vitreous hemorrhage. [201] Cyclists, especially children who suffer the majority of serious head injuries from bicycling accidents, would avoid most head, face and eye injuries if they wore adequate head protection whenever they rode. Bike helmets reduce the risk of head injury by 85%. The universal use of helmets by all bicyclists would prevent one death every day and one head injury every four minutes. [655-663]

A layer of stiff foam in the helmet reduces the peak energy of a sharp impact by crushing. The spongy foam inside a helmet is for comfort and fit, not for impact. The helmet should be brightly colored for visibility and must fit level on the head, touching all around, comfortably snug but not tight. The helmet should not move more than about an inch in any direction, and must not pull off no matter how hard the cyclist tries. A helmet should not have: snag points sticking out, a squared-off shell, inadequate vents, excessive vents, an extreme "aero" shape, dark colors, thin straps, complicated adjustments, or a rigid visor that could snag in a fall.

A sticker inside the helmet tells what standard it meets. Helmets made for US sale after 1999 must meet the US Consumer Product Safety Commission standard. ASTM's standard F-1447 is comparable. Snell's B-95 and N-94 standards are tougher but seldom used. The weak ANSI Z90.4 standard is inadequate. Replace any helmet if you crash. The Bicycle Helmet Safety Institute (http://www.bhsi.org/), from which the above paragraphs were abstracted, constantly updates helmet information.

Many cyclists have constant gritty eye irritation from wind and sun exposure, especially when traveling at high altitude in arid regions. Although a lubricating ointment will give temporary relief from dry eye symptoms, the best protection is a good pair of polycarbonate lenses that shield the eyes from dust, dirt, wind, and UV light. Eye protection certified to the high-velocity/high-mass specifications of ANSI Z87, the specifications of ASTM F803, or the military eyewear fragment specification would protect from flying road debris and would add to the protective effect of the helmet for the eyes in case of a crash.

Most bicycle injuries could be prevented if bicyclists (1) avoid loose sand or gravel, especially when turning or going downhill; (2) avoid riding double; (3) properly maintain their bicycles; (4) wear protective clothing, including helmets; (5) obey basic traffic laws; and (6) use lights and reflectors and wear light-colored clothing. [664, 665] Cyclists should be separated from motor vehicles as much as possible and children should delay cycling until developmentally ready. [666] Long, competitive races require an extensive medical support network with safety regulations, such as the mandatory use of helmets. The US Cycling Federation (USCF) requires that riders wear helmets. In 8 years of competition, 606 riders broke many helmets in crashes each year but only two serious head injuries were recorded. [667]

Batteries

Common to most vehicles is the storage battery, which can explode and cause open globe injuries, surface and intraocular foreign bodies, and chemical burns. [668-673] Strict adherence to Prevent Blindness America jump-start instructions could prevent almost all battery explosion eye injuries, which also could be life saving if the vehicle is an all-terrain or snowmobile in a remote location. To safely jump-start a dead battery:

a. keep sparks and flames away from batteries at all times;

b. wear safety goggles conforming to ANSI Z87;

c. be sure vent caps are tight (if available place a damp cloth over the vent caps), battery fluid is not frozen, both electrical systems are of the same voltage, and the vehicles are not touching;

d. using cables and clamps specifically designed for jump starting a battery, clamp in the sequence (1) one end of first cable with care to only touch the battery terminal, to positive (+) terminal of dead battery, (2) other jumper end of first cable to positive (+) terminal of good battery, (3) one end of second cable to negative (-) terminal of good battery, (4) make final connection on engine block of stalled engine (not to battery negative post) away from battery, carburetor, fuel line, any tubing or moving parts;

e. start vehicle with good battery then the disabled vehicle;

f. remove cables in reverse order, starting by first removing cable from engine block or metallic ground. [674]

Batteries explode because a spark ignites the hydrogen gas that is often present in the vicinity of a battery and in the battery cells. Remembering that the last connection in the jump-start sequence always sparks, and that the last connection is always to a ground away from the potentially explosive hydrogen gas will help one remember the proper sequence. Safety goggles and the jumper cables should be kept together.

All-terrain vehicles

The vast majority of all-terrain vehicle accidents involve males younger than the age of 30. Because of the high incidence of injuries to the face and head, and accidents associated with poor judgment and alcohol, protective headgear, as well as training and abstinence from alcohol while driving, are advised. [675, 676] Because of increasing catastrophic spinal injuries to children, it has been suggested that the use of off-road vehicles should be limited to those who hold a valid driver's license or who have passed a test certifying that they understand the risks associated with these vehicles. [677] Helmets with integral face and eye protection would decrease the incidence of facial fracture and ruptured globes. [678]

Automobile racing

Championship Auto Racing Teams (CART) have an accident frequency of one per 1,414 miles of racing with one injury per 9.5 accidents. The rate of accidents at the Indianapolis Motor Speedway is less at one per 3000 miles raced, but the frequency of injury was higher at one injury per 3.2 accidents. Despite speeds of 200 miles per hour, most automobile racing injuries are limb, rather than life, threatening. [679] This is due to sophisticated race car design and safety equipment, which includes a driver's helmet in compliance with the Snell Institute standards [680] fire-retardant clothing, restraining harness, fire extinguisher system, and (optional) compressed air supply to create positive pressure within the helmet to keep out smoke and fumes. [681] The combination of high gravitational forces plus harness compression in car-flipping accidents has resulted in acute retinal angiopathy, with minimal injury elsewhere, to five drivers. Although good visual acuity recovered, these drivers had evidence of permanent retinal vasculature and anatomic changes that resulted in scotomas, color vision defects, and changes in contrast sensitivity. [682] Considering the magnitude of the forces involved, it appears that the potential for eye injury has been reduced to an acceptable minimum with present safety equipment.

