CHAPTER 9

The Science of Biomechanics

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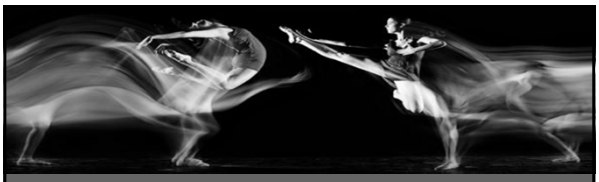
THE SCIENCE OF BIOMECHANICS

- Study of internal and external forces acting on human body and their effects
- Relatively young
- Extremely diverse and multifaceted
- Contributes significantly to our knowledge of human movement



TYPES OF STUDY

- **Quantitative versus Qualitative Analysis**
- **Kinematics Versus Kinetics**

QUANTITATIVE VS. QUALITATIVE ANALYSIS

- Depends on
  - Environment
  - Availability of high-tech equipment

QUANTITATIVE ANALYSIS

- Using high-tech instrumentation
- Usually intended for researchers
- Measuring variables to optimize athletic performance
  - Foot forces on sprinter's blog
  - Muscle contraction sequence during running
  - 3-D body segment movements during a high jump




FOCUS ON TECHNOLOGY

Measurement Technology in Practice

Force Platforms

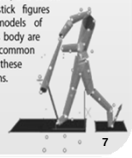
Force platforms are special computerized biomechanical instruments that measure the forces generated on the ground by athletes performing athletic skills. The devices are firmly secured to the floor to eliminate any vibrations. As an athlete stands, lands, or steps on the platform during a skilled performance, three-dimensional (3-D) force data are generated that reveal forces in the vertical, anteroposterior, and mediolateral directions. Force–time graphs are created that enable the biomechanist to analyze force patterns generated by the athlete and reveal performance faults.

Electromyography

Electromyography (EMG) measures and records the electrical activity generated by the muscles as they are stimulated by the athlete's nervous system. In this procedure the electrodes are placed either on the skin (surface EMG) or directly into the muscle (indwelling EMG). The system records the electrical processes of the contracting muscles and determines their timing (onset and duration of the contraction) during performance.

Computerized Motion Analysis

Computerized motion analysis systems allow multiple forms of biomechanical instrumentation to be synchronized for more sophisticated collection of data from athletic performance. The system generates synchronized data related to the athlete's body positions, joint angles, movement speeds, accelerations, forces, torques, and so on. Animated stick figures and 3-D models of the athlete's body are the most common results of these investigations.



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QUALITATIVE ANALYSIS

- Using sight and hearing
- Usually done by coaches and teachers
- To identify and correct errors: **"Observe, analyze and correct."**
- Requires framework and a set of principles

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KINEMATIC VS. KINETICS

- Two ways to describe human motion

1. Without reference to forces causing motion
2. Describing motion in terms of forces that cause it

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KINEMATICS

- Describing human motion without its forces
- Focusing on motion's spatial and timing characteristics
- Measurements:
  - **Time**
  - **Displacement**
  - **Velocity**
  - **Acceleration**

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KINETICS

- Describing forces leading to motion
- **Internal forces**
  - Muscles pulling on bones
  - Bone-on-bone, inside joints
- **External forces** acting on the body
  - Without contact (e.g., gravity)
  - From contact with ground, opponent or equipment

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MODELS OF HUMAN MOTION

- Understanding and observing human movements is complex
- All body tissues undergo shape deformation
- Most movements occur in three dimensions
- 3 models, simplify the study of human movements:
  - **Particle model**
  - **Stick figure model**
  - **Rigid body segment model**

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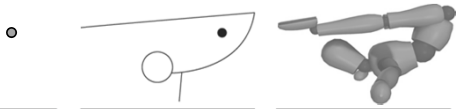


Particle Model	Stick Figure Model	Rigid Body Segment Model
• Dot represents centre of mass • Used when body or object is airborne and in flight • i.e., projectile motion	• Body segments = sticks • Used when body in contact with other objects • Describe gross motor skills in 2-D	• Body segments = irregular 3-D volume • Used for sophisticated 3-D analyses • Includes shape deformation of body segments

Centre of Mass

The point around which the body's mass is equally distributed in all directions is known as the centre of mass, or centre of gravity (CG). The CG of a perfectly symmetrical object of homogeneous density is at the exact centre of the object. For example, the CG of a bowling ball or golf ball is at its geometric centre. If the object is a homogeneous ring (such as a ringette ring), the CG is located in the hollow centre of the ring.

