INTRODUCTION

What were my reasons for choosing the title of this book and the name of this chapter? Well, after teaching, researching and consulting in sports biomechanics for over 30 years, my definition of the term has become, quite simply, ‘the study and analysis of human movement patterns in sport’.

Nothing about ‘the scientific methods of mechanics’ or ‘the effects of various forces’ or ‘Newton’s laws’ or vectors or . . . ? No, nothing like that – just ‘the study and analysis of human movement patterns in sport’. Sounds exciting, doesn’t it? Indeed it is – a wealth of fascination. So, let us begin our journey.

Having offered my definition of sports biomechanics, it becomes obvious what sports biomechanists do – we study and analyse human movement patterns in sport. But why do we do it? Well, the usual reasons are:
To help people perform their chosen sporting activity better. We should note here that this does not just apply to the elite athlete but to any sportsperson who wants to improve his or her performance.

To help reduce the risk of injury.

From a pedagogical perspective, we might add:

To educate new generations of sports biomechanists, coaches and teachers.

And, from a personal viewpoint:

Because it is so fascinating. Yes, it is fascinating, otherwise so many of my generation would not still be doing it. It is also intellectually challenging and personally gratifying – if you can contribute to reducing an athlete’s injury risk or to improving his or her performance, it gives you a warm glow.

Most sports biomechanics textbooks, including the first edition of this one, have strongly reflected the mathematical, engineering or physics backgrounds of their authors and their predominant research culture. Hence, the mechanical focus that is evident, particularly in earlier texts, as well as a strong emphasis on quantitative analysis in sports biomechanics. However, over the last decade or so, the ‘real world’ of sport and exercise outside of academia has generated – from coaches, athletes and other practitioners – an increasing demand for good qualitative movement analysts. Indeed, I will often use the term ‘movement analyst’ instead of ‘sports biomechanist’ to reflect this shift from quantitative to qualitative analysis, and I will broaden the term somewhat, as will be apparent later. So, qualitative analysis is our main focus in this chapter –

### Box 1.1 Learning Outcomes

After reading this chapter you should be able to:

- think enthusiastically about analysing movement patterns in sport
- understand the fundamentals of defining joint movements anatomically
- appreciate the differences – and the similarities – between qualitative and quantitative analysis of sports movements
- describe, from video observation or pictorial sequences, some simple sport and exercise movements, such as walking, running, jumping and throwing
- appreciate why breaking these movements down into phases can help simplify their description and later analysis
- be familiar with finding supplementary information – particularly videos – on the book’s website
- feel enthusiastic about progressing to Chapters 2 and 3.
and the next two. However, everything in these chapters is also relevant for quantitative movement analysts – you cannot be a good quantitative movement analyst without first being a good qualitative analyst.

**DEFINING HUMAN MOVEMENTS**

In this section, we look at how we can define human movements, something to which we will return in more detail in Chapter 6. To specify unambiguously the movements of the human body in sport, exercise and other activities, we need to use an appropriate scientific terminology. Terms such as ‘bending knees’ and ‘raising arms’ are acceptable in everyday language, including when communicating with sport practitioners, but ‘raising arms’ is ambiguous and we should strive for precision. ‘Bending knees’ is often thought to be scientifically unacceptable – a view with which I profoundly disagree as I consider that simplicity is always preferable, particularly in communications with non-scientists. We need to start by establishing the planes in which these movements occur and the axes about which they take place, along with the body postures from which we define these movements. These planes, axes and postures are summarised in Box 1.2.

**BOX 1.2 PLANES AND AXES OF MOVEMENT AND POSTURES FROM WHICH MOVEMENTS ARE DEFINED**

Various terms are used to describe the three mutually perpendicular intersecting planes in which many, although not all, joint movements occur. The common point of intersection of these three planes is most conveniently defined as either the centre of the joint being studied or the centre of mass of the whole human body. In the latter case, the planes are known as cardinal planes – the sagittal, frontal and horizontal planes – as depicted in Figure 1.1 and described below.

Movements at the joints of the human musculoskeletal system are mainly rotational and take place about a line perpendicular to the plane in which they occur. This line is known as an axis of rotation. Three axes – the sagittal, frontal and vertical (longitudinal) – can be defined by the intersection of pairs of the planes of movement, as in Figure 1.1. The main movements about these three axes for a particular joint are flexion and extension about the frontal axis, abduction and adduction about the sagittal axis, and medial and lateral (internal and external) rotation about the vertical (longitudinal) axes.

- The sagittal plane is a vertical plane passing from the rear (posterior) to the front (anterior), dividing the body into left and right halves, as in Figure 1.1(a). It is also known as the anteroposterior plane. Most sport and exercise movements that are almost two-dimensional, such as running and long jumping, take place in this plane.
The frontal plane is also vertical and passes from left to right, dividing the body into posterior and anterior halves, as in Figure 1.1(b). It is also known as the coronal or the mediolateral plane.

