# Risk of Eye Injury and Effectiveness of Protective Devices for Specific Sports: Small Projectiles, Golf, and Racket Sports

In this section, sports are arranged roughly according to the size of the potential impacting object. SGMA International data, estimating the number of people who participated in selected sports activities at least once in calendar year 2001, are presented in each subsection. [1]

## *Small, penetrating projectiles*

Penetrating projectile eye injuries, 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 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.

There are no reliable participation data for non-target-shooting air rifles 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. [2] Military participation varies greatly depending on combat activity. The SGMA International data for the shooting sports, archery, fishing, and darts are presented in ***Table 10***. The main participants in the shooting sports are males in their thirties with a concentration of veterans and relatively few beginners. Only about 8% of the hunters were new to the sport in 2001, and nearly 60% have been involved 10 years or more. There was 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 were also hunters. 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.

***Table 10. Shooting Sports, Archery, Darts, and Fishing (millions of participants)***

| | Participants | Frequent Participants | Average age | Average years participated | % males | % change 2000-2001 |
|---|---|---|---|---|---|---|
| Target shooting, rifle [14] | 14.0 | 3.2 | 30.5 | 13 | 80 | +7.7 |
| Target shooting, pistol [16] | 11.4 | 2.8 | 35.6 | 14 | 78 | +9.6 |
| Hunting w/ rifle or shotgun[16] | 16.7 | 5.3 | 34.0 | 17 | 87 | +1.2 |
| Trap/skeet [13] | 3.9 | 1.0 | 30.8 | 11 | 84 | +2.6 |
| Sporting clays [11] | 3.3 | | | | | +17.9 |
| Archery [16] | 6.4 | 1.6 | 23.9 | 7 | 72 | +6.7 |
| Bow hunting [15] | 4.4 | 1.3 | 31.7 | 11 | 88 | 7.3 |
| Darts [22] | 19.5 | 4.2 | 27.6 | 7 | 58 | +5.4 |
| Fishing: | 53.1 | | | | | -1.3 |
| Freshwater (non-fly) [17] | 43.5 | | | | | -1.4 |
| Fly [13] | 6.0 | | | | | -9.1 |
| Saltwater[13] | 13.9 | | | | | -5.4 |

[ ] = average days of participation 2001

### 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 (Airsoft guns in the Japanese literature) [3] are viewed in their proper role as sports equipment, and used safely with appropriate supervision, the injury problem can virtually be eliminated.

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 0f 1995—and still have not been included in 2003. [4, 5] BB or pellet guns are responsible for 5.13% of all injuries in the USEIR database. [6] Although the occurrence of eye injuries from BB guns and air guns (including paintball) increased between 1984 and 2001, ***Appendix 1 from Mechanisms and Prevention of Sports Eye Injuries*** there is no information as to the injury incidence, since the use of BB guns and air guns is not known and the proportion of the injuries related to paintball cannot be separated from the total. What is known is that: approximately 3 million air guns were sold in the United States in 1980; that there are about 31,500 BB/pellet-gun-related injuries every year, of which about 2,000 are hospitalized; and that 80 % of the injuries occur in the 5-14 age group. [7] 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, and using it without adult supervision. [8, 9]

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 highest velocities—more than 900 ft/s. (3) Compressed-CO2 guns have typical muzzle velocities in the 400 to 500 ft/s range. [7, 10, 11] 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. [12] 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. [10]

Despite advances in surgical technique, [13] the majority of eyes perforated

with pellets or BBs suffer permanent visual loss, with many resulting in enucleation. [9, 14-16] 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. [17-19]

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. [20] BBs caused 8 of 48 perforating (through and through) injuries to the globe. The fact that perforating BB injuries have a poor prognosis is due to the tremendous force transmitted to the globe as it creates two blunt openings approximately 5 mm in diameter ***Figure 12*** [21] 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. [22] Twenty-three of 278 childhood traumatic eye injuries admitted to Wills Eye Hospital were the result of BBs. [23]

BB guns and air guns are not given the respect they deserve as potential weapons with blinding and killing power. [15, 24, 25] In 2001, NEISS estimated that 29,617 injuries from gas-, air-, and spring-operated guns were seen in US 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.