However, your centre of mass is not always found inside the body (as in the case of the figure skater). In general it is located about 15 cm above the groin area at approximately 55 percent of standing height in females and 57 percent in males, which means females generally have a lower centre of gravity than males.

The location of the CG in the human body is of interest because a body behaves as though all of its mass were concentrated at the CG. Therefore, the force of gravity acting on this point of mass would be the same as the force of gravity acting on the total body. Or when the human body acts as a projectile, as in a long jump, the body's CG follows a parabolic trajectory, regardless of what the various segments of the body do while in the air.

MOTION CONCEPTS

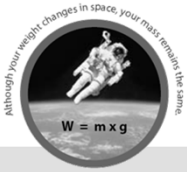
- **Mass, Gravity, and Inertia**
- **Types of Motion**
- **Causes of Motion**
- **Lever Systems and Motion Mechanics**

MASS, GRAVITY, INERTIA

Mass
- Amount of matter in an object
- Objects are reluctant to go change state of motion
- A measure of inertia

Moment of Inertia
- Reluctance of rotating object to change state of motion
- Depends on mass and its distribution around axis of rotation

Gravity
- Force of attraction between two bodies
- E.g., human body and planet earth



WEIGHT VERSUS MASS

There is a difference between mass (m) and weight (W). **Mass** is a measure of inertia, while **weight** is a measure of the force of **gravity** (g) acting on the body. Mass is measured in kilograms (kg), while weight is measured in Newtons (N). A person's weight varies directly with the magnitude of the acceleration due to gravity (9.8 m/s^2). Thus in space where there is no acceleration experienced due to gravity we weigh 0 N but have the same mass as we do on earth.

FOCUS ON TECHNOLOGY

Keep Your Eye on the "Smart" Ball

After many years of research and development, a major sporting goods manufacturer has unveiled the Smart Ball – a regulation-size soccer ball fitted with two data-collecting sensors, an accelerometer and a magnetometer. The sensors are designed to track the ball's trajectory, spin rates and angles, contact point, launch speed, and bend of flight. The flight characteristics, touch, and bounce of the Smart Ball are indistinguishable from those of traditional balls. The wide range of data provided through Bluetooth enables coaches to make real-time and objective analyses of player performance during training. Tracking such elements of performance helps players refine their games to a greater degree than ever before.

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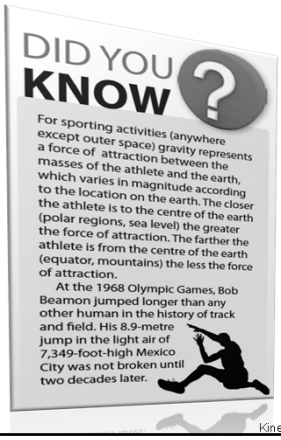

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TYPES OF MOTION

- Human movement composed of a number of fundamental types of motion:
  - **Linear motion / translation**
  - **Angular motion / rotation**
  - **General motion**

- All body parts move same distance and direction, at the same time
- **Translation**: linear motion of the whole body

Linear motion

- Body moves on a circular path and rotates about axis of rotation
- Body segments rotate about their joints
- E.g., twisting somersault

Angular motion

General motion

- Body / segments move linearly and rotate at the same time
- True for most athletic and every day activities
- E.g., gymnastics floor routine, diver falling downward and at the same time rotating in a somersault

