

GOLF RESEARCH PROJECTS

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There has been a great deal of golf research, published and unpublished, on the technical aspects of the swing. (See Hay 1981, a bibliography of golf pp. 280-282.) Published work emphasizing the analysis of the swing was done by Budney and Bellow (1979); Carlsoo (1967); Cooper, Bates, Bedi and Scheuchenzuber (1974); Nagao and Sawada (1977); Milburn (1982) and Williams (1969). These studies attempt to explain the major factors contributing to a better swing by measuring club and body segment velocities and accelerations, joint angles, forces on the feet and ball velocities and trajectory. Cochran and Stobbs (1968) did the most extensive work on all aspects of the swing and also emphasized factors related to ball impact and equipment. The golfers have benefited by gaining knowledge about the techniques of good golfers and some changes in club design have resulted, but presenting scientific data in a way that golfers can interpret and use remains a problem. This paper summarizes several research projects selecting information that should have practical application and help golfers reduce their score.

Analysis of the Swing

Over 100 golfers of all levels of ability were analysed, so many variations in swing styles, resulting in a wide range of club head velocities, could be assessed. Tournament players analysed include Palmer, Floyd, Casper, Jacklin, Beard, Sanders, Weiskopf, Littler, Player, Lema, Garrett, Dickinson, Henning, Marr, Sikes, Watson, Rogers, Nelson and Graham. In addition, Vardon, Hagen, Jones, Hogan and Snead were analysed from the PGA film, "Evolution of the Golf Swing." Women professionals were filmed in 1968 and include Wright, Mann, Hanie, Whitworth, Berg and, from "Evolution," Weathered. Thirty teaching professionals (men) were filmed for stroke analysis and 63 others participated in a hand strength project. 25 club players of varying ability were compared to the professionals and other special projects on the club-ball relationship were done.