Motorcycling

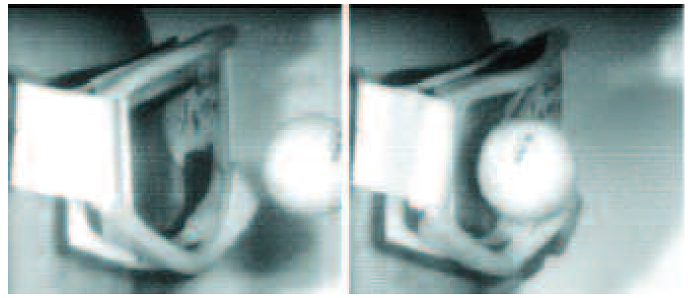
Mandatory helmets reduce head injuries to motorcyclists. [683-686] Faceguards attached to the helmet add a significant degree of eye and face protection. [687] Motorcycle goggles decrease the incidence of pingueculae, pterygia, keratitis, and ocular foreign bodies in motorcycle riders. [688, 689] ***(Figure 32)*** The US Supreme Court in the 1972 case of Simon v. Sargent upheld the concept that society has the right to mandate protective equipment that appears, on the surface, to affect only the individual. "From the moment of injury, society picks the person up off the highway; delivers him to a municipal hospital and municipal doctors; provides him with unemployment compensation if, after recovery, he cannot replace his lost job, and if the injury causes permanent disability, may assume the responsibility for his and his family's subsistence. We do not understand a state of mind that permits a plaintiff to think that only he himself is concerned." [690]

Snowmobiling

Most eye and facial injuries to snowmobilers can be avoided by a combination of safe driving, avoidance of alcohol and drugs while driving, and full-face protection. [691, 692] Protection against snowblindness and ocular windburn is available with shatter-resistant face masks or goggles. As more snowmobilers are wearing head and face protection, the leading anatomic site of injury, in Wisconsin, shifted from the head and face to the extremities over 15 years. [693]

The leading contributors to snowmobile fatalities are excessive speed, inattentive or careless operation, alcohol, and inexperience. Efforts to reduce snowmobile fatalities should focus on improving safety measures, including establishing speed limits, strengthening enforcement of snowmobile operating rules, and promoting safety education. [694, 695] The American Academy of Pediatrics recommends the restriction of snowmobile driving by children under 16, graduated licensing for older children, and universal helmet usage. [696]

Figure 32. Motorcycle goggles



Impact on a motorcycle goggle by a golf ball at 60mph. This simulates hitting a flying piece of gravel. The goggle remains intact and there is no eye contact.

Other Active Sports

Exercise, running, and jogging

Elastic cords (used for repetitive resistance exercises) may snap or release from a handle or hook and cause an eye injury. [697] The rapid deceleration associated with bungee jumping causes a sudden rise in intraocular pressure and intravenous pressure that may cause retinal hemorrhage [698-707] and orbital emphysema. [708]

Eye injuries to runners and joggers usually result from striking branches, twigs, pipes, and so on while running in low light conditions in unfamiliar terrain. In sports, retinal detachment is usually caused by direct trauma to the globe. [89] Physical activity such as running and jogging do not increase the incidence of retinal detachment. [709, 710] Bird attacks, which caused a fatal accident to a bicyclist in Melbourne, usually are from birds of prey attacking the runner from the rear. Scalp lacerations, but no eye injuries, have been reported. Fake eyes affixed to the back of a jogger's cap may discourage a bird attack to the jogger or runner. [711, 712] Foreign bodies projected from the road surface with sufficient energy to penetrate the globe are easily stopped with polycarbonate eyewear. [713]

Inverted posture may be hazardous to some participants. The practice of hanging upside down by means of "gravity boots" was associated with a retinal tear in a highly myopic patient. [714] Inverted posture raised the intraocular pressure from a pre-inversion average of 19 mm Hg to an average of 35 mm Hg after inversion for 3 minutes; this returned to normal within one minute after seated posture was resumed. [715] Glaucomatous patients experience a higher rise in pressure to 37.6mm Hg ± 5.0 after inversion for only 30 seconds. The inverted posture probably raises intraocular pressure by increasing episcleral venous pressure which is closely related to increased venous pressure in the orbit. The episcleral venous pressure rise almost immediately follows posture inversion, with a typical normal subject's pressure, normally 16mm Hg sitting, increasing to 27mm Hg after 10 seconds of inversion, then increasing to 32mm Hg within 30 seconds, after which it remains unchanged. [716-718]

Patients with ocular hypertension, glaucoma, and retinal vascular disease should be discouraged from maintaining the inverted posture that doubles the intraocular pressure and the diastolic ophthalmic artery pressure; increases the systolic ophthalmic artery pressure by 60%; constricts the retinal arterioles; reduces pattern reversal visual-evoked potentials; and causes transient visual field defects in many subjects. [719, 720] Yoga exercises that use the shoulder-stand and headstand positions may contribute to field loss in glaucoma patients by significantly elevating the intraocular pressure while the participant is in the inverted position. [721]

Although the inverted posture may be harmful to those with glaucoma, other forms of exercise can be beneficial. Regular aerobic exercise is associated with a reduction in intraocular pressure and may represent an effective nonpharmacologic intervention for patients suspected of having glaucoma. [722-729] However, some young patients with advanced glaucomatous optic neuropathy may experience exercise-induced visual disturbance from an exercise-induced 'vascular steal'. These patients should be advised to limit activities that induce their symptoms. [730]