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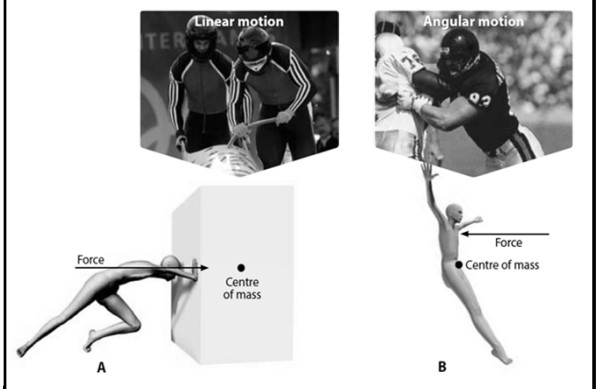
Causes of Motion

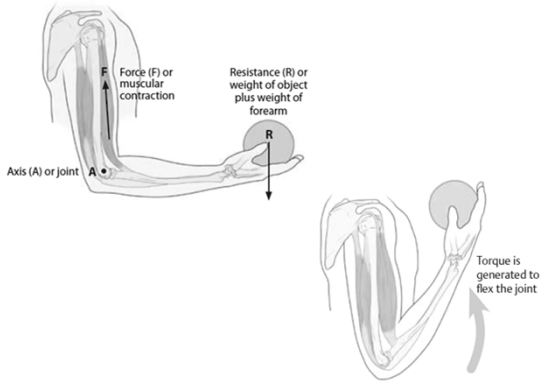
- Application of internal or external forces
- Force is any action, push or pull, that tends to cause an object to change is state of motion by experiencing acceleration or as state of constant velocity
- **Linear motion** = force acting on centre of mass/ pivot point
- **Angular motion** = force not acting on centre of mass/ pivot point and result in torque (**moment of force**)



Lever systems and Motion Mechanics

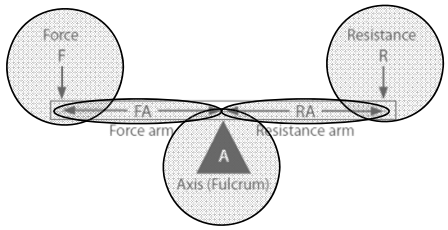
Lever system

- Mechanical device performing angular motion
- Components:
  - Axis of rotation
  - Fulcrum (pivot)
  - Lever attached to fulcrum
- Human muscles, bones and joint work together as lever systems



How Do Levers Work

- Force is applied and if greater than resistance
- Rotation at the axis / fulcrum occurs
- To determine force amount, consider the length of **force arm** and **resistance arm**



How Do Levers Work

- When lever rotate around and axis / fulcrum:
  - Moment of force or torque is produced
- How much torque occurs?

Torque = Force arm x Force

- Therefore, with a **longer force arm**:
  - **Less force** is needed
  - **Greater torque** is produced

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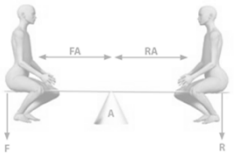
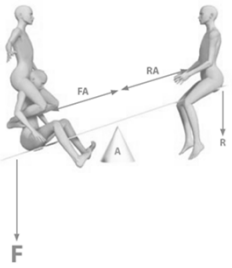
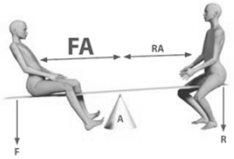
No rotation: F=R, FA=RA



Rotation: **F>R**, FA=RA



Rotation: F=R, **FA>RA**

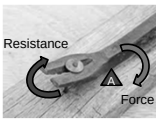


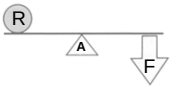
Types of Levers

- Levers perform different functions
- Three basic types of lever exist
  - **First class**
  - **Second class**
  - **Third class**
- Differ based on mechanics and how these components are positioned
  - Axis
  - Resistance
  - Force

First Class Levers

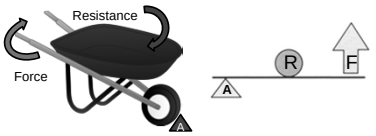
- Applied force and resistance on opposite side of axis, at un/equal distance from one another
- Example: crowbar
- Human body: head flexion

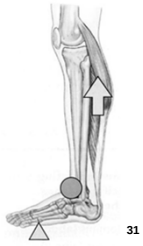




Second Class Levers

- Applied force and resistance on same side of axis; resistance closer to axis
- Example: wheelbarrow
- Human body - hard to find: toe raise





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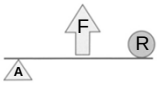
Third Class Levers

- Applied force and resistance on same side of axis; force closer to the axis
- Example: fishing
- Human body – many: forearm flexion



AS EASY AS 1, 2, 3 . . .