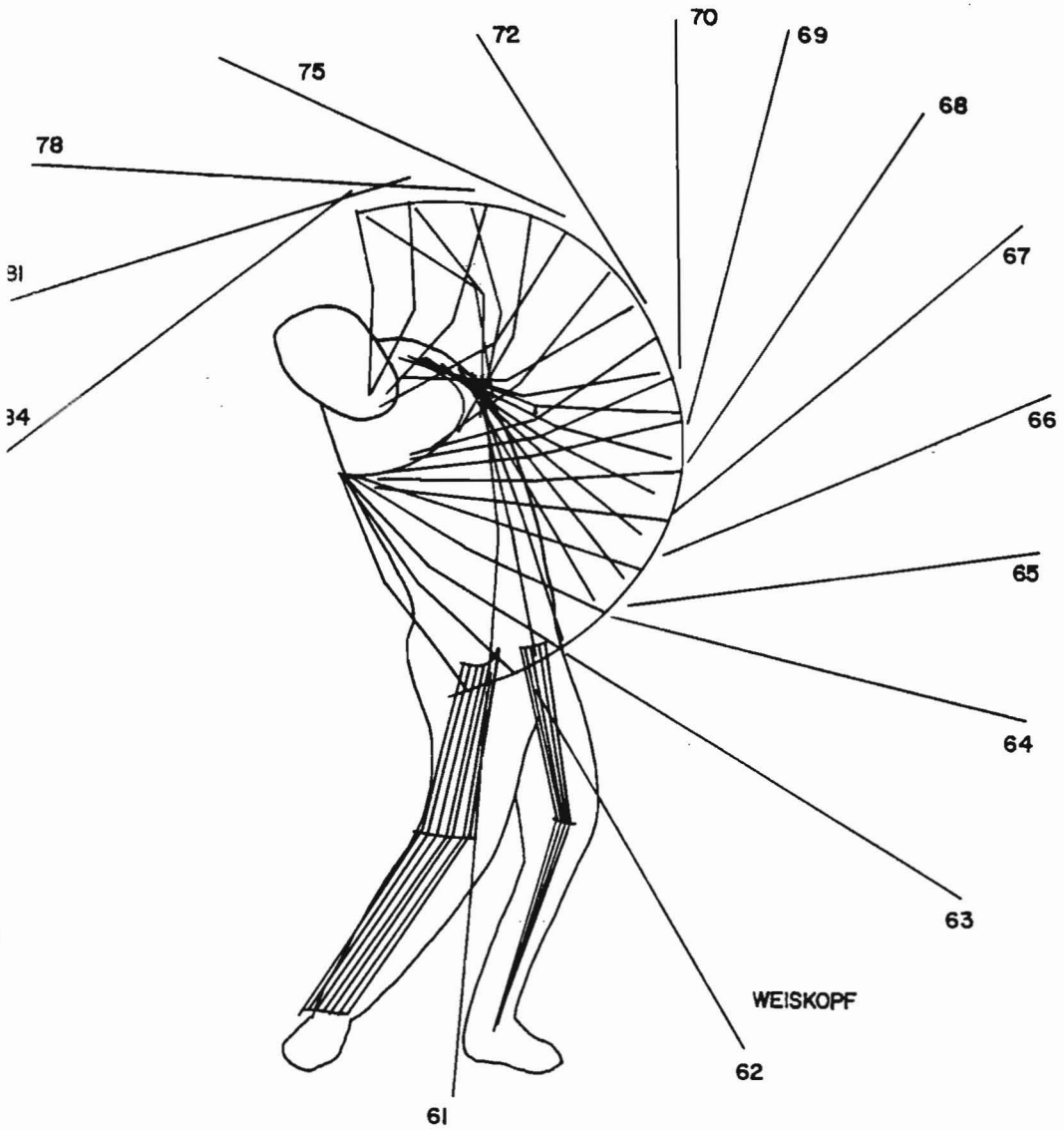


Figure 1a PATHS OF JOINT CENTERS

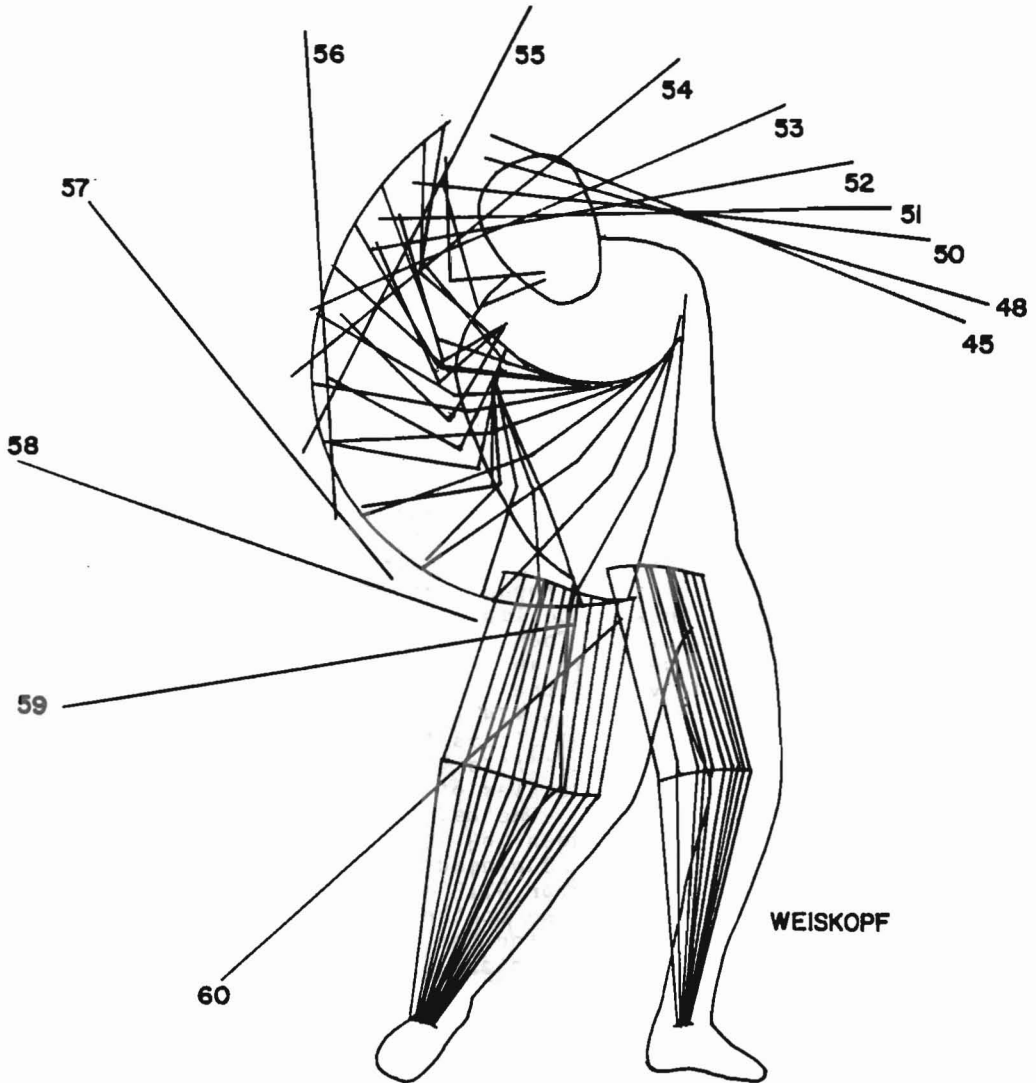


Figure 1b PATHS OF JOINT CENTERS

The measurements selected to compare these golfers were:

1. the paths of the club head and body joint centers (Figure 1,) 2. the length of the backswing (Figure 2a,) 3. the minimum left wrist angle, 4. the club shaft to left forearm angle when the forearm is horizontal (Figure 2b,) 5. the position of the left forearm when the club-forearm angle is 90° (Figure 2c,) 6. the body position at impact (Figure 2d,) 7. the time of the backswing, 8. the time of the forward swing to impact, 9. the club head velocities, 10. the ball velocities and flight angle, 11. the plane of the swing (Figure 3,) 12. the head movement patterns (Figure 4,) and 13. the ball-club relationship to the body at impact (Figure 5.) Close up films of the club were taken at 500 to 7500 frames per second to analyse the shaft vibration pattern and the club head movement due to impact.

Some of the data obtained is presented here to show that the swings and the ball flight resulting from the swings vary greatly. The length of the backswing varied from 19° short of the horizontal to 15° past the horizontal, excluding Sanders who was 50° above the horizontal. (See Figure 2a.) The minimum left wrist angle varied from 25° to 107° and occurred when the left forearm was anywhere between 5° and 40° before reaching the horizontal on the downswing. (See Figure 2b.) The position of the left forearm, when the club to forearm was 90° , was between 22° and 53° below for the women professionals, and between 30° above to 40° below the horizontal for the men club players. (See Figure 2c.) The time of the backswing varied from 0.54 to 1.1 seconds and the time of the downswing to impact varied from 0.4 to 0.6 seconds. The downswing to impact time varied from 25% to 60% of the backswing time. These wide variations resulted in a ball velocity between 217 and 248 ft/s (average 230 ft/s or 156.9 mph) for drives of the men professionals from club head velocities between 130 and 174 ft/s (average 148 ft/s or 100.9 mph.) The ball velocities for the women professionals varied between 175 and 201 ft/s (average 186 ft/s or 126.9 mph) from club head velocities of 104 to 137 ft/s (average 121.8 ft/s or 83.1 mph.) The ball velocities for the men club players varied between 184 and 228 ft/s (average 202.7 ft/s or 138.2 mph) from club head velocities of 127 to 163 ft/s (average 142.7 ft/s or 97.3 mph.) The average initial ball flight angle was close to the same (8.5°) for everyone, but the range was greater for the club players (3° to 16° versus 3° to 11° for professionals.) To these wide variations add differences in body segment positions relative to each other, the degree of trunk turn, including the relative turn of the shoulders on the hips, and the plane of the swing. The total shift in the center of gravity, the head movement pattern, the placement of the feet, the ball place-