Glaucoma patients with pigment dispersion syndrome may experience symptomatic elevation of intraocular pressure (to 47mm Hg) after strenuous exercise, such as playing basketball for two hours. Pretreatment with 0.5% pilocarpine 30 minutes before the physical exertion prevents the pressure spike and the pressure lowers, as is usual in glaucoma patients who do not have pigment dispersion. Pressure rises in those with pigment dispersion occur with exercises that involve jumping or jogging for several hours, [731] but not after comparable periods of equivalent cycling. It is believed that the jumping increases iris-zonule contact, which is prevented by pretreatment with pilocarpine. [732] Nd:Yag laser iridotomy prevents the bicycle ergometer induced iris concavity that results in pigment dispersion in some patients. [733]

Topical timolol (a nonselective beta1 and beta2-blocker) interferes with exercise endurance probably by reducing the maximal obtainable heart rate. [734] It is interesting that topical betaxolol (a selective beta1-blocker) does not cause this side effect, despite the fact that betaxolol is a potent beta-blocker when administered systemically. There is most likely insufficient active drug in the blood after ocular administration to cause a measurable cardiac effect in normal persons. It would be prudent to attempt glaucoma control with betaxolol rather than timolol in those patients with glaucoma who require a beta-blocker but also happen to be endurance athletes. [735]

Weightlifting

Weightlifting may cause extreme blood pressure elevations during and immediately after exertion. Five experienced body builders had a mean elevation of blood pressure to 355/281 mm Hg, with one subject reaching an alarming 480/350 mm Hg after a series of double leg presses. Even a series of single arm curls raises the mean blood pressure to 293/230mm Hg. Subarachnoid hemorrhage explained severe post-weightlifting headaches in two women, aged 16 and 25. [736] Ruptured aortic aneurysms, [737] carotid dissection, [738] and pre-macula hemorrhage with sudden visual loss (personal observation) all have followed lifting heavy weights. The intraocular pressure can increase markedly (>10 mmHg) in some who are bench pressing, especially if the breath is held. [739, 740] Patients with vascular eye disease or glaucoma in whom acute, severe elevations of blood pressure or intraocular pressure may be harmful, should train with lighter weights, using more repetitions.

Frisbee

Frisbees typically cause lid lacerations and hyphemas, but there is at least one open globe injury from shattered sunglasses that had glass lenses. Injuries to the eye can be avoided with shatter-resistant eyewear. It is probably impossible to make a Frisbee eye-safe without destroying desirable aerodynamic characteristics.

Mountaineering

Mountaineers at altitudes higher than 12,000 feet (3658 meters) are subject to retinal hemorrhages, probably secondary to hypoxic vasodilation combined with sudden rises in intravascular pressures. The hemorrhages resolve spontaneously with return of normal visual acuity on return of the climber to a lower altitude, but the climber may be left with permanent reduction in critical flicker fusion frequency, visual fields, and dark adaptation. [197, 741-744] One climber, on a Mount Everest ascent to 5,909 meters, had a permanent visual loss to finger counting after an ischemic central retinal vein occlusion with vitreous hemorrhage. Higher baseline intraocular pressure and the use of non-steroidal anti-inflammatory drugs are risk factors for the development of altitude retinopathy. [745] The severity of high-altitude retinopathy is correlated with potentially fatal high-altitude cerebral edema—and progression of both conditions may be prevented with oxygen, steroids, diuretics, and immediate descent. [746]

The level of environmental hypobaric hypoxia that affects climbers at the summit of Mount Everest (8848 m [29,029 ft]) is close to the limit of tolerance by humans. [747] Optic disc swelling, most likely the result of hypoxia-induced brain volume increase, occurs frequently in high-altitude climbers. [748]

Hemoconcentration and hypoxia—the undlerlying factors of acute mountain sickness, high-altitude cerebral edema, pulmonary edema, thromboemebolism, and high-altitude retinopathy—should be treated in patients with high-altitude retinopathy. [749]

A 77-year-old man with low endothelial cell counts developed endothelial decompensation necessitating a penetrating keratoplasty when he drove to 12,500 feet. [750] A 15-year-old boy had the transient loss of light perception secondary to the expansion of a perfluoropropane gas bubble used to treat a giant retinal tear when he was driven over a 4,289-foot mountain pass. [751] Since this ascent is comparable to that of commercial airline jets reaching cruising altitude in which the cabin pressure is the equivalent of approximately 7,000 feet, patients with intraocular gas bubbles risk significant elevation of intraocular pressure due to expansion of the intraocular gas and probably should remain at lower altitudes and avoid aircraft flight until the bubble diminishes in size. [752]

The prevention of snowblindness secondary to overexposure to UV light is essential. Because the thinner atmosphere does not filter out as much of the sun's UV light as does the thicker atmosphere at sea level, and ice and snow reflect approximately 85% of UV light, the climber is twice exposed—by both direct and reflected UV light. A severe case of snowblindness may be asymptomatic for 8 to 12 hours after exposure, then be totally disabling for several days while the climber is unable to keep the eyes open because of extreme pain, photophobia, and lid edema. Mountaineering sunglasses or goggles should filter out at least 90% of wavelengths below 400 nm and be designed to block most reflected light coming from the sides and below. In an emergency, goggles may be made of cardboard with a thin slit. Sherpa and Balti porters have been known to protect their eyes by pulling their hair down over their faces. Mountaineers should understand that UV light protection is as important under overcast conditions as it is in full sunlight. Erythropsia (vision that is temporarily tinged red) is due to retinal overexposure to UV light and eliminated by the use of UV light-absorbing glasses. [753, 754]

Eyes that have radial keratotomy are prone to significant hyperopic shift that can impede vision and increase mountaineering risk. [755-759] Eyes that have had LASIK or PRK to treat myopia are less prone to visual fluctuation at high altitude, usually from a myopic shift. [758, 760, 761] Exposure to extreme cold and high winds can damage the corneas, cause epitheliopathy from extreme dryness, and freeze a contact lens to the cornea. An extra pair of goggles is recommended for those involved in these activities.

