CHAPTER

11 GOLF

The basic techniques of golf have probably been subject to more widespread examination than those of any other sport. One manifestation of this interest in the techniques of the game is the large number of instructional books and articles written on the subject by players, coaches, teachers, and others. Unfortunately, within this considerable volume of material there exist numerous areas of disagreement as to what constitutes the optimum technique for making each of the various shots. In addition, most of the arguments presented in favor of one technique over another are based upon nothing more secure than personal opinion and experience. The outstanding exception to this is a book by Cochran and Stobbs.[1] This book, the end product of a 6-year research project sponsored by the Golf Society of Great Britain (G.S.G.B.), examines objectively some of the basic techniques in the game of golf. It provides scientifically established answers to many of the questions about which there has been so much discussion and disagreement hitherto. Many of the results obtained in the G.S.G.B. project are referred to in this chapter.

BASIC CONSIDERATIONS

The objective in golf is to displace the ball from one position to another with the least number of shots possible. The initial position of the ball is on the tee, and the desired final position is within the hole some prescribed distance away.

The displacement of the ball is usually effected by a shot, or sequence of shots, in which the ball travels some distance through the air and then bounces and rolls a farther distance. With the exception of putting, the initial passage of the ball through the air (the carry) is generally responsible for a greater proportion of the displacement achieved than is the bouncing and rolling (the run) that follows. The contributions of the carry and the run in a series of typical drives are shown in Table 11-1. (The figures in this table have been obtained using equations derived by the G.S.G.B. research team.[2])

The Carry

For any given case, the length of carry obtained depends on (1) the speed and (2) the direction at which the ball leaves the face of the club; (3) the height of the ball at that instant; and (4) the air resistance that it encounters in flight.

Speed of Release. The speed of a body immediately following an elastic impact is governed by the masses and initial velocities of the bodies involved in the impact and by their mutual coefficient of restitution (pp. 80–95). In the case of a golf ball struck by a club, three of these five factors are either fixed by the rules or are subject to such little variation that they may safely be regarded as constant. These are the mass of the ball (4.4 g); the initial velocity of the ball (0 m/s); and the coefficient of restitution which, although it varies for differing speeds of impact, is primarily a function of the materials of which the clubhead and ball are constructed.

Variations in the mass of the clubhead, the second body involved in the impact, effect the ease with which the club can be swung and thus the speed of the clubhead at impact—increasing the mass of the clubhead reduces its impact speed, while decreasing the mass increases its impact speed. A

TABLE 11-1 The Relative Contributions of the Carry and the Run to the Total Length of a Drive

Total Length of Drive (m)	*Carry (m)*	*Percentage of Total Length*	*Run (m)*	*Percentage of Total Length*
160	127	80	33	20
180	151	84	29	16
200	175	88	25	12
220	199	91	21	9
240	223	93	17	7
260	247	95	13	5
280	271	97	9	3

Note: (1) These results are for "squarely struck *drives*" with a British 4.1-cm diameter ball. Differences between these figures and the equivalent figures for an American 4.3-cm diameter ball are almost certainly negligible. (2) The computation of the total length of drive assumes "some sort of average ground conditions."

change in impact speed tends to have a corresponding effect on the speed of the ball at release. Thus, for example, increasing clubhead mass decreases the impact speed and tends to decrease the speed of the ball at release. However, if there were no difference in impact speed, an increase in clubhead mass would tend to increase the speed of the ball at release. With an increase in clubhead mass tending therefore to both decrease and increase the speed of the ball, it is of some importance to establish which of these two tendencies dominates.

The effects that changes in the mass of the clubhead have on the initial velocity of the ball, and thus on the length of a shot, have been reported by Daish.[3,4] Following an analysis in which four golfers of "varying ages . . . and a fair range of golfing ability" swung a club whose weight was varied from 1.0 N to 3.4 N, Daish concluded that "varying the mass of the clubhead over the wide range from 5 to 11 oz [1.4 N to 3.1 N] has little or no significant effect on the initial velocity imparted to the ball" and "should produce no difference of any consequence in the length of shot obtained." In short, it appears that these two contrary tendencies effectively cancel each other and the speed of the ball at release is unaltered.

While it might well be thought that the "body" interacting with the ball during impact is a combined unit of club-plus-golfer-plus-earth, experiments have shown that this is not the case. In fact, at impact the clubhead behaves essentially as if it were not directly connected to the golfer. The truth of this has been dramatically demonstrated by the G.S.G.B. research team,[5] who found that the length of drives hit with a No. 2 wood with a freely moving hinge between the clubhead and the clubshaft varied little from those hit with a normal club—30 drives with each club yielded averages of 197 and 201 m, respectively. Even then, it was considered likely that this small difference was probably due to factors other than those operating at impact.

Because each of the factors so far considered has been shown to allow little effective variation, it is apparent that observed differences in the speed at which the ball leaves the club must be mainly due to differences in the one remaining factor—the speed of the clubhead at impact. Now, because the clubhead is momentarily at rest at the peak of the backswing, its speed at the instant of impact must be determined by the forces exerted on the club during the downswing and the times over which these forces act (impulse-momentum relationship). Of these forces (gravity, air resistance, and the muscular forces applied to the grip), it is clearly the last that is capable of the widest variation. Differences in the speed at which the ball leaves the club are therefore more likely to be due to differences in the muscular forces applied to the grip than to differences in any other single factor.

Direction of Release. The direction in which the ball is moving at release must be considered in terms of both the angle that the vector representing the velocity of the ball makes with the horizontal (the angle of release) and the angle it makes with the intended line of the shot. These angles are measured in vertical and horizontal planes, respectively.

The angle of release is governed primarily by the inclination of the clubface (that is, its loft). Consider the velocity of the clubhead immediately before impact to be resolved into two components—one acting perpendicular (or normal) to the clubface and the other acting parallel with the clubface (Fig. 11-1[a]). At impact the natural tendency of the clubhead to keep moving as it was an instant earlier (Newton's first law) results in the ball experiencing forces in the same direction as these components (Fig. 11-1[b]). The normal force causes the ball to be accelerated in that direction. The end product of this acceleration (the normal component of the velocity of the ball as it leaves the club) is influenced by the elasticity of both bodies—the less the elasticity, the less the magnitude of this component. The effect of the force along the clubface is governed by the limiting friction between the surfaces in contact—those of the clubface and the ball. If the force exerted exceeds that of the limiting friction, some slippage occurs and the component velocity of the ball in this direction following impact is reduced. In fact, if the surfaces were perfectly smooth, the release velocity of the ball would have a zero component along the clubface and the ball would fly off in a direction perpendicular to this surface. However, because the surfaces of the clubface and the ball are both "rough," this situation is unlikely to apply in practice. Instead, the ball is generally acted upon by a friction force that not only causes it to be released in a direction slightly below the perpendicular to the clubface, but also causes it to acquire a certain amount of backspin.