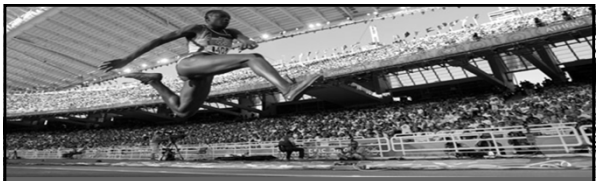
The acronym **ARF** helps us remember the arrangement of the axis (A), resistance (R), and force (F) for each of the three lever systems. A is associated with a first class lever and is positioned between the resistance and the force (**RAF**); R is associated with a second class lever and is positioned between the axis and the force (**ARF**); and F is associated with a third class lever and is positioned between the axis and the resistance (**AFR**). All you need to do is remember which component is positioned in the middle!

Your Levers at Work

Most third class lever systems in the human body sacrifice mechanical advantage for speed, which means we are generally built more for speed than for strength. Throwing and running are two examples of how the body's musculoskeletal lever systems can work together to generate explosive, coordinated movements.

The throwing motion is a coordinated sequence of body positions and movements that progress from the largest muscle groups and body segments to the smallest. The pelvis, trunk, shoulder girdle, arm, forearm, and hand each operate as separate lever systems around the hip, intervertebral, sternoclavicular, shoulder, elbow, radioulnar, and wrist joints. Multiple movements occur concurrently at several of these joints during the throwing motion.

Running gait is also an example of a rotating third class lever system. During running, our legs and each leg segment rotate about a joint axis (the hip, the knee, and the ankle). The lever at each of these joints is considered third class because the muscle attachments at each joint are very proximal to the respective axis of rotation, and the resistance to move the joints is farther away.



Newton's Laws of Motion

- **Law of Inertia**
- **Law of Acceleration**
- **Law of Action–Reaction**

Sir Isaac Newton

- 300 years ago
- Explained effect of forces acting on an object
- Through 3 laws

LAW OF INERTIA

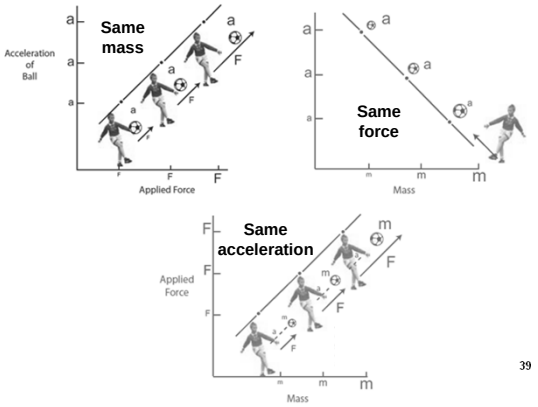
Newton's First Law

"Objects will not change their state of motion unless acted on by an unbalanced external force"

LAW OF ACCELERATION

Newton's Second Law

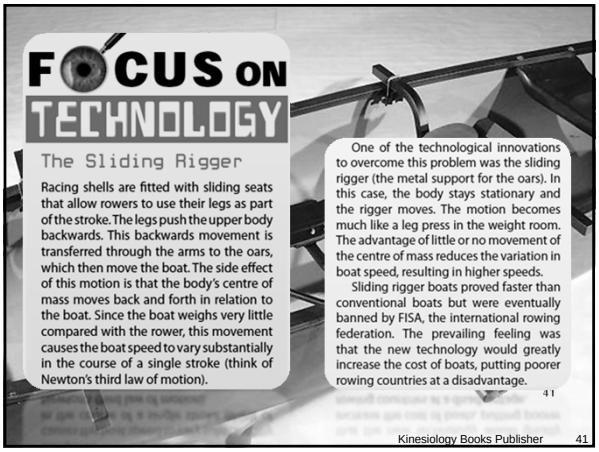
"Objects will experience a change in velocity or acceleration proportional to the unbalanced external force"