***Table 11 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.

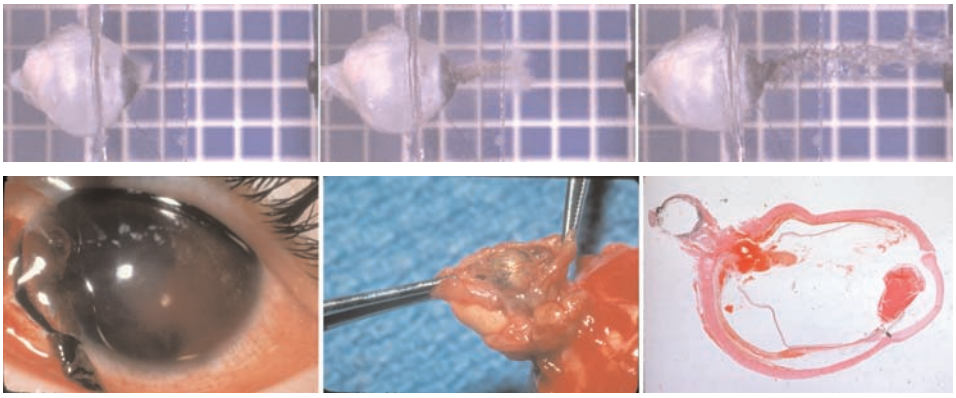
[26] Patients that require hospitalization and surgical intervention from BB eye injuries have a high risk of enucleation. [27] Of 32 patients treated with surgical intervention at the Wilmer Eye Institute between 1970 and 1981, 22 had penetrating injuries from the pellets, 19 had their penetrated eyes enucleated, and the remaining three had vision worse than 5/200. [28] 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. [29]

A standard BB (0.345 g) will penetrate the globe at speeds higher than 236 ft/s (161mph) and result in injury at the vitreous base at an average speed of 205 ft/s (140mph). [30] Round, smooth, relatively light-weight BB's are prone to embolize if they enter the vascular system, with potential severe visual and systemic results. [7, 11, 31] Higher-powered general-purpose air rifles, advertised in children's magazines, may have muzzle velocities as high as 620 ft/s (423mph), which is well above the 408 ft/s (278mph) velocity required "for penetration of skin, bone, and moderate tissue, or if no bone is encountered, of skin and deep tissue."

Since BB guns cannot be made safe and still have any utility ***Table 11***, the only means of controlling injuries is to keep air and BB guns out of the hands of unsupervised children and subject them to the same safety precautions and laws as apply to weapons using gunpowder (firearms). [11, 32] Air and BB gun sales are closely controlled in New York City, [11] but are mentioned in the laws of only 28 states. Some of that legislation explicitly excludes them from consideration as dangerous weapons or firearms. [10] 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. First, 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, [33] 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. [34] When parents

***Figure 12. BB perforation of human eyes***



Top: BB perforation of human cadaver eye. Continuation of Figure 1a-c in Mechanisms and Prevention of Sports Eye Injuries. 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

purchase such a gun, they must recognize it is a firearm, 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. [35]

Second, 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. [9, 14, 17, 28, 36-39] As in the case of most eye injuries, the best way to prevent loss of vision from air guns it to prevent the injury from occurring. [8]

Third, 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 (29mph). When fired in the horizontal direction from a height of 5 ft, the BB would travel a mere 24 feet, [32] and thus would appeal only to the most placid child. The child and the parent must realize that an air rifle pellet contains more energy than an individual duck/pheasant shotgun hunting shot. ***Table 12***

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

Fifth, 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) [9] to the user [40] 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. [8] 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.