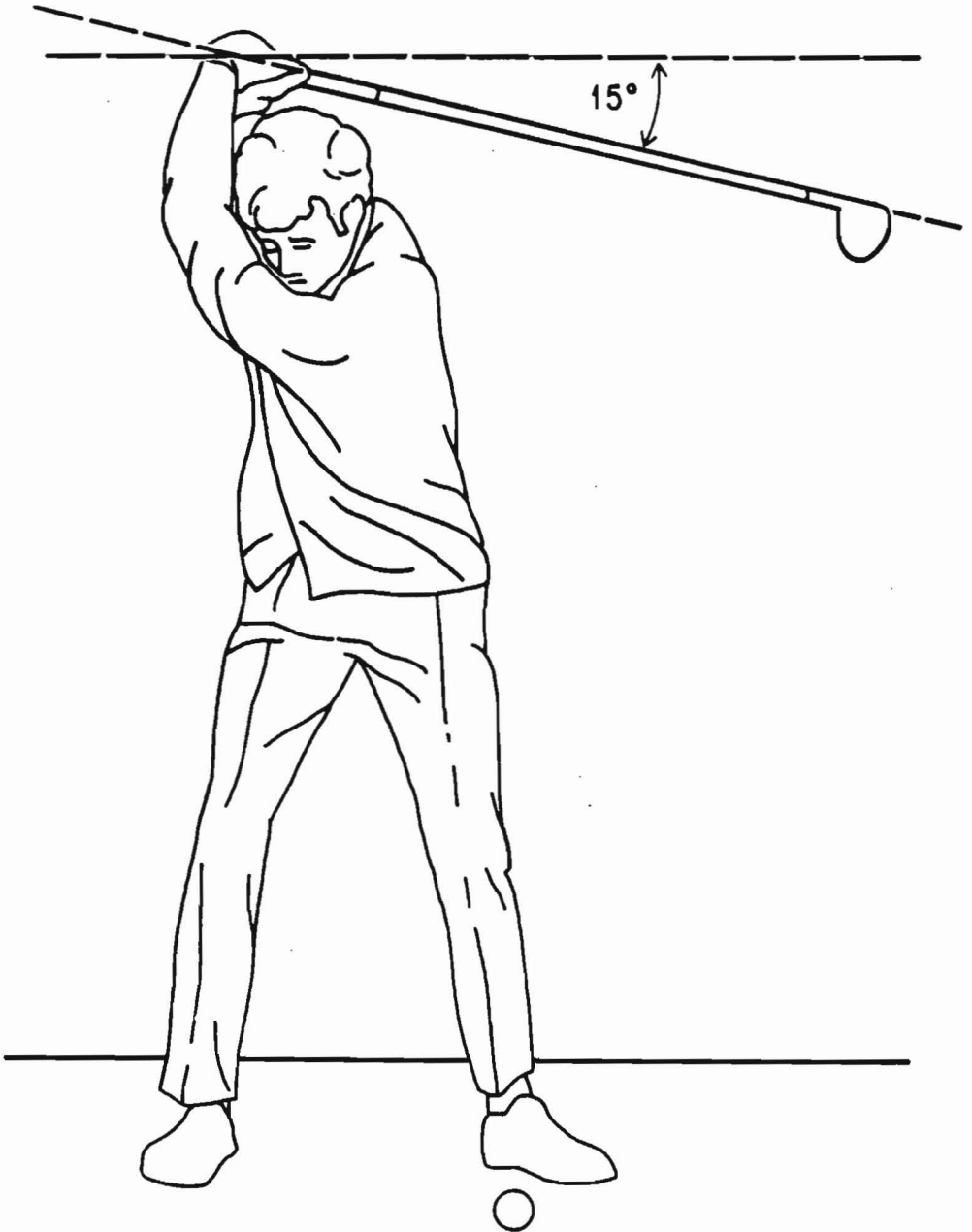


Figure 2a LENGTH OF BACKSWING

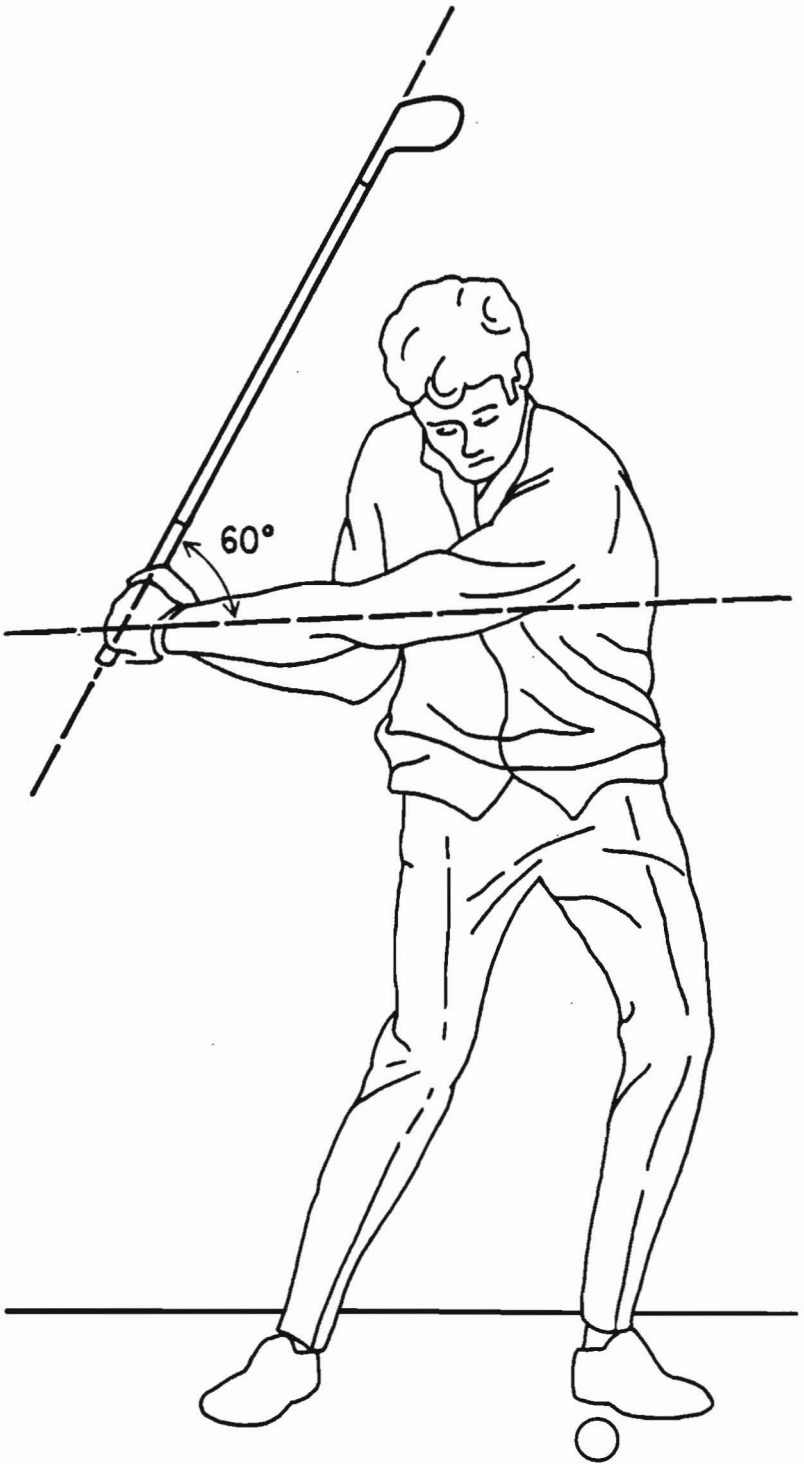


Figure 2b CLUB POSITION-FOREARM HORIZONTAL

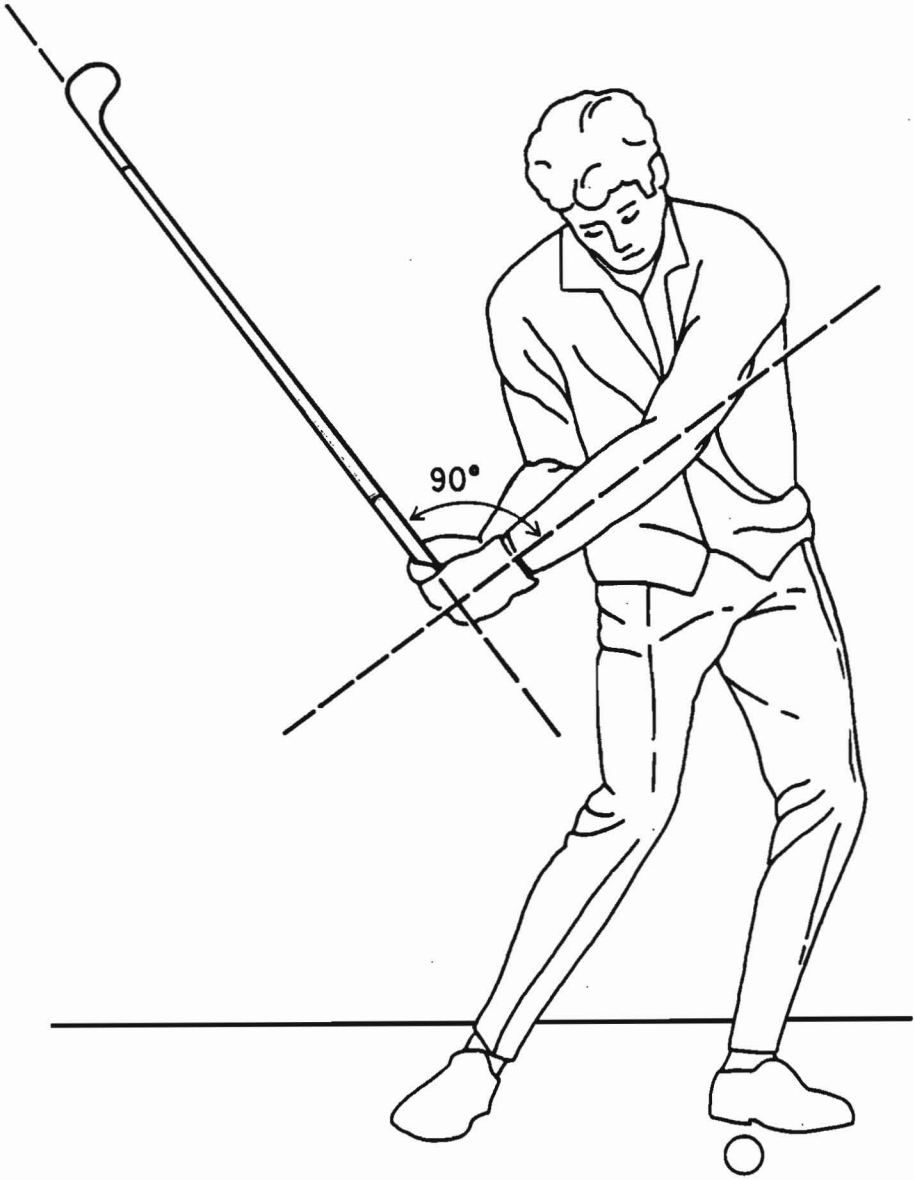


Figure 2c LEFT FOREARM POSITION-CLUB TO FOREARM ANGLE 90°

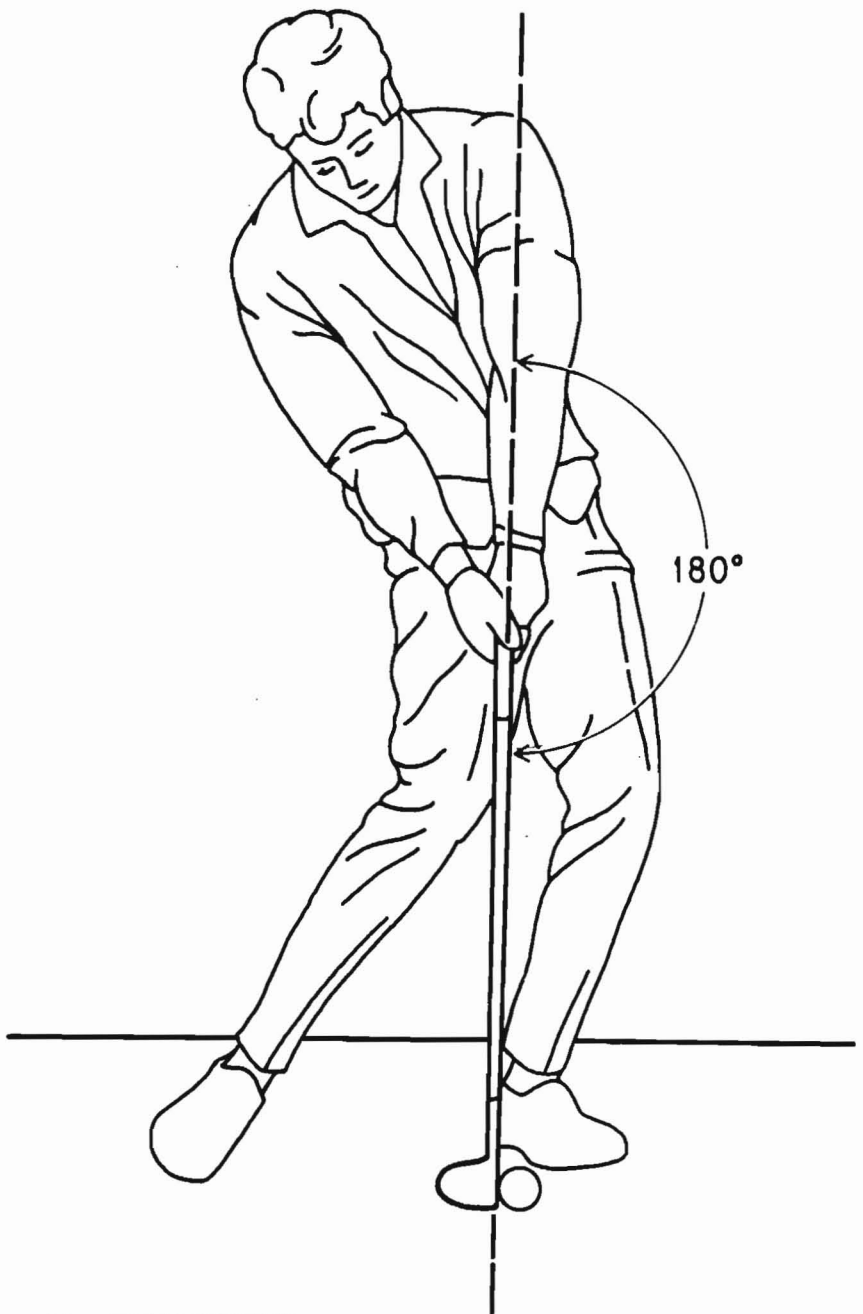


Figure 2d IMPACT POSITION

ment relative to the feet, and the path of the descending club head add greatly to the complexity of the total motion. The hand placement, grip squeeze, amount of roll of the arms and forearms, and the emphasis placed on the use of each hand further complicate matters. All these data should be very confusing, but they point out that the complexity of the combinations available to a golfer are staggering. It should be obvious that there are many ways to attain a high club head speed at ball impact, that high club head speed is not the only factor in producing a long distance and that many factors contribute to the accuracy of the shot.

Two long distance hitters were compared to show how the same club head speed can be achieved through different means. The drives selected went 280 yards, both attained a club head velocity of 169 ft/s and a ball velocity of 248 ft/s with an initial ball flight angle of 4° . Golfer A had a wider stance of only 3 cm., but placed the ball back from the front foot (ankle joint) 17.1 cm. compared to 7.6 cm. for golfer B. They both took the club back to a position 14° below the horizontal with golfer A taking 0.84 sec. to reach the top of the backswing, while golfer B took 0.98 sec. Player A then took 0.49 sec. and B 0.51 sec. for the downswing to the point of impact, or 58% and 52% of their backswing time. However, an important factor is that 40% of this downswing time is used at the beginning of the motion, before the left forearm reaches the horizontal. The unhurried motion of the arms allows the wrists to close to the minimum angle while the total body weight shifts forward.

There were two large differences between the golfers; the minimum left wrist angle for golfer A was only 70° while golfer B was 39° (a planar projection of the wrist angle,) and golfer A used much more lateral motion of the body early in the swing. When the club shaft to left forearm angle was 90° , the left forearm was 18° below the horizontal for golfer A, but 55° for B showing how the wrist angle was held to a very acute angle for a long time. (Figure 6.) Golfer A's total center of gravity moved 16 cm. before ball impact with 75% of this distance taking place before the left forearm reached the horizontal. Golfer B moved about one half this distance. The movement of the center of gravity of the head is indicative of their differences. Golfer A moved his head 10.5 cm. horizontally and 4 cm. vertically, while golfer B moved only 4 cm. horizontally but 7.6 cm. vertically. The different body action gave each a club head approach angle to the ball of 5° and both had their hands forward of the ball at impact. This comparison shows how two different techniques can produce the same results.