The horizontal plane divides the body into top (superior) and bottom (inferior) halves, as in Figure 1.1(c). It is also known as the transverse plane.

The sagittal axis (Figure 1.1(b)) passes horizontally from posterior to anterior and is formed by the intersection of the sagittal and horizontal planes.

The frontal axis (Figure 1.1(a)) passes horizontally from left to right and is formed by the intersection of the frontal and horizontal planes.

The vertical or longitudinal axis (Figure 1.1(c)) passes vertically from inferior to superior and is formed by the intersection of the sagittal and frontal planes.

The movements of body segments are usually defined from the fundamental (Figure 1.2(a)) or anatomical (Figure 1.2(b)) reference postures – or positions – demonstrated by the athlete in Figure 1.2. Note that the fundamental position is similar to a ‘stand to attention’, as is the anatomical position, except that the palms face forwards in the latter.
By and large, this chapter focuses on movements in the sagittal plane about the frontal (or mediolateral) axis of rotation (Figure 1.1(a)). Consider viewing a person side-on, as in Figure 1.3; he bends his elbow and then straightens it. We call these movements flexion and extension, respectively, and they take place in the sagittal plane around the frontal axis of rotation. Flexion is generally a bending movement, with the body segment — in the case of the elbow, the forearm — moving forwards. When the knee flexes, the calf moves backwards. The movements at the ankle joint are called plantar flexion when the foot moves downwards towards the rear of the calf, and dorsiflexion when the foot moves upwards towards the front of the calf.

The movement of the whole arm about the shoulder joint from the anatomical reference position is called flexion, and its return to that position is called extension; the continuation of extension beyond the anatomical reference position is called hyperextension. The same terminology is used to define movements in the sagittal plane for the thigh about the hip joint. These arm and thigh movements are usually defined with respect to the trunk.

Sports biomechanists normally use the convention that the fully extended position of most joints is $180^\circ$; when most joints flex, this angle decreases. Clinical biomechanists tend to use an alternative convention in which a fully extended joint is $0^\circ$, so that flexion increases the joint angle. We will use the former convention throughout
Because the examples of movement patterns that we will study in this chapter are mainly in the sagittal plane, we will leave formal consideration of movements in the other two planes until Chapter 6. The main ones are shown in Box 1.3.

**BOX 1.3 MAIN MOVEMENTS IN OTHER PLANES**

Movements in the frontal plane about a sagittal axis are usually called abduction away from the body and adduction back towards the body, as in Figure 1.4. For some joints, such as the elbow and knee, these movements are not possible, or are very restricted.

Movements in the horizontal plane about a vertical axis are usually called medial (or internal) and lateral (or external) rotation for the limbs, as in Figure 1.5, and rotation to the right or to the left for the trunk. The movements of the whole arm forwards from a 90° abducted position are horizontal flexion in a forwards direction and horizontal extension in a backwards direction, as in Figure 1.6.
Figure 1.4 Abduction and adduction of the arm about the shoulder joint and the thigh about the hip joint.

Figure 1.5 Medial (internal) and lateral (external) rotation of the arm about the shoulder joint.
The website for this book contains many video clips of various people performing some movements that are fundamental to sport and exercise. These people include the young and the old, male and female, who are shown walking, running, jumping and throwing in various conditions. These include: locomotion on a level and inclined treadmill and overground; vertical and broad jumping; underarm, sidearm and overarm throwing; in different footwear and clothing; and with and without skin markers to identify centres of rotation of joints. An in-depth study of these videos is recommended to all readers.

The video sequences shown in the figures below have been extracted from these clips using the qualitative analysis package siliconCOACH™ (siliconCOACH Ltd, Dunedin, New Zealand; http://www.siliconcoach.com).

When analysing any human movement, ask yourself, ‘What are the “constraints” on this movement?’ The constraints can be related to the sports task, the environment or the organism. This ‘constraints-led’ approach serves as a very strong basis from which to develop an understanding of why we observe particular movement patterns. In the video examples and the sequences in the figures below, an environmental constraint might be ‘overground’ or ‘treadmill’ (although this might also be seen as a task constraint). Jumping vertically to achieve maximum height is clearly a task constraint. Organismic constraints are, basically, biomechanical; they relate to a given individual’s body characteristics, which affect their movement responses to the task and environmental constraints. These biomechanical constraints will be affected, among many other things, by genetic make-up, age, biological sex, fitness, injury record and stage of rehabilitation, and pathological conditions. Not surprisingly, the movement patterns observed when one individual performs a specific sports task will rarely be identical to
those of another person; indeed, the movement patterns from repetitions of that task by
the same individual will also vary – this becomes more obvious when we quantitatively
analyse those movements, but can be seen qualitatively in many patterns of movement,
as in Chapter 3. These variable responses, often known as movement variability, can
and do affect the way that movement analysts look at sports movements. The qualita-
tive descriptions in the following sections will not, therefore, apply to every adult, but
will apply to many so-called ‘normals’. The developmental patterns of maturing
children up to a certain age show notable differences from those for an adult, as in
Figures 1.12 and 1.18 below.