***Table 12. Target and Hunting Gun Muzzle Velocity and Energy***

| | | Total Shot Mass g | Number of Projectiles | Individual Shot Mass g | Muzzle Velocity ft/s | 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* |

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. [41] 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. [42] 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. [43] 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, skeets) with shotguns.

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. [44-46] 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 shotgun 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. [47, 48] 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. [49]

Although most firearms injuries are the result of intentional assault, [50, 51] 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 wear-

ing 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 a 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, three cut their eye while cleaning a shot deer, three were hit by tree branches, and two 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. [52] Since 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 and training would help to reduce firearm injuries. [53] In 1995, 17 million persons purchased hunting licenses in the United States. 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. [54, 55] 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, [56-58] sometimes bilateral, [59, 60] eye injuries frequently occur with shotgun pellets from longer distances, gunpowder blasts, [61] blank cartridges, [62] ricochets, and impacts with other objects (tree limbs, knives, wire) [6] that can be prevented with appropriate eyewear. Eyewear with polycarbonate or Trivex 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. [63, 64] Eyewear that passes both ANSI Z87+ and the much more stringent military ballistic test for eye armor [65] is readily available and inexpensive.

## Archery

Archery target shooting (longbow, recurve, compound or cross bows, with or without sighting aids) has a minimal eye injury risk. 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 hemorrhage), 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. [66-68] and Norway. [69] Adult [70] and toy [71] 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. 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. [72, 73] Of all hospitalized casualties of the Yom Kippur War of 1973, 6.7% sustained ocular injuries, of which 24.4% were bilateral. [74] Ophthalmic injuries, usually caused by munitions blast fragments, [75] 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 US soldiers with eye injuries were wearing them at the time of their injury. [76] None of the military who suffered eye injuries (6.8% of all casualties) in the Lebanon war were wearing eye protection. [77]

Between 1980 and 1993 there were over 27,000 deaths among the US 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 deaths while 60% died from largely preventable unintentional injuries that occurred during their day to day activities and off-duty. [78] Most military eye injuries also were not combat related, but occured from motor vehicle accidents, fighting, and occupational or sports activities. One in 58 eye injuries required treatment in a hospital. [79]

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. [80] Laser eye protection can impact performance and color identification in protected military personnel. [81] 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. [82, 83]

The need for a comprehensive eye protection program in the military cannot be overemphasized. [84] 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. [85] The military has a combat eye armor program underway that is well accepted and has prevented eye injuries. [86, 87] Since soldiers have occupational exposure to eye hazards that are comparable to those in civilian industry, [88] the military should enforce interventions to prevent work-related eye injuries that have been effective in preventing civilian occupational eye injuries. [89, 90] Protective sports eyewear should be issued to military personnel at risk for sports eye injuries.

## Fencing

Although fencing is a relatively eye-safe sport with available facemasks ***Figure13***, two fatal injuries (penetration

of a face mask by a broken foil with intracranial entry through the orbit and penetration of the neck over a 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 clothing (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). [91] 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 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. [92]

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. [93-95] Games involving darts are not appropriate for children unless there is strict adult supervision and the rules of play are followed

## Fishing

Fishing (53.1 million participants) was second only to bowling (55.5 million participants) as the most popular activity in the SGMA study. 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. Only 7% of non—fly freshwater fishers were new to the activity in 2001, while more than half have been involved ten years or more.

Fishing was responsible for 113 of the 702 (16.1%) total sports eye injuries and 50 of the 177 (28.2%) open-globe injuries due to sports in the USEIR database. [6] The fact that 44.2% 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, [96-98] sinkers, [99-103] pole tips, [6] and fishing spears or harpoons [104, 105] 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. [106]

## Shattered eyewear

Lacerating eye injuries from shattered eyewear are almost totally preventable as discussed in ***Mechanisms and Prevention.***

# *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 246ft/s (168mph). The projectiles have caused hyphema, vitreous hemorrhage, and cataract. The airsoft has blinding potential and should not be sold as a toy. [3, 107, 108]

## 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, now played in over 40 countries, continues to grow in popularity, with an increase in the United States from 5.9 million participants in 1998 to 7.7 million participants in 2001. The average player is a man (81%) 20.7 years old, who has played for three years. Frequent players (more than 15 days per year) number 1.4 million. [1]

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, ani-

mal, or object other than the intended target. [42] 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 started a cottage industry of air gun and paint capsule manufacturers as well as field operators. Early on, the rapidly growing sport had no controls—as exemplified by the lack of age restrictions on the sale of paintball guns.