Equestrian Sports

There are over 1.2 million horse owners younger than age 20 and more than 27 million riders older than age 12 in the United States. Horseback riding is an extremely diverse sport including dressage and show jumping in arenas, cross-country endurance, fox hunting through wooded trails, 24-hour mountain endurance races, tetrathlons (races that combine riding with running, swimming, and shooting), calm trail riding, rodeo, polo (discussed in prior section), racing on horseback or while mounted or in a sulky, activities for the handicapped, and the formal moves of the Spanish Riding School of Vienna. [762]

Approximately 20% of equestrian injuries are to the head and face. There are between 105 and 257 deaths a year, mostly due to head injuries, a number which could be greatly reduced by the universal use of headgear that stays on the head in accidents, resists penetration, and prevents transmission of concussive forces. [763-767]

The risk of injury in US Pony Club (USPC) events in order of decreasing incidence is cross-country, horse/pony jumping, stadium jumping, dressage, hunter equitation, pony club games, gymkhana, hunter, and vaulting. The USPC has required mounted members to wear hats that have passed protective standards since June 1, 1983. [763] Protective standards have become more stringent with the advent of the ASTM standard Fl163 specification for headgear used in horse sports and horseback riding in 1990. Helmets are tested to the standard and independently certified by the Safety Equipment Institute (SEI). As more riders wear headgear that bears the SEI seal, it is expected that injuries will continue to decrease. [768] Most USPC riders face and eye injuries result from jumping. The increased size of the ASTM helmet, which acts as a buffer, taking impacts first before they reach the face, has resulted in a decrease in eye and face injuries in USPC riders. [769] From 1990 to 1992 the USPC reported a decrease in head injuries by 26% and in face injuries by 62%. [770]

The mandatory use of helmets and face guards to prevent concussions and facial injuries in rodeo events that involve large animals is controversial, [771, 772] but more bull riders, the competitors most likely to suffer head and face injury, [773, 774] are voluntarily using the protective headgear. [775]

Winter Sports

Skiing

Both cross-country and downhill skiers can suffer ski pole injuries [776] and snowblindness. Two perforated globes as a result of skiing were reported to NETS. The first occurred in a skier who was not wearing glasses or goggles and was struck in the eye by a piece of plastic on the end of a cord. The second occurred when a streetwear spectacle lens shattered on impact from the handle of a ski pole. Serious periocular injuries have occurred when ski goggles shattered. Ski eyewear should conform to the high-impact requirements of ASTM F659.

One death occurs per 1.6 million Alpine skier days. The fact that 82% of deaths involve head injuries, and that deaths are extremely rare in downhill ski racers who are required to wear helmets, [777] indicates that universal use of helmets would greatly reduce skiing deaths.

Sleds, toboggans, snowboards, and tubes

The incidence of eye and face injuries in these sports is unknown. It is believed that tubing may be the most dangerous of winter sports. [778] The close proximity of participants, excessive speed on slopes that are too steep, and fixed objects, such as rocks and trees, account for the majority of collision injuries. [779] Luge does not pose a significant eye injury hazard but is responsible for severe post-run headaches in the majority of participants. Although the cause of lugers' headaches, possibly due to the strain of holding up the head aggravated by jolts from an uneven track, is not yet known, they seem not to have permanent adverse effect. [780]

Blind Athletes

The year 1976 was a turning point for blind athletes: the United States Association for Blind Athletes (USABA) enabled blind and partially sighted athletes to participate in competition on a national level, and the Olympiad for the Physically Disabled was the first Olympiad with full competition for blind, paralyzed, and amputee athletes. [781, 782] Events included track and field, gymnastics, wrestling, the 10-km run, and goal ball—a fast-paced game developed especially for blind athletes in which a 4.5-lb ball containing bells is rolled on a 30x60-ft mat, past opposing players, across an end. To eliminate the advantage the partially sighted may have over the totally blind, all players, including the totally blind, wear blindfolds for the game. Athletes of all ages are divided by vision into three groups: Class A, totally blind or light perception with no acuity, with less than three degrees of visual field; Class B, 20/400 or less with 3 to 10 degrees of visual field; and Class C, less than 20/200 and/or between 10 and 20 degrees of visual field.

Due to encouragement from organizations such as the USABA, the blind are participating in more active sports—such as beep baseball, tandem cycling, golf, downhill and cross-country skiing, skating, wrestling, judo, track, and swimming—in addition to the usual activities of the blind such as bowling, nature hikes, boating and fishing, picnics, and dances. Beep ball was invented by the Telephone Pioneers of America and uses a sound-emitting softball with sound-emitting bases. All players wear head, face, and chest protection. The sport is so popular that the National Beep Baseball Association drew a crowd of 1200 spectators at a national tournament. [783] The US Blind Golfers Association (USGBA) is the oldest organization that promotes organized sport for totally blind athletes. Ski for Light, the Blind Outdoor Leisure Development (BOLD), and the American Blind Skiing Foundation promote skiing for the blind.

The sports achievements of the blind are impressive: Harry Cordellos, blind from diabetes, completed the Boston Marathon in under 3 hours with the help of a sighted companion. Craig MacFarlane is competitive with sighted golfers. Sky-diver Tom Sullivan pulls the rip cord at the signal (by helmet radio communication) from his sighted sky-diving companion. Tom O'Connor completed a triathlon in the remarkable time of 3:49:06 without being tethered to a guide. For the 0.9 mile swim, he swam in a lane formed by 20-ft tubes pulled by a kayak, he ran 6.2 miles with a guide alongside him, and cycled 25.1 miles guided only by verbal commands shouted from a guide car.