LAW OF ACTION-REACTION

Newton's Third Law

"For every action there is an equal and opposite reaction; forces act in pairs that are equal in magnitude and opposite in direction"

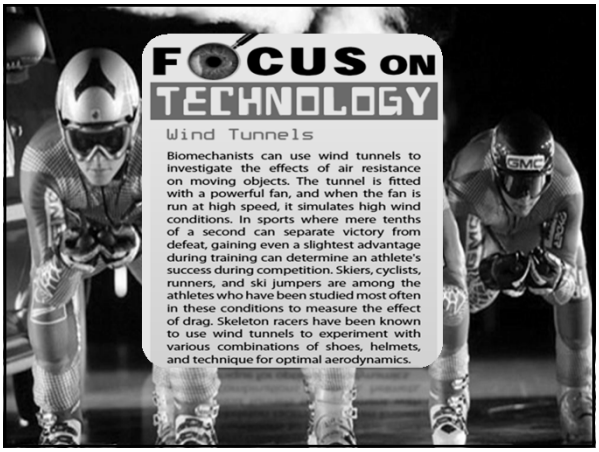


FLUID DYNAMICS

- **Fluid Drag Forces: The Dynamics of Air**

Fluid Dynamics

- Knowledge of the forces generated by a fluid environment such as
  - **Water**
  - **Air**
  - **Water + Air**
- All athletic event take place in a fluid environment
- **Unaffected**: gymnastics, dancing
- **Affected**: running, cycling, skiing, speed skating, swimming, badminton, baseball, etc.

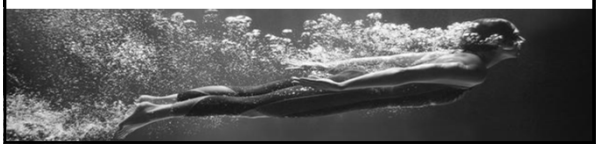


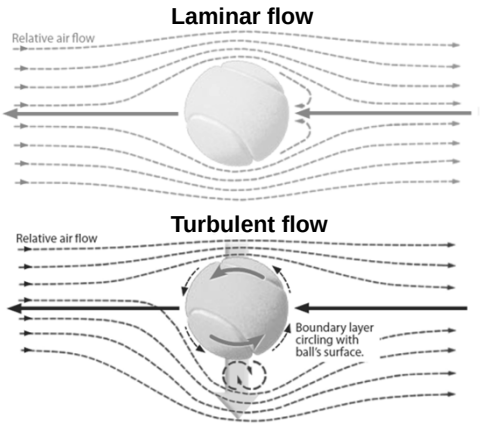
Drag Forces: Air

- **Drag** is a type of fluid force
- **Profile drag**: caused by object's size and shape
- **Surface drag**: cause by object's roughness
- Acts in opposite direction to body's travel and slows it down relative to body's
  - Velocity
  - Size and shape
  - Roughness
- Fast-speed sports especially affected
  - ↑ velocity = ↑ drag^2 (10x faster, 100 x more drag)

SURFACE DRAG

- Body size and surface roughness = surface drag
- **Boundary layer**
  - Thin layer of fluid adjacent to skin and carried along with body's motion, towing along outer fluid layers
- **Laminar flow**
  - Small, streamlined, smooth, slow-moving bodies
  - Smooth, layered flow pattern with no disturbance
- **Turbulent flow**
  - Most human activities
  - Disturbed flow pattern that changes flow conditions





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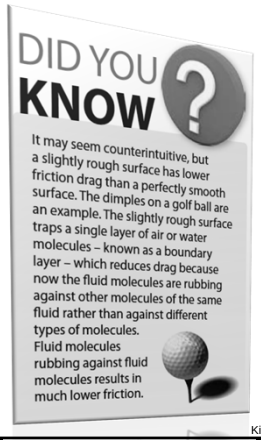

