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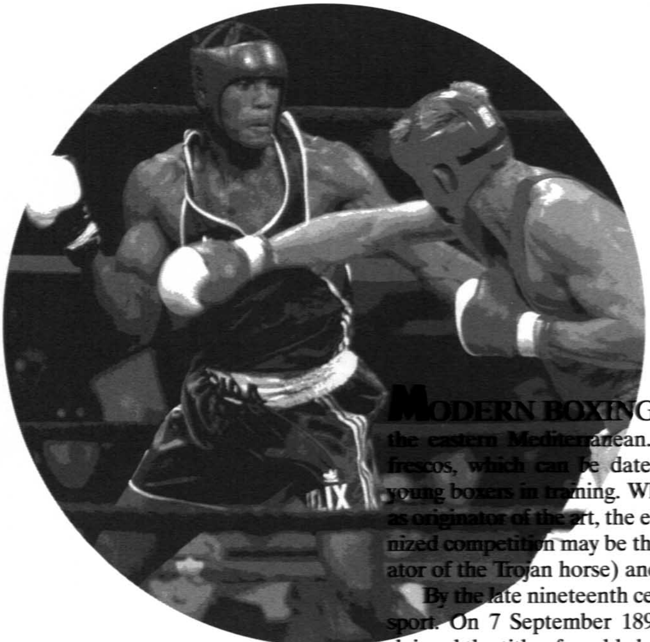

Boxing

MODERN BOXING has its origins in the ancient cultures of the eastern Mediterranean. In the archaeological record, Minoan frescos, which can be dated to approximately 1600 B.C.E., depict young boxers in training. While Greek mythology designates Apollo as originator of the art, the earliest hard literary reference to an organized competition may be the story of the match between Epios (creator of the Trojan horse) and Euryalos in Book 23 of the *Illiad*.

By the late nineteenth century, boxing had evolved into a modern sport. On 7 September 1892, an American boxer, James Corbett, claimed the title of world champion by knocking out John L. Sullivan in a fiercely contested 21-round battle. With a purse of $20,000 and a stake of $10,000, the contest ushered in a new era of popularity for prizefighting. In a rushed determination to outlaw these "brutal bare-knuckle battles," American legislators introduced the Marquis of Queensberry rules—use of gloves and three-minute rounds.

Nearly 4,000 years after the Minoans and more than 100 years after Corbett and Sullivan, prizefighting continues to enjoy popularity as a sport. Heavyweight-title fights often net each fighter more than $20 million for 36 minutes of work.

Critics continue to argue that boxing—with its frequent injuries and occasional deaths—is too brutal to be considered a sport; and given the considerable money involved in professional boxing, officials have shown some willingness to placate the critics with minor rule changes. Following the nationally televised knockout of Du Ku Kim by Ray ("Boom Boom") Mancini in 1982, which resulted in Kim's death shortly thereafter, protesters marched to Washington, D.C., demanding that boxing be banned in the United States. To preempt congressional action, prizefight promoters limited fights to 12 rounds (many championship fights had gone 15). Other than this one concession, however, boxing officials have done little to protect prizefighters since the time of Sullivan and Corbett.

In the twentieth century, hundreds of fighters have died as a direct result of boxing (450 since 1918, when records were first kept). Thousands need to be hospitalized immediately following a bout—often suffering damage that permanently affects the quality of their life. Although statistical evidence is not available, it is probable that a great many boxers have suffered premature deaths as a result of

Activity	Kcal/hr. /lb. of body weight
Boxing, in ring	6.04
Running, 8-min. mile	5.68
Cross-country skiing	2.7–5.5
Swimming, freestyle	3.48
Cycling (10 MPH)	3.18
Aerobics	3.02
Golf, walking	2.32
Golf, power cart	0.9–1.4
Sitting	0.47

Table 1. *As an alternative to the monotony of aerobics, treadmills, and stair climbing, many men and women are turning to boxing for physical fitness. Boxing is increasingly popular among white-collar professionals, perhaps because it relieves frustrations and burns calories. Most participants engage in shadow-boxing—rather than actually pummeling an opponent—as part of a rigorous aerobic session. (Adapted from Lamb, 1984)*

boxing injuries. In addition to internal injuries, the severe beatings received by professional boxers cause disfiguring scars and other cosmetic damage that serve as lifelong reminders of their time in the ring.