With respect to motion in the horizontal plane—strictly, a horizontal plane upon which the path of the ball is considered to be projected—the success of any given shot depends on bringing the clubhead to meet the ball so that the horizontal directions in which the clubhead is moving and the

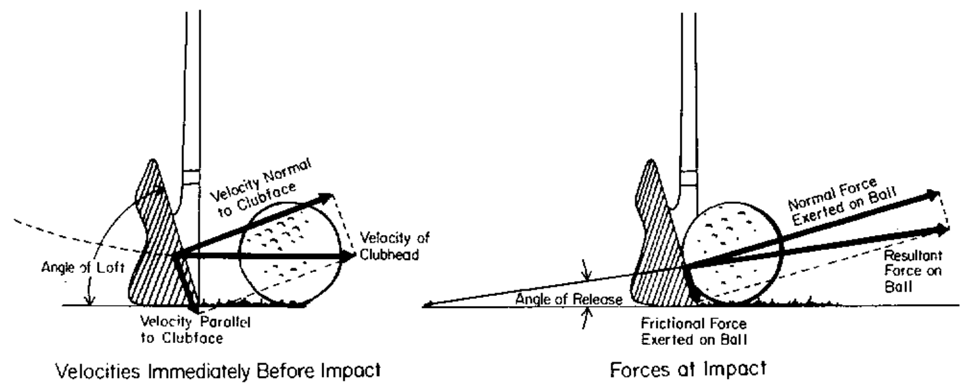

Figure 11-1. (a) Components of clubhead velocity immediately before impact. (b) Components of the force exerted on the ball at impact.

clubface is "pointing" both coincide with the direction in which it is intended the ball should go (Fig. 11-2[a]). Failure to achieve this consistency in directions causes the path of the ball to deviate laterally from that intended (Fig. 11-2[b]).

Height of Release. While the height of the ball at release, relative to the height of the point at which it will land, is a significant factor in determining the length of the carry, it is one over which the golfer has very limited control.

Air Resistance. A golf ball in flight is subject to forces exerted upon it by the air through which it passes. These forces may be regarded as the summed effects of a resistance to the linear motion of the ball through the air (drag) and a resistance to the angular motion of the ball as it spins about an axis through its center of gravity. Of these two it is only the latter over which the golfer could be said to exert any real measure of control.

The resistance to the angular motion of the ball serves to modify the drag and also causes the ball to deviate vertically and/or laterally from the path it would otherwise travel. There are basically four types of angular motion that may be imparted to a ball—topspin, backspin, "slicing" sidespin, and "hooking" sidespin.

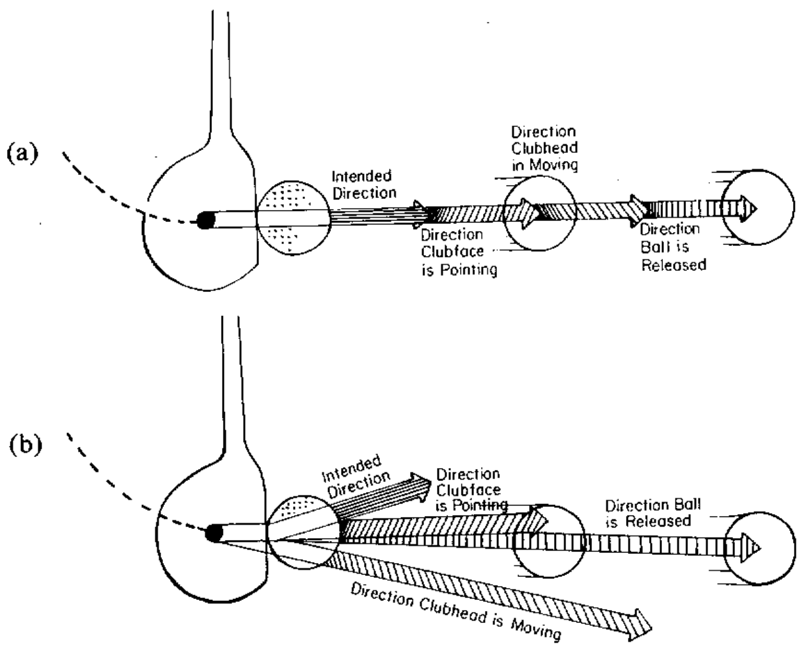

Figure 11-2. (a) To obtain the intended direction of release, the directions in which the clubhead is moving and "pointing" must both coincide with that intended direction. (b) Failure to obtain the required coincidence of the three directions results in the ball deviating laterally from the desired direction.

Topspin, which markedly reduces the lift component and therewith the time of flight and the distance of the carry, is normally applied only in error. This most frequently occurs when the ball is "topped" (that is, the clubhead hits only the top part of the ball).

Backspin, on the other hand, is directly attributable to the "down-the-clubface" (or frictional) component of force that a lofted club normally applies to the ball. As already indicated (p. 194), this backspin provides the lift that the ball experiences and thereby lengthens the time it is in the air and the distance it carries. The magnitude of the lift obtained is closely related to the speed at which the ball rotates. In an experiment in which the effects of air resistance were measured by dropping a ball into the moving airstream within a wind tunnel (see relative motion, pp. 183–184), Davies[6] found that at an airspeed equivalent to what might normally be obtained with a high-iron shot the lift varied from 0 N (no spin) to 0.24 N (at 8000 rpm). Thus, at this latter rate of rotation (again, roughly that to be expected from a high-iron shot) the lift force was more than half the weight of the ball (0.45 N).

It is perhaps of interest to note that the shape of the grooves on the clubface has an influence on the amount of backspin applied to the ball. Neal and Hubinger[7] analyzed 160 shots by a low-handicap golfer, half hit with a 5-iron with U-shaped grooves and half with a 5-iron with V-shaped grooves. The mean angular velocity of the ball as it left the club was 107.9 rev/s (in the first case) and 73.6 rev/s (in the second).

Sidespin generally results from bringing the clubface across the intended line of the shot, during the period in which it is in contact with the ball. If the clubface moves across the intended direction line and toward the golfer (a movement known as bringing it from "outside-in"), a "slicing sidespin" is imparted to the ball. For a right-handed golfer this type of sidespin causes the ball to curve to the right of the intended line. A "hooking sidespin" is produced when the clubface is moved across the intended direction line in the opposite direction (that is, from "inside-out") and for a right-handed golfer causes the ball to curve to the left during its flight.