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 bear the warning that they are not designed for sports use. [109] This eyewear often failed, resulting in severe injury to players who had assumed they were protected ***Table 13.***

As the sport grew, there was a slow shift in philosophy away from the original "hunt and be hunted." [110] 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.

***Figure 14. Paintball eye and face protector certified by PECC to ASTM F1776***

Note chin strap which is recommended to help keep protector in placewhen impacted from below.

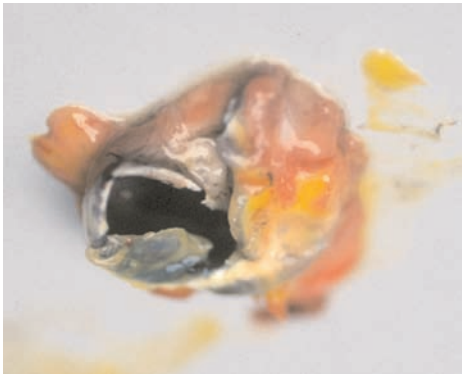
Paintball now has its own ASTM subcommittee and there are now standard specifications for paintball eye protective devices (ASTM F1776), ***Figure 14*** field operation (ASTM F1777), marker warnings (ASTM F2041), and paintballs (ASTM F1999). Tree-marking capsules, with indelible paint, have been replaced 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." Automatic markers, in which more than one paintball is discharged for one depression and release of the trigger, have almost totally been eliminated, but the complete elimination awaits finalization of a marker standard. Red paintballs (which may be confused with blood) are prohibited from many fields.

At this time, the paintball mark is a non-toxic, water-soluble dye, contained in a spherical, usually gelatin capsule—the paintball (3.3g, 17mm 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 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

***Table 13. Paintball Eye Injuries Related to Protective Eyewear***

| Author | Reported Cases | Open Globe | Eyewear Use Not Stated | Eyewear 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) [187] | 6 | | | | 4 | 2 | |
| Anders (1994) [188] | 3 | | | 3 | | | |
| Dawidek (1989) [189] | 1 | | | | | 1 | |
| Easterbrook (1985/8) [113, 190] | 44 | 2 | | 43 | 1 | | |
| Farr (1998) [191] | 2 | | | 1 | 1 | | |
| Fineman (2000) [192] | 35 | 2 | | 13 | 19 | 3 | |
| Gazagne (1994) [193] | 6 | | | 6 | | | |
| Hargrave (2000) [194] | 4 | | | 4 | | | |
| Hansen (1994) [195] | 1 | | | 1 | | | |
| Karel (2002) [196] | 1 | | 1 | | | | |
| Kruger (1999) [197] | 6 | | | 5 | | 1 | |
| Mamalis (1990) [198] | 1 | | | 1 | | | |
| Martin (1987) [199] | 1 | | | | | 1 | |
| Mason (2002) [200] | 10 | | | 7 | | 2 | 1 (? ASTM) |
| Morgan (1989) [201] | 2 | | 2 | | | | |
| Pakoulas (1989) [202] | 2 | | | | 1 | 1 | |
| Ryan (1986) [203] | 1 | | | | 1 | | |
| Schwartz (2000) [204] | 141 | 16 | 52 | 63 | 19 | 7 | |
| Tardif (1986) [205] | 13 | 1 | | | 13 | | |
| Thach (1999) [206] | 13 | 3 | | 4 | 7 | 2 | |
| USEIR [6] | 12 | 1 | | 10 | 1 | | 1 (poor fit over Kevlar helmet) |
| Verburg (1993) [207] | 5 | | | | 5 | | |
| Wellington (1989) [6] | 1 | | | | 1 | | |
| Welsh (1989) [208] | 4 | | | 1 | 1 | 2 | |
| Wrenn (1991) [209] | 2 | | | 2 | | | |
| Zwaan (1996) [210] | 2 | | | | 2 | | |
| TOTALS | 319 | 25 | 55 | 164 | 76 | 22 | 2 |