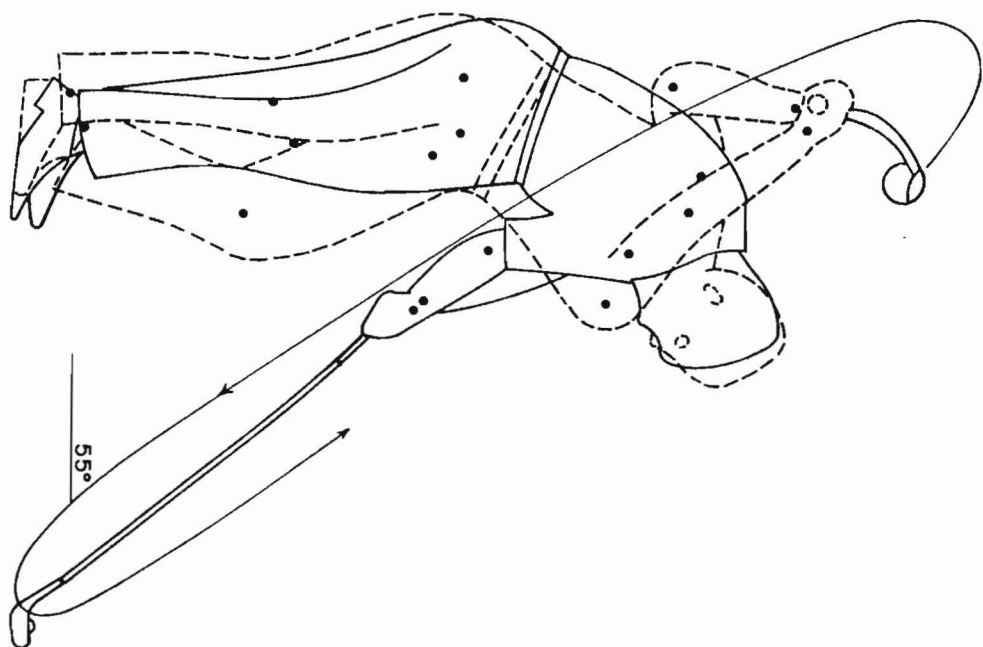


Figure 3 PLANE OF THE SWING

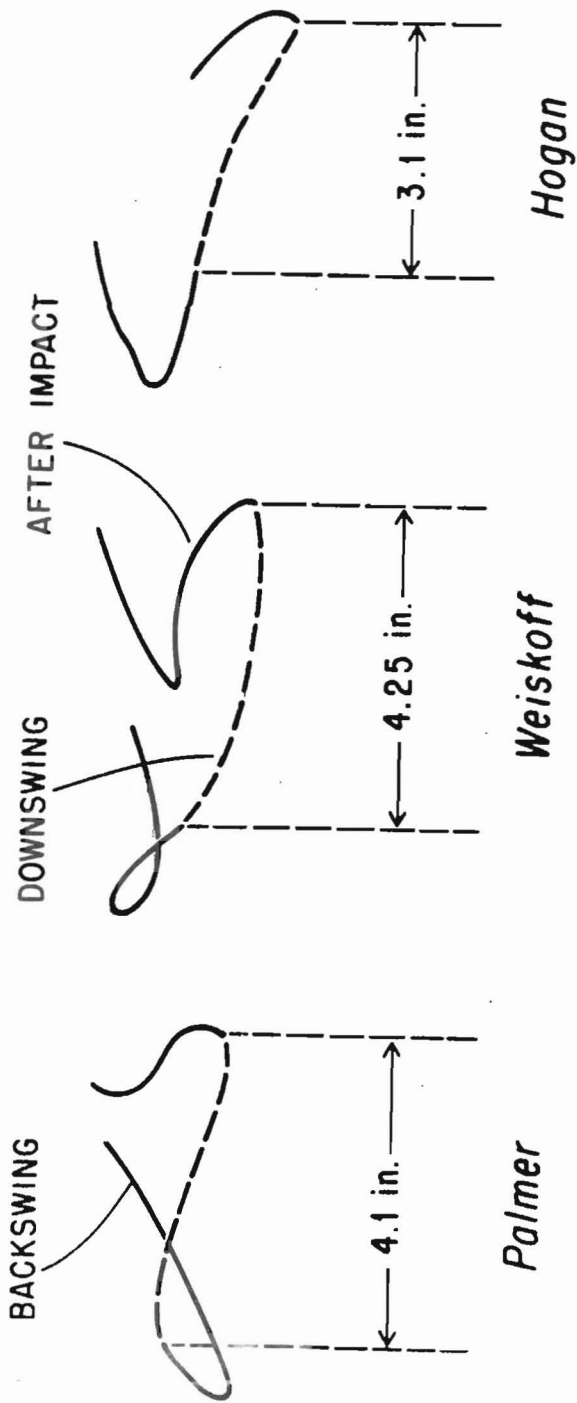
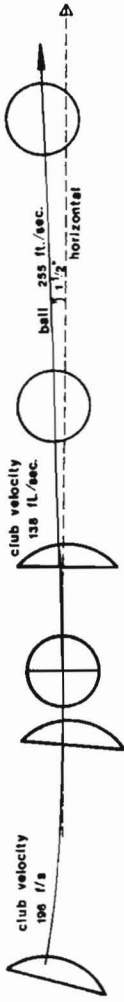


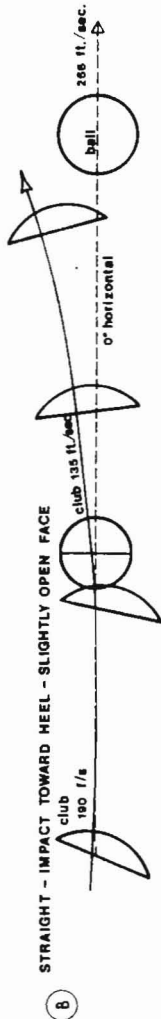
Figure 4 PATH OF CENTER OF GRAVITY OF HEAD

TOP VIEW

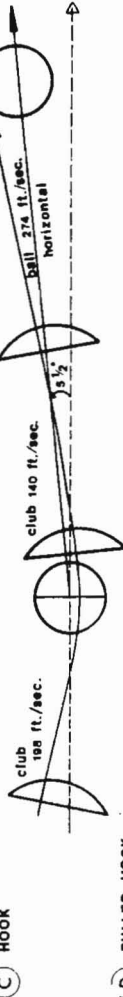
(A) STRAIGHT IMPACT TOWARD HEEL



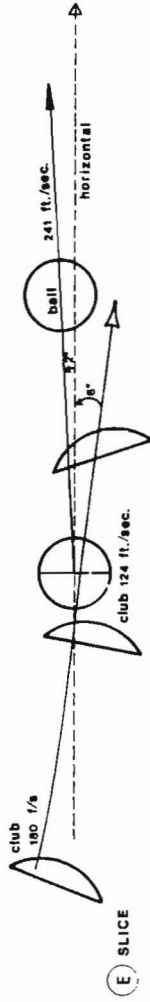
(B) STRAIGHT TOWARD HEEL - SLIGHTLY OPEN FACE



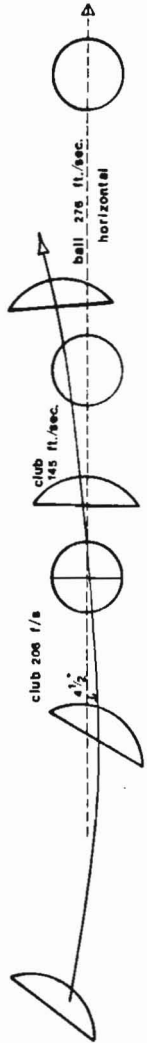
(C) HOOK



(D) PULLED HOOK



(E) SLICE



Grip Firmness Research

The contribution of the hands was unanswered by the films used for the analysis of the swings, so other projects were done to solve the question of grip firmness. Budney (1979) used force transducers in the grip to measure grip pressure throughout the swing. He showed that the grip pressure increased markedly just before impact for good players and that poorer players gripped tightly too early in the downswing. What affect this had on the swing and impact was undetermined, so three projects were done to try to assess the importance of the grip.

One player was measured for forearm strength before and after a seven-week intensive strength program and another exercised the total body for five months using Nautilus weight machines. Both low handicap golfers increased their distance of the drive over ten yards. It could not be determined if this increase was totally due to strength training because there were many other variables that were unmeasured.