The Run

Of all those factors that have a part in determining what happens once the ball hits the ground, the only one that is capable of much variation and is not essentially fixed by the initial impact between club and ball is the coefficient of restitution. If the coefficient of restitution is zero (that is, the impact is an inelastic one), the ball simply imbeds itself in the ground at the point at which it lands. However, if the coefficient of restitution is greater than zero, as is normally the case, the ball bounces following impact with the ground. In such instances, the distance covered during the bounce (and during each successive bounce) depends very largely on the magnitude of the coefficient. For example, if the ground is hard and the coefficient is therefore high, the ball is likely to cover greater distances with each bounce and to bounce more often than it would if the ground were soft. (According to Diaz,[8] the record for the longest drive stands at 632 yd [578 m]. This drive was made by an Irish professional golfer [Liam Higgins] during a long-driving contest held at Casement Aerodrome in Baldonnel, Ireland—a site chosen expressly for the purpose of ensuring high coefficients of restitution and long runs.)

After a number of bounces, the vertical velocity with which the ball strikes the ground decreases to the point where the ground-reaction force is insufficient to carry it once more into the air. At this point the ball begins to roll, the distance it rolls being governed by its horizontal velocity at the time and by the forces (for example, gravity and rolling friction) that subsequently act upon it.

The relationships between the displacement that a golf ball experiences and the factors that determine that displacement are summarized in Fig. 11-3.

Putting

In putting, the golfer has three distinct tasks to perform:

- Determine the direction to hit the ball in order to have it fall into the hole. If a straight line joining the ball and the hole runs directly uphill or downhill or goes across a part of the green that is smooth and flat,

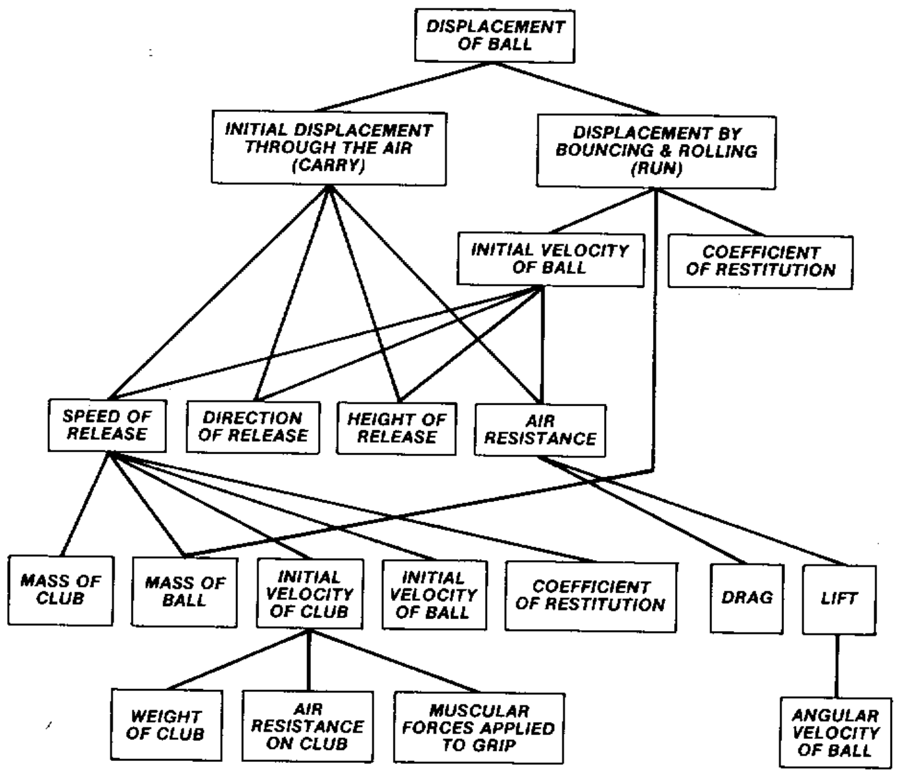

Figure 11-3. Basic factors in a golf drive.

choosing the best direction to hit the ball is a simple matter—it should be hit directly along this line. More common, though, are cases in which the surface between ball and hole slopes to one side or perhaps slopes in different directions at different points. In such instances, the golfer must take heed of the effect that gravity will have on the path the ball will take. For example, if the green slopes down to the right of the straight line between the ball and the hole, and the golfer directs the ball along this line, that component of the ball's weight that acts downhill will accelerate it in that direction. As a result, the ball will follow a curved path below the direct line between ball and hole and, unless the distance of the putt is very short or the slope of the green very small, this downward deviation will cause the ball to pass some distance below the hole. An experienced golfer therefore chooses to direct the putt above the line between ball and hole, knowing that gravity will tend to bring it down and around toward the hole.
- Determine how hard the ball must be hit to impart to it the speed necessary for it to cover the required distance. In this assessing of the "strength" of the putt, the experienced golfer takes particular note of the distance of the putt; the extent to which it is an uphill or downhill shot; whether the green is soft or hard, or dry or wet; and the length of the grass and the direction in which it lies.
- Finally, having thus determined the velocity that he (or she) intends to impart to the ball, the golfer's task is to execute the putting stroke in a manner consistent with this intention. Basically, this means that the golfer must have the face of the putter at right angles to the chosen line throughout the short period of impact and moving at a speed that will result in the desired speed being imparted to the ball.

TECHNIQUES

Grip

There are three principal methods of gripping the club for driving strokes—the overlapping (or Vardon) grip, the interlocking grip, and the baseball (or two-handed) grip. With respect to the relative merits of these three, the results of an experiment by Walker[9] are of interest. After comparing the performances of 24 male golfers who used each of the three grips in turn, Walker found that no one of the grips was statistically superior to either of the others, in terms of greater distance or accuracy.

Stance

The placement of the feet relative to one another and relative to the intended direction of the shot are of some importance in determining the velocity with which the clubhead meets the ball.

If the feet are placed together, the narrowness of the base inevitably makes the golfer conscious of the need to maintain balance and thus precludes a maximum contribution of force from the muscles of the legs and hips. A stance with the feet wide apart also hampers the production of force by these muscles. Logically, therefore, most skilled players use a spread of their feet somewhere intermediate between these two extremes—slightly more than shoulder width apart for shots requiring maximum or near-maximum effort, and closer together for shorter shots requiring only a limited contribution from the legs and hips.

The placement of the feet relative to the intended direction of the shot (as in baseball, the terms *open, square*, and *closed* are used to describe the basic variations) also depends to some extent on the length of shot required. For shots requiring maximum or near-maximum effort, there appears to be very little evidence to suggest that one option is superior to any other. However, for those shots (and particularly short pitches, etc.) where accuracy rather than maximum distance is the prime consideration, a somewhat open stance tends to restrict the range of the backswing, thereby decreasing the scope for errors in the execution of the swing, without preventing the required force from being obtained.

The Swing*

The swing, that succession of movements that culminates in the clubhead striking the ball, may be regarded as the central element about which the whole game of golf is built.