A first step in the analysis of a complex motor skill is often to establish the phases
into which the movement can be divided for analysis. For example, the division of a
throwing movement into separate, but linked, phases is useful because of the sheer
complexity of many throwing techniques. The phases of the movement should be
selected so that they have a biomechanically distinct role in the overall movement,
which is different from that of preceding and succeeding phases. Each phase then has a
clearly defined biomechanical function and easily identified phase boundaries, often
called key events. Although phase analysis can help the understanding of movement
patterns, the essential feature of all sports movements is their wholeness; this should
always be borne in mind when undertaking any phase analysis of a movement pattern.

Walking

Walking is a cyclic activity in which one stride follows another in a continuous pattern.
We define a walking stride as being from touchdown of one foot to the next touchdown
of the same foot, or from toe-off to toe-off. In walking, there is a single-support phase,
when one foot is on the ground, and a double-support phase, when both are. The
single-support phase starts with toe-off of one foot and the double-support phase starts
with touchdown of the same foot. The duration of the single-support phase is about
four times that of the double-support phase. Alternatively, we can consider each leg
separately. Each leg then has a stance and support phase, with similar functions to those
in running (see pages 15–23). In normal walking at a person’s preferred speed, the stance
phase for one leg occupies about 60% of the whole cycle and the swing phase around
40% (see, for example, Figure 1.7). In normal walking, the average durations of stance
and swing will be very similar for the left and right sides. In pathological gait, there may
be a pronounced difference between the two sides, leading to arrhythmic gait patterns.

The book’s website contains many video clips of side and rear views of people
walking. These illustrate differences between males and females, between young and
older adults and young children, between overground and treadmill locomotion and at
different speeds and treadmill inclines, and with various types of footwear. Figures 1.7
to 1.12 contain still images from a selection of these video clips. Observing these
figures, you should note, in general, the following patterns of flexion and extension of
the hip, knee and ankle; you should also study the video sequences on the book’s
website to become familiar with identifying these movements on video. The hip flexes
during the swing phase and then begins to extend just before touchdown; extension continues until the heel rises just before toe-off. The hip then starts to flex for the next swing phase, roughly when the other foot touches down. The knee is normally slightly flexed at touchdown and this flexion continues, although not necessarily in slow walking. Some, but not much, extension follows before the knee starts to flex sharply immediately after the heel rises; this flexion continues through toe-off until about
halfway though the swing, when the knee extends again, before flexing slightly just before touchdown. The ankle is roughly in a neutral position at touchdown, as in the reference positions of Figure 1.2. The ankle then plantar flexes until the whole foot is on the ground, when dorsiflexion starts; this continues until the other leg touches down. Plantar flexion then follows almost to toe-off, just before which the ankle dorsiflexes quickly to allow the foot to clear the ground as it swings forwards. As you
should note from Figures 1.7 to 1.12 and from the video clips on the book’s website, this sequence of movements varies somewhat from person to person (see also, for example, Figure 3.11(a)), with the shoes worn, the surface inclination, the walking speed, and between overground and treadmill walking. The movement pattern for a child walking (Figure 1.12) is very different from that of an adult.

So, what would we seek to observe as movement analysts looking at walking patterns
(we would then be functioning as gait analysts)? Differences from this normal pattern, for one, but also right–left side differences, variations across strides, how joint and contralateral limb movements are coordinated, and how external factors, such as changed task or environmental constraints, affect the gait pattern. Video sequences, as in Figures 1.7 to 1.12, are not necessarily the best movement pattern representation for these purposes, as we shall see in Chapter 3.
Figure 1.11 Young male walking on a 20% inclined treadmill at his preferred speed in work shoes. Top left: left foot touchdown (0 s); top right: right foot toe-off (0.16 s); middle left: left foot mid-stance; middle right: right foot touchdown (0.52 s); bottom left: left foot toe-off (0.68 s); bottom right: right foot mid-stance.
Running, like walking, is a cyclic activity; one running stride follows another in a continuous pattern. We define a running stride as being from touchdown of one foot to the next touchdown of the same foot, or from toe-off to toe-off. Unlike walking (see Figure 1.12).
running can basically be divided into a support phase, when one foot is on the ground, and a recovery phase, in which both feet are off the ground. The runner can only apply force to the ground for propulsion during the support phase, which defines that phase’s main biomechanical function and provides the key events that indicate the...
start of the phase, touchdown (or foot strike), and its end, toe-off. The support phase starts at toe-off and ends at touchdown; at this stage, we will consider its function to be to prepare the leg for the next touchdown. In slow running, or jogging, the recovery phase will be very short; it will then increase with running speed.