A project was then done using a golf analyser which records the club head speed, ball velocity, swing direction and ball contact point on the club face. Sixty-three teaching professionals participated in the experiment. Several balls were hit until a good center hit was made and the professionals attained their best club head velocity. They were then tested for right and left hand strength using a hand dynamometer. The grip strength tests showed a correlation of .69 on the basis of grip strength being over the mean when the club head velocity was over the mean. (Means - right hand 53.6 lbs., left hand 49 lbs., and club head velocity 165.2 ft/s or 112.7 mph. This machine was not calibrated with the film.) This still did not isolate grip firmness so the data is inconclusive because there is no way of determining what proportion of the club head came from the timing, the total body strength, or the grip.

The only way to eliminate all the factors except grip variations was to use a mechanical hitting machine. Twenty balls were hit with a driver using a very tightly clamped grip, a grip with the clamps loosened so the club could twist and a grip encased in foam rubber. The club head velocity was set at 143 ft/s and center hit balls gave the ball a velocity of 230.9 ft/s. Balls hit $\frac{1}{2}$ inch toward the toe showed a drop of 3.7 ft/s, and balls hit $\frac{1}{2}$ inch toward the heel showed a 7.1 ft/s drop in velocity. The scattergram of the ball distances showed an in-line accuracy of less than five yards for center and toe hits, but a ten yard spread right to left for heel hits. The

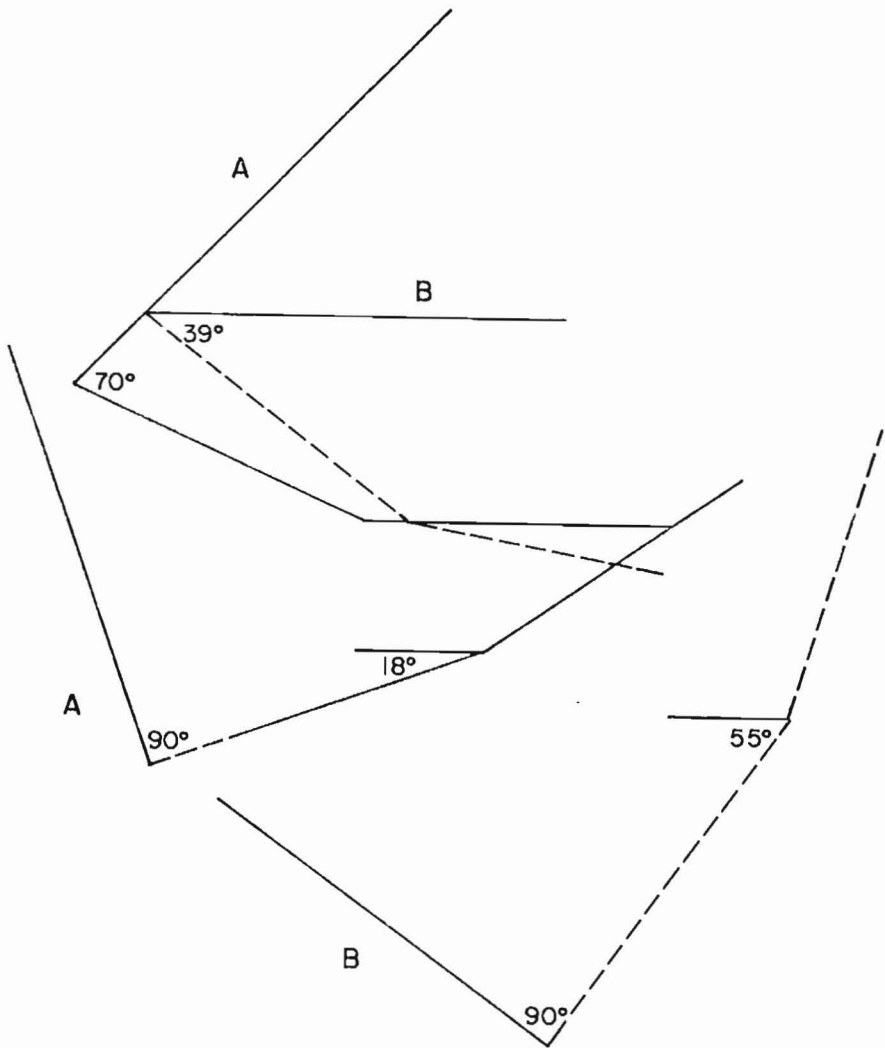


Figure 6 GOLFERS A AND B COMPARED

average distance was 251.3 yards for center hits, 245 yards for toe hits and 239.5 yards for heel hits with a 9° initial ball flight angle.

When the grip was loosened so twist could occur, the club head velocities were maintained and the mean distance for all hits was nearly the same. However, all balls were sprayed right to left in a pattern that covered 18 yards. When the foam rubber was placed around the grip and clamped firmly, the club head speed was maintained, the ball velocity was not significantly changed and the distances were only slightly different. Center and toe hits were two yards less and heel hits were 5.5 yards less. Toe hits showed a scatter right to left of only seven yards, while the center and heel hits scattered between 15 and 20 yards. An important factor happened with the foam rubber in that the ball flight was reduced to 7°, and the ball placement relative to the machine had to be changed for the tests to maintain the 9° flight angle. This showed that the foam rubber affected the shaft vibration pattern -- a very significant factor toward understanding the importance of grip firmness.

Club Shaft Vibration Patterns

The proper shaft vibration pattern contributes to the ball velocity and also affects the club face angle at impact. Williams (1969) discusses the whole swing pattern relative to the shaft, recognizing the fact that the roll of the face occurs at different points in the swing and has an affect on the shaft pattern. High speed motion pictures of ten professionals were taken to measure the vibration patterns just before impact. Figure 7 shows how the bend should be continuing forward as the club face is squared ready for impact. If there is less bend than a few inches previous to impact, the shaft pattern is wrong for the swing pattern. Also, the greater the bend forward, the more lofted the club face at impact. A golfer can change both the face angle and shaft vibration pattern with a swing change, a ball placement change, a hand position change relative to the ball at impact, or a variation in the grip firmness. It is better to select a club that fits the swing than to try to adapt the swing to a club.

Ball Direction and Spin

A filming project was done to show the club-ball relationship at impact, because of some confusion about how to put spin on a ball and get the proper direction. A staging was built for overhead filming and pictures were taken at 500

