Module Five:

Introduction to Biomechanics

INTRODUCTION

In Level One you learnt to divide a skill into meaningful phases, identify the key elements within each phase, and develop an observation plan to analyse the key elements of a skill. The aim of this module is to develop an understanding of biomechanical principles, and apply these to the analysis of a complex sport movement sequence.

Upon completion of this module, you will be able to:

EXPLAIN THE PRINCIPLES OF BIOMECHANICS AS THEY APPLY TO SPORT TECHNIQUE

APPLY THE PRINCIPLES OF BIOMECHANICS TO THE ANALYSIS OF A COMPLEX SPORT MOVEMENT SEQUENCE

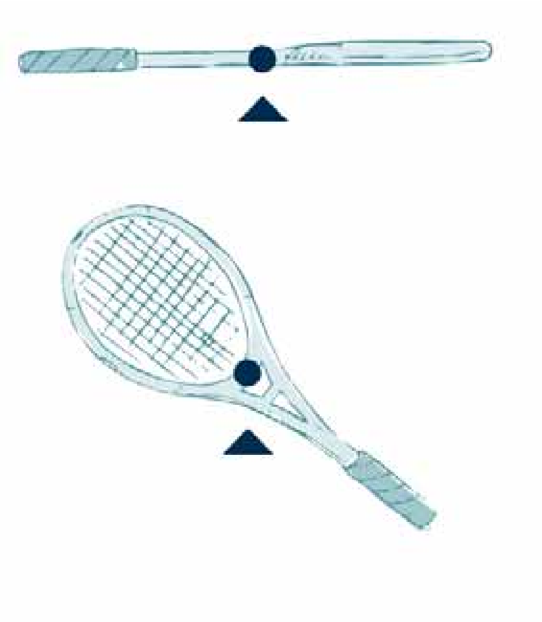
EXPLAIN THE PRINCIPLES OF BIOMECHANICS AS THEY APPLY TO SPORT TECHNIQUE

This section introduces basic biomechanical principles, illustrating them with examples of how they apply to sports skills.

BALANCE

Centre of Mass

The centre of mass, or centre of gravity, of an athlete or object is that single point which we can use to represent the overall movement of the body. We may refer to the centre of mass of a tennis racquet, a person's forearm, or their entire body. If we were to balance a racquet on a knife edge, the centre of mass would lie above it (Figure 1).



The location of the centre of mass changes when we move our body. When we stand upright, facing forwards with our arms by our sides, our centre of mass is located slightly above and between the hip joints (Figure 2). If you raise both arms forwards and upwards, your centre of mass will also move forwards and upward (Figure 3). At the peak of the pole vault when the athlete is piked over the bar, the vaulter's centre of mass would lie outside of their body, further up the trunk and in front of the body (Figure 4).

Fig. 2

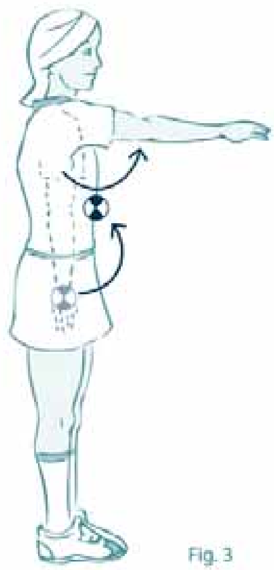


Fig. 3

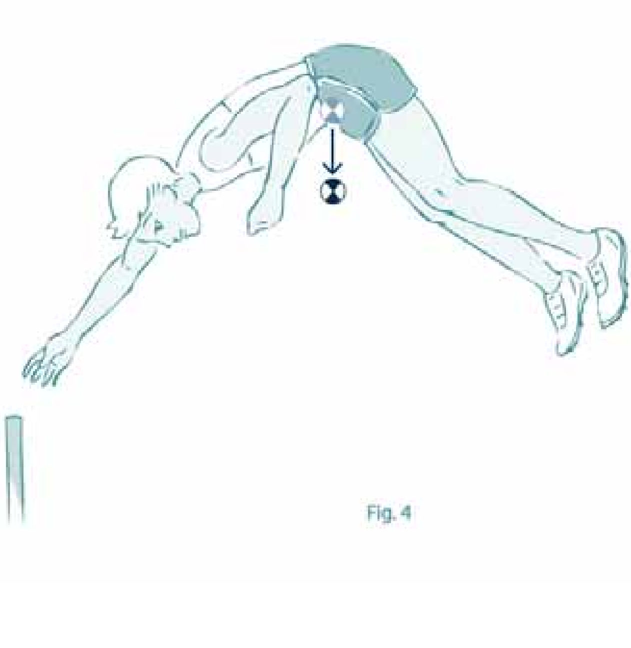


Fig. 4

Maintaining balance is part of controlling the body in sport. Being balanced is really maintaining a position of equilibrium, where the forces acting on you are not going to change your body position. There are three categories of equilibrium:

1. **stable equilibrium** – where a push will move you, but you will return to your previous stable position, e.g. hanging from the rings in gymnastics (Figure 5),
2. **neutral equilibrium** – where a push will move you to a new position which is still in neutral equilibrium, e.g. a round ball lying on the floor, (Figure 6), and
3. **unstable equilibrium** – where a push will make you start to fall, e.g. standing upright and someone pushes you from behind, causing you to take a step (Figure 7).

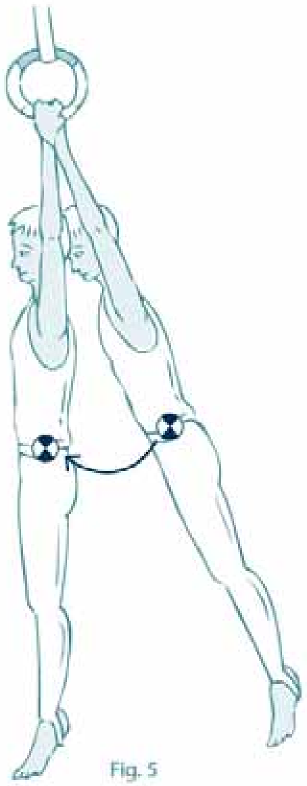


Fig. 5

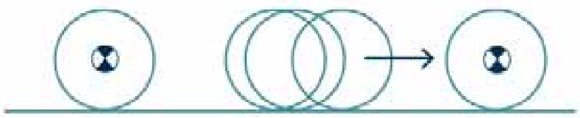


Fig. 6

We balance in positions of unstable equilibrium.

In general, the more unstable you are, the harder it is to balance. Your stability depends partly on your base of support. See Figure 8a, b, c for examples of this. Your base of support may be small, e.g. for someone doing a one-handed handstand (Figure 8a), or larger, e.g. in normal standing (Figure 8b), or quite large, e.g. for a sprinter in their start position (Figure 8c). However, it's not the size of your base of support which is important, but the distance between a vertical line through your centre of mass (your gravity line) and the edge of your base of support.

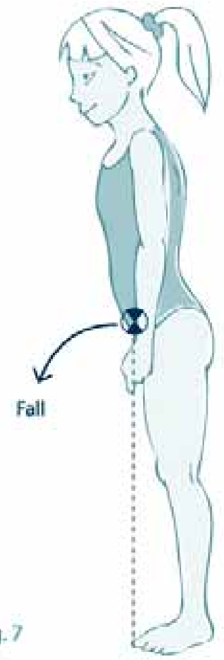


Fig. 7

Fig. 8a

Fig. 8b

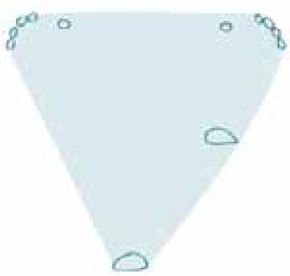


Fig. 8c

Stability is directional. For example, sprint starters will be relatively unstable in a forward direction (their gravity line is close to their fingertips), while being very stable in a backwards direction (Figure 9). When we want to start moving in a particular direction quickly, we prepare by making ourselves move unstable in that direction.

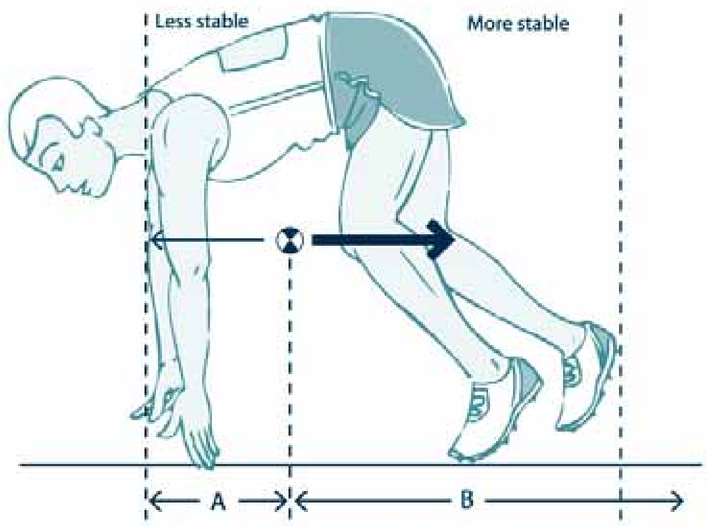


Fig. 9

Other factors that affect your stability are your mass (more mass equals more stability), and the height of your centre of mass above the surface (more height equals less stability).

When you are moving, one more factor which affects your stability, or balance, is your straight line speed. The faster you are moving, the more stable you are, and the less effect a push will have in deflecting you.

MOTION

We frequently describe three components of motion. These are position, speed (or velocity), and acceleration. These terms apply to both linear and angular motion. We use these terms to describe characteristics of skilled movement.

Position refers to an object's person's location at some time. **Speed** is how quickly your position changes over a period of time, while **acceleration** is the rate of change of your speed over time. In other words, acceleration is how fast your speed is increasing or decreasing. In sprinting, both your top speed and your acceleration to top speed are important in winning a race. Evading a tackle in rugby may depend on your ability to increase your speed quickly, i.e. your acceleration.

Linear or straight line motion is when all parts of a body move the same distance, in the same direction, at the same time, i.e. same distance, direction, time. Examples of this are a dart player's hand while throwing a dart, or a roller blade skater gliding along a flat surface (Figures 10, 11).

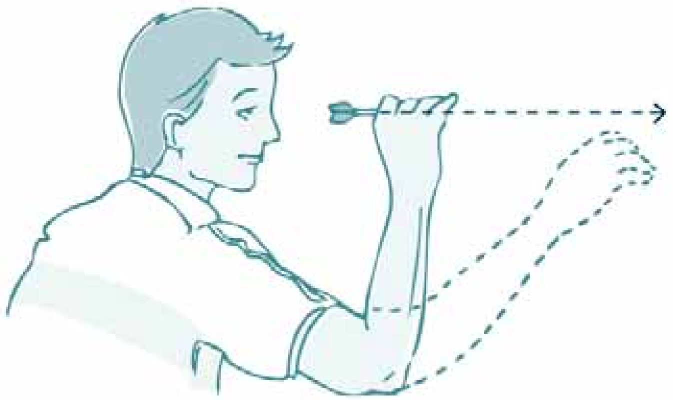


Fig. 10

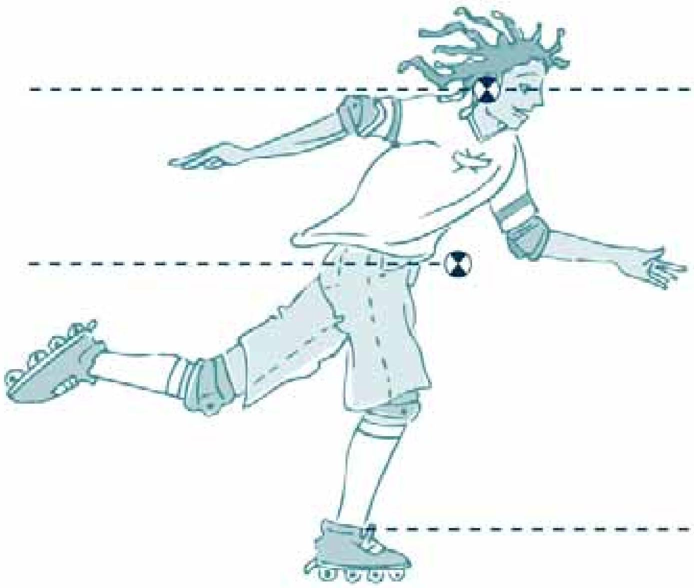


Fig. 11

Angular or rotational motion is when all parts of a body move through the same angle, in the same direction, in the same time, i.e. same angle, direction, time. Examples of this are the bowling arm of a cricketer, or a gymnast doing a giant swing on the high bar (Figures 12, 13).

A special case of linear motion is called curvilinear motion. This occurs when all parts of the athlete's body still exhibit linear motion, i.e. same distance, direction, time, even though they might be moving along a curved path. An example would be a skier gliding over the top of a small hill (Figure 14).

Most motion is a combination of the above, and we describe it as complex or general motion. Examples of complex motion would be a runner, where angular motion of the foot, leg and thigh produces linear motion of the trunk, or the entire arm of the darts' player, where angular motion of the upper arm and forearm produces linear hand movement (Figure 15a,b).

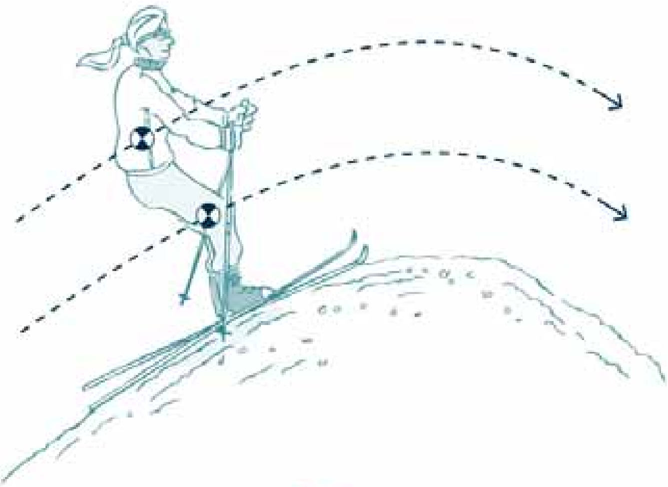


Fig. 14

Fig. 12

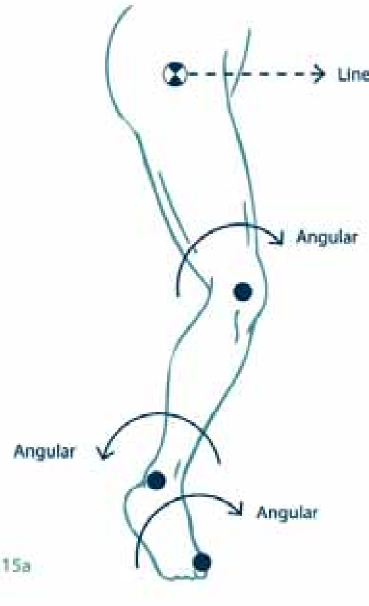


Fig. 15a

Fig. 13

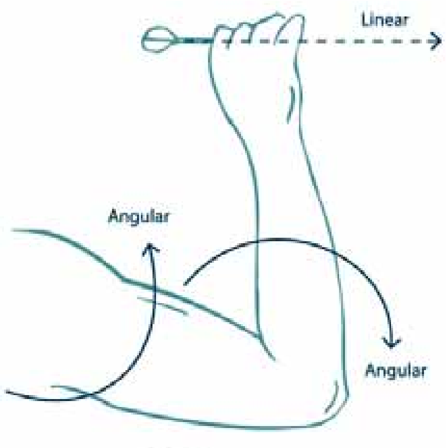


Fig. 15b

The movement of objects in the air is another special motion case. These objects, or projectiles, have a constant horizontal speed, except when air resistance is significant, but their vertical speed is altered by the effect of gravity from the moment of take-off, or release, until they contact the ground again. During the time a projectile is in the air, its upward speed is decreasing by-10m/s every second.

A ‘projectile’ can be a shot put in flight, a basketball player performing a jump shot, a gymnast doing a back somersault, or a badminton player leaping to play a smash (Figure 16a, c, d). All projectiles, unless affected by air resistance, follow a trajectory known as a parabola (Figure 17).

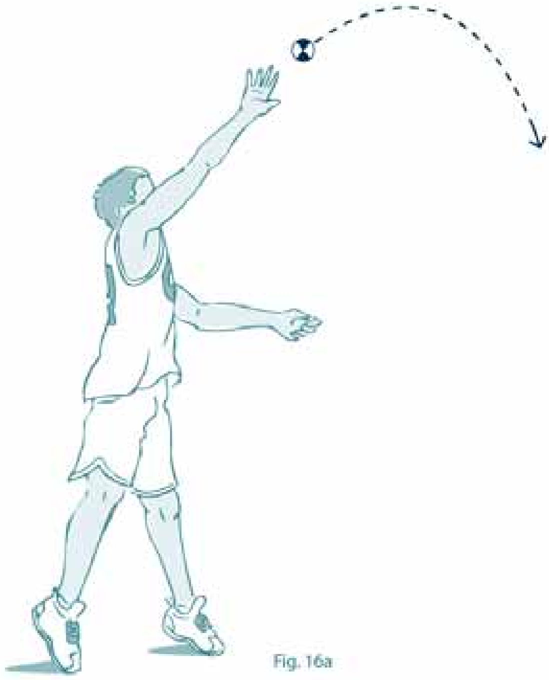


Fig. 16a

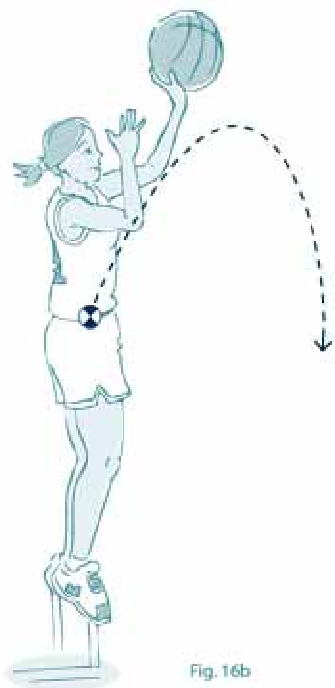


Fig. 16b

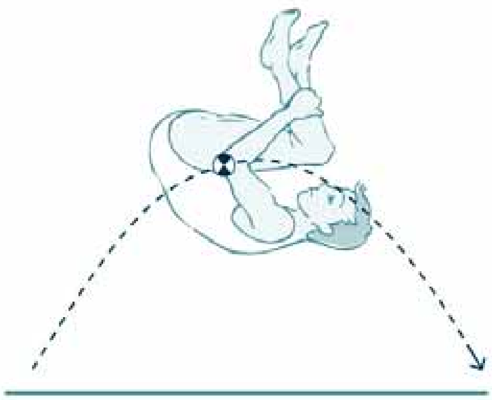


Fig. 16c

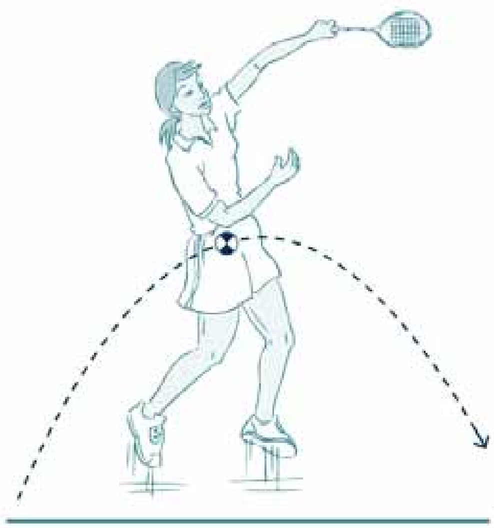


Fig. 16d

Forces

Forces cause or tend to cause a change in an object's or person's motion. The change in movement is in the same direction as the force exerted.

Weight is the gravitational force exerted by the earth on all objects. It equals mass times the acceleration of gravity, and has units of Newtons. We frequently refer to our body weight as, for example, 70kilograms. Technically this is incorrect: our mass is 70 kg and our weight is 70kg x 10m/s/s = 700 Newtons (Figure 18).

What happens when more than one force acts on a body? If we see movement, it is due to the sum of the forces acting. Consider a shot put lying on the ground. Until you exert a force larger than its weight it won't move (see Figure 19a, b). Once you produce a larger force, the portion causing movement is the difference between the shot put's weight and your force (Figure 20).

If the forces on a body act at some angle to each other, their effect is combined. When you have two forces acting on a body, their joint effect can be estimated by visualising a parallelogram with the combined, or resultant force joining the start and finish of the box (Figure 21).

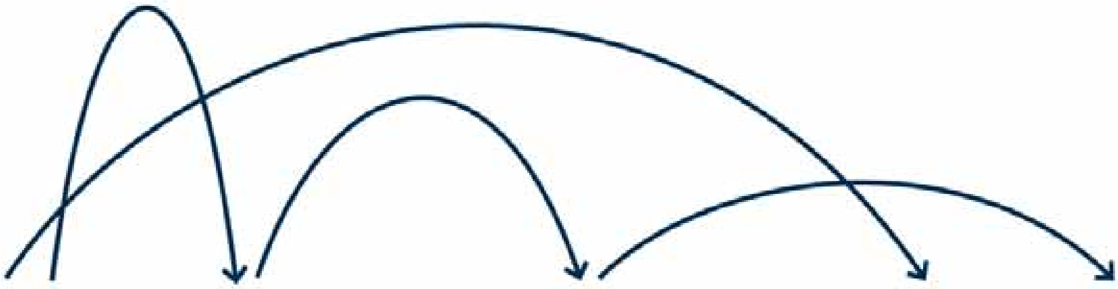


Fig. 17 Parabolas.

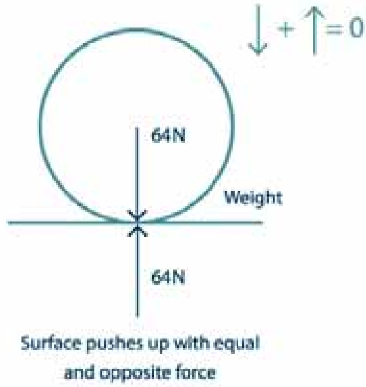


Fig. 19a

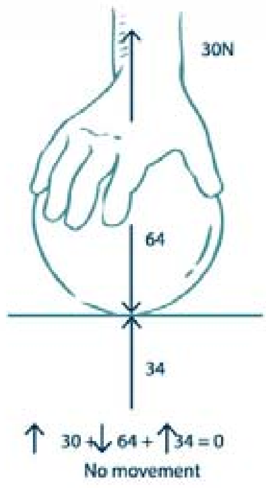


Fig. 19b

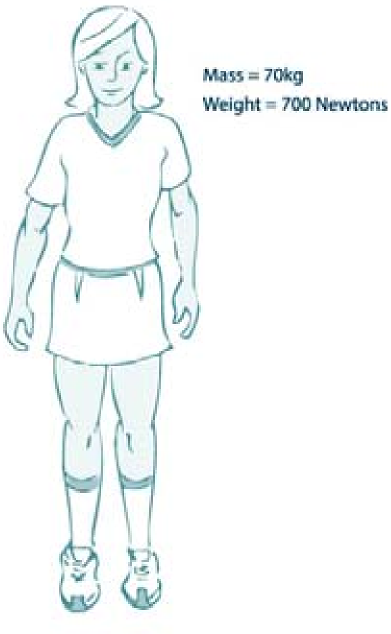


Fig. 18

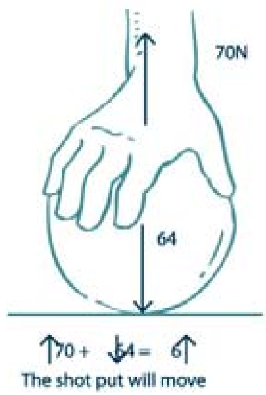


Fig. 20

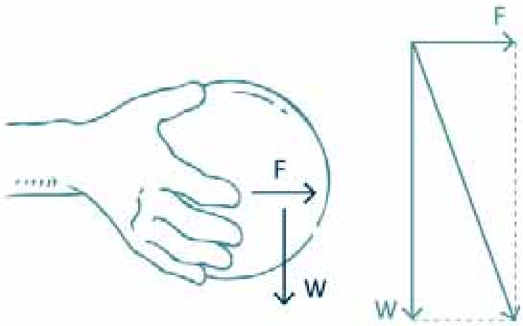


Fig. 21

Newton's First Law, referred to as the "conservation of momentum" law, states that without any resultant forces acting on them, objects maintain a constant velocity, which might be zero. In reality there are always some forces acting on the person, such as air or water resistance, or friction. An example of this would be a skateboarder on a level surface. They would have a constant velocity, except for the friction in the wheels slowing them down. Similarly, a ball on a pool table will not move unless an external force, like a pool cue or another ball, acts on it.

Newton's Second Law tells us that when a resultant force acts on a body, it produces an acceleration which is proportional to the force, inversely proportional to the mass of the body, and in the same direction as the force. For example, when you throw a ball, producing a large force will produce a large acceleration, while exerting a smaller force will result in less acceleration. When a weight lifter produces an upward force of 1000 Newtons, they will produce a large acceleration of a dumbbell with a mass of 10kg, but a smaller acceleration of a 90kg barbell (Figure 22a, b).

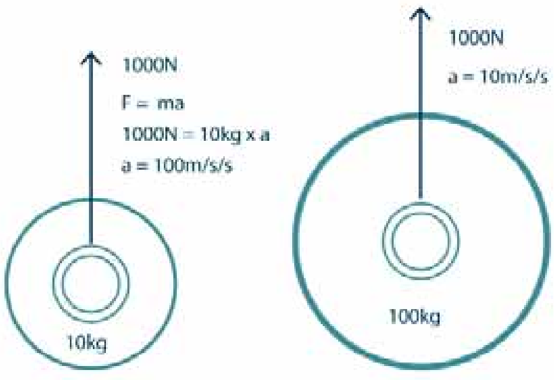


Fig. 22a Fig. 22b

Newton's Third Law, 'action-reaction', notes that objects exert equal but opposite forces on each other. Thus, when a long jumper pushes down on the ground during their take-off, the earth pushes back on them in the opposite direction with the same size force, at exactly the same time, and the athlete moves in the opposite direction (Figure 23). This force is called the ground reaction force. To make the most of this force in the performance of many sports skills, it is important to 'keep your feet on the ground'.

Examples of the application of Newton's Third Law to other sporting situations include when a swimmer pushes back the water, they move forward. As a tennis player swings the racquet during a serve, while the player pulls in on the racquet, the racquet pulls out on the player's hand (Figure 24).

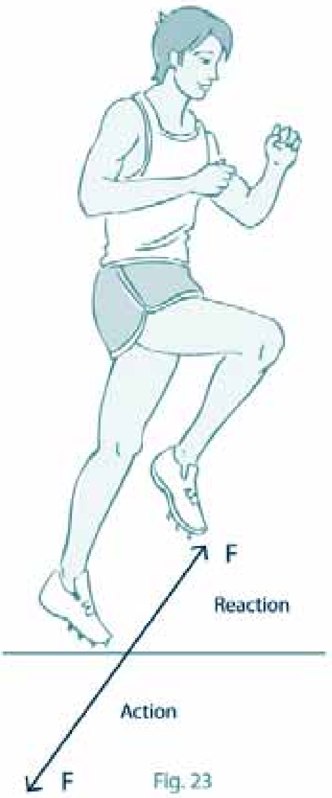


Fig. 23

Fig. 24

Levers

The muscles and bones in our body form a system of levers which generate the movement to produce most of our sports skills. There are three classes of lever, classified according to the relative positions of the force (or point of effort), the fulcrum, and the resistance (or weight). In first class levers, the fulcrum lies between the resistance and the force, for example, a crow bar, a seesaw, and a pair of scissors. Examples of second class levers include lifting a wheelbarrow, opening a door using the handle, and supporting your body weight on the balls of your feet. In these examples, the resistance lies between the fulcrum and the point of effort. Although we can find examples of all three classes of lever in the body, most of them are class three, where the force acts between the fulcrum or joint and the resistance or weight (Figure 25).

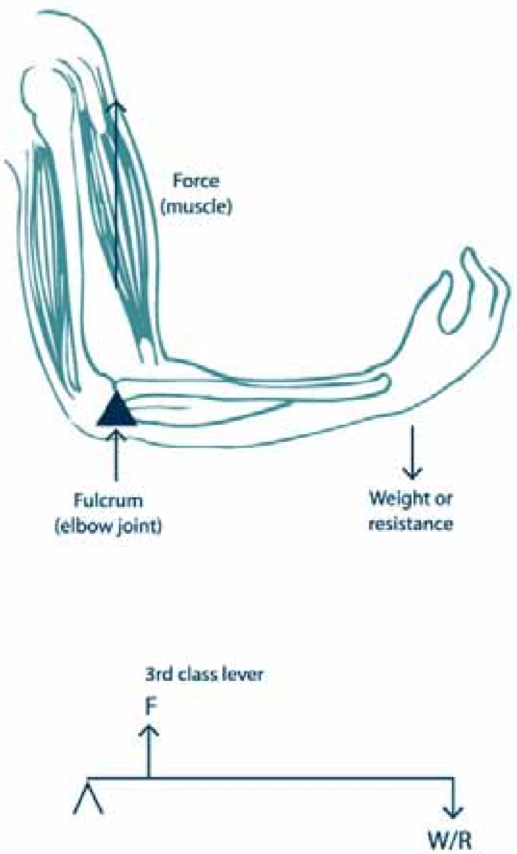


Fig. 25

There are advantages and disadvantages to having mostly third class levers. The main advantage is it allows us to produce very high speeds at the end of the levers, our hands and feet. The disadvantages are that this lever system requires the muscles to exert much larger forces than the weight of the object they are moving, and this has implications for injury.

“WE’RE MADE FOR SPEED, NOT FORCE”

Summation of Forces

Many movements in sport are the result of the combination of a number of forces which are performed in a sequence, e.g. weight lifting, rowing, and projectile sports such as throwing events in athletics, softball, tennis, and rugby. **For athletes to produce maximum velocity of a projectile or implement, each segment of the movement should be moved at the instant the previous segment begins to slow down.**

The speed of the last part of the body at the moment of contact or release will determine the velocity attained by the projectile (ball, javelin, discus, etc.) or the implement (racquet, stick, bat, etc.). This is particularly important if maximum force is desired, as in weightlifting, shot put, and bowling in cricket, for example, when as many body parts as possible should be used.

In other words, optimal performance requires the body movements to be performed in the correct sequence, with the correct timing. For example, in a well-timed kick in soccer or rugby, the leg begins to extend at the knee joint as the thigh reaches maximum velocity. The final velocity will be less than maximal if this leg action begins either earlier or later than this point. See Figure 26. In practise, the strongest and slowest body parts begin to move first (i.e. the thighs and trunk), followed by the weaker and faster extremities (i.e. lower leg, feet, arms, and hands).

In some sports, several actions occur simultaneously, and to achieve maximum force, the body parts are required to produce force explosively at the same time, e.g. gymnastics vault, judo kick, netball chest pass, and breaststroke leg kick.

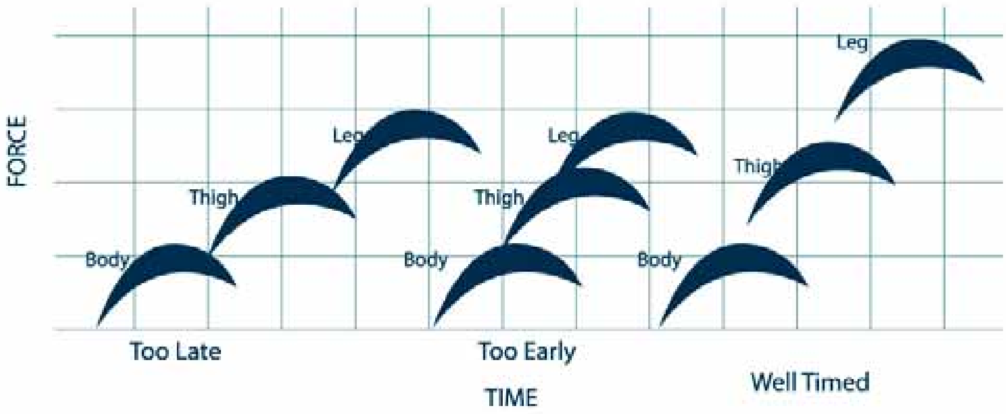


Fig. 26

Forces that Oppose Motion

There are forces that act to slow us down in most situations. These are forces such as fluid (air or water) resistance, or frictional forces. When you push off from the edge of a pool and try to glide as far as possible, you eventually stop because of the resistance from the water. A skydiver has a maximum ('terminal') speed for any particular body position. This point is reached when the forces due to air resistance equal their weight, and you have a situation where there are no resultant forces acting on the skydiver (Figure 27).

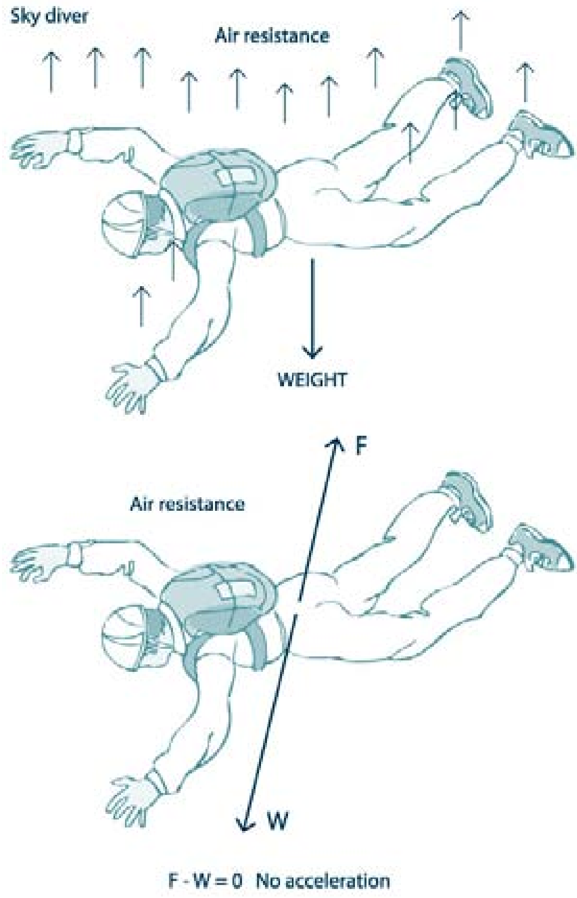


Fig. 27

Another factor affects our ability to increase or decrease our speed. This factor is called inertia and is the tendency of the body to resist change in motion. Both Newton's First and Second Laws are important here. The inertia of a person or object is related to their mass: the greater the mass, the greater their inertia. A rugby player with a mass of 100kg running at 5m/s is harder to stop than a 50kg player moving at the same speed. Remember that inertia means it is just as hard to speed something up as it is to slow it down.

Momentum

Momentum is the 'quantity' of motion possessed by a body, and is measured by multiplying the body's mass by its speed. Momentum is important in collisions, such as a tackle in rugby, deflecting a pass in netball, or striking a ball with a bat. The greater an object's momentum, the less it will be affected by some other force. When we apply this concept to athletes, we find in many cases, it is the athlete's momentum which is important. Since the athlete's mass is constant, the important factor is their speed. A greater speed will make them harder to stop or deflect. In contact sports, Some players 'bulk up' to increase their quantity of motion.

QUESTIONS & EXERCISES

Explain each of these biomechanical principles and apply the principles to examples from your own sport.

- *Balance* • *Summation of forces*
- *Motion* • *Forces that oppose motion*

- *Forces*
- *Momentum*
- *Levers*

e.g. How do your players maintain balance when performing a volleyball serve or when being tackled in soccer or at the start of a swimming race?

e.g. When do your athletes deliberately place themselves in positions where they are not well balanced?

APPLY THE PRINCIPLES OF BIOMECHANICS TO THE ANALYSIS OF A COMPLEX SPORT MOVEMENT SEQUENCE

This section applies the principles of biomechanics to the analysis of a jump shot in basketball. You will then be asked to go through the same process, applying the principles to a complex movement sequence from your own sport.

LEVELS OF ANALYSIS

Qualitative

Chart 1 represents a qualitative model of a basketball jump shot. As we can see, the objective is to put the ball through the basketball hoop. Since the ball is a projectile, its movement is determined by three factors, height, angle, and speed of release (ignoring the minimal effect of air resistance). The major factors which influence each of these are shown. A number of assumptions are made, including things such as: the player is able to shoot straight at the basket (that is, the only problem is the distance of the shot, and the angle at which the ball approaches the hoop), the spin on the ball will not adversely affect the shot, and the player has the strength to shoot the ball the required distance.

Quantitative

In order to maximise the chances of putting the ball through the hoop, while still keeping a realistic speed of release, the optimum angle of release is between 48º and 55º. The speed of release depends on the distance of the shot.

DESCRIPTION OF A SPORT MOVEMENT SEQUENCE – JUMP SHOT

Preparation

From a balanced position, with the foot of the shooting hand slightly in front of the body, the knees flexed and the ball held in two hands, either in front of the shooting shoulder, or above the head and in front of the shooting shoulder, the player initiates an upward jump. The height of this jump must be sufficient to allow them to shoot over any opponent attempting to block the shot, while still remaining in control. There should be little or no horizontal movement in the jump.

Execution

The player propels themselves upwards. Just before reaching the peak of the jump the player should initiate the shooting motion with the shooting arm. This should consist of shoulder flexion, elbow extension, and wrist flexion in sequence.

Follow Through

The player should allow the wrist to flex naturally after the shot, providing backspin on the basketball. They should then slightly flex the knees and hips, and planter flex the ankle joints, in preparation for landing.

BIOMECHANICAL PRINCIPLES INVOLVED IN THE MOVEMENT OF THE BODY

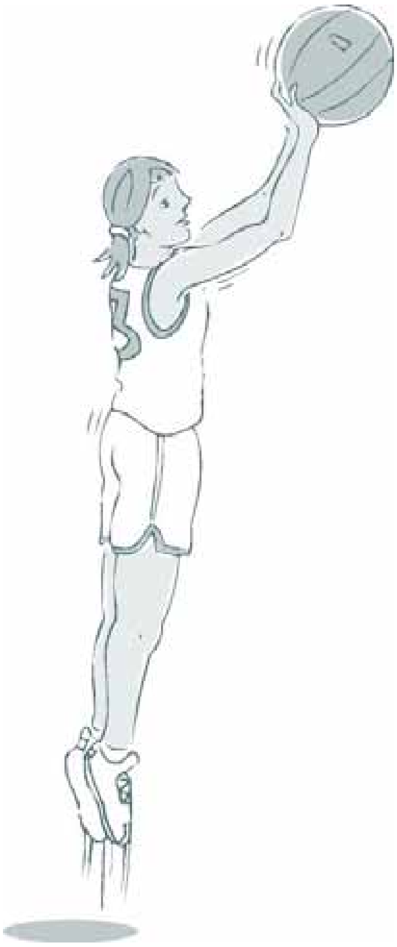
Preparatory Phase

In order to control the shot effectively, the player must be balanced prior to starting the jump shot. Since they will usually be moving, this means they need to be balanced in a dynamic sense. They must complete the preparatory phase with the centre of mass over the base of support in order to control the jump.

The player's motion in this phase is predominantly linear. The player will usually land with some forward speed prior to the jump shot and need to reduce this speed to almost zero, otherwise they will introduce complications in judging how much speed to give the ball during the shot.

In this phase, the player produces forces on the ground which reduce their forward speed to almost zero. This is done by landing with the feet in front of the centre of mass and pushing forward on the ground. The player will usually have more control of these forces if they have a staggered stance; that is, with one foot (the shooting hand side) in front of the other. This also increases the forwards/backwards size of the base of support, providing more control of forwards motion.

The forward momentum of the player is reduced to almost zero in this phase. Similarly, the player should have little or no angular momentum at the end of this phase. This is controlled by producing forces on the ground to minimise the natural tendency of the body to rotate forwards when the feet stop on the ground, but the rest of the body wants to continue moving forwards above it. This development of forward angular momentum is commonly seen in landing or take-off skills, and is controlled by the forces exerted on the ground.



Execution Phase

The player must be balanced, with the centre of mass above the base of support, prior to starting the jumping motion. There should be little or no horizontal motion, since any horizontal speed at take-off will be transferred to the ball, making the assessment of how much force to generate with the shooting arm more complicated. One of the characteristics of players who do not have sufficient arm strength to project the ball the required distance is that they will jump forward in an attempt to increase the horizontal speed of the basketball.

The player should produce only upward motion of the body, without introducing any angular movement. If the player produces any whole-body rotation while in the air, they will have problems landing in a balanced position.

The player should shoot the ball at, or close to, the peak of the jump. Again, this is done so that the player has virtually no forward or upward/downward speed, which would have to be factored into the judgement of how much force to exert on the ball. Most players start the shot just before the peak of their jump, so the ball is released at the peak. There are two advantages to this. One is that it makes the production of the shot simpler and more consistent, and the other is that is maximises the height of release, making the shot harder to block. A player should strive for a consistent jump in the shot, in order to make the 'base' for the shot the same every time.

After release, the ball is a projectile governed by its height, angle and speed of release. If the ball is released at a height below the basket, the angle of release will have to be greater than 45º above the horizon. The lower the player is, the greater the angle they will need. Most players who shoot from a ball height of, say 2.2 metres, must release the ball at an angle of about 50º in order for it to pass through the hoop cleanly.

There are two main sets of forces produced here. The first is to project the body off the ground in the jump; and the second is those which are exerted on the ball. The forces in the jump are produced mainly by the hip, knee and ankle extensor muscle groups. In a jump, all the muscle groups are typically fired up together, but because the hip extensors are stronger than the knee extensors, which are stronger than the ankle extensors, we see a sequence of motion starting with the hip movement, progressing to the knee and finishing with ankle extension. These forces need to act upwards through the centre of mass, so that whole-body rotation is NOT produced.

The second group of forces are produced in the shooting arm. Again, since the shot is closer to a push than a throw, and because there is a high level of accuracy required, the muscles of the shoulder, elbow and wrist are all initiated at once. These forces act to increase the speed and determine the direction and angle of projection of the ball, ultimately determining the success of the shot.

These two groups of forces, acting over their respective time periods, produce linear momentum of their objects. The forces on the ground produce linear momentum of the body plus the ball, while the actions of the shoulder, elbow, and wrist produce forward and upward momentum of the ball.

Follow Through Phase

The player needs to land in a balanced position that allows them to prepare immediately for the next action. Landing with a staggered stance and the centre of mass over the base of support enables the player to be balanced on landing, in a position where movement can be executed quickly. Their own safety is an important consideration in landing as
they must avoid other players.

The follow through is largely determined by what happens in the previous phases. The body is also a projectile, the flight of which is governed by the angle and speed at take-off. Any horizontal motion at take-off could result in a collision with another player on landing, as that motion will continue and need to be controlled as the player lands.

The follow through of the wrist and arm will be dependent on the movement of the arm and the elbow position during the preparation and execution phases. Any deviation from the optimum path to the basket during those phases will be transferred to the follow through.

OBSERVATION OF PERFORMANCE

Coaches should observe the control of whole-body movement from the side during the preparatory phase. This is also the best place to observe the jump, since the most common mistake is to jump forwards. It may however, also be useful to view the jump from behind in order to check for uneven leg extension or lateral trunk lean. The arm action in the shot must be assessed from the side, for full extension of the arm, timing of the shot relative to the peak of the jump, and for an appropriate follow through of the arm and hand. It may help to watch the arm action from behind, to examine the arm segment positions and the forces they produce on the ball.

IDENTIFICATION AND EVALUATION OF FAULTS

A flow chart is sometimes useful for identifying and evaluating faults (see Chart 2). One approach is to define what the error was in biomechanical terms, and then work backwards to the possible causes.
For example, suppose the shot is short of the hoop. There are several possible reasons for this and the most likely two are insufficient horizontal ball speed, or a lack of time in the air, which is due to insufficient vertical ball speed.

Horizontal ball speed is affected primarily by the forces exerted by the arms, the angle of release, and the horizontal speed of the body (i.e. is the person jumping forwards or backwards in the shot?). For a specific speed of ball release, a higher angle of release will give lower horizontal speeds. Vertical ball speed is mainly the result of the forces exerted, the angle of ball release (as explained above), and the vertical speed of the body (i.e. was the shooter moving downwards when they released the ball?). All of these factors may result in a shot that falls short of the hoop.

QUESTIONS & EXERCISES

Identify and describe one complex sport movement sequence from your sport, breaking it down into the preparation, execution and follow through phases.

Analyse the movement sequence, applying the biomechanical principles outlined in this module, and following the models presented on the following pages. You should look at:

- *levels of analysis, both qualitative and quantitative,*
- *biomechanical principles involved in each phase of the movement sequence,*
- *observation of performance, i.e. how the movement sequence should be observed in order to identify all of the points noted, and*
- *identification and evaluation of faults, i.e. identify common errors players make when performing this movement sequence, and discuss possible causes and solutions.*

BASKETBALL JUMP SHOT

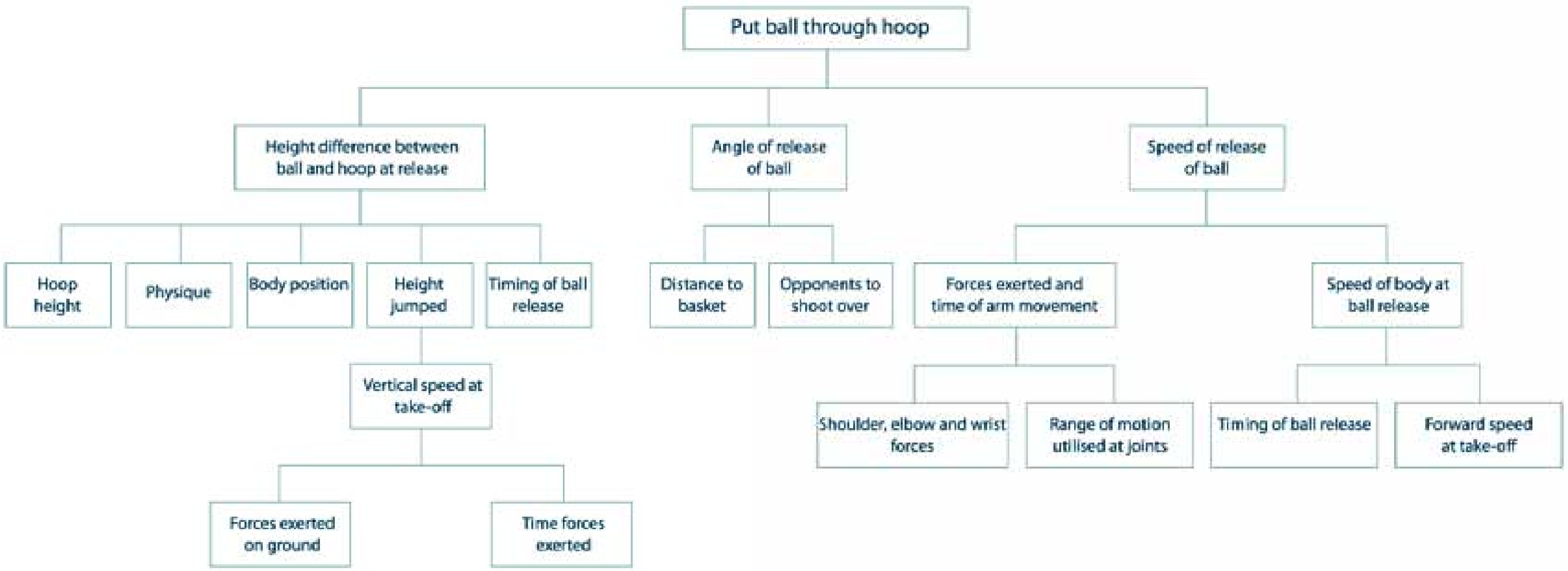


Chart 1. Qualitative model of a basketball jump shot.

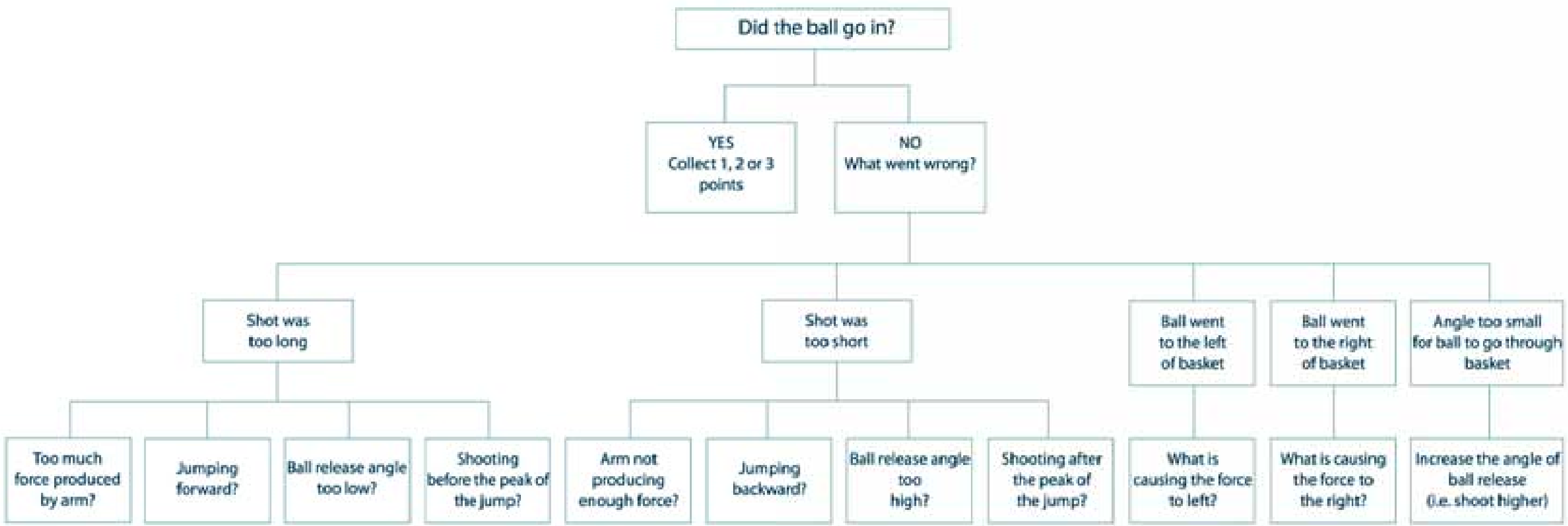


Chart 2. Identification and evaluation of faults.