As for walking, the book’s website also contains many side- and rear-view video

Figure 1.14 Another young female running at her preferred speed in dress shoes. Top left: right foot toe-off (0 s); top right: left foot touchdown (0.14 s); middle left: left foot mid-stance; middle right: left foot toe-off (0.38 s); bottom left: right foot touchdown (0.54 s); bottom right: right foot mid-stance.
clips of people running. These illustrate differences between males and females, between young and older adults and young children, between overground and treadmill locomotion, at different speeds, and with various types of footwear. Figures 1.13 to 1.19 contain still images from a selection of these video clips. Observing these figures, you should note, in general, the following patterns of flexion and extension of the hip, knee and ankle; you should also study the video sequences on the book’s website to become
familiar with identifying these movements on video. The hip continues to extend early in the swing phase, roughly until maximum knee flexion, after which it flexes then begins to extend just before touchdown; extension continues until toe-off. The knee is normally slightly flexed at touchdown and this flexion continues, depending on running speed, to absorb shock, until the hip is roughly over the ankle. Knee extension then proceeds until toe-off, soon after which the knee flexes as the hip continues to extend. The knee starts to extend while the hip is flexing and continues to extend.
almost until touchdown, just before which the knee might flex slightly. The ankle movements (see also, for example, Figure 3.13(b)) vary depending on whether the runner lands on the forefoot or rear foot. The ankle is roughly in a neutral position at touchdown, as in the reference positions of Figure 1.2. For a rear foot runner, in particular, the ankle then plantar flexes slightly until the whole foot is on the ground; dorsiflexion then occurs until mid-stance. The ankle plantar flexes from mid-stance
until toe-off, as the whole support leg lengthens. The ankle then dorsiflexes to a neutral position in the swing phase and plantar flexes slightly just before touchdown. As you should note from Figures 1.13 to 1.19, and from the video clips on the book’s website, this sequence of movements varies somewhat from person to person (see also, for example, Figure 3.11(b)), with the shoes worn, with running speed, and between overground and treadmill running. The movement pattern for a child running (Figure 1.18) is very different from that of an adult.
So, what would we seek to observe as movement analysts looking at running patterns? Differences from this normal pattern, certainly, but also right–left side differences, variations across strides, and how joint movements are coordinated within a limb as well as between legs and with the arm movements. We might also want to look at how external factors, such as changed task or environmental constraints, affect the running pattern. As we also noted for walking, video sequences (as in

Figure 1.19 Young male sprinting in spikes. Top left: left foot toe-off (0 s); top right: right foot touchdown (0.12 s); middle left: right foot mid-stance; middle right: right foot toe-off (0.24 s); bottom left: left foot touchdown (0.38 s); bottom right: left foot mid-stance.
Figures 1.13 to 1.19), are not necessarily the best movement pattern representation for these purposes.

Jumping

Jumps, as well as throws, are often described as ‘ballistic’ movements – movements initiated by muscle activity in one muscle group, continued in a ‘coasting’ period with no muscle activation, and terminated by deceleration by the opposite muscle group or by passive tissue structures, such as ligaments. Many ballistic sports movements can be subdivided biomechanically into three phases: preparation, action and recovery. Each of these phases has specific biomechanical functions. In countermovement jumps from a standing position, such as those in Figures 1.20 to 1.25, the preparation is a lowering phase, which puts the body into an advantageous position for the action (raising) phase and stores elastic energy in the eccentrically contracting (lengthening) muscles. The action phase has a synchronised rather than sequential structure, with all leg joints extending or plantar flexing together. The recovery phase involves both the time in the air and a controlled landing, the latter through eccentric contraction of the leg muscles.
Jumps that involve a run-up, such as the long or high jump, or that have a more complex structure, such as the triple jump, benefit from being divided into more than three phases. In jumps with arm movements, the coordination of the arm actions with those of the legs is very important to performance.
The standing vertical jump

The standing vertical jump looks simple. The extensor muscles of the hips and knees and the plantar flexors of the ankle contract eccentrically to allow the knees and hips to flex and the ankles to dorsiflex simultaneously in the preparation phase. The action phase involves the simultaneous extension of the hips and knees and plantar flexion of the ankles through shortening (concentric) contraction of the muscles that extend or plantar flex these joints and drive the body vertically upwards. This sequence is evident in Figures 1.20 to 1.23. The main difference between the countermovement jump with no arm action in Figure 1.20 and that with a free arm action in Figure 1.21 is that the arm actions in the latter jump, if properly coordinated with those of the legs, will enhance performance of the jump. You should compare Figure 1.21, in which the jumper used his normal arm action, with the simpler arm action in Figure 1.22, based on a simple biomechanical ‘model’, and the uncoordinated arm action in Figure 1.23. The jumper performs as well with the model action as with his normal action, part of which is nearly identical to the model. However, the arm action of Figure 1.23, which is roughly the reverse of the model action, causes a marked decline in jump performance. In the model and normal jumps, the arm and leg movements are well
coordinated, unlike in the abnormal jump, in which the arm and leg movements are poorly coordinated.

In a standing vertical jump, we would first seek to observe coordination of the movements within and between the legs, and of the leg movements with those of the arms. The standing vertical jump is often used as a field test of leg power, so the movement needs to be fast and powerful, as well as coordinated, to result in a successful – and high – jump.