Although all actions of the golfer's body and the club from the first movement following the address (the position adopted by the player before beginning the swing) must be coordinated into one smooth sequence, it is convenient for the purposes of analysis to consider the full swing as consisting of four major parts—*backswing (or upswing), downswing, impact*, and *follow-through*.

In both backswing and downswing the motion is essentially rotary and for simplicity may be considered in terms of two levers rotated about their respective axes. These levers are the club itself, rotating about an axis passing through the golfer's hands, and a combined shoulders-arms-hands lever, rotating about an axis inclined to the horizontal and passing through the golfer's chest (Fig. 11-4).

Backswing. The purpose of the backswing is to put the golfer and the club into the optimum position from which to start the downswing.

The backswing begins with a simultaneous backward movement of the clubhead and the hands and a rotation of the trunk to the right. These first movements are sometimes preceded by a "pressing" or "cocking" action in which the golfer gently pushes the right knee in toward the left one and then, as the knee returns to its original position, begins the withdrawal of hands and club. This movement (evident in the results of Carlsöö's study[10] of forces and muscular actions in the golf swing, and occasionally referred to by golf writers[11 12 13]) may serve to help the golfer initiate the backswing

* In the analysis of the swing that follows, it is assumed that the golfer is right-handed and executing a drive for maximum distance. The terms *forward* and *backward* are used with reference to the direction in which the golfer intends to hit the ball: *forward* is in that direction, and *backward* is the opposite direction.

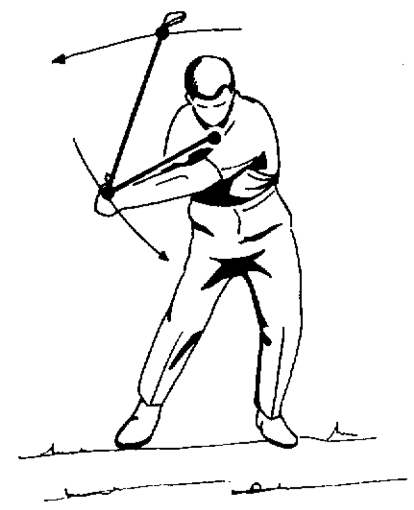

Figure 11-4.
The golf swing may be analyzed in terms of a shoulder-arms-hands lever rotating about an axis through the upper chest and a club lever rotating about an axis through the hands.

in a systematic and relaxed manner, but apart from this would appear to have no particular merit, for it merely adds to an already wide range of possible sources of error.

As the combined backward movement of the hands and club and the rotation of the trunk continue, the left arm is raised and swung across the trunk, the wrists are cocked (or bent sideways toward the thumbs), and the left forearm is rolled so that the back of the left hand lies in an approximately vertical plane.

The end of the backswing is reached with the hands at or slightly above head height, the trunk rotated approximately 90° from its original position, and the wrists cocked so that the club shaft lies over and behind the head at some 45° above the horizontal.

According to Williams,[14] an objective examination of the paths followed by the hands and the clubhead during the upswings of top-class players reveals that the path of the hands varies hardly at all from player to player while the path of the clubhead varies considerably. He therefore concluded "that the path followed by the clubhead in the upswing has little significance and is a matter of personal preference."

Carlsöö[15] also reached some interesting conclusions regarding the backswing. He concluded, for example, that the backswing could be divided into two consecutive parts—an accelerating movement backward and upward lasting about 0.3 s and a retarding or braking movement lasting until the top of the swing about 0.35 s later. This retardation was characterized by a change in the direction of the horizontal couple that the feet exerted against the ground and by marked changes in muscular activity; the activity of those muscles that had initiated the backswing diminished and that of their antagonists (that is, those muscles that perform the opposite function) increased. Furthermore, the muscles that produced this retarding or braking effect on the backswing continued to be active in the downswing during which they acted as "very essential movement-promoting muscles."

Downswing. The objective of the downswing is to have the clubhead arrive at the point of impact moving at maximum speed in the required direction and with the face of the club "pointing" in that same direction.

The downswing begins with a forward movement of the hips that, with good golfers, actually begins approximately 0.1 s before the clubhead reaches the limit of its backswing.[16] This moving forward of the hips rotates the whole upper body (Fig. 11-5) and moves both levers through the first part of the downswing. The forces responsible for this forward movement of the hips and the lesser forces exerted by the same hip and leg muscles later in the downswing have been estimated to account for 2½ hp (1864 W) of the total 3-4 hp (2337–2983 W) generated in a good drive. Thus it can readily be seen that "the muscles of the hips and legs constitute the main source of power in long driving."[17]

The positions of the shoulders, arms, hands, and club relative to one another are unchanged as the hips are driven forward. Then, when the left arm reaches an approximately horizontal position, this first stage (the "one-piece stage" as Williams[18] calls it) comes to an end and the included angle between clubshaft and left arm, previously about 70°–80°, becomes progressively larger. From this point onward, the hands continue to move along their circular arc at a fairly constant speed while the clubhead's speed increases dramatically as the angle between the left arm and the clubshaft straightens out.

These relationships are summarized in Fig. 11-6. In this figure, ø is the angle between the shoulders-arms-hands lever and a downward vertical

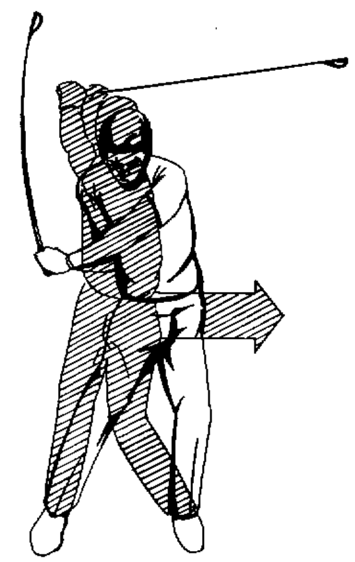

Figure 11-5.
A forward movement of the hips initiates the downswing.