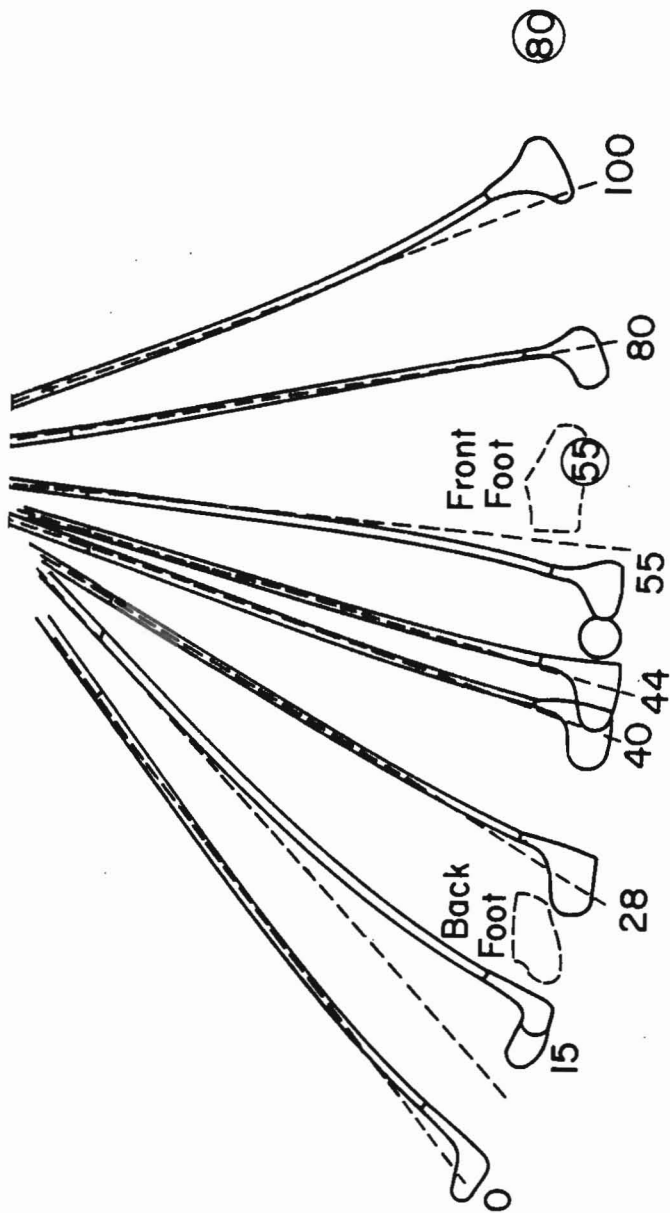


Figure 7 CLUB SHAFT VIBRATION PATTERN

f/s with a 30° shutter. Figure 5 shows the results of the top view pictures. Due to the curvature of the face, balls hit off center start off in the direction of the face angle. If the swing is at an angle to this initial path, spin is imparted and the ball hooks or slices. Side view pictures show that the ball leaves the face of a driver at 90° to the loft with a slight spin due to the angle of the swing relative to the face angle which is usually between 8° and 11°. Figure 8 shows a pitching wedge shot to illustrate the most extreme relationship between the angle of descent of the club head, the shaft angle which sets the club face loft, and the ball direction, velocity and spin. The ball leaves the face only 3° off the perpendicular line to the club face when the swing angle is 42°. With the hands forward of the club head, the loft angle of 27° is added to the downward swing angle of 15°. This large angle across the ball produces a large ball spin. Figure 9 shows how the different swings of two golfers hitting a 5-iron produce different results. These figures show that the club face angle determines the ball direction and the club head path determines the ball spin.

Muscular Balance

A final project, very relevant to golfers who have played the game for a few years, was done due to recurring low back problems often incurred by golfers. The golf swing may be classified as a one sided sport because of the high force levels used in one direction. Because the swing is specifically repetitive, this non-symmetrical action results in muscular imbalances which lead to undue stresses in parts of the body. One of the most common ailments is low back pain on the left side. X-rays of five golfers in their fifties showed a common posture; a dropped right shoulder, a slight right scoliosis at the thoracic level and a left lumbar curve. It is imperative that golfers begin total body exercises at a young age, not only to enhance their golf game, but to extend their golf years with a strong, balanced musculature.

Conclusions

Conclusions are drawn by comparing swing patterns of a wide range of ability levels from several thousand feet of slow motion pictures and from the special research projects presented.

1. Address. Every player has a characteristic pre-backswing pattern consisting of feet and hand adjustments, club waggles and tempo of preparation. The amount of forward

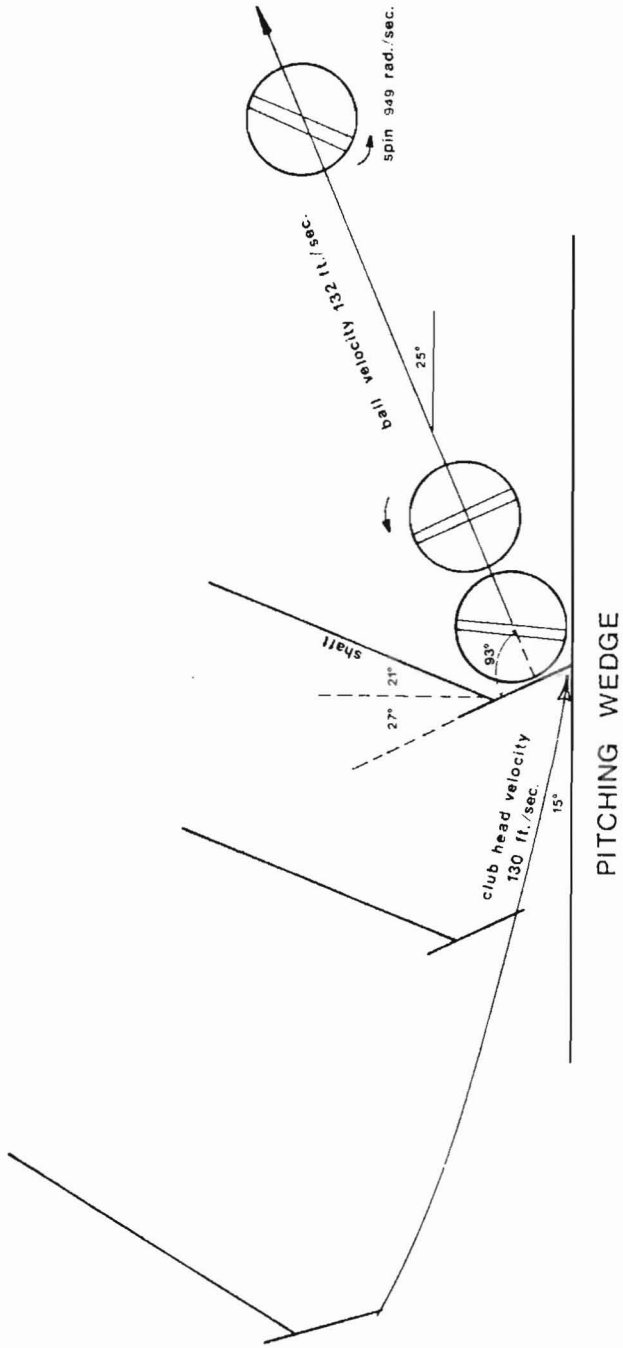


Figure 8 BALL DIRECTION AND SPIN RELATIVE TO CLUB FACE ANGLE

press and body position at address differ and it is difficult to find any two golfers who are identical in preparation. All good golfers become extremely consistent in their pattern before the backswing begins and any change in tempo or pattern is generally an indication of trouble to follow.

2. Stance. The back foot is generally 10° to 20° outward from the body mid-line and the front foot is generally 25° to 40° outward. The width of the stance and the position relative to the ball are large variables. Ball placement relative to the stance is extremely important when the club swing pattern is considered and a change in ball placement can produce a considerable change in the ball flight without altering the swing pattern.