Boxing represents a mixture of brutality and artistry that often draws an emotional response from its proponents as well as its critics. Proponents argue that boxing is a sport that requires strength, coordination, conditioning, endurance, strict discipline, and courage. Yet for every bout between equally matched fighters, there are ten or twenty ugly fights between mismatched, slow, or unskilled boxers. Such fights raise an outcry from people who ask how a civilized nation can condone, and even encourage, a sport in which the objective is to knock the opponent out by damaging—sometimes permanently—neural tissue in the vital centers of the brain. It is true that participants in football and other contact sports also face risks to their health and safety, but in these games injuries are a side effect rather than the objective. Nevertheless, the willingness of fans to spend enormous amounts of money to watch boxing matches ensures that the sport will continue unless it is outlawed.

Not all boxing is the same, however. Amateur bouts have little resemblance to professional prizefights. The equipment and rules used in amateur boxing stress skills and limit the chance of a knockout, making it a far safer sport than professional boxing.

In this article, the physics and biomechanics of amateur and professional boxing are explored. An understanding of how much force a boxer can generate, what happens when a fighter strikes a target, and the relative merits of protective equipment requires a wider knowledge of the underlying physics of boxing.

Punching Power

Punching power is a combination of linear and angular momentum. Linear momentum (mass × velocity) from the forward acceleration of a punch develops as the fist moves toward its target; angular momentum (rotation around a fixed axis) from the accelerating forces created from the body's twisting motion develops as the punch is delivered (*see also ACROBATICS and FIELD ATHLETICS: THROWING*). Some punches depend primarily on either linear or angular momentum, but big blows usually maximize both forces.

Because jabs, hooks, uppercuts, and straight punches draw on different linear and angular momentums from the body, a range of deliverable forces and damaging effects will result from each blow. For example, the left-hand jab of a right-handed boxer is delivered off the lead foot, with power coming from the linear momentum of stepping forward. In comparison, the hook, uppercut, and straight punch, delivered with the dominant right hand, can generate considerably more power, for two reasons. First, a punch gains force from

Why Do Men Fear a Low Blow?

As the champion pummeled the challenger, the crowd cheered with a deafening sound. The dazed and desperate challenger swung wildly in response, delivering a punishing low blow to the champion's groin. In almost complete unison, the wild cheering gave way to a pained sigh: "Ouuhhh."

Around the arena, hundreds of men grabbed their own groins as if the low blow had hit them, not the fighter. The previous blows, even those causing deep cuts and profuse bleeding, had drawn little or no empathy. Why do men look at a blow to the groin in a different light? A low blow is, of course, incapacitating—the pain leaves a man feeling totally helpless—but it may also reflect a man's primal fear of castration and impotence.

The rules governing low blows are extremely stringent: points are taken away from a fighter who delivers an illegal blow; and a 3-minute recovery time, and even one or more rounds, may be awarded to the receiver. At one time, the penalties were much worse: a fighter who received a low blow could be awarded the victory. However, it was possible for a fighter to feign receiving a low blow, and this feigning became so common and so successful that officials rethought the rule. Eventually, a "no foul" rule was established to ensure that a fighter could not win by feigning a low blow: every fighter had to wear a foul-proof cup, which prevents incapacitating blows to the groin.

The sensitivity and vulnerability of the groin area can make scrotal contusion particularly debilitating, causing excruciating pain and nausea. However, the damage is usually only temporary, even if a fighter is not wearing the cup. As with any contusion, the degree of bleeding, swelling, and muscle spasm depends on the intensity of the blow. The possibility has been suggested that blows to the testicles might cause testicular cancer later on; but to date, there is little evidence to support this theory. In fact, lifelong damage from sports-related injuries to the groin is very rare indeed. This is primarily because a projectile—whether a hockey puck, baseball, elbow, or fist—can rarely generate enough force to cause permanent damage to either the groin or the internal abdominal organs.