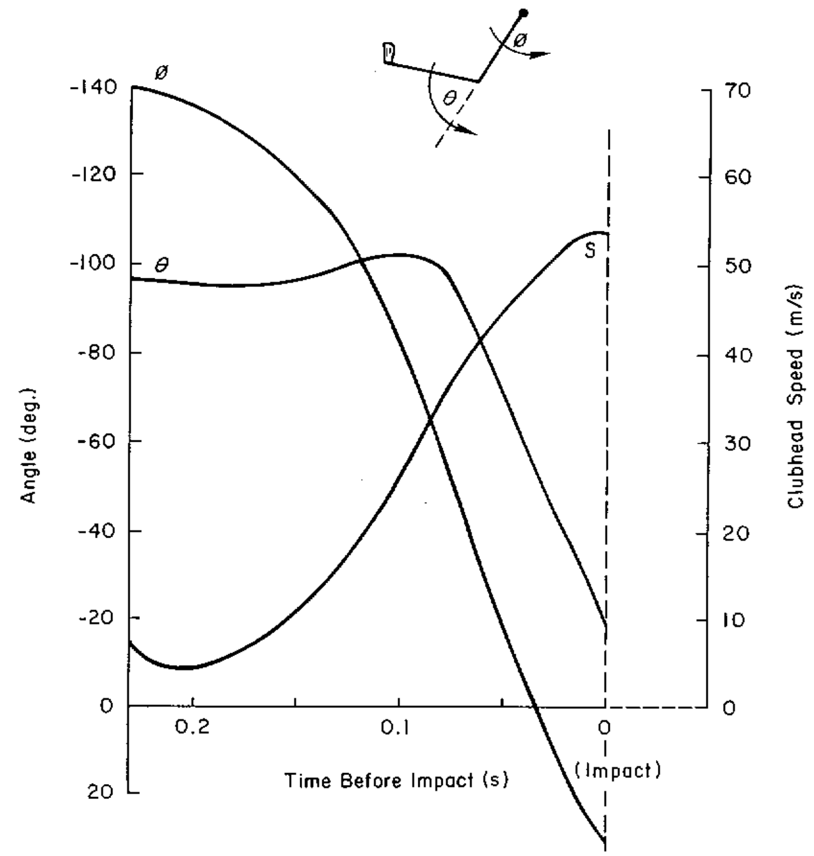

Figure 11-6. Changes in position and speed during a golf drive. (Adapted from Budney, D. R., and Bellow, D. G. [1979]. Kinetic analysis of a golf swing. *Research Quarterly*, 50:171–79.)

through the axis about which it rotates, θ is angle between the line of this lever and the shaft of the club, and S is the speed of the clubhead. (*Note:* The data on which this figure is based[19] were gathered on a professional golfer who exerted a "wrist-cocking" torque just before impact and thus slightly reduced his clubhead speed at impact).

To understand what happens during this second stage of the downswing, it is necessary to consider the forces that the golfer's hands apply to the grip of the club (Fig. 11-7). The resultant of these forces may be resolved into two components:

1. A *radial component* (or centripetal force) acting toward the axis about which the shoulders-arms-hands lever rotates. This component serves to constrain the motion of the handgrip of the club to a circular arc and, because its line of action does not pass through the center of gravity of the club, also tends to cause the club to be

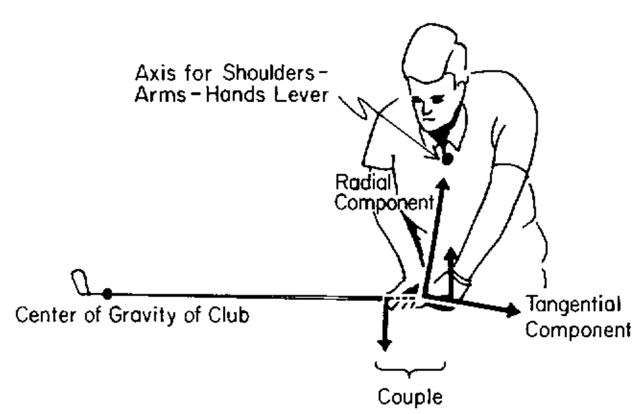

Figure 11-7.
The forces applied to the handgrip of the club, considered relative to the axis through the chest.

rotated (or, more precisely, to be angularly accelerated) relative to an axis through this point. The direction of this rotation is consistent with an "uncocking" of the wrists or, to put it another way, with a decrease in the angle formed by the lines of the club shaft and the left arm.

2. A *tangential component* acting, as the name suggests, in a direction tangential to the path followed by the handgrip of the club. This component serves to accelerate the handgrip, and the club as a whole, in the direction in which it acts. When its line of action does not pass through the center of gravity of the club, this component also tends to angularly accelerate the club in a direction opposite to that of the radial component. The net effect of these two components is to accelerate the club along a circular path and to cause it to rotate relative to an axis through its center of gravity. The direction of this rotation is governed by how the opposing tendencies of the two components compare.

In addition to the resultant force that the hands exert on the grip, there exists the possibility that the combined actions of the hands also result in a couple being applied to the grip. For, if the right hand is pressed down forcefully against a resistance of equal magnitude provided by the left hand, a couple that tends to uncock the wrists comes into existence. The question of whether such a couple exists is a source of some disagreement in the literature. Following an analysis of the swing of Bobby Jones, Williams[20] concluded emphatically that "The mathematics . . . proves beyond any argument that hand (or wrist-uncocking) leverage has nothing to do with accelerating the clubhead in what is usually referred to as the 'hitting area'." This view is supported by Milburn[21] who, after analyzing the drives of four "right-handed collegiate-level golfers and one right-handed low-handicap golfer from the community," concluded that the left wrist behaved as a "free hinge" during the latter stages of the downswing.

Cochran and Stobbs,[22] on the other hand, profess the more widely held view. Without presenting any evidence in support of their contention—their book is intended for the lay reader and therefore does not include all the detailed scientific evidence upon which it is based—they state that "The obvious way to add speed to the clubhead is by applying some effort at the hinge [the hands]. . . . To do this, the right arm has simply . . . to *push:* that is to try to straighten out at the elbow."

Until this question is satisfactorily resolved, any analysis of the second stage of the downswing should probably consider both possibilities. If the golfer does not apply a couple that contributes to the uncocking action of the wrists, this action must result solely because the torque due to the radial component exceeds that due to the tangential component. Alternatively, if a couple is applied via the hands, this couple, together with the radial component of the resultant force, must produce the characteristic "uncocking" action despite the contrary tendency of the tangential component.

The "uncocking" of the wrists during the second part of the downswing is often attributed to a centrifugal force acting on the clubhead to pull it outward, away from the axis about which it is rotating. While this explanation might have some superficial appeal, it is inconsistent with the facts of the matter, as a consideration of the forces acting on the club reveals.

Apart from gravity and air resistance (both of which can be instantly dismissed as having no direct bearing on the question), the only external forces acting on the club are those applied at the grip. Now, for the purposes of examining this particular question, consider the resultant of these forces to be resolved into a radial (or centripetal) component that acts *inward* along the line of the clubshaft and *toward the axis through the hands,* and a tangential component acting perpendicular to the line of the clubshaft. (*Note:* These are not the same radial and tangential components referred to earlier, *relative to the axis through the golfers chest*—compare Fig. 11-7 and 11-8). The reaction to the centripetal force exerted by the hands *on the club* is a centrifugal force that the club exerts on the hands. Thus, since the only centrifugal force involved, in the rotation of the club about an axis through the hands, acts not on the club but on the hands, it cannot possibly be responsible for pulling the clubhead outward.