It is important to encourage those who become partially sighted or blind to pursue sports activities through one of the many organizations that are expert in promoting active sports that are challenging, and safe, bolster self-esteem, and especially are fun. [784-788]

Vision Performance and Training

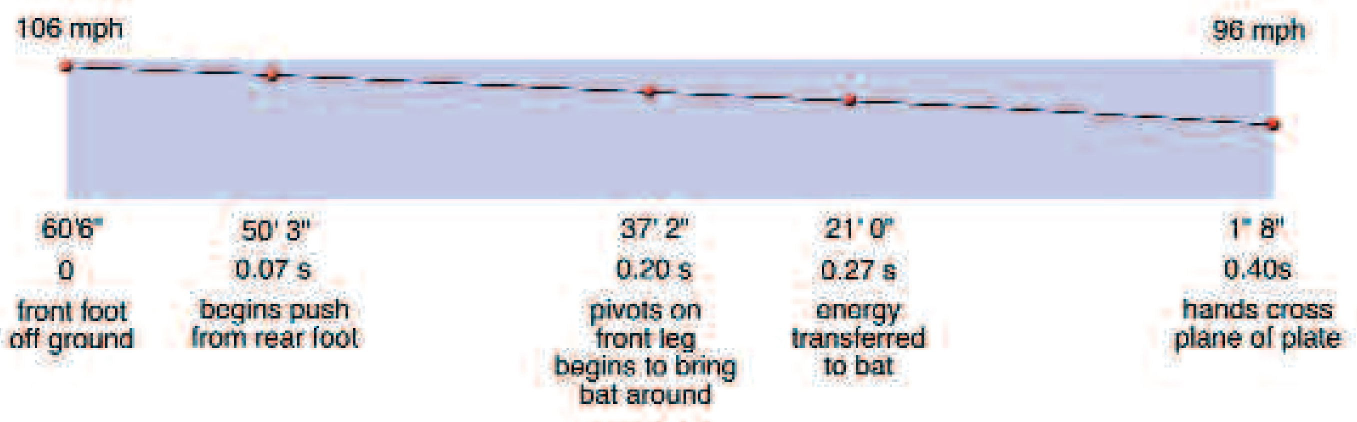
The use of visual training to improve athletic performance is increasing in popularity as more practitioners enter the field. The controversy surrounding visual training and athletic performance does not center around whether visual parameters that are not commonly measured—such as dynamic visual acuity (visual ability with the athlete, the object of regard, or both, in motion), eye tracking ability (the ability to maintain fixation on a moving target], glare recovery, visualization [the ability to see an image in the mind's eye), visual concentration (the ability to concentrate on the visual task at hand and exclude distractions), central-peripheral field awareness (the ability to be aware of or even concentrate on objects or players eccentric to fixation), speed and span of recognition (the ability to see, often separate, objects quickly and accurately) and quiet-eye time (the release of fixation on a target after the brain has sufficient information for the body to react appropriately))—are important for athletic performance, they clearly are. Yet to be determined is whether visual training can improve athletic performance, and, if so, what training is appropriate.

Personal observations of one-eyed athletes raise questions about some of the current concepts of visual performance and vision training and suggest areas for future research. Many people with severe limitations of vision in one eye function at the highest levels of sport in which it is commonly assumed that true stereopsis is essential. A few examples are: After enucleation of his dominant eye, a flight instructor continued a demanding career flying airplanes; A trap shooter remained a top competitor after losing sight in his dominant eye; A semi-pro baseball pitcher lost an eye to a line drive, then successfully continued his career; A high school athlete lost an eye playing basketball, then excelled in college varsity baseball, football, and basketball; A football quarterback with dense amblyopia who also played basketball and baseball for a major university excelled in all three sports; A major league outfielder was an excellent batter despite mild macular degeneration and 20/30 vision in each eye with no measurable stereopsis. How can these players and others (such as Babe Ruth who had dense amblyopia) perform so well without vision skills that are usually considered essential for performance? Hitting a baseball is considered one of the most demanding athletic tasks, yet 5 of the 7 athletes mentioned above were able to play baseball at college, semi-pro, and professional levels without true stereopsis. A trap shooter, compensated for loss of his dominant eye in a sport in which sighting with the dominant eye is considered essential.

Studies on the physics of baseball and the visual activity of baseball batters give insight into the timing required to hit a baseball. [493, 789] The motion analysis of Mark McGuire's 70th home run in St. Louis on September 27, 1998, is depicted in ***Figure 33***. The ball left Carl Pavano's hand at 106 mph and slowed to 96 mph in the 0.4 seconds it took to reach home plate. McGuire had his front foot off the ground as the ball was released, started his swing when the ball was half way to the plate, and was essentially fully committed to the path of the swing when the ball was still 21 feet from home plate. The 34.5", 33-ounce bat had a tip speed of 80 mph when it collided with the ball and propelled the ball at 110 mph with 2,000 rpm back spin for a home run. Pavano, throwing the ball on the same initial trajectory, could have placed the ball almost anywhere in the strike zone by varying the speed and spin on the ball. ***Figure 34*** relates the ball speed, the ball revolutions per minute (rpm), (the revolutions of the ball between the pitcher and home plate are in parenthesis), the direction of ball spin as viewed by the batter, and the final position of the ball in the strike zone. With all of these final ball positions possible from the same release point and the same initial trajectory, it was essential that McGuire predict the type of pitch to by thrown by analyzing both the speed and spin of the ball as Pavano was going through the delivery motions—before the ball was even released. A swing timed to hit a home run off of a 91 mph fast-ball will miss a 96 mph fast-ball completely. Minor variations in Pavano's delivery and arm speed would be a clue as to the ball speed. Seeing the grip Pavano had on the ball at the time of release would be a clue as to the type of spin the ball would have. McGuire did all of this subconsciously at the visual-motor memory level—the reflex reaction of an excellent batter. All batters analyze pitchers, their delivery, and the pitches they usually throw, but no batter I know of has said they consciously analyze any of this while at bat. They simply hit the ball with the bat.