The groin and the abdominal organs are structured so that a significant amount of body fat and muscle acts as a buffer against external blows. The abdominal region consists primarily of hollow organs, such as the intestine and urinary bladder, but includes some solid organs, such as

angular momentum in addition to linear momentum as the shoulder and hip rotate forward toward the target. Second, the stronger, more practiced hand has more speed as well as power (work time). Doubling the speed of the fist also doubles stopping time, and—more important—it quadruples stopping distance. However, the punch itself possesses four times the kinetic energy (energy of motion), which means that the blow penetrates four times as deep. Not surprisingly, much of a boxer's training focuses on increasing hand speed.

Although punching power is very important, the point at which the punch contacts the target is equally so. The effect felt by the recipient of the blow depends largely on location. The impact of a body blow is absorbed across a large surface area, mitigating its debilitating effect. But when a blow lands across the bridge of the nose—hitting a very small surface area—it becomes far more debilitating. A relatively weak blow across the bridge of the nose can be far more damaging than a maximum-force blow to the torso.

Heavyweights and Heavy Punching

Boxing fans devote much of their attention to heavyweights, large boxers who are not necessarily among those most skilled. In fact, the heavyweight division includes the greatest number of slow, plodding, the liver and kidneys. When a hollow organ is not full, it absorbs impact force much better than a solid organ. A solid organ is less capable of dissipating energy from an impact, and this makes it more vulnerable to injury.

Of the solid abdominal organs, the kidneys are perhaps at greatest risk. The kidneys are two bean-shaped organs located near the skin surface just above the iliac crest (hips), one on each side of the spine. Although they are surrounded by a capsule and by a protective layer of fat—which is encased in a second layer of fat—the kidneys nonetheless make an inviting target for boxers, who often find themselves in a clinched position. While a fighter's arms are locked around the opponent, the kidneys are often the only target accessible for punching. Not only boxers but also football quarterbacks and receivers (who are sometimes "speared" from behind by an opponent's helmet) can receive blows that injure the kidneys.

A blow delivered to a kidney at a certain angle and with enough force can lead to flank pain, nausea, vomiting, and shock. In addition to pain that does not subside, the clearest indicator of kidney damage is the appearance of blood in the urine. Bleeding usually stops on its own, but surgery may occasionally be necessary to repair fractures to one or both kidneys. Repeated blows may result in a scarred, poorly functioning kidney; long-term effects may include hypertension (elevated blood pressure), insufficient kidney functioning, and even kidney failure. If both kidneys experience repeated trauma, or if an athlete has only one kidney (this can be a congenital defect), dialysis may become necessary. Dialysis is, in a sense, an "artifical kidney," but it is not an implant: it is a repeated process of artificially altering and regulating the concentration of toxic substances in the blood.

Top boxers, who keep their body fat extremely low in order to perform at high levels, are very susceptible to kidney contusions and fractures—their protective layer of fat may be only 1 centimeter (0.4 in.) thick. In contrast, in an obese or less-conditioned athlete, the fatty layer may be from 8 to 15 centimeters (3 to 6 in.) thick, providing far more protection.

Overall, however, the risk of injury from groin and abdominal blows is minimal. Thus it is ironic that boxing fans cheer as a fighter beats the opponent's head but consider a deliberate blow to the groin poor sportsmanship.

David L. Zumerchik, M.D.

clumsy, wildly swinging fighters. Perhaps the reason for the popularity of this division is that heavyweights have the ability to inflict the greatest damage and deliver more knockouts.

British engineers at the University of Manchester measured the punching force of boxers and found that well-trained boxers deliver an average punching force of 3,400 newtons (764 pounds). Deliverable punching force is determined by the effective mass and velocity of the fist, which in turn is determined by the fighter's skill, strength, weight, and arm length, and the distance at which the punch is thrown.