As the downswing is executed, the right elbow is brought down and close to the right side of the body, in the process transmitting to the grip the force produced by the contraction of muscles on the right side of the body. During the final few centimeters that the hands travel in the downswing, the wrists are "rolled" through approximately 90° so that the back of the left hand and the clubface (until this time in a near-vertical plane parallel to the intended direction of the shot) are brought around perpendicular to that direction.

Impact. The critical features of the swing at the instant of impact are the orientation of the clubface, the position of the clubhead, and the velocity at which it is moving. Theoretically—provided the clubface is at right angles to the required direction, the center of gravity of the clubhead is directly behind the center of the ball, and the clubhead is moving forward with the maximum speed possible, under the circumstances—the position of the

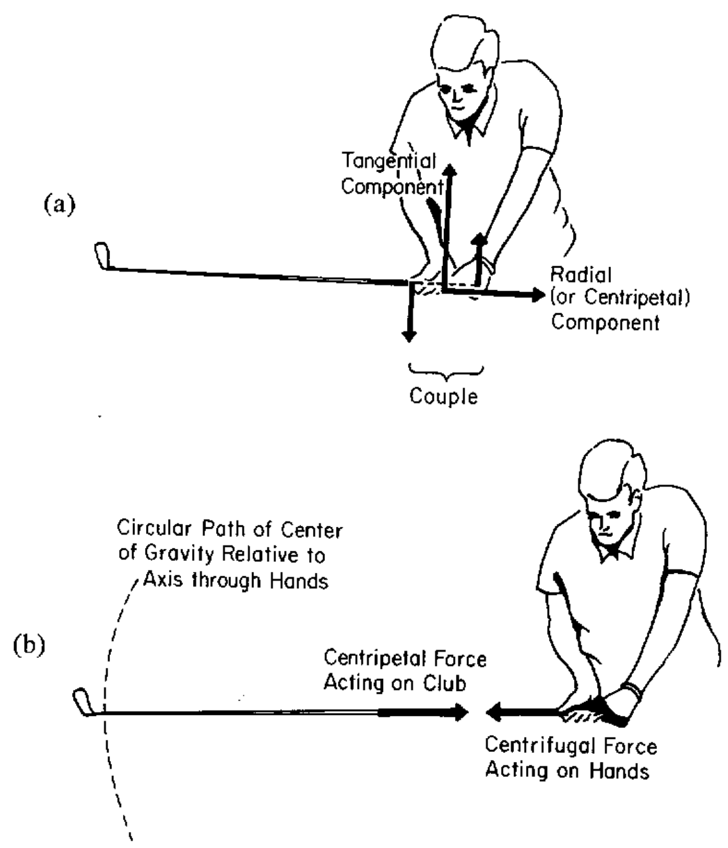

Figure 11-8.
Forces applied to the handgrip of the club, considered relative to the axis through the hands.

golfer is of little consequence. Experience suggests, however, that the need to satisfy these three conditions allows only minor variations in the position of the golfer at impact and that the optimum position has the following characteristics (Fig. 11-9).

- The clubhead is level with or just behind the hands. (Computer studies and observations of good golfers, referred to by Cochran and Stobbs,[23] suggest that the clubhead is moving fastest at, or possibly just before, the point where it catches up with the hands.)
- The back of the left wrist and hand is in a vertical (or near-vertical) plane perpendicular to the intended direction of the shot.
- The golfer's center of gravity is forward of a midline between the feet, thus placing a greater proportion of the body weight on the left foot than on the right one. In his study of a Swedish champion, Carlsöö[24] found that at impact the left foot transmitted a vertical force of 726 N to the ground, while the corresponding figure for the right foot, 235 N, was less than one-third of this. (*Note:* While some of this vertical force resulted from the actions taking place at impact—the golfer himself weighed only 823 N—it is clear that by far the greater proportion of the golfer's weight was supported on his left foot.)
- The axis of the shoulders-arms-hands lever, passing through the golfer's chest, is in the same position it has been in throughout the downswing. The golfer brings this about by inclining the trunk, the lower end of which has been driven forward earlier by leg and hip action, slightly backward and by inclining the head forward with the eyes firmly focused on the ball. This latter serves to ensure that the axis is not lifted and thus tends to eliminate any risk of the ball being "topped."

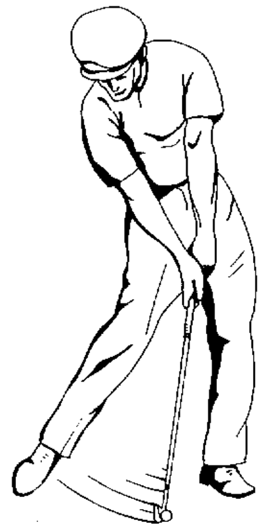

Figure 11-9.
The position at impact.

Follow-through. The follow-through, which serves the same purposes as it does in other similar activities, consists of a gradual slowing down of the body and club movements that led up to the moment of impact.

Putting

Unlike driving, in which the need for maximum clubhead speed at impact largely determines the body actions that can be successfully employed, success in putting can be achieved using a wide variety of techniques (Fig. 11-10). For, aside from the obvious need to meet each of the three requirements mentioned earlier (pp. 282–283), present knowledge of putting techniques sheds very little light on what methods are most suitable. The truth of this statement was well borne out by the results of a cinematographical analysis of 16 "first-class" professionals in which it was found that "The only features where the professionals showed a measure of constancy were the ball position and the head position. Most of them had the ball placed opposite the left foot and their eyes almost directly above the ball."[25]

A study by Mann, Griffin, and Rodger has subsequently confirmed the first of these findings and raised doubt about the second. They found that

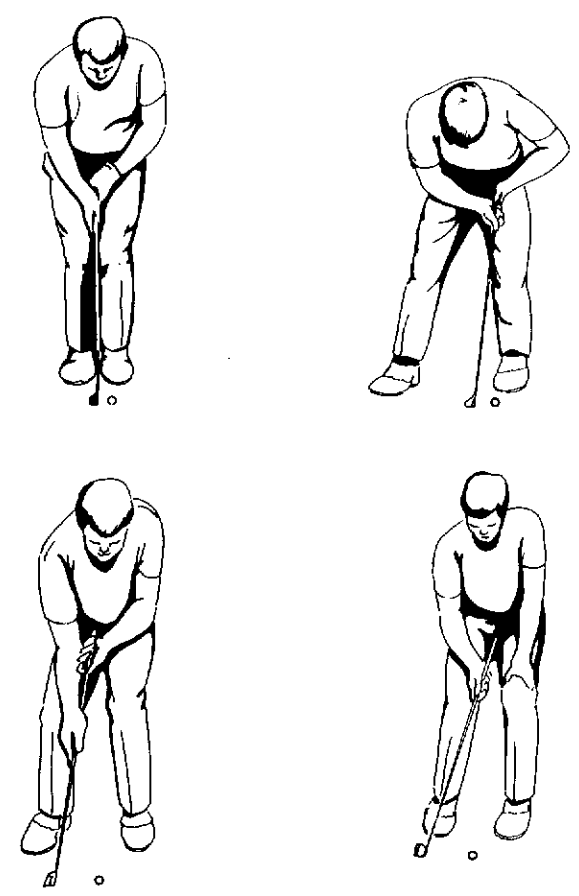

Figure 11-10.
Success in putting has been achieved using a wide variety of techniques.