***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.

part of the game. However, the impact of a paintball on the unprotected eye is associated with severe injury. Pig eyes rupture when impacted with paintballs fired from closer than 4 meters ***Figure 15.*** [111]

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. [110] 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. [112]

The widespread use of protective eyewear has greatly decreased paintball eye injuries, [113] 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. The sport needs a governing body with the authority to control potentially unsafe practices of some marker manufacturers and field operators.

## Golf

There are 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. Golf players tend to be older (average 38.2 years), participate longer (average 13 years) and be more affluent than the players of most other sports. [1]

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. [114] 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.

Golf is not a common cause of eye injuries, but those that do occur from the ball or club (or rarely the golf tee) [115] are usually very serious. [116-118] A 59mph golf ball ruptures a pig eye. [119, 120] 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. [6] 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%). [29] 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. [121]

Most persons do not realize that liquid-center (liquid contained under pressures as high as 2,000–2,500psi) [122] golf balls may explode [123-126] and are potentially hazardous if cut open, releasing the liquid with force sufficient to penetrate the eye and orbital structures. [122, 127, 128] Fortunately, major manufacturers use nontoxic liquids (such as corn syrup with added salts) [114, 129] rather than the sulfuric acid, barium sulfate and zinc sulfide compounds used in the past. [122, 127, 130, 131] 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. [132] Golfers should wear sunglasses or prescription eyewear with polycarbonate or Trivex lenses.

# Racket and paddle sports

These sports are enjoyed by approximately 40 million Americans ***Table 14.*** Racquetball has the strongest core (over 25%) of frequent players. The traditional family games—table tennis and badminton—have suffered as family time diminished and children turned to TV, computers and video games. Overall the participation in racket and paddle sports has diminished over the past five years, however, the percentage of female tennis participants grew from 40% in 1990 to 50% in 2001. [1]

Racket sports are a common cause of serious eye injuries. In Canada, the 1,135 racket sport injuries (47 blind eyes) accounted for 24.5% of all reported sports eye injuries and 8.8% of eyes blinded from sports. [133] 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. [134] 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. [135] A survey of 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. [136]

***Table 14. Racket and Paddle Sports (millions of players)*** [1]

| [ ] = average days of participation 2001* | 2001 participants | Change1987-2001 | Frequent (≥ 25 days) 2001 participants | % Females |
|---|---|---|---|---|
| Tennis [22] | 15.1 | -28.4% | 3.5 | 48.5% |
| Table Tennis [16] | 13.2 | -34.3% | 1.9 | 41.5% |
| Badminton [14] | 7.7 | -48.0% | 0.9 | 57% |
| Racquetball [24] | 5.3 | -49% | 1.4 | 33% |
| Squash [14] | .36 | n.a. | n.a. | n.a. |

* 2000 for squash

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. [137] Many studies have shown the ocular risk of participating in squash, racquetball, tennis, and badminton. [138] There is no correlation of player's level of experience with eye injury. [139-141]

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. [142] 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. [143] 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***. [139 141, 144-146]

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. [147, 148]

Despite the acceptance of ASTM racket sport standards and the existence of certification councils in the United States and Canada, some major manufacturers still promote unsafe eyewear for use in racket sports. ***(also see figure 9 in the Mechanisms and Prevention of Sports eye injuries)*** 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. [145, 149]