Although a bigger fighter and a smaller fighter may deliver comparable force, greater impulse (force × time; or the amount of linear momentum transferred) explains why a larger fighter inflicts more damage. For example, a 140-pound (63.6-kg) boxer, such as Julio Chavez, and a 220-pound (100-kg) boxer, such as Mike Tyson, may both generate a punching force of 3,400 newtons at impact. Even if the impact occurs at the same part of the opponent's body, the punch from the 220-pound fighter will be more effective because for any given force, a blow from a more massive fighter takes longer to stop. Thus, the distance of the head snap and the extent to which the brain is slammed against the skull depend on the size of the impulse. A force of 3,400 newtons delivered for 1 microsecond by a fly might

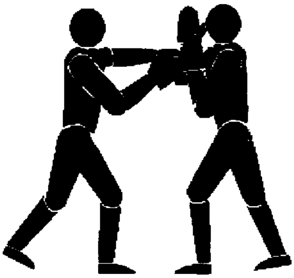

Figure 1. *The stance used in most sports—feet apart, knees bent, and crouching forward to lower the center of gravity—is completely different from that used by a boxer. If such a stance were used, the boxer would present the opponent with the largest possible target and could be toppled backward by even the lightest of punches. Instead, boxers position themselves with one foot forward and one back, nearly perpendicular to the opponent. When they are hit, this stance enables them to keep their center of gravity between their two feet and not fall backward. Often, when a fighter lands a powerful punch, the force of the blow sends the opponent stumbling backward until the back foot can be repositioned behind the center of gravity to regain balance.*

sting a little but would cause no harm at all. By contrast, the same force delivered to the chin for a few milliseconds by a heavyweight could jar the head abruptly enough to cause unconsciousness.

Heavyweight fighters also face a greater risk of permanent injury. All fighters learn to "punch through" the target, to concentrate on a fictitious target within the actual target, training to terminate a punch several inches within the opponent's body. To maximize the effect of a blow, a boxer applies the greatest possible force for as long as possible. Lengthening the period of contact makes the linear momentum of the blow more effective. When a punch is terminated "within" the target, instead of at the point of contact, mass is more important than velocity. This is due to inertia (a component of mass)—the tendency of something in motion to stay in motion and something at rest to stay at rest. When a fist collides with a body, two inertial forces are at work. The reaction force of the body being hit acts on the fist: this inertial force slows the fist's acceleration. At the same time, the reaction force applied to the contacted body is equal and opposite to the inertial force of the fist and therefore determines the direction and acceleration of the body. These accelerations must be moving in opposite directions. This explains why an extended follow-through of a heavyweight like Mike Tyson delivers a much more effective blow than that of a much smaller fighter like Julio Chavez, especially when hand speed is about equal.

Punching Power and Mistakes

A punch becomes even more effective when the opposing fighter makes a costly miscalculation, such as stepping into the punch. When a powerful fist collides with a skull, each possesses linear momentum in the direction of the other. The fighter receiving the blow quickly comes to a stop, and the acceleration of the head reverses, or snaps back. By stepping into the punch, fighters inflict additional damage on themselves because the force of the blow is sustained over a longer period of time. Thus good fighters try to "roll" with a punch, extending the time of impact and "riding" the punch by moving the head back (instead of forward and into the punch).

Head Movement and Concussions

When a part of the brain suffers trauma, the result is often a concussion, or a disturbance of neurological function. Concussions can be caused when a cyclist's head strikes a curb during a fall, when players' helmets collide in football, or when a boxer receives a blow to the head.

In boxing, a blow that produces an angular acceleration of the head causes more brain movement than a linear force that does not rotate the head. Blows of identical magnitude and force that occur tangentially—not through the head's center of gravity—produce a much higher acceleration. For example, a punch directed crosswise that catches the side of the chin would result in at least 3.5 times

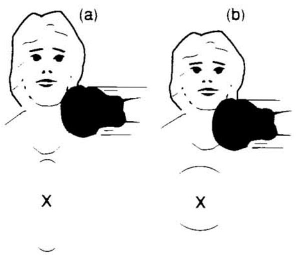

Figure 2. *The angular rotation of the head depends, in part, on the shape of the head. A tangential blow to an ellipsoid-shaped head and to a rounder head result in different rotational accelerations. When a football and a soccer ball are kicked below center, the ellipsoid football rotates more in flight than the round soccer ball. Likewise, a fighter with an ellipsoid-shaped head will experience more rotational acceleration when receiving a blow to the chin than a fighter with a rounder head, because the radius (dotted line) from the head's center of gravity is greater.*

greater acceleration of the head than a blow to the cheek, directly through the center of gravity. In practice, the acceleration is more than 3.5 times greater—the calculation for a solid sphere. Because the head is a nonsolid ellipsoid (oblong), the acceleration may be as much as 4.2 times greater (*see Figure 2*). Headgear may actually worsen this effect, as it provides an enlarged target that makes the head susceptible to even greater rotational acceleration.