To see how the ball is held in the pitcher's hand requires good visual acuity. Perhaps one reason that baseball batters usually have excellent static visual acuity (81% better than 20/15) is that good visual acuity is necessary to predict where

Figure 33. The timing of a home run swing



Analysis of mark McGuire's 70th home run by Paul Lagace, professor of Aeronautics and Astronautics at MIT.

the ball will be when it crosses home plate. Distance stereoacuity [790] and contrast sensitivity, which also measure significantly better in professional baseball players than the general population also probably play a major predictive role in final ball position. [791] If we put baseballs on thin poles, one 29 feet from home plate, and the other 30 feet from home plate, the batter cannot tell which ball is further away, unless one ball hides part of the other. As the ball approaches the plate, the angular velocity in relationship to the batter's eyes increases rapidly, so that when the ball is within 10 feet of the plate, the angular velocity exceeds 500 degrees per second and is impossible to track. The maximum smooth pursuit velocities in professional baseball players are 30 degrees per second for the head and 130 degrees per second for the eyes In the initial tracking of the ball, it has been shown that professional batters move their head as well as their eyes to track the ball as long as possible. [789]

McGuire was probably using distance stereopsis, but he was not using (usually measured and trained) near stereopsis to any significant degree when he started his swing. He was tracking the ball, moving both his head and his eyes until tracking became impossible within ten feet of the plate. Distance stereopsis could be used to modify the plane of his swing until the ball was 10 feet from the plate, but changing the plane of the swing after the batter has transferred energy to the bat at about 20 feet is very difficult.

Accommodation and convergence are too slow to have played any role in hitting the ball. The image was 34 degrees off McGuire's fovea when the ball was two feet in front of home plate. It is apparent that McGuire could hit a very blurry baseball out of the park because he has the gifts of natural ability and superior motor memory that have been fine-tuned with practice. If McGuire were rigidly trained to keep his head still and track the ball to the moment of contact from an early age [792] and he rigidly followed these instructions, he probably would not be very good at hitting a baseball. When we train athletes, we must be certain that what we are teaching actually will help and not interfere with performance. Analysis of many photographs of athletes contacting balls or pucks with bats, rackets, or crosses show that they almost never are looking at the point of contact between the ball and the racket, bat, stick or crosse. It clearly is detrimental to performance to instruct an athlete to watch a fast-moving ball make contact with the bat, racket, or glove etc.

Would McGuire be as good a batter if he hit fewer baseballs and spent more time doing various types of visual training in an eye care professional's office? While many visual abilities are trainable, the transfer to real-world tasks that are related to sports has not been demonstrated. [793] The essential factors needed to hit a baseball (and other sports balls) well are: innate ability, excellent visual and motor memory, total body timing, quick visual learning, concentration, and dynamic visual acuity. Important factors include, distance stereopsis, contrast sensitivity, peripheral awareness, and visualization. Not important are accommodation and vergence amplitude and speed.

A batter has to be a quick visual learner. He sees the pitched ball for less than 0.5 seconds per pitch. He has about 7 pitches per each at bat and 4 at bats per game. Each game, the batter has 14 seconds of learning about a particular pitcher. The batter learns the most from the last third of each pitch as he correlates how the final path of the ball relates to the delivery and release of the pitcher. Learning is a total system approach. To be effective in hitting the ball, the batter must see the pitcher's total motion, including the release of the ball. Then he must correlate the biomechanics of his own swing and his visual-motor memory, with the pitcher's delivery and release and the trajectory of the ball.

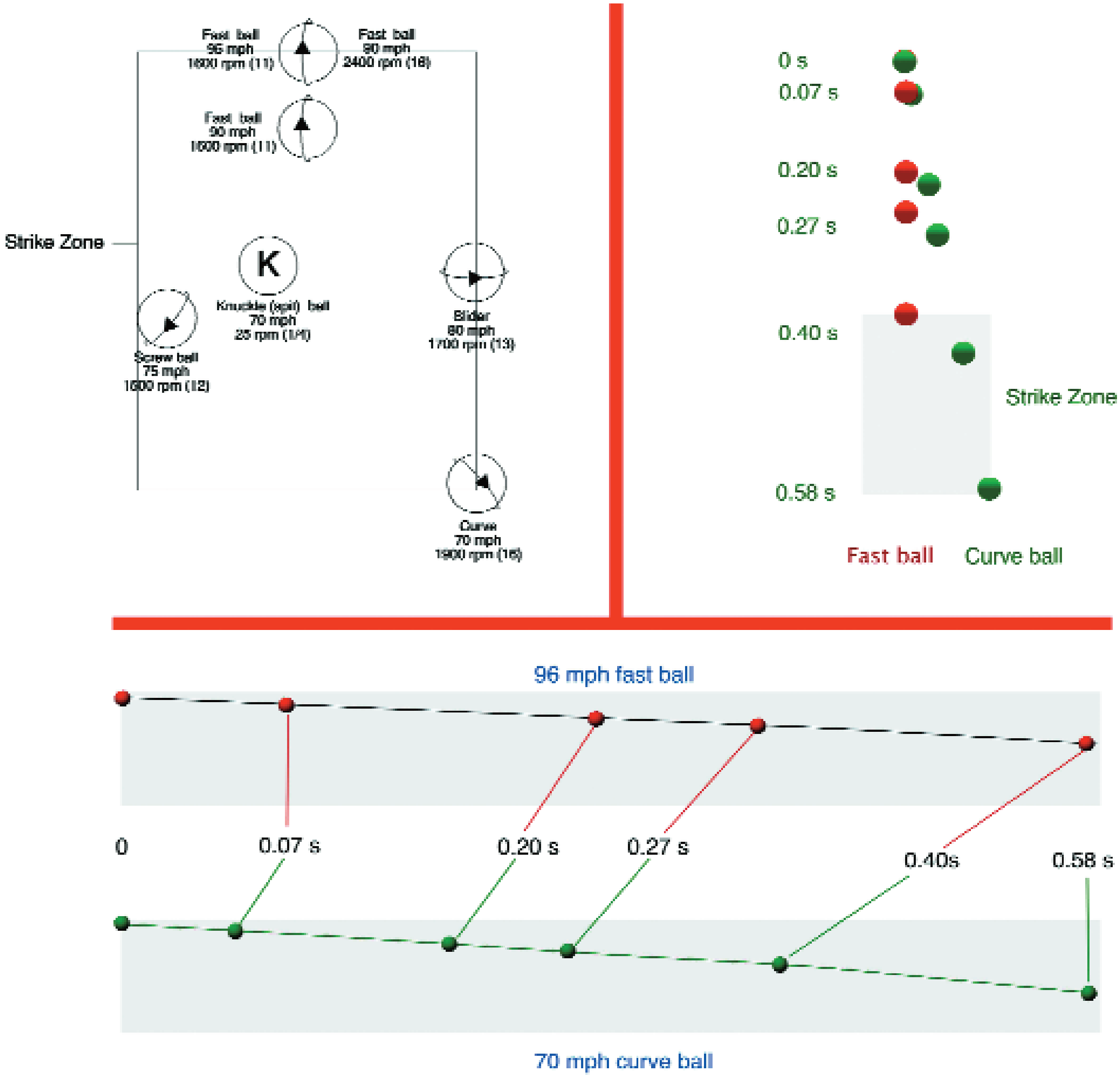
To help the athlete perform better, vision therapy research and practice should:

1. Be certain that the athlete has correction that allows the best possible vision for their particular sport and that there are no significant ocular abnormalities that will diminish input quality. Some sports (baseball) require excellent vision, while others (basketball) have no significant reduction in set shot shooting performance over the visual acuity range of 6/6+ to 6/75. [794]

2. Use actual field conditions as much as possible. It is the constant motor feedback of the total game environment that will give the athlete the totality of information needed to put input and response into the subconscious and react quickly to rapidly changing game situations.

3. Use video replays in conjunction with coaching to help

Figure 34. The effect of initial velocity and spin on the final position of a baseball in the strike zone, when thrown on the same initial trajectory by the pitcher



Upper left: The position of the ball in the strike zone when thrown by a right-handed pitcher on the same initial trajectory with varying velocity and spin. mph = velocity of ball as it enters the strike zone; arrow = direction of rotation as seen by the batter; rpm = revolutions of the ball per minute; (xx) = revolutions of the ball between the Pitcher and home plate; rotation of knuckle ball varies.

Upper right: Fast ball (red) compared to curve ball (green) as seen by batter over time (s)

Lower: Fast ball (red) compared to curve ball (green) as seen by batter over time (s) as seen from the side. Note: the distance from the plate the slow curve is when compared to the fastball as it crosses the plate in 0.40 seconds and how the batter would see the curve ball as "falling off the table" in the final 0.18 seconds. [506, 789]

the athlete visualize effective technique.

4. Avoid evaluations and treatments that are probably not important for performance—they only take time from the important. It is probably possible to degrade performance by having the athlete spend time doing stupid training (Watch the ball hit the racket strings. Keep your head still. No, NO. Watch the ball hit the strings. Keep your head still. No, NO. Watch the ball hit the strings. Keep your head still. No, NO. etc, etc.) which detract from true learning.

5. Learn what visual functions are important, and develop consistent and reliable diagnostic techniques, normal values, and standardized training protocols.

6. Set up test protocols that will give real answers as to the methodology by which performance actually can be im-

proved. [795-805] Standardized test methods, normal values, and controlled studies are needed. Before treatment is done on many people, the procedures should be proven effective—for example, the concept of biofeedback to treat ophthalmologic disorders, such as blepharospasm and voluntary torsions, has been applied to the treatment of myopia. [806, 807], however, a double-masked study of the effect of biofeedback on myopia showed no difference between the control and experimental subjects. [808]

7. We should keep an open mind on this active area. Practitioners and researchers in the area of visual training should continue to develop standardized tests and gather data on the normal range of values. Visual training may not only prove a valuable technique for improving athletic performance, but the techniques learned may also help in other areas such as macular disease and field loss.

Legal Implications of Sports Eye Injuries

Prescribing and/or dispensing eyewear for athletes is fertile ground for litigation because there is significant potential for injury and the sale of a product is frequently involved. Legal claims can be directed on the grounds of negligence as well as those of product liability. Negligence awards for the plaintiff have arisen from failure to prescribe the lens material of choice and failure to warn of the differences in impact resistance between various lens materials. Manufacturers of sunglasses and protective eyewear have had product liability judgments against them for defects in design that resulted in an otherwise preventable injury. [809, 810] It would be legally imprudent for anyone writing a prescription or dispensing eyewear to athletes not to prescribe polycarbonate [811] or Trivex lenses or not to be certain that prescribed sports eyewear meets applicable safety standards. [157] The dispenser should beware of the stylish sunglass with the CR39 or glass lens that could shatter if struck with a tennis ball, frisbee, or softball. It is apparent that malpractice negligence and product liability suits will remain a significant factor in sports-related eye injuries and that there are both good and bad aspects to the present legal situation.