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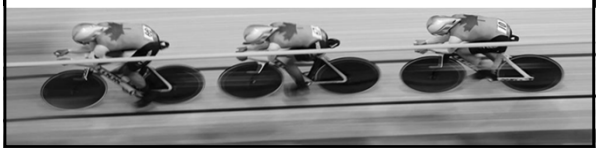
PROFILE DRAG

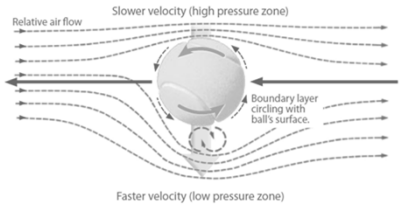
- Main form of drag in fast-moving sports
- Characterized by **turbulent flow**
  - Velocity of air flow past object is too fast for air to follow body's contour
  - Backflow occurs at object's surface causing large, turbulent low-pressure zone behind the body
  - This zone is continually formed and increases object's work
- Profile drag-reducing strategies
  - ↓ frontal surface area (e.g., lugers are supine)
  - ↓ sources of turbulence (e.g., speed skaters with arms behind back)
  - **Drafting**



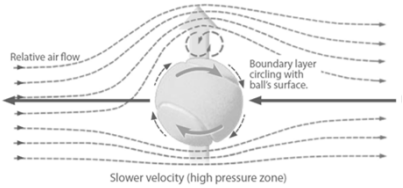
MAGNUS EFFECT

- A rotating body carries a boundary layer that interacts with surrounding air
- Boundary layer flow opposite to relative airflow
  - Air is slowed by friction
  - Zone of increased pressure created
- Boundary layer flow same as relative airflow
  - Air is not slowed down
  - Zone of increased pressure created
- Net difference in pressure on opposite sides of rotating object = **Magnus force**
- **Magnus effect** is mostly found in ping pong, tennis, soccer, and baseball

Top spin: downwards Magnus force



Back spin: upwards Magnus force



WHY A CURVEBALL CURVES

The pitcher holds the index and middle fingers close together along the seams of the ball and twists the hand while releasing the ball to give it a very fast spin (approximately 1,800 revolutions per minute). The ball revolves 15 times in the less than 1/2 second it takes to reach the plate. The ball's 108 stitches pull a thin layer of air with them as they spin. That layer makes the air on the bottom of the ball flow faster than the air at the top of the ball, which produces the curve ball (i.e., Magnus effect). Split finger fastballs, sliders, and screw balls all rely on different kinds of spin – and the Magnus effect – to change direction.

BODY BALANCE AND STABILITY CONTROL

- **Equilibrium**
- **Balance**
- **Stability**

EQUILIBRIUM

- **Equilibrium** is a state of a system **not** experiencing change in direction and speed
- **Static equilibrium**: body's at rest
- **Dynamic equilibrium**: body's moving at constant velocity

BALANCE

- Balance: process where body's equilibrium is controlled for a purpose
- Affected by two factors:

1. **Base of support**, area of contact between body and surface
   - Wider base, greater balance
2. Location of **line of gravity**, imagery vertical line that passes through centre of mass
   - Has to pass through base of support for balance

STABILITY

- Stability is a measure of the difficulty with which equilibrium can be disturbed
- Net internal force required to overcome static or dynamic equilibrium
- During critical performance times there is a trade-off between maximizing stability and acquiring speed

↑Stability
Static Equilibrium

↑ base size	↑ body size	Lower centre of gravity	↑ distance between gravity line intersecting base and outside base edge

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↑Stability
Dynamic Equilibrium

Widen base towards oncoming external horizontal force	Move centre of gravity towards base edge during quick acceleration	Shift centre of gravity towards oncoming force	Use reflex movement to regain loss of balance

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MAINTAINING A BALANCED ATTACK

In judo and wrestling, athletes must be aware of the danger of shifting their centre of gravity too close to the perimeter of their base of support. Both competitors may be pushing and leaning into each other. However, if one athlete suddenly stops pushing and instead pulls hard, the opponent may find her centre of gravity suddenly outside her base of support – her own push has suddenly been increased by the addition of the opponent's pull – putting her in danger of being thrown.