The internal dynamic properties of the head are not as easily measured as the external blow's impact on the skull. Several complex biological factors play a role: (1) mass, (2) oscillation of the head (vibration), (3) damping (of vibration), and (4) the involuntary nervous-system reaction to the blow. Factors 2, 3, and 4 are, for the most part, heavily dependent on factor 1: mass. Because the head-neck system remains fairly stationary, change in the head's momentum decreases with greater head mass. Heavyweights not only have the advantage of greater punching power but are less likely to be affected by head blows because of the greater mass of their head-neck system, which includes a larger, more muscular neck.

The thickness of a fighter's skull is probably a minor factor in determining the probability of concussions. Numerous studies have shown that bone mass varies among individuals. The skull consists of soft, cancellous bone—interlocking plates and a porous bone structure. A thicker skull can significantly reduce the risk of hematoma (a blood clot at the point of impact) but probably has little or no effect on the conditions causing long-term brain damage: inertia of collision as the brain is forced backward and against the skull (*see also SKELETAL SYSTEM*).

Forces on the Brain

The central strategy of boxing is to launch a series of powerful blows so that fatigue, exhaustion, and injury collectively crush the opponent's will to continue fighting. To accomplish this, a skilled fighter focuses on pummeling the head, because the head houses the strategic command center—the brain. A fight is all but over when the brain loses some or all of its functions: balance, coordination, reflex, memory, instinct, and strategy. In many ways, a boxing match is much like a war: just as the first strategy in warfare is to disable an enemy's strategic command center, a boxer's primary target is the brain.

As noted above, boxers attempt to maximize their follow-through by accelerating "through" the target. The surface of a boxing glove, as opposed to a bare-knuckle blow, delivers the force over a wider area. A punch to the head is therefore not particularly damaging to the face itself: rather, it causes a rapid rearward acceleration of the head. The force of gravity is 9.8 meters per second squared (32 lb. sec.^{2}): a well-executed, clean (nondeflected) blow to the head can cause an acceleration of the head 80 times this. A boxer's fist functions as a small projectile that is rapidly accelerated toward a small

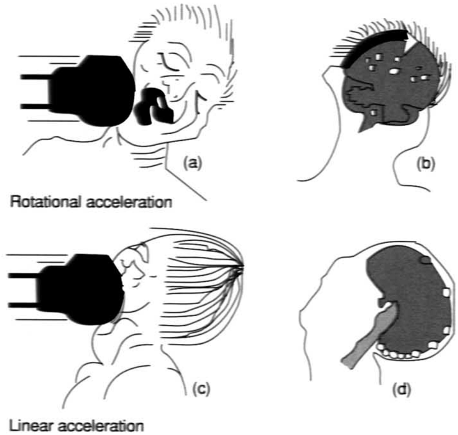

Figure 3. *Brain damage may be caused by different types of head blows. The small circles (shown in b and d) connote areas of acute trauma. In a blow that causes rotational acceleration of the head (a), the brain bounces about inside the skull (b). In a blow causing linear acceleration of the head (c), damage is caused as the head snaps back against the neck (d). (Adapted from Lampert, 1984)*

target, the head. After a blow to the head, the muscles of the neck prevent the head from snapping back and create a force countering the punch. Since the brain floats in the skull much as an egg yolk floats in the shell, it lags behind the accelerated head and ricochets around in the skull, straining brain tissue and stretching and tearing blood vessels.