The negative aspects—extravagant awards, capricious juries and judges, inconsistency in awards for apparently similar injuries in apparently similar circumstances, long delay in trials so that physicians and manufacturers are often held to a state of the art that has advanced since the time of the injury, escalating insurance premiums, a long "tail" on protective equipment that has become obsolete yet is still used by the athlete, lawyers' greed and tendency to instigate suit for high awards—are well known to physicians and manufacturers and must be corrected by the legal profession. Product liability suits concerning football helmets resulted in cancellation of the NOCSAE insurance, which would not be replaced by another insurer. This resulted in a withdrawal from NOCSAE of important organizations such as the NCAA, National Federation of State High School Associations, the National Junior College Athletic Association, and the National Athletic Trainers Association, because members of these organizations on the NOCSAE board withdrew to protect themselves from liability. [812] It seems counterproductive to the welfare of athletes that a standards setting organization that has done a great deal for sports safety can be radically changed by uninsurability. Rising insurance costs and huge liability awards are threatening some sports and recreation programs. [813]

However, the present legal climate, as much as it desperately needs improvement, does have a significant positive attribute—it is the most efficient check on the small fraction of manufacturers, retailers, and health care professionals who are incompetent or are without conscience and motivated solely by greed. The fact is that the potential of the injured athlete to obtain large awards from the courts has forced manufacturers to gather together to write voluntary consensus standards to upgrade protective devices and help keep inferior products off the market. Administrators are studying risk management, with resultant safer facilities. [814] Although suits against eye care professionals for improperly prescribing optical devices are uncommon, [815, 816] they certainly will increase in frequency as lawyers become aware of advances in eyewear protection that the professional should advise for athletic patients exposed to specific risks. Another area of significant liability risk appears to be failure to warn RK, PK, and other patients with increased risk of ruptured globe of the extra need for eye protection against traumatic rupture of the globe likely to occur from the energy used in many sports. The optician, dispensing optometrist, and ophthalmologist should take a sports, industrial, and hobby history and advise the use of appropriate protective eyewear. Manufacturers must participate in the voluntary standard-setting process and test their products before release to the general public. Sports officials must be certain that athletes under their supervision are properly protected. Devices that are advertised as protective then fail to give adequate protection will result in litigation.

The responsibilities of teachers and coaches of motor skill activities as well as the agencies that sponsor them were further defined in a $6.3 million award to an injured Seattle high school football player. [817] Although this case involved football, the legal principles would probably apply to all supervised sports. The student must be instructed in appropriate skills, be warned of potential dangers, and have available the latest safety precautions and techniques. The participants in sports are also not immune from litigation if they act with more aggression than permitted by the rules of the sport or use the sport as an excuse for acts of violence. Athletic administrators, coaches, doctors, and equipment manufacturers realize that injuries cannot be entirely eliminated from sports, but they must strive to at least minimize the risk of serious injury. [818] The best defense in a legal suit seems to be the ability to demonstrate that all concerned were acting responsibly, using state-of-the-art protective devices and playing surfaces, and using conditioning and training techniques to protect the athlete to an acceptable level of risk considering the nature of the sport. [145, 819]

Ethics

All who are in position of authority have a responsibility to act in a positive manner for the benefit and welfare of those under that authority. This responsibility is fuller and stronger when the responsible person is dealing with those who are in a position of diminished ability to be responsible for themselves. [445] Therefore, the athletic director or coach of a grammar school team is more responsible to ensure the safety of his or her charges than is the professional coach who is dealing with adults who can make an informed consent. A sport official is ethically responsible for the safety of the players especially in the school setting, in which the school official is acting in a parental role, supervising a minor who is under his or her care during the time of sports participation. To ignore a situation in which there is a preventable cause of injury and force participants to play without the benefit of a device that would greatly reduce the probability of injury is clearly unethical and irresponsible. [820]

It is vital to realize that to be beneficial to a child a sport must be fun. Children should have the right to: participate regardless of skill, ability or sex; decide whether they want to participate in sports at all; know that a failure in sports is not a failure in life; have a competent coach; safe facilities, and properly maintained equipment; have their fair share of public funds and facilities; be treated like children, not like miniature adults; competent medical treatment; stop playing when hurt or sick without fear of reprisals; their own individuality; have compassionate organized sports programs; play opponents who are carefully matched in age, weight and size; have a wide variety of sports to choose from. [821]

In colleges, football, hockey, and basketball are the income producers that support other sports programs. [822] There must be constant vigilance that college players are not viewed as income-producing assets with more attention paid to performance at the expense of safety. The college or professional coach must realize that persons should not have to go along with stupid things and that, while the informed adult may opt to take a risk for himself or herself, he or she should not put other persons at risk. College and professional team physicians must be extremely careful of the dilemma of divided loyalties—to the team that pays the physician's salary and expects winning performance from the athlete as opposed to the athlete who is, in fact, the patient. It is essential that the team physician avoid ambiguity at all costs. If the relationship differs from the customary physician-patient relationship, it is crucial to tell the patient. [820, 823-826]

Role of Eye-Care and Athletic Professionals in Eye Injury Prevention

In preventing and treating athletic eye injuries, the well-being of the athlete must be placed above all other considerations. Ophthalmology, optometry, and optician organizations should emphasize prevention as an important part of eye care practice. The ophthalmologist or optometrist can help the athlete protect his or her eyes by knowing what to advise, discussing the advise with the athlete, and writing a specific sports-eyewear prescription. A section of every optical dispensary should be a display of sports and industrial eyewear that meets applicable standards, as well as handouts that give specific advice on eye protection for various activities.

The school committee members should be sensitive to their responsibility to properly educate their interscholastic coaches and provide athletic trainers. The athletic trainer is the bridge between the medical staff and the athletes and is invaluable in monitoring the athletes for fitness to participate and ensuring that protective equipment complies with applicable safety-standards, fits properly and is properly maintained. Since it is only the coach who is with the athlete before, during, and after both practices and games, the coach assumes the role of everyman. In addition to producing winning teams and teaching proper playing techniques, the coach is expected to keep the athletes healthy and injury free. Since certified athletic trainers and physicians are not present at every game, the coach should have a basic knowledge of injury prevention, recognition, and first aid.

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