The standing broad, or long, jump

The sequence of movements and the principles of the standing long – or broad – jump are very similar to those of the standing vertical jump. However, as the task is now to jump as far as possible horizontally, the jumper needs to partition effort between the vertical and horizontal aspects of the jump, mainly through forward lean – this somewhat complicates the task. As in the standing vertical jump, the coordinated swing of the arms improves performance, as can be seen by comparing the jump without (Figure 1.24) and with (Figure 1.25) an arm swing. Coordination of all limb actions is again critically important. We would also look for a take-off angle of 35–45° as an
indicator of how well the jumper had partitioned effort between the horizontal and vertical components of the jumps. We could do this by trying to observe the difference between the height of the jumper’s centre of mass – indicated roughly by the height of the hips – at take-off and at landing. The higher the take-off height above the landing height, the smaller the take-off angle should be. If the take-off and landing heights are equal, the optimum angle would be 45° (see also Chapter 4, page 145).
Throwing

This section focuses on the principles of those sports or events in which the participant throws, passes, bowls or shoots an object from the hand or, in the case of lacrosse, from an implement. Some, or all, of these principles relate to: throws from a circle – hammer and discus throws, shot put; crossover skills – javelin throw and cricket bowling; pitching in baseball and softball; shooting and passing movements in basketball, netball, handball, water polo and lacrosse; throwing-to skills – baseball, cricket, soccer, rugby, American and other variants of football; underarm bowling; and dart throwing. Some of these are used as examples in this section. As with other ballistic sports movements, many throws can be subdivided biomechanically into three phases: preparation, action and recovery. Each of these phases has specific biomechanical functions. The later phases depend upon the previous phase or phases. In a basic throw, such as those in Figures 1.26 to 1.28, the preparation phase puts the body into an advantageous position for the action phase and increases the acceleration path of the object to be thrown. In skilled throwers, the action phase demonstrates a sequential action of muscles as segments are recruited into the movement pattern at the correct time. The recovery
phase involves the controlled deceleration of the movement by eccentric contraction of the appropriate muscles. Throws that have a more complex structure, such as the hammer throw (Figure 1.29), or that involve a run-up, such as javelin throwing (Figure 1.30) or cricket bowling (Figure 1.31), benefit from being divided into more than three phases (see also Appendix 2.2 for a phase breakdown of the javelin throw).

Throwing movements are often classified as underarm, overarm or sidearm. The last two of these can be viewed as diagonal movement patterns, in which trunk lateral flexion, the trunk bending sideways, is mainly responsible for determining whether one of these throws is overarm or sidearm. In the overarm pattern, the trunk laterally flexes away from the throwing arm, in a sidearm pattern the trunk laterally flexes towards that arm.

The goal of a throwing movement will generally be distance, accuracy or some combination of the two, acting as a task constraint. The goal is important in determining which of the movement principles discussed in detail in Chapter 2 are more, and which are less, applicable. Some movement analysts distinguish between throw-like movements for distance, in which segmental rotations occur sequentially, and push-like movements for accuracy, in which segmental rotations occur simultaneously. However, few throws in sport have no accuracy requirements. Even those, such as javelin,
discus and hammer throwing and shot putting, in which the distance of the throw is predominant, have to land in a specified area and have rules that constrain the throwing technique. In throws for distance, the release speed – and therefore the force applied to the thrown object – is crucial, a theme to which we will return in Chapter 4.

In some throws, the objective is not to achieve maximal distance: instead, it may be accuracy or minimal time in the air. The latter is particularly important in throws from the outfield in baseball and to the wicketkeeper in cricket. In such throws, the release speed, height and angle need to be such that the flight time is minimised within the accuracy and distance constraints of the throw. In accuracy-dominated skills, such as dart throwing and some passes and set shots in basketball, the release of the object needs to achieve accuracy within the distance constraints of the skill. The interaction of speed and accuracy in these skills is often expressed as the speed–accuracy trade-off. This can be seen, for example, in a basketball shot in which the shooter has to release the ball with both speed and accuracy to pass through the basket.

Figure 1.27 Underarm throw – female bowling a ‘draw’. Top left: starting position; top right: end backswing; bottom left: delivery; bottom right: follow-through.
Underarm throws

Underarm throws with one arm are characterised by the shoulder action, which is predominantly flexion, often from a hyperextended position above the horizontal, as for the fast drive shot in lawn bowling (Figure 1.26) but not for the slower draw shot (Figures 1.27 and 1.28). In the preparation phase, the weight transfers to the rear foot and the front foot steps forwards; this step is often longer for skilled throwers. Weight transfers onto the front foot during the action phase, as the pelvis and trunk rotate to the left (for a right-handed thrower). The elbow extends during the action phase and, at release, the throwing arm is parallel to, or slightly in front of, the line of the trunk. Curling and softball pitching are underarm throws, as are tenpin and various other bowling actions used, for example, in lawn bowling (Figures 1.26 to 1.28), tenpin bowling and skittles. You should study carefully the sequences in Figures 1.26 to 1.28 and the video clips on the book’s website to observe differences between individuals and tasks in underarm throwing, or bowling, patterns (see Study task 7). Video clips of these and other underarm throws, such as the softball pitch and rugby spiral pass (the latter of which is a two-handed throw), are also available on the book’s website.
Sidearm throws