Table tennis requires no eye protection, and there are 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. [150] 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 effective racket sport eye protectors are available ***Figure 11 from Mechanisms and Prevention of Sports Eye Injuries.*** Their widespread use will reduce eye injuries in these sports. [151]

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

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

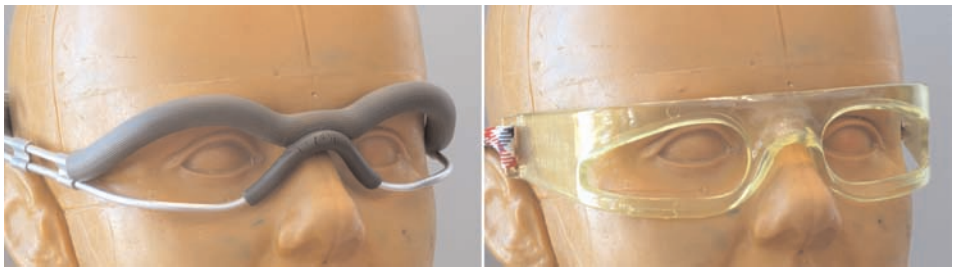
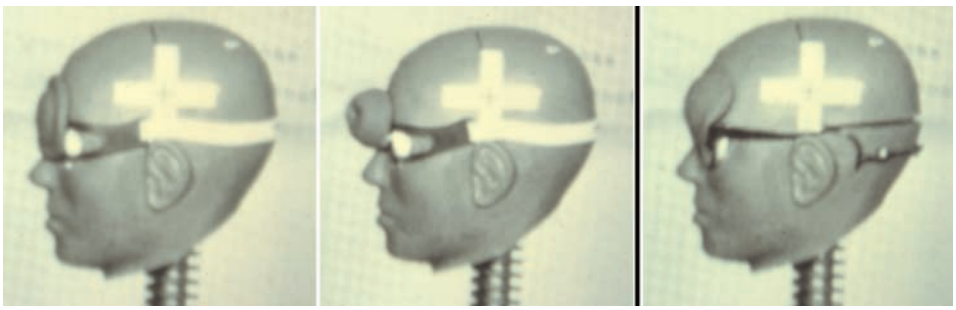


***Figure 17. Racquetball eyeguard testing for ASTM F803 (1983)***



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. [146]

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.

players and decreasing in protected players. ***Table 15***

## Handball

Handball (the original "racket 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), [146] with the hand wearing a non-webbed, snug-fitting, soft glove.

Handball's responsiblity for about 900 eye injuries a year is a statistic that 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 lensless eyewear has not prevented hyphema, commotio retinae, and retinal tears, [152] 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. [153] 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. [146]

The ocular hazards of squash were first documented in the early 1970's. In 56 reported cases, the ball caused about

***Table 15. 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 |

Note: eye protection resulted in a decrease in all racket sport injuries because of the protection in racquetball and squash. The percentage of injuries to mostly unprotected badminton and tennis players increased.