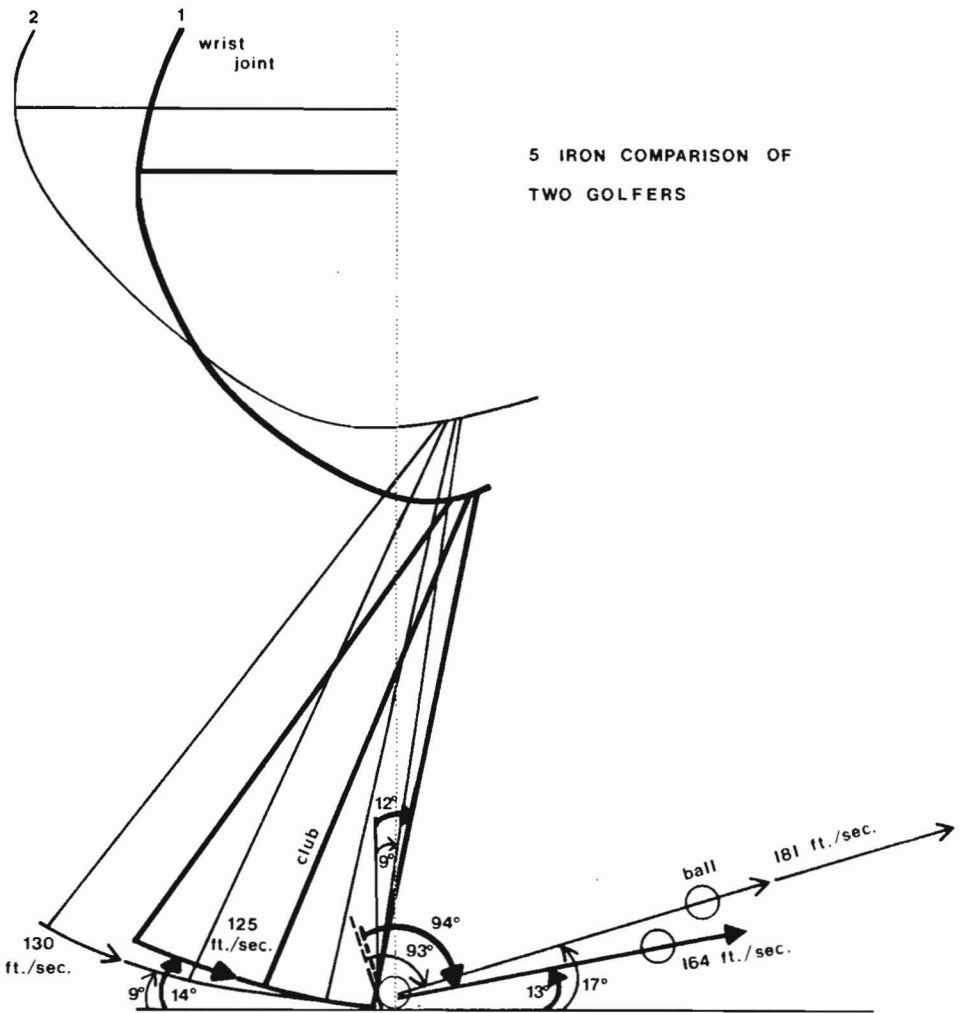
3. Backswing. The time interval between the start of the backswing and the end of the backswing has increased over the years. Today's golfers have a very deliberate, controlled start of the backward motion with no club head drag.

Most good golfers turn the shoulders 90° to the ball flight line at the top of the backswing. In past years it was common to turn the pelvis almost as far as the shoulders by lifting the left heel quite high. Today, more golfers keep the left heel close to the ground which controls the pelvic turn and produces a greater relative motion of the shoulders on the pelvis. This more extreme shoulder position on the pelvis is one of the major changes in the modern day swing.

The early champions bent the left elbow a great deal at the top of the backswing. Jones was the first to look modern by getting the left elbow within 20° of a straight line. Most of today's golfers are within 10° to 20° of being straight and this decreases slightly before ball impact takes place.

4. Downswing. The best golfers showed less variation in their swing pattern in all aspects such as tempo (time of backswing to downswing and total time of swing,) shift of weight, the pattern of the total body motion, the position at impact, the head movement pattern and the grip placement.

The minimum left wrist angle should be less than 90° , preferably as low as 50° to 70° and the left forearm should be below the horizontal when the left wrist angle is 90° , preferably 10° to 30° below. This is probably the measurement that is most predictive of a golfer's ability to hit long distances.



5 IRON COMPARISON OF TWO GOLFERS

Figure 9 RESULTS OF TWO DIFFERENT SWING PATTERNS

The total body center of gravity must move forward early in the downswing. Palmer's total body center of gravity is $2\frac{1}{2}$ inches from the left ankle joint at ball impact and he is within two inches of this position before his left forearm reaches the horizontal. Most golfers will have at least 75% of their total forward motion covered before the forearm crosses the horizontal.

Most of the long hitters have the roll out of the club head to a square position take place as close to impact as possible. Consistency of attaining squareness may require less roll performed early.

A properly timed pattern of decelerations of each body segment from the front foot to the hands is necessary to generate club head speed. The full turn on the backswing, the early forward motion of the whole body, the holding of the left forearm-club angle to a low position, the timing of the deceleration of the left arm as the wrist angle is released and sufficient muscle to perform this total motion with controlled force produces good club head speed. A golfer with an extreme wrist angle will have a longer downswing time between the forearm horizontal position and impact than one with less wrist angle. This usually means a person with less wrist angle has a greater left arm velocity and less deceleration of the arm than a person with a greater wrist angle. This type swing would require the use of more muscle to attain similar club head speeds. This shows that the timing of the motion of the body parts should take top priority to strength, but both are contributors to generating club head speed.

The bent right arm and hand straighten as impact approaches as the body motion is similar to an underhand throwing motion. It helps maintain the minimum wrist angle before the force is applied to generate maximum club head speed. Although the amount of use varies considerably, the right hand behind the club is in a position to contribute to the increasing club speed just prior to impact.

The downswing requires a specific grip firmness to maintain control to assure a consistent return to the ball. This firmness should be consistent from one swing to the next, to keep the shaft vibration pattern the same, to assure maintaining the same club face angle at impact and the same flight angle.

The slope of the swing as seen from the rear view is between 45° and 55° for most drives, over 60° for the mid-

irons and over 65° for the short irons. The higher slope pattern makes it easier to hit with a more descending angle to produce backspin, while a lower slope angle makes it easier to swing from the inside out and produce a hook swing. Anatomical differences often account for a person's comfort in the top of the backswing thus establishing the slope of the swing.

5. Impact. Consistency of ball impact on the same spot on the club face is probably the most important factor toward playing a controlled game. However, hitting toward the heel produced the poorest results in every case for distance and accuracy when using the mechanical hitting machine.

A very firm grip is needed during impact if the ball is hit off center or accuracy is lost. This means there is a difference in the grip pressure while swinging and during impact and the transition must be made smoothly and timed so the firmness of impact does not interfere with the swing pattern.

The club face angle determines the ball direction and the club head path determines ball spin. A greater descending club produces more backspin. A swing from the inside produces a left spinning ball and a swing from the outside produces a right spinning ball. Because the face of the woods are curved, the swing direction must be related to the point of impact on the club face to determine the reason for a slice or a hook as well as a mis-directed ball flight.

The forward position of the hands relative to the ball is characteristic of long hitters and produces a rising ball off a low initial trajectory.

The right hand supports the club from behind and the base of the index finger is the pivot point about which the club tries to turn due to the impact. The left hand in front of the grip counters the force of impact by maintaining a backward pressure.

6. Follow-through. The motion after impact reflects the swing pattern before impact. Although styles vary considerably to decelerate the total motion, most players have the right forearm and club shaft in alignment 50° to 60° past the vertical of impact. The free back leg and high heel lift allows a full rotation to make it possible to stop at a gradual rate.

General Comments

Muscular strength of the whole body is important for performance as well as preventing injuries. All golfers should do exercises to maintain good muscular balance.

The variations in technique are extreme due to anatomical and ability differences and no personal conclusions should be made based on the swing pattern of others. There is no one perfect swing for everyone.

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