Most knockouts are caused by a blow to the chin, and unconsciousness occurs almost immediately following the blow. Some doctors argue that a knockout takes place so suddenly because a nerve in the chin is damaged, sending the brain into shock. Others argue that the sudden head rotation disrupts the balance mechanism, the vestibular system, located in the inner ear (*see also ACROBATICS*). Although the complete physiological explanation for the abrupt chin knockout remains unclear, part of the reason is the chin's distance from the center of gravity (mass) of the head. As mentioned above, a blow to the tip of the chin creates greater peak acceleration of the skull than a blow landing elsewhere on the head.

The rotational acceleration caused by a blow to the chin represents the greatest possibility of stretching and twisting the brain stem (*see Figure 3*). Because all nerve signals to and from the body pass through the brain stem, its operation, or lack thereof, affects motor control throughout the body. The brain stem also controls the rhythm of breathing and the rate and force at which the heart pumps blood.

Any hard blow to the head can transiently affect the brain stem and cause a concussion, but continuous head blows damage the surface and interior of the brain, killing nerve cells and splitting blood vessels. Unlike the internal surface of an eggshell, the internal surface against which the brain ricochets is nonsymmetrical. The many protrusions of the skull concentrate the impact force over a smaller

The Value of Headgear

Headgear can reduce the acceleration of the head for blows at or near the head's center of gravity by 15 to 25 percent. Yet despite thick padding around the lower jaw and chin, there is no measurable reduction in head acceleration from blows to the chin. Because the chin is the point on the head farthest from the head's center of gravity and axis of rotation, the head experiences the greatest angular acceleration from a blow to the chin.

area of the brain, causing greater trauma to the small part of the brain hitting the protruding parts of the skull.

By rolling with punches, a fighter limits adverse effects on the brain. Maintaining a strong, stiff neck—an asset shared by many championship fighters—may, paradoxically, be a leading contributor to long-term damage to the brain. Recoiling, or "giving a little," lengthens the impact of an opponent's punching force. The boxer receiving a blow moves the head backward in unison with the impact to increase the distance of the stopping action. The effect is similar to that achieved in the picnic game of egg toss. A tossed egg is least likely to break if the catcher extends the arms as far forward and upward as possible. This position allows the catcher to move the hands backward at a speed slightly slower than that at which the egg is traveling and to lengthen the time of impact. To prevent the egg from breaking, the catcher utilizes a very long impact interval—gradually slowing the backward velocity of the egg by moving the hands from the front of the body to well behind it (*see also CATCHING SKILLS*).

In the same way, the strong, stiff neck muscles of an alert fighter may increase the impact of a head blow on the brain. Stiff neck muscles cause the brain to accelerate more quickly in relation to the skull and to ricochet around inside the skull with great force—the same dynamics that make an egg likely to break when caught by hands that are held in place. Although weak or loosely held neck muscles might also facilitate a knockout, the chance of permanent damage to the brain is decreased because the looser neck muscles absorb impact over a longer period and over a wider area.

The strategy of rolling with punches should not to be confused with grogginess, in which the neck is flaccid. A fighter who becomes groggy is not alert enough to slowly decelerate the skull when hit and thus usually suffers the worst damage. The head accelerates quickly upon collision, and then sharply snaps back as the boxer falls down and crashes on the surface of the mat.

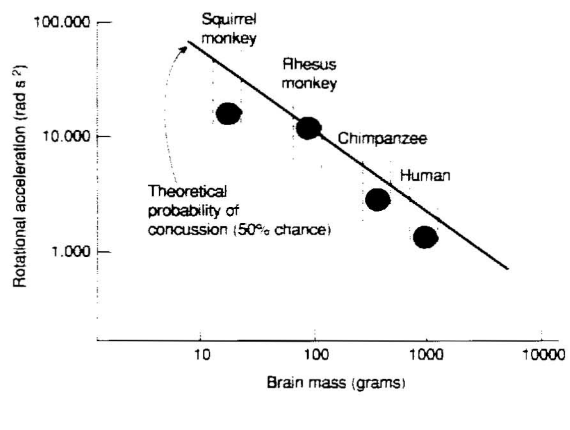

Figure 4. *The diagonal line represents the theoretical 50 percent probability of concussion. The greater a primate's brain mass, the more likely that it will suffer a concussive blow from rotational acceleration. From any rotational accelerating force, a human being, with the massive human brain, is twice as likely to suffer a concussion as a chimpanzee and more than 10 times as likely as a squirrel monkey. (Adapted from Ghista, 1982)*