the ball was consistently "played off the left heel"[26] and that "not one of the elite putters investigated positioned the eyes over the ball".[27]

They also found[28] that the 19 touring professionals, who were the subjects of their study, placed the left foot in virtually the same position, relative to the ball and the intended direction line, irrespective of the length of the putt. In this position, the ball was located "off the left heel" with both feet turned slightly towards the target. The position of the right foot was similar for all subjects but not as consistent as the left foot—a finding that Mann and his colleagues attributed to differences in physiques.

The time from the beginning of the backswing to contact with the ball (the completion time) ranged from 0.65 s (Paul Azinger) to 1.27 s (Don Pooley). For each subject, the completion time was virtually the same regardless of the length of the putt—from 4 ft (1.2 m) to 32 ft (9.8 m). This consistency in the completion times is illustrated in Table 11-2, which shows the results for Greg Norman (Australia) and Tom Kite (U.S.A.), two of the subjects. On the basis of these findings, Mann and his colleagues concluded that a near-constant completion time was a critical feature of a successful putting technique.

TABLE 11-2 Putting Times for Different Lengths of Putt

Length of Putt (m)	*Backswing (s)*	*Downswing (s)*	*Completion Time (s)*	*Follow-through Time (s)*
Greg Norman (Australia)				
1.2	0.62	0.30	0.92	0.70
2.4	0.63	0.29	0.92	0.75
4.9	0.63	0.30	0.93	0.74
9.8	0.63	0.30	0.93	0.73
Average	0.63	0.30	0.93	0.73
Tom Kite (U.S.A.)				
1.2	0.62	0.29	0.91	0.53
2.4	0.62	0.28	0.90	0.52
4.9	0.65	0.27	0.92	0.49
9.8	0.62	0.29	0.91	0.49
Average	0.63	0.28	0.91	0.51

Adapted from Mann, R., Griffin, F., and Rodger, P. (1991). Putting. *Golf Illustrated,* 7:43–46.

The average backswing distances increased from 17 cm (for a 1.2-m putt) to 39 cm (for a 9.8-m putt) and the average follow-through distances (that is, the distances traveled by the clubhead after impact with the ball) from 26 cm (for a 1.2-m putt) to 60 cm (for a 9.8-m putt). For each putting distance, the length of the average follow-through was thus about one and one-half times the length of the backswing.

With differing backswing times for different lengths of putt and near-constant completion times, the speed with which the clubhead was moved obviously varied accordingly. In short, the speed of both backswing and downswing increased as the length of the putt increased.

Cochran and Stobbs[29] also reported the results of a number of valuable experiments on putting. Among their many findings were the following:

- For all practical purposes it is impossible with a normal putter to put any useful spin on the ball.
- If the ball is hit off-center, the clubhead tends to rotate and the length and direction of the putt are affected. For example, an otherwise 20-ft (6.10-m) putt stops 4–6 ft (1.22–1.83 m) short and about 7 in (18 cm) to one side if it is hit 1 in. (2.5 cm) off-center. (If the reaction that the ball exerts on the club at impact does not pass through the center of gravity of the clubhead, it will tend to rotate the clubhead relative to an axis through the point—see eccentric force, p. 111–112. In this event the direction in which the ball is hit deviates laterally from that in which it would otherwise have moved. And, because the part of the clubface with which the ball is in contact is moving at a lesser speed than it would have been if the impact had not been off-center, the speed imparted to the ball is also reduced.)
- Distances lost and lateral deviations from the desired direction due to the balls being hit off-center could be reduced if some of the weight

of the clubhead could be shifted to the heel and some to the toe, still leaving the center of gravity in the middle. (An eccentric force exerted by the ball at impact causes the clubhead to be angularly accelerated. For any given case, the magnitude of this angular acceleration, and consequently the effect produced on the ball's subsequent motion, is inversely proportional to the moment of inertia of the clubhead—see angular analogue of Newton's second law, pp. 000-000. Thus, since the suggested redistribution of the weight of the clubhead increases its moment of inertia, the effects of an off-center hit will be less marked with such a putter than with one in which the weight is not so distributed.)

- The direction in which the ball sets off is governed more by where the face of the putter is pointing than by the direction in which the head of the putter is moving. Having the blade "square" at impact is therefore the most important single point to concentrate on in holing out.
- Random irregularities in the green ensure that putts hit in precisely the same manner will not necessarily yield the same results. An experiment designed to determine the importance of such irregularities on success in putting revealed that 2 percent of the missed putts from 6 ft (1.83 m), 50 percent of those from 20 ft (6.10 m), and 80 percent of those from 60 ft (18.29 m) could be attributed solely to this factor.
  (Incidentally, Diaz[30] has reported that the success rates of touring professional golfers is not as high as commonly supposed. Following a study in which data were gathered at 15 tournaments on the PGA tour—and in which at least 118 putts were hit at each 1 ft [0.3 m] interval from 2 ft [0.6 m] to 25 ft [7.6 m] from the hole—it was reported that the subjects made 83.1 percent of their putts from 3 ft [0.9 m], 54.8 percent from 6 ft [1.8 m], 33.5 percent from 10 ft [3 m], 16.8 percent from 15 ft [4.6 m] and 10.2 percent from 25 ft [7.6 m].)
- Comparison of the performances of professionals using blade, center-shafted, and mallet-style putters during tournament play revealed that no one type was significantly better than another.
- A scratch golfer would save something like six shots per round if the regulation diameter of the hole 4½ in. (11.43 cm) were doubled.

Recommended Readings

Chase, A. (1984). In W. Schrier and W. F. Allman (Eds.), *Newton at the Bat: The Science in Sports*. New York: Scribner's, pp. 29–32 (A slice of golf).

Cochran, A., and Stobbs, J. (1968). *The Search for the Perfect Swing*. London: Morrison & Gibb Ltd.

Notes

1. Cochran, A. C., and Stobbs, J. (1968). *The Search for the Perfect Swing*. London: Heinemann Educational Books.
2. Ibid., p. 229.
3. Daish, C. B. (1965). The influence of clubhead mass on the effectiveness of a golf club. *Institute of Physics and the Physical Society, Bulletin 16*, September, pp. 347–49.
4. Daish, C. B. (1972). *The Physics of Ball Games* (pp. 14–15, 102–9). London: The English Universities Press Ltd.
5. Cochran and Stobbs. *The Search for the Perfect Swing* (pp. 145–47).
6. Davies, J. M. (1949). The aerodynamics of golf balls. *Journal of Applied Physics*, 20:821–28.