Sidearm throws are sometimes considered to differ from underarm and overarm throws, mainly by restricted action at the shoulder joint. The dominant movement is rotation of the pelvis and trunk with the arm abducted (see Box 1.2) to a position near the horizontal. Unlike the other two throwing patterns, in which the movements are mainly in the sagittal, or a diagonal, plane, frontal plane movements dominate in sidearm throws. The discus throw and some shots in handball are of this type. The hammer
throw (Figure 1.29) is probably best characterised as a sidearm throw rather than an underarm throw.

**Overarm throws**

Overarm throws are normally characterised by external rotation (see Box 1.2) of the upper arm in the preparation phase and by its internal rotation in the action phase.
These movements are among the fastest joint rotations in the human body. Many of the other joint movements are similar to those of the underarm throw. The sequence of movements in the preparation phase of a baseball pitch, for example, include (for a right-handed pitcher), pelvic and trunk rotation to the right, horizontal extension and lateral rotation at the shoulder, elbow flexion and wrist hyperextension. These movements are followed, sequentially, by their anatomical opposite at each of the joints mentioned plus internal rotation of the forearm, also known as pronation.
Baseball pitching, javelin throwing (Figure 1.30), throwing from the outfield in cricket and passing in American football are classic examples of one-arm overarm throws. The mass (inertia) and dimensions of the thrown object – plus the size of the target area and the rules of the particular sport – are constraints on the movement pattern of any throw. Bowling in cricket (Figure 1.31) differs from other overarm throwing patterns, as the rules restrict elbow straightening (extension) during the latter part of the delivery stride. The predominant action at the shoulder is, therefore, circumduction – a combination of shoulder flexion, extension, abduction and adduction.

The soccer throw-in uses a two-handed overarm throwing pattern. The shot put combines overarm throwing with a pushing movement, because of the event’s rules and the mass of the shot. Basketball shooting uses various modifications to the overarm throwing pattern, depending on the rules of the game and the circumstances and position of the shot – including release speed and accuracy requirements. Passing in basketball, in which accuracy is also crucial, varies from the overarm patterns of the overhead and baseball passes to the highly modified pushing action of the chest pass. In dart throwing, the dominant requirement for accuracy restricts movements in the action phase to elbow extension with some shoulder flexion–abduction.

You should study carefully the video clips of the different individuals on the book’s website to observe differences in their overarm throwing patterns (see Study task 7).

MOVEMENT PATTERNS

Most of you (readers of this book) will be undergraduate students in the earlier stages of your career. You will be familiar with human movement patterns from sport – when viewed live, or as a performer, coach or spectator – whether these are movement patterns of individuals or of teams as a whole. An example for an individual sport can be presented as a sequence of still video frames, as in Figures 1.7 to 1.31; most packages for qualitative video analysis make it easy to observe, and to compare, such movement patterns.

Video recordings, still video sequences, and player tracking patterns in games are probably the most complex representations of sports movements that you will come across. It is only your familiarity with sports videos that enables you to understand such patterns – watch a video of a game or sporting activity for which you do not know the rules (environmental and task constraints), and the complexity of video representations of movement patterns becomes obvious. This is true not only for the movements of the segments of the body of one performer, which sports biomechanists generally focus on, but also for the movement patterns of the players as a team. Sequences of still video frames are rarely used in analysing player movements and interactions in team games, such as rugby, netball and soccer, or in individual vs individual games, such as squash or table tennis. To understand why, imagine tracking (using the Global Positioning System, for example), just a single point on each player in one extended squash rally or, worst still, for each player in a soccer team for just 10 minutes of play. The resulting
movement patterns would not be easy to analyse at first sight. Such movement patterns in games will not be considered further in this book – sports biomechanists, to date, have rarely been involved in analysing such movement patterns.

To appreciate why I say that video recordings are complex, did you find it easy to follow all the flexion and extension descriptions for walking and running in the previous section? Could you easily perceive within-leg and between-leg coordination patterns in walking, or arm and leg coordination patterns in running, using the sequences above or videos from the book’s website? If your answers to these questions are a resounding ‘YES’, then you are already a talented qualitative movement analyst!

Many of us struggle at times to extract what we want from video or from selected video picture sequences; for one thing they contain so much information that is irrelevant to the patterns the movement analyst wishes to observe. So, what alternative representations of a movement are available, not only to the quantitative analyst but also to the qualitative analyst? We will answer this important question in Chapter 3.