Skating

AT THE 1994 WINTER OLYMPICS in Lillehammer, Norway, many spectators from abroad were surprised that the Norwegians seemed to have so little interest in figure skating, which is usually one of the most popular events. The Norwegians' lukewarm reception of figure skating was not a matter of failing to appreciate its pageantry, style, and grace; it was simply a consequence of their obsession with another type of skating: speed skating. In countries like Norway—and the Netherlands, to take another example—speed skating is the paramount winter sport. Fans are transfixed by the seemingly effortless yet impressively long and powerful glides of the top speed skaters. One reason why speed (and distance) skating has predominated in Scandinavia is that the setting is perfect: the climate is suitable, and there are numerous wetlands, canals, and lakes that are frozen for a good part of the year. Moreover, this kind of skating has traditionally been an integral part of the culture—for one thing, because frozen waterways could be used to visit friends and relatives who would otherwise have been difficult to reach in winter.

The origins of skating date to at least 1,000 B.C.E. Skating and skiing probably developed first in the Scandinavian countries, where people foraged for food by moving across ice and snow with pieces of wood strapped to their feet. Originally, skaters propelled themselves less with their legs and generated forward motion more by poling with a small staff or stick, much like skiers. The two sports diverged when these ancient peoples realized that skates—blades fashioned from polished bone—were superior for sliding over ice.

A revolutionary change in skating came during the ninth century, when the iron blade replaced polished bone. On the basis of archeological discoveries, some historians argue that this development marked a move beyond simple sliding to true skating. The squared-off, flattened bottom of the iron blade (as opposed to a knife-edge blade) allowed skaters to grip the ice with either edge of the runner and thus to move with less effort by increasing the amount of propulsive force generated in the sideward push-off. In addition, the flatter blade, which was also longer, extended the distance of the glide.

Initially, speed skaters used a blade similar in length to the blades used for hockey and figure skating, which are only slightly longer than the boot. Early speed skaters quickly learned, however, that speed could be vastly increased by using longer blades. A greater surface

Speed Skating for Fitness

Speed skating lends itself well to a lifelong program of exercise and conditioning. Gliding on near-frictionless ice makes the sport preferable to high-impact activities, such as jogging and running. Given that speed skating is also an aerobic exercise that burns many calories with low impact, it is an attractive option for those who want to exercise yet dislike running.

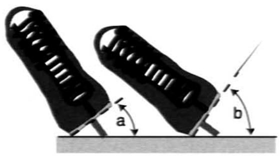

Figure 1. *As compared with the center-set blade (a), the offset speed-skating blade (b) allows the skater to lean farther inward before the edge of the boot scrapes the ice. Angle (b) is greater than angle (a). Speed skaters can use offset blades because they skate in only one direction around a track.*

length minimizes friction and increases the efficiency of the stroke: less effort is needed to restore the skater's momentum, that is, mass × velocity. (This gives rise to a natural question: If a long blade increases speed, why not use a blade as long as a ski? The answer is that there is a trade-off between speed and control. Blades are proportional to shoe size to enable the skater to maximize speed without losing control.)

As the longer iron blades came into use, competitions emerged for skaters to test the limits of speed. Some of the first races were held in the Netherlands in the sixteenth century. Local competitions were organized by the nobility, who offered prizes. Most of these early contests involved short distances, until the seventeenth and eighteenth centuries, when long-distance races grew in popularity.

Speed skating was firmly established in North America during the nineteenth century. Canada held its first speed-skating championship for men in 1887, and the United States followed a few years later.