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

***Table 16 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 detachment or tear | Lensless eyeguards |
|---|---|---|---|---|---|---|---|---|---|---|---|
| North [155] | 1968-70 | 35 | 33 | 34 | 27/8 | 5 | 1 (racket) | 3 | 30 | 1 | 0 |
| Ingram [154] | 1973 | 21 | 20 | 21 | Of 14 severe injuries: 7B; 6R; 1U | 8 of 14 severe injuries | 4 (R3; B1) | 7 | 4 | 2 | 0 |
| Moore [211] | 1974-5 | 38 | | | 22/11 | 5 (all racket) | 3 (racket) | 2 | 33 | 1 | 0 |
| Easterbrook [212] | 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 [213] | 1975 | NA | | | | 4 | 2 | | | 6 | 0 |
| Vinger [141] | 1976-7 | 6 | | | 1 | 2 | 1 (racket) | 1 | 2 | | 0 |
| Easterbrook [214] | 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 injury |
| Easterbrook [215] | 1978-9 | 7 | 7 | 7 | 6/1 | | | | 4 | | All injuries to players wearing lenseless eyeguards. Lensed eyeguards recommended |
| Mondon [216] | 1981 | 11 | 11 | 9 | 8/3 | Probably 2 | | | 4 | 2 | |
| Easterbrook [149] | 1978-81 | 154 | | | | 1 lens shattered 1 frame failed | 1 (racket) | 10 | 80 | 7 | 16 players wearing at time of injury |
| Barrell [137] | 1978-9 | 58 | | | 41/17 | | | 1 | | 1 | |
| Bankes [217] | 1982-3 | 339 | 251 between 20 and 39 | 278 | 235/103 (collision with wall = 3) | | | 40 | 147 | 5 | |
| Jones [135] | 1987 | 14 | | | | 1 | 1 (racket) | 1 | | | |
| Kahle [218] | 1989-90 | 78 | | | | | | | 12 | | |

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. [154, 155] 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. [156]

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, [157] almost boring in their regularity and predictability ***Table 16.*** 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. [158] 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. [159]

The risk of one eye injury for each 5,329 squash matches [160] 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 [161] (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. [162] 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). [163] 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. [164]

Eye protection for United States and Canadian squash players has been promoted since 1976, and is now mandated for most players ***Table 17***. 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.

## Racquetball

This relatively 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. [146]

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. [165] 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

***Table 17. 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. Louis 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 |

***Table 18. 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 | Lensless eyeguards |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rose [166] | 1975-6 | 20 | 19 | 15 | 15/5 | | | | 4 | | No players wore eye protection |
| Vinger [141] | 1976-7 | 1 | 1 | 1 | 0/1 | 1 lens popped through frame, struck eye | | | 1 | | 0 |
| Doxanas [140] | 1978-9 | 37 | | | 15/22 | | | | 5 | | No injured players wore eye protection |
| Easterbrook [214] | 1978-80 | 18 | mean age: 32 | 15 | 15/3 | 1 | 1 (racket) | 2 | 17 | 1 | 7 players wearing at time of injury |
| Easterbrook [215] | 1978-9 | 12 | | 7 | 11/1 | | | | 4 | | All injuries to players wearing lenseless eyeguards. Lensed eyeguards recommended |
| Easterbrook [149] | 1978-81 | 91 | | | 82/9 | 21 (squash plus racquetball) | 8 (squash plus racquetball) | 3 | 46 | 2 | 36 players wearing at time of injury |

each 11,760 participation hours. 166 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, with the racket injuries often self-inflicted. [140, 167]

## 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. [146]

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. [168] 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% [169] 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, [135, 170] but there have been no reports of a spectacle lens shattering on impact from the shuttle. [171] Most injuries from the shuttle are to players at the net. [135]

In Canada, where two of the 11 eye injuries reported in the 1976-1977 season resulted in legal blindness, [172] 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. [173] School children, suffer badminton induced hyphemas while supervised by physical education teachers who rarely recommend protective eyewear. [174] Badminton is responsible for 19% of severe sports-related eye injuries in the United Kingdom. [175]

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. [176] No eye injuries have been reported in any player wearing an eye protector that passed ASTM F803.

## 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, [141] 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 [177] or have lenses weak enough to fracture on racket impact. [178] Tennis is the leading cause of eye injuries in west-suburban-Boston working-aged women [179] for three reasons: Massachusetts women enjoy the game, eye protection is rarely worn, and the tennis ball has sufficient energy to detach the retina. [180] Injured players tend to return to the game, even after loss of an eye [181] or a retinal detachment. [182] Even players who have had an eye injury from tennis tend not to wear eye protection when they recover and resume play. [181, 182]

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 depicted in refractive surgery advertisements as an example of the ability to "play sports without glasses". A well-known ophthalmologist who had RK [183] 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". [184] If a 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. [185, 186]

### 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.

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