**COMPARISON OF QUALITATIVE AND QUANTITATIVE MOVEMENT ANALYSIS**

Sports biomechanists use two main approaches to analysing human movement patterns in sport – qualitative and quantitative analysis. The previous section focused on qualitative analysis. A third approach fits somewhere between the two and is often known as semi-quantitative analysis. These approaches will be developed and explained more fully in later chapters, but here I give a bullet-pointed outline of each, focusing on the two main approaches, including why they are used and by whom, as well as some advantages and drawbacks of each.

**Qualitative analysis**

**What do we use for this?**

- Video recording or observation.
- Other movement pattern representations, such as graphs (see Chapter 3), focusing on their patterns, not their quantification.
- Qualitative analysis software packages, such as siliconCOACH™.

**Who uses this?**

- Teachers, coaches, athletes, physiotherapists, gait analysts, and judges of ‘artistic’ sports, such as ice dance and gymnastics.
- ‘Performance analysts’ working with athletes and others.
- Movement coordination researchers (this one might surprise you, but it shouldn’t once you have read Chapter 3).
Why is it used?

- To differentiate between individuals or teams.
- To improve movement or performance, as in gait analysis and video analysis.
- To provide qualitative feedback.

Semi-quantitative analysis

What do we use for this?

- Mostly as for qualitative analysis plus some simple measurements such as:
  - joint ranges of motion
  - durations of sub-phases of the movement, such as the stance and support phases in running, and their ratios to the overall movement time
  - distances, such as stride length
  - joint angles at key times, such as knee angle at take-off for a jump
  - notation – goals scored, passes, etc.

Who uses this?

- Pretty much as for qualitative analysis excluding, perhaps, teachers.

Why is it used?

- Pretty much as for qualitative analysis, but when comparisons are more important.
- Scaling aspects of a performance; for example, poor to excellent on a 1–5 point scale.

Quantitative analysis

What do we use for this?

- Image-based motion analysis, mostly using video (see Chapter 4) or automatic marker-tracking systems plus, when occasion demands, electromyography (see Chapter 6) and force or pressure plates or insoles (see Chapter 5).
- Statistical modelling of technique or of movement patterns in games, artificial intelligence, computer simulation modelling.
- Quantitative movement analysis and notational analysis software packages.

Who uses this?

- Mainly researchers.
Why is this used?

- To aid performance comparisons.
- To predict injury risk.
- To provide quantitative feedback.

Qualitative vs quantitative analysis

- Qualitative analysis describes and analyses movements non-numerically, by seeing movements as ‘patterns’, while quantitative analysis describes and analyses movement numerically.
- Quantitative analysis can sometimes appear more objective because of its ‘data’; however the accuracy and reliability of such data can be very suspect, particularly when obtained in competition.
- Qualitative analysis is often more strongly rooted in a structured and multidisciplinary approach, whereas quantitative analysis can appear to lack a theoretical grounding and to be data-driven.

Background to qualitative analysis

To be objective and scientific, qualitative analysis needs to use a structured approach, moving from preparation, through observation, diagnosis–evaluation, to intervention (and review) – this approach will be explained fully in Chapter 2. From the outset, the movement analyst should involve the coach, or whoever commissioned the analysis, in a ‘needs analysis’, and should keep the coach in the loop at all stages. Qualitative analysis requires applying basic biomechanical principles to the movement. We need to know what to observe; coaches have important knowledge and contributions to make here too.

Qualitative analysts need an excellent grasp of the techniques – or movement interactions – in a specific sport or exercise; coaches have great depth and breadth of that knowledge. Deterministic models (see Chapter 2) can give a theoretical basis to the analysis, which can otherwise become discursive. This modelling approach can be represented graphically so as to be coach-friendly.

Good-quality digital video cameras are needed, with adequate frame rates and shutter speeds. This equipment is familiar to coaches and extra equipment is rarely necessary. Qualitative analysis should uncover the major faults in an unsuccessful performance by an individual or a team; it is the approach actually used by most coaches and teachers.
**Strengths and weaknesses of qualitative analysis**

**Strengths**
- No expensive equipment (digital video cameras).
- Field-based not laboratory-based, which enhances ecological validity.
- When done properly, it is highly systematic.
- Movement patterns speak far more loudly than numbers – remember the cliché, a picture is worth a thousand words.
- Coach-friendly.

**Weaknesses**
- Apparent lack of ‘data’ (but is this really such a weakness?).
- Need for considerable knowledge of movement by analysts.
- Reliability and objectivity are questionable and often difficult to assess; observer bias.

**Background to quantitative analysis**

Mathematical models based on biophysical laws can give a sound theoretical basis to the analysis, which can otherwise become data-driven; most of these models are too far removed from coaching to be of practical use. Good quantitative analysts need a sound grasp of techniques or movement interactions involved in a specific activity, as do good qualitative analysts. However, not all quantitative analysis follows this principle, which might make much of their work dubious in a practical context.

A quantitative analyst needs to decide upfront the measurement techniques and methods to obtain the information required. Careful attention should be paid to what to measure, research design, data analysis, validity and reliability.