The modern speed skating of the 1990s takes two forms: the traditional long-track, or metric, style; and the short-track, or pack, style. In the long-track style, competitors skate against the clock; in the short-track style, they compete against each other. The 111-meter (120-yd.) short-track events, which became a Winter Olympic sport in 1992, take place on a standard hockey rink. Because racers compete against one another, rather than against the clock, there is plenty of inadvertent contact among skaters as they aggressively approach turns. These tight turns require a greater inward, or centripetal, force to counter the natural tendency to move outward. Thus the skaters lean more and often wear reinforced skates. Since they skate in only one direction, most of them use offset blades, which allow them to lean even further inward (*see Figure 1*). Both long-track and short-track speed skating (even though the latter uses a hockey rink) are relatively inaccessible to the general public because facilities are limited; as a result, participation in these sports has also been limited.

Figure skating, on the other hand, has become very popular worldwide. The term *figure skating* was originally apt but is now something of a misnomer: the compulsory exercise of carving traced patterns ("figures") on the ice is now only part of any national or international competition. Free skating has become the most visible and emphasized aspect of competitions, and skaters may perform singly or in pairs. In the 1990s, freestyle figure skating and ice dancing are extremely popular spectator sports. Expanded television coverage of innovative professional competitions, designed to please the audience and unconfined by the rigid restrictions imposed on official events, has also played a major role in the sport's popularity.

Figure skating is of much more recent origin than speed skating. The person often considered the founder of this sport is Jackson Haines, a Chicagoan of the 1850s. Haines was an accomplished dancer who was able to transpose his art to ice; he was also an early innovator in skate design. He developed a "rockered," or curved, blade that was distanced from the boot and fixed to a toe and heel plate; this made changing directions smoother and more effortless (*see also the box "The Evolution of Figure Skates"*). In 1864, toward the end of the

Civil War. Haines took his workshop and technical innovations on a tour across North America and Europe, capturing the imagination of audiences and revolutionizing skating. He also mounted a touring show, with ornate costumes and a large variety of well-choreographed routines set to music. Haines's showmanship endeared him to many; and Vienna, then known as the city of music, was so impressed by his new art form that it named an ice rink after him.

After Haines, though, interest in figure skating gradually waned—until the swanlike Norwegian skater Sonja Henie arrived on the scene in the 1920s. Henie, a ballerina with the typical slight build (she was 5 ft. 2 in. tall and weighed only 79 lb.), incorporated many ballet movements into her routines. People packed into arenas from coast to coast to watch her, and she won ten consecutive women's world figure skating championships (1927–1936) and three Olympic gold medals (1928, 1932, and 1936) before turning professional in 1936. As a professional, she became by far the richest athlete, male or female, of her time.

The innovative, acrobatic routines of the early pioneers of figure skating were expanded on by later generations. Single and double acrobatic spins were replaced by triple and quadruple spins. In the 1990s, few exhibitions featured slow, measured movements; instead, skaters performed a series of high-speed movements, because speed makes even simple moves seem more daring and spectacular. There is considerable speculation about what direction figure skating will take in the future, and some observers predict that athleticism will come to dominate over the earlier emphasis on grace.

Endurance in Figure Skating

To finish a 4-minute skating routine strongly, figure skaters undergo intense conditioning and stamina training: a mixture of anaerobic and aerobic training much like that used by a middle-distance runner or a basketball player. Because figure skating incorporates artistry into every movement and is coordinated with music—and often involves a partner—it requires many years of practice, on and off the ice, for a skater to reach the Olympic and world-class level.

The Ice

This section will take up some significant aspects of the ice skater's medium: the ice itself.

Ice and Friction: A Mystery

As skaters glide across a frozen pond or rink, they experience the unique properties of ice that make near-frictionless movement possible. Friction is the force that resists the motion of an object in contact with another object: for example, as a box slides down a ramp, friction works against the force of gravity to slow the box's movement. The friction from contact between blade and ice in skating is best categorized as kinetic friction—an inhibition that results because two objects are sliding over each other.

As a skater slides over the ice, friction impedes progress. Two concepts are relevant here: (1) "reaction" force, which is the combination of vertical and horizontal forces applied to the skater from the ice; and (2) "normal" force, which is a component of the reaction force—the component that is perpendicular to the surface. Assuming no lean, reaction force and normal force would be the same: perpen-