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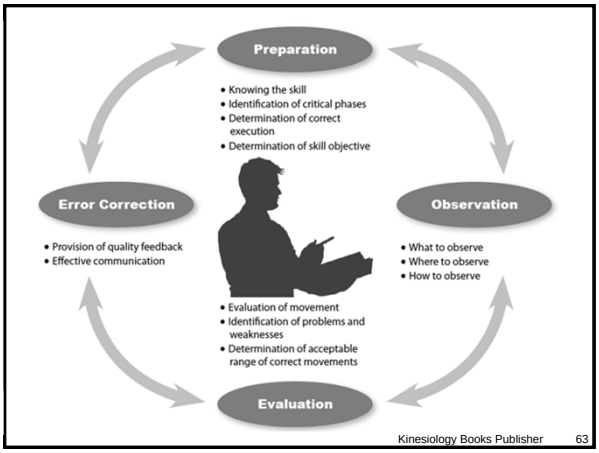
Qualitative Analysis of Human Motion

- **Skill Objective**
- **Analyzing a Skill**
- **Observation of Performance**
- **Error Detection and Correction**

Qualitative Analysis

- Subjective yet systematic evaluation of human motion without measuring and using numbers
- Based on visual observation or video recording
- Allows discovery of movement tendencies and generates immediate and specific feedback
- Depends on coach's understanding of skill
- Based on a model integrating 4 aspects of quality instruction



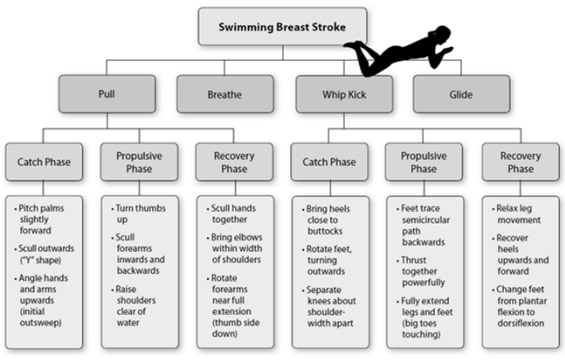
Skill Objective

- Can be described and identified for all skills
  - E.g., blocking a lineman
- Secondary objectives may exist, referring to speed or accuracy required
- Skills with similar overall objectives are governed by similar biomechanical principles
  - Throwing, striking, kicking object for maximal horizontal surface

Analyzing Skill

Dividing skill into phases
- Should make sense to the coach and how the skill is being defined and taught

Identifying key movements for each phase
- Their execution determines successful accomplishment of biomechanical purpose of the phase and overall performance of the skill

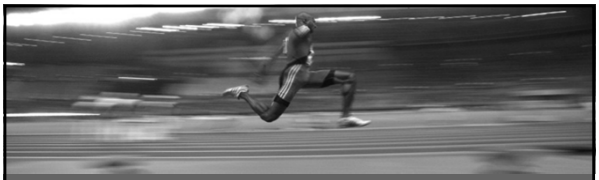


Observation of Performance

- Difficult task because of skill speed
- Observation plan beforehand identifies what, why, where and how observation will occur
- Coaches must use vision (dominant), hearing and feeling as well as look for tracks and traces
- Confirm observation accuracy with athlete and video recording (if possible)

Error Detection and Correction

- Error sources
  - Mental: concentration lapse or fear
  - Physical: lack of strength, poor habits
- Detection is visual via direct observation video analysis, or traces/marks observation
- Correction
  - Should keep in mind athlete's physical and mental abilities, competition level, age and development level
  - Verbal, demonstration, video
  - Ongoing; 1-2 errors at a time starting with earlier



Putting It All Together

- Biomechanics is the physics of human movement with the main goal to optimize performance by focusing on movement kinematics and kinetics
- Motion results from internal and external forces in ways that can be understood via Newton's laws
- Fluid affects athletic performance via surface and profile drag and Magnus effect
- By manipulating base and centre of gravity characteristics athletes can increase stability and reach equilibrium
- Coaches and athletes use qualitative analysis to evaluate skills and detect and correct errors