7. Neal, R. J., and Hubinger, L. M. (1989). The effect of club-face groove on spin of a golf ball. In R. J. Gregor, R. F. Zernicke, and W. C. Whiting (Eds.), *Congress Proceedings: XII International Congress of Biomechanics* (No. 303). Los Angeles: University of California.
8. Diza, J. (1985). Set for takeoff? Well uh . . . *Sports Illustrated*, 62, January 14, pp. 86–87.
9. Walker, A. (1964). The relationship of distance and accuracy to three golf grips. M.S. thesis, Springfield College.
10. Carlsöö, S. (1967). A kinetic analysis of the golf swing. *The Journal of Sports Medicine and Physical Fitness*, 7:80–81.
11. Boros, J. (1968). *Swing Easy, Hit Hard* (p. 68). New York: Cornerstone Library.
12. McGurn, R., and Williams, S. A. (1969). *Golf Power in Motion* (p. 29). New York: Cornerstone Library.
13. Snead, S. (1965). *The Driver Book* (p. 57). New York: Cornerstone Library.
14. Williams, D. (1969). *The Science of the Golf Swing* (pp. 46–55). London: Pelham Books Ltd.
15. Carlsöö. A kinetic analysis of the golf swing, pp. 81–82.
16. Cochran and Stobbs. *The Search for the Perfect Swing* (p. 82).
17. Ibid., p. 81.
18. Williams. *The Science of the Golf Swing*, pp. 17–20.
19. Budney, D. R., and Bellow, D. G. (1979). Kinetic analysis of a golf swing. *Research Quarterly*, 50:171–79.
20. Williams. *The Science of the Golf Swing* (p. 23).
21. Milburn, P. D. (1982). Summation of segmental velocities in the golf swing. *Medicine and Science in Sports and Exercise*, 14:60–64.
22. Cochran and Stobbs. *The Search for the Perfect Swing* (p. 66).
23. Ibid., p. 58.
24. Carlsöö. A kinetic analysis of the golf swing, pp. 79, 81.
25. Cochran and Stobbs. *The Search for the Perfect Swing* (p. 136).
26. Mann, R., Griffin, F., and Rodger, P. (1991). Putting. *Golf Illustrated*, 7:43–46.
27. Mann, R., Griffin, F., and Rodger, P. (1991). Model putting: The mechanics. Personal communication.
28. Mann, Griffin, and Rodger. Putting.
29. Cochran and Stobbs. *The Search for the Perfect Swing* (pp. 128–42).
30. Diaz, J. (1989). Perils of putting. *Sports Illustrated*, 70, April 3, pp. 76–79.

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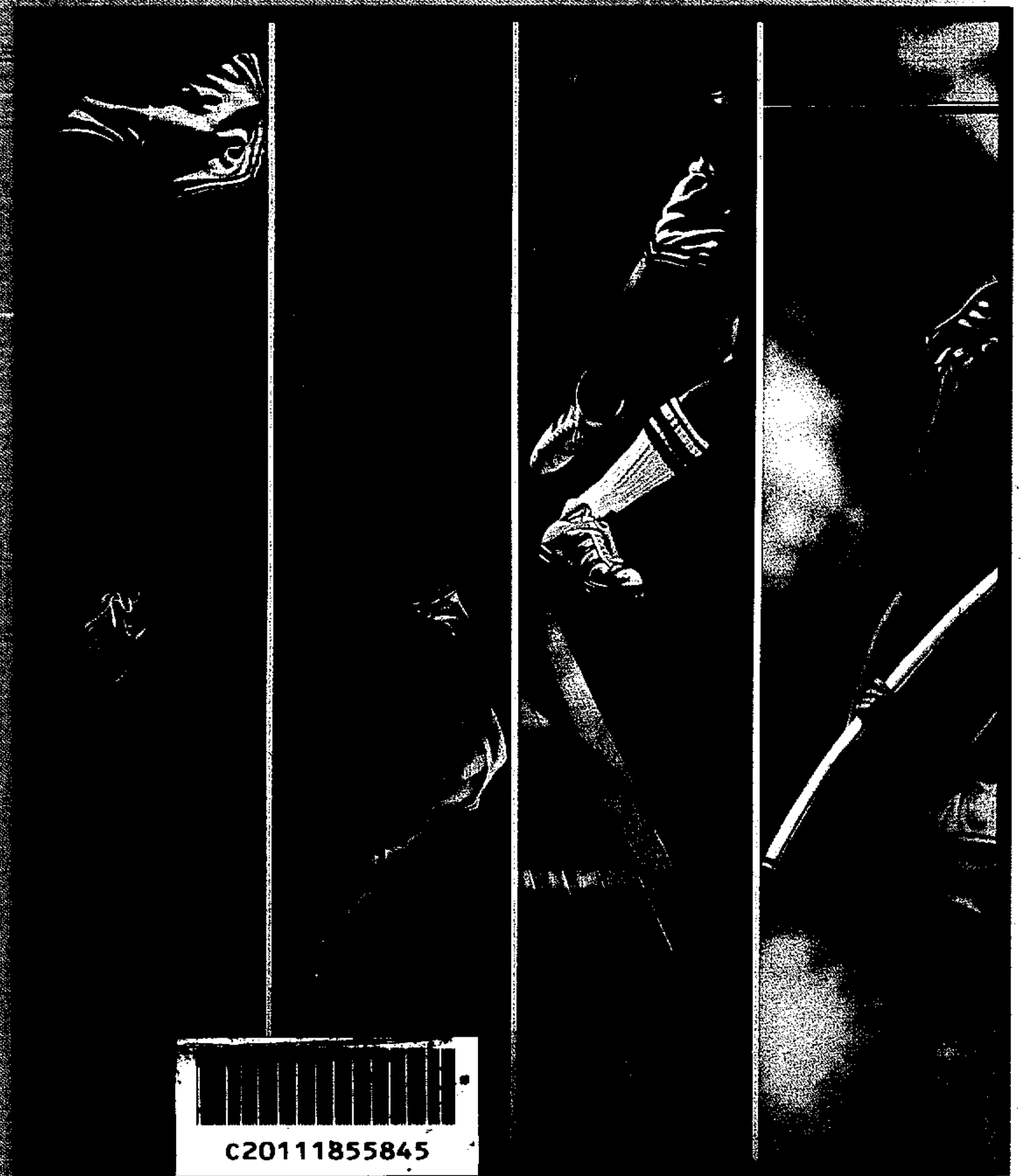

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