**Strengths and weaknesses of quantitative analysis**

**Strengths**
- Lots of biomechanical data (but is this really a strength?).
- Reliability and objectivity can be easily assessed, even if they rarely are.

**Weaknesses**
- Expensive equipment and software; user requires technical skills.
- Often laboratory- and not field-based, which reduces ecological validity.
- Apparent lack of a theoretical basis.
- When done badly, which it often is, it is highly non-systematic.
• Need for careful data management, as there’s so much information available.
• Not coach-friendly.

**SUMMARY**

We started this chapter by outlining a novel approach to sports biomechanics and establishing that our focus in this chapter would be the qualitative analysis of human movement patterns in sport. We defined movements in the sagittal plane and touched on those in the frontal and horizontal planes. We then considered the constraints-led approach to studying human movements, and went on to look at examples of walking, running, jumping and throwing, including the subdivision of these fundamental movements into phases. In these movements, we compared movement patterns between ages, sexes, footwear, inclines and tasks. We then compared qualitative and quantitative analysis, looking at their background, uses, and strengths and weaknesses.

**STUDY TASKS**

1. Name and sketch the movements at the hip, knee and ankle in the sagittal plane, as observed, for example, in walking, running and jumping.
   Hint: You may wish to reread the section on ‘Defining human movements’ (pages 3–6) and watch several video clips of walking and running on the book’s website before undertaking this task.

2. Name, and illustrate, the movements about the shoulder in all three planes as might be observed, for example, in overarm throwing.
   Hint: You may wish to reread the section on ‘Defining human movements’ (pages 3–6) and the subsection on ‘Overarm throws’ (pages 33–5), and watch several video clips of throwing on the book’s website before undertaking this task.

3. Outline the phases into which running and walking are most simply divided. Give one important role of each phase for each activity. What distinguishes walking from running?
   Hint: You may wish to reread the subsections on ‘Walking’ (pages 9–15) and ‘Running’ (pages 15–23) and watch several video clips of walking and running on the book’s website before undertaking this task.

4. Download a walk-to-run transition sequence from the book’s website. For each of the five speeds in the sequence calculate, by counting frames and division:
   (i) The ratios of the durations of the single-support to double-support phases and of both these phases to the overall stride time in walking.
   (ii) The ratios of the no-support to the single-support phases and of both these phases to the overall stride time in running.
Explain the changes in these ratios through the sequence from slow walking to fast running.

Hint: You may wish to reread the subsections on ‘Walking’ (pages 9–15) and ‘Running’ (pages 15–23) before undertaking this task.

5 Download the video sequences for the four standing vertical jumps and two standing long jumps for the young male from the book’s website. Try to explain why the height and distance jumped are affected by the use of the arms.

Hint: You may wish to reread the subsection on ‘Jumping’ (pages 23–8) before undertaking this task.

6 Outline the three phases into which a throw is usually divided. What is the main function of each phase?

Hint: You may wish to reread the subsection on ‘Throwing’ (pages 28–35) before undertaking this task.

7 Download a series of video sequences from the book’s website of various underarm, sidearm or overarm throwing movements by different people. Note and try to explain the differences between them.

Hint: You may wish to reread the subsection on ‘Throwing’ (pages 28–35) before undertaking this task.

8 Outline the advantages and disadvantages of qualitative and quantitative movement analysis and explain in what circumstances one would be preferred over the other.

Hint: You may wish to reread the section on ‘Comparison of qualitative and quantitative movement analysis’ (pages 36–40) before undertaking this task.

You should also answer the multiple choice questions for Chapter 1 on the book’s website.

GLOSSARY OF IMPORTANT TERMS (compiled by Dr Melanie Bussey)

**Axes** The imaginary lines of a reference system along which position is measured.

**Axis of rotation** An imaginary line about which a body or segment rotates.

**Ballistic** Rapid movements initiated by muscular contraction but continued by momentum.

**Countermovement** A movement made in the direction opposite to that of the desired direction of motion – as in a countermovement jump.

**Pathological movement** An exceptionally (or awkwardly or inconveniently) and atypical example of movement usually linked to an underlying anatomical or physiological cause, such as injury or disease.

**Plane of motion** A two-dimensional plane running through an object. Motion occurs in the plane or parallel to it. Motion in the plane is often called planar.

**Reference system** A system of coordinates used to locate a point in space.

**Reliability** The consistency of a set of measurements or measuring instrument.

**Spatial** Refers to a set of planes and **axes** defined in three-dimensional space.
Hay, J.C. (1993) *The Biomechanics of Sports Techniques*, Englewood Cliffs, NJ: Prentice Hall. This well-regarded book by the late Dr James Hay was the first biomechanics text to influence my approach to the discipline some 30 years ago. He takes a typically mechanistic approach to biomechanics, but it is one of the easiest such texts for a student to follow. Read the sports chapters that interest you, as these are the greatest strength of the book – has any other biomechanics author had such knowledge and insight into